Evidence Based Data In Hand Surgery And Therapy

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Grey Giddins dedication:
I dedicate this book to my family Jane, Imogen, Miranda and Hugo who have supported me through many long years of work and to my parents who have supported me for many decades.

Gürsel Leblebicioğlu dedication:
To my wife Meral and to my son Can; this work has only been realised through the loss of precious time together.

CONTENTS

1. GENERAL TOPICS

1.1 Basic Concepts 1
Gürsel LEBLEBİCİOĞLU, Egemen AYHAN

1.2 Hand Outcome Measurements 23
A Systematic Review of Performance-Based Outcome Measures and Patient-Reported Outcome Measures
Çiğdem ÖKSÜZ, İlkem Ceren SIĞIRTMAÇ, Gürsel LEBLEBİCİOĞLU

2. CONGENITAL HAND PROBLEMS

2.1 Congenital Hand Surgery 87
Michael A. TONKIN, Jihyeung KIM, Goo Hyun BAEK, Anna WATSON, Konrad MENDE, David A. STEWART, Christianne Van NIEUWENHOVEN, Steven E.R. HOVIUS, Jose A. SUURMEIJER, Konrad MENDE, Pratik RASTOGI, Richard D. LAWSON, George R.F. MURPHY, Branavan SIVAKUMAR, Gill SMITH, Paul SMITH

3. BONE AND JOINT

3.1 Management of Common Hand Fractures: The Evidence 201
David SHEWRING, Robert SAVAGE, Dyfan EDWARDS, Grey GIDDINS, Ryan W. TRICKETT, Jeremy N RODRIGUES, Will COBB, Wing Yum MAN, Ryan W. TRICKETT, Daniel MG WINSON, Anca BREAHNA, Andy LOGAN

3.2 Scaphoid Fractures- the Evidence 283
David WARWICK, Clare MILLER, Avishek DAS, Tim DAVIS, Joe DIAS, Mark BREWSTER, Richard PINDER, Lindsay MUIR, Shai LURIA, Lizzie PINDER

3.3 Tendon Reconstruction of the Unstable Scapholunate Dissociation. A Systematic Review 355
Marc GARCIA-ELIAS, Diana Marcela ORTEGA HERNÁNDEZ

3.4 Thumb TMC Joint Osteo-Arthritis 369
Massimo CERUSO, Giovanni MUNZ, Christian CARULLI, Gianni VIRGILI, Alessandro VIVIANI, Nadine HOLLEVOET, Grey GIDDINS

3.5 Systematic Review of the Management of Distal Radial Fractures 429
Charles PAILTHORPE, Nick JOHNSON, Joe Dias, Andrew DUCKWORTH, Shivkumar GOPAL, Lisa LEONARD, Adam WATTS, James WHITE, Adam BROOKS, Jamie BROSCH, Joelle CHALMER, Tim CHESSER, Zoe CLIFT, Clare GRANVILLE, Helen HEDLEY, Ian MCNAB, Alexia KARANTANA, Claire PULFORD, Pida RIPLEY

4. SOFT TISSUES

4.1 Systematic Review of Flexor Tendon Rehabilitation Protocols after Acute Flexor Tendon Repair in Zone 2 451
Thomas GIESEN, Maurizio CALCAGNI

4.2 Postoperative Care After Extensor Tendon Repair 459
Jin Bo TANG

4.2.1 Rehabilitation of Extensor Tendons in the Finger Zones I to V 459
Koji MORIYA, Takae YOSHIZU

4.2.2 Rehabilitation of Extensor Tendons in the Hand and Forearm Zones VI to IX and of Extensor Pollicis Longus Tendon 475
Adnan PRSIC, Jonathan L. BASS, Jin Bo TANG

4.3 Comparison of Outcomes Following Nerve Transfers versus Nerve Grafting. 491
A Systematic Review of Individual Participant Data for Restoration of Elbow Flexion after Adult Brachial Plexus Injuries.
Francisco SOLDADO, Egemen AYHAN, Cesar G. FONTECHA, Jayme A. BERTELLI, Gürsel LEBLEBİCİOĞLU

4.4 Evidence in Compression Neuropathies 537

4.4.1 Evidence in Carpal Tunnel Syndrome 537
Alessandro POZZI, Loris PEGOLI, Giorgio PIVATO

4.4.2 Evidence-Based Approach to the Treatment of Cubital Tunnel Syndrome 547
Krzysztof A. TOMASZEWSKI, Michael Henry BRANDON, Patrick POPIELUSZKO, Przemysław A. PĘKALA, Mariusz BONCZAR

4.5 Injection Therapy in Hand Surgery 564
Balazs LENKEI

5. MISCELLANEOUS

5.1 Complex Regional Pain Syndrome (CRPS) Treatment. A Systematic Review. 573
Andrzej ŻYLUK

5.2 Future for Evidence Based Data in Hand Surgery 595
Miriam MARKS, Daniel B. HERREN

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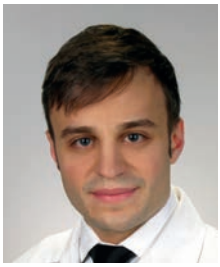

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FOREWORD

This FESSH instructional course book is unique amongst FESSH instructional books in concentrating on Evidence Based Medicine through systematic reviews. It was conceived by Zsolt Szabo the Chairman of the 2017 FESSH organising committee. We were asked to chair the instructional course and edit the instructional book. A systematic review of every topic in Hand Surgery was plainly impossible. We have commissioned a range of topics outlining Evidence Based Medicine and how it works, and a range of Elective and Trauma topics in Hand surgery. We have tried to cover a broad range of subjects. Not everyone who was approached could deliver their work in time so there are common conditions that we treat which we have not covered. This was inevitable given how much work there is in writing a systematic review especially in some parts of Hand Surgery where there is extensive published literature. In other sections there is very little published work making the chapters rather sparse. That reflects the work we as Hand Surgeons need to do, not the work of the authors.

Editing the chapters has been very instructive. Some have confirmed what we already know. Others have challenged our beliefs usually showing that what we believed we knew is not so clear-cut. For a few sub-topics we can be clear we have achieved a reasonably definitive position, e.g. endoscopic carpal tunnel release does not give better results than open surgery; in most we have highlighted how little we know. This may seem a disappointment and in some ways it is; many dedicated, often brilliant, surgeons, therapists and

others have worked incredibly hard to advance our speciality, but what we know definitively is surprisingly small. Science moves on and what was good science 20 or more years ago is often (but not always) inadequate. It is important that we highlight this rather than perpetuating errors.

That does not mean that what we are doing is wrong (although sometimes it will be), but that we cannot be sure enough that what we are doing is right. We hope this work, combined with other systematic reviews and Cochrane reviews will provide a basis from which to develop our speciality along more scientific lines to try to ensure what we do is right. Read these chapters, learn what we know and where you see what we do not know set out to answer those many questions. However young you are you will still have plenty of work left to complete by the end of your career.

We want this work available to anyone working to advance the care of patients with hand problems. This electronic book will be given to everyone attending the FESSH meeting in Budapest and can be distributed widely from there to help all clinicians and scientists in interested in advancing Hand care through Evidence Based Medicine.

We have been honoured to do this work for FESSH. We are tremendously grateful to the editors and authors of the chapters who have done an enormous amount of work to produce this book. We hope we have made a small contribution to the advancement of Hand Surgery by throwing some light on what we know and especially on what we do not know.

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CHAPTER 1

GENERAL TOPICS

1. GENERAL TOPICS

1.1 Basic Concepts

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Introduction

Why do we read? Any of us will answer this question similarly: I am curious, I am looking for answers, or I am working on a research project. But, how much do you read per patient? Seconds, or minutes? What do you read? Textbooks, or journals?

Traditionally, if our clinical experience is sufficient to solve the problem of the patient, we used to rely on that only. If we are not sufficiently experienced, acting upon the well-known motto *-medical teaching is a kind of master and apprentice model-*, our next step may be to consult an expert. Finally, we read textbooks and medical journals. However, these are conflicted: as we grow older, our experience expands but our up-to-date knowledge weakens; the research evidence behind our (or the expert's) treatment weakens; and it is not possible to keep up with all the published knowledge even in hand surgery. We all need an easily available source of valid, up-to-date information in a short time.

This has led to emergence of "evidence-based medicine" (EBM) leading to a paradigm shift in medicine, trivializing the expert opinion and case studies and emphasizing randomized clinical trials and systemic researches (Hoppe and Bhandari, 2008).

SUBTOPICS

History and Evolution of Evidence-Based Medicine
Practice of EBM

- Asking a Focused Question
- Finding the Best Evidence
- Critical Appraisal of the Evidence
- Integration of the best evidence with clinical expertise and patient values
- Self-evaluation (of the previous steps)

PRISMA Methodology
Industrial Considerations

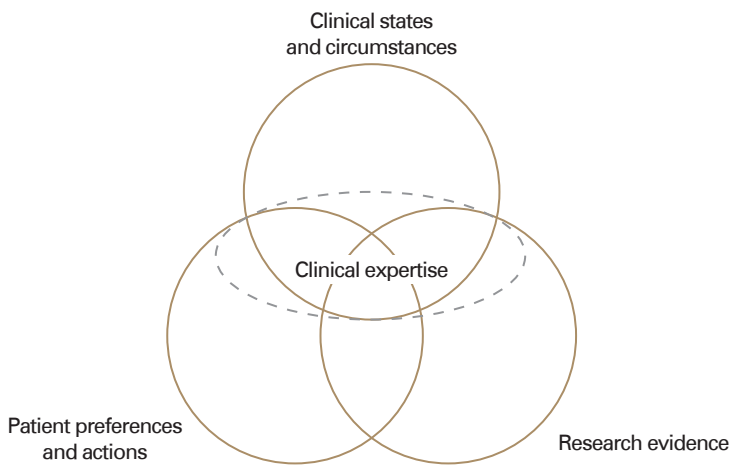
History and Evolution of Evidence-Based Medicine

In the early 1980s, as the seeds of the paradigm shift, Dr. David Sackett used the term "critical appraisal" to describe the systematic examination of the medical literature to extract best evidence at McMaster University (Hoppe and Bhandari, 2008; Sackett et al., 2000). In 1992 the term Evidence Based Medicine (EBM) was used to describe a new approach to medical practice, by a group led by Gordon Guyatt (Guyatt et al., 1992). The Oxford Centre for Evidence-Based Medicine (CEBM) was established in 1995 by the efforts of Dr. Muir Gray, who invited Dr. David Sackett to be director of CEBM. The CEBM is now an internationally renowned not-for-profit organization for practice, teaching and dissemination of high quality evidence based medicine to improve healthcare in everyday clinical practice. In 1996, Sackett et al., (1996) defined EBM: *"Evidence based medicine is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients."* The same year, Haynes et al (1996) described the *"conscientious use"* phrase as the evidence is applied consistently to each patient for whom it is relevant. They described the *"judicious use"* phrase as the clinical application to the patient's unique clinical circumstances and preferences. These concepts were schematized (Figure 1).

Figure 1

In 2000, Sackett et al., refined their definition: *"EBM is the integration of current best research evidence with clinical expertise and patient values."* Based on this revised definition, Haynes et al., (2002) offered an advanced diagram for evidence-based decisions (Fig 2). As an alternative definition of EBM, Trisha Greenhalgh and Anna Donald pointed to the use of mathematics for an evidence-based approach (Greenhalgh, 2014): *"Evidence based medicine is the use of mathematical estimates of the risk of benefit and harm, derived from high-quality research on population samples, to inform clinical decision-making in the diagnosis, investigation or management of individual patients."*

Figure 2 Clinical state and circumstances



The Cochrane library is one of the most important results of the paradigm shift to evidence-based medicine (Sheridan and Julian, 2016). The Cochrane Centre was established in 1992 under the management of Iain Chalmers (Chalmers et al., 1992). It originated from Archie Cochrane's idea about the value of randomized controlled trials in improving the UK National Health Service (NHS) (Cochrane, 1972). It is an independent, international, non-profit scientific organization, consisting of more than 37,000 volunteers over 130 countries (Cochrane, 2016). The contributors work together to prepare over 400 systematic reviews of randomized controlled trials a year along strict guidelines. They are published in the Cochrane Library (The Cochrane Library Oversight Committee, 2012). Some authors claim that Cochrane and evidence-based approach is not as ideal as is suggested (Sheridan and Julian, 2016). A major criticism since the introduction of the evidence-based approach is the decline of original science research (Sheridan and Julian, 2016). Because evidence-based approach is based on comparative research, it is criticized as being evaluation of what is known. Original science, which explores what is unknown, seems to lose its importance. Moreover, relegation of clinical judgment and over-reliance on the reliability of clinical trials and statistics, are other criticisms for EBM (Sheridan and Julian, 2016).

It is now widely accepted that the evidence-based decisions depend on three critical elements: clinical state and circumstances; patient preferences and actions; and research evidence, integrated by clinical expertise (Haynes et al., 2002; Tilburt, 2008). The clinical state and circumstances are of paramount importance, because a patient with chest pain admitted to a primary care center or a tertiary care center will face different approaches to diagnosis or treatment. Patient preferences that may affect their choices include their wish and ability to cooperate with treatment, their tolerance of risk, personal beliefs and even health care insurance. Like the traditional approach, the EBM paradigm assumes that clinical experience and the development of clinical instincts are crucial elements of physician competence. Overall EBM has two important

characteristics: the definition of the problem of the unique patient; and the selection of the best diagnostic and treatment options for that unique patient.

The paradigm shift affected all of the medical disciplines and the evidence-based medicine term became a popular icon. In a recent analysis of four major hand surgery journals, Mei et al., (2016) reported a 2.1-fold increase in the number of published articles each year between 2005 and 2014. Although a tendency towards randomized controlled trials is appearing in recent years, hand surgery has fallen behind other medical fields in being evidence based; most of the evidence in hand surgery is level III - IV studies (Hammert et al., 2013; Post et al., 2014).

Practice of EBM

EBM is a structured approach with five discrete steps (Sackett et al., 2000):

Step 1: Convert the problem (information needed) into a focused question

Step 2: Find the best evidence to answer that question (explore the literature)

Step 3: Critically appraise that evidence for its validity and applicability

Step 4: Integrate the results with clinical expertise, patient values and circumstances, and apply the results in clinical practice

Step 5: Evaluate the efficiency of all of the steps to improve them for the next time

Asking a Focused Question (O'Keefe et al., 2013; Szabo and MacDermid, 2009)

This is the groundwork for EBM. Clinical expertise is necessary to define the specific question. An erroneous question will waste time and effort and lead to the wrong answer. A focused and answerable clinical question facilitates the task of finding the best evidence. This is most easily done with the PICO(T) approach.

"**P**" describes the patient/population characteristics. The characteristic must be specified. This may be the disease, their age, their gender or some key prognostic feature e.g. a 35-year-old basketball player with an extraarticular radius distal fracture.

"**I**" describes the intervention (diagnostic test, medication, surgical treatment) that might potentially be used.

"**C**" describes the comparison i.e. compared with nonsurgical treatment

"**O**" describes the outcome of interest e.g. resolution of pain or increased movement. Patient priorities must be considered carefully.

"T" refers to time. **"T"** can be added to the acronym because outcomes are often time-dependent e.g. early return to work.

Finding the Best Evidence

As noted above the traditional paper based repositories of knowledge e.g. textbooks, or journal articles are already out of date by the time they are published (Haynes et al., 2002) and are frequently biased, relying on expert opinion (Tilburt, 2008), and there are too many publications for any individual to assess thoroughly (Hoppe and Bhandari, 2008).

Critical Appraisal of the Evidence (Karlsson et al., 2011; MacDermid et al., 2009; O'Keefe et al., 2013; Sackett et al., 2000; Szabo and MacDermid, 2009)

The highest quality evidence that applies to a given clinical question is sought. The question is *"What is a high level study?"* A high level study comprises five components (Groves, 2010):

Eligibility

- High level studies need to design strict and clearly outlined inclusion and exclusion criteria in order to gain homogeneity and to minimize confounding factors. But, to recruit enough number of eligible patients will be difficult. Rarity of the subject (e. g. brachial plexus surgery) is another obstacle to recruit sufficient number of patients for a high level study.

Number of subjects

- In order to detect subtle differences the study population must be sufficient. The sample size required can be calculated statistically in the beginning of the study. The risk of losing follow-up of the patients must be kept in mind.

Follow-up time

- Patients must be followed for an adequate time period to observe the outcome. Any patients that are lost to follow-up must be recorded. But, long follow-up periods are needed for many interventions of the hand surgery. This may be longer than a surgeon's life.

Generalizability

- The external validity (i.e., generalizability) of the study must be strong. It describes the applicability of the study findings to other patients. The individual patient characteristics play important role for the outcomes, and those must be clearly declared on the studied patients. In addition, the surgeons' experience and working environment must be taken into account. Clinicians must consider all of these factors before applying the study findings during practice. But, for hand surgery, many solutions are custom made, and not applicable to other patients. For multi-center trails, standardizing the key steps of any surgical technique can be very difficult. Surgeons perform the same surgical procedure differently for different patients (Meshikhes, 2015).

No missing data

- The outcome measures must be comprehensive. It should include both objective and subjective data.

It is not easy to design a prospective randomized study. Many surgeons lack the basic training, expertise and possibly even the desire to perform randomized clinical trials. Therefore, surgeons have been slow to embrace evidence-based medicine (Meshikhes, 2015). Moreover, it was claimed that well-designed non-randomized observational studies may suffice as a feasible alternative to randomized controlled trials (Barton, 2000).

Critical appraisal of the evidence is performed to determine whether the results of individual studies are true (internal validity); to determine whether the results apply to a given patient (generalizability/external validity); and to determine the nature and strength of recommendations based on synthesis of several individual evidence resources.

Internal validity relates to the believability of the study. Low quality studies do not bear strict methodology and are prone to be affected by bias or confounding that weakens the believability of the study. To determine the internal validity of the studies the Oxford Centre for Evidence-Based Medicine (CEBM) has developed the level of evidence system in order to develop a hierarchy for studies (Table 1) (Howick et al., 2011). Research studies are ranked according to their quality which is largely based on the study design and methodology (Figure 3). They are ranked as follows with the first ones being the higher ranked:

Figure 3

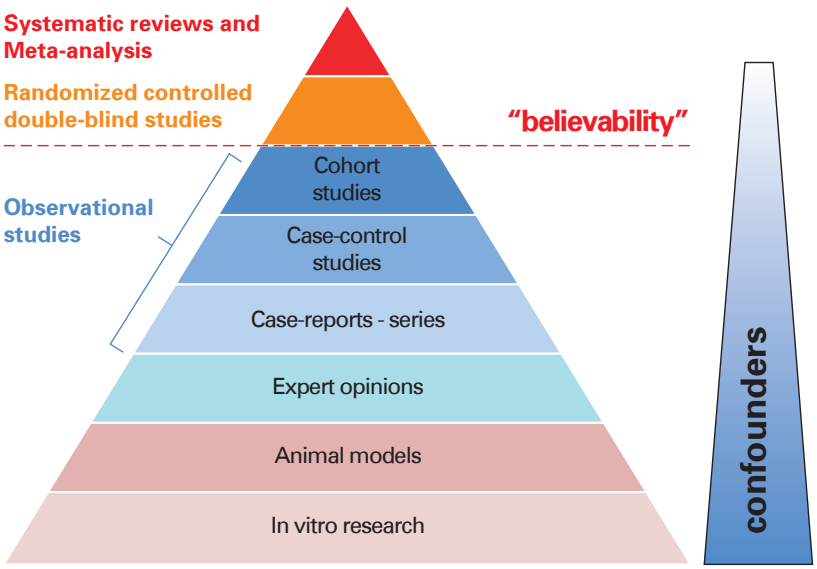


Table 1 Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence

Question	Step 1 (Level 1*)	Step 2 (Level 2*)	Step 3 (Level 3*)	Step 4 (Level 4*)	Step 5 (Level 5)
How common is the problem?	Local and current random sample surveys (or censuses)	Systematic review of surveys that allow matching to local circumstances**	Local non-random sample**	Case-series**	n/a
Is this diagnostic or monitoring test accurate? (Diagnosis)	Systematic review of cross sectional studies with consistently applied reference standard and blinding	Individual cross sectional studies with consistently applied reference standard and blinding	Non-consecutive studies, or studies without consistently applied reference standards**	Case-control studies, or "poor or non-independent reference standard**	Mechanism-based reasoning
What will happenif we do not add a therapy? (Prognosis)	Systematic review of inception cohort studies	Inception cohort studies	Cohort study or control arm of randomized trial*	Case-series or case-control studies, or poor quality prognostic cohort study**	n/a
Does this intervention help? (Treatment Benefits)	Systematic review of randomized trials or *n*-of-1 trials	Randomized trial or observational study with dramatic effect	Non-randomized controlled cohort/follow-up study**	Case-series, case-control studies, or historically controlled studies**	Mechanism-based reasoning
What are the COMMON harms? (Treatment Harms)	Systematic review of randomized trials, systematic review of nested case-control studies, *n*- of-1 trial with the patient you are raising the question about, or observational study with dramatic effect	Individual randomized trial or (exceptionally) observational study with dramatic effect	Non-randomized controlled cohort/ follow-up study (post-marketing surveillance) provided there are sufficient numbers to rule out a common harm. (For long-term harms the duration of follow-up must be sufficient.)**	Case-series, case-control, or historically controlled studies**	Mechanism-based reasoning
What are the RARE harms? (Treatment Harms)	Systematic review of randomized trials or *n*-of-1 trial	Randomized trial or (exceptionally) observational study with dramatic effect			
Is this (early detection) test worthwhile? (Screening)	Systematic review of randomized trials	Randomized trial	Non-randomized controlled cohort/follow-up study**	Case-series, case-control, or historically controlled studies**	Mechanism-based reasoning

* Level may be graded down on the basis of study quality, imprecision, indirectness (study PICO does not match questions PICO), because of inconsistency between studies, or because the absolute effect size is very small; Level may be graded up if there is a large or very large effect size.

** As always, a systematic review is generally better than an individual study.

- **Meta-analysis of high quality RCTs:** Metaanalyses extract the results from individual studies and use accepted statistical methodology to combine evidence.
- **Systematic review**
- **Randomized controlled trial**
- **Cohort study:** Prospective or retrospective studies that follow a population group or compare study groups over time without randomization are called cohort studies. In a prospective cohort study, the question is generated before the collection of data, the patients in the sample are followed over time, and the outcomes are assessed. A cohort study is retrospective if the question is posed after data collection and patient follow-up. Because the patients are not randomized, there may be some bias.
- **Case studies:** These include case reports, case series, and case-control studies. Case studies begin by identifying individuals who have the outcome of interest, in contrast with the cohort and randomized study designs, which begin by identifying patients who do or do not have defined risk factors before onset of outcome.
  - **Case-control study:** In case-control studies, patients with an outcome of interest are retrospectively compared with control patients to identify the prevalence of risk factors. These are often less reliable than RCTs and cohort studies because they contain more sources of bias.
  - **Case series/report:** These are descriptive studies without a control group for comparison. In a case report, one patient with the outcome of interest is identified, and the treatment and associated risk factors are described. If there are more patients with the same outcome of interest, the study is called a case series. Case reports are useful for studying rare conditions; they can serve as a starting point for future studies.
- **Bias:** Bias is defined as a systematic error in the design of a study that causes inaccurate findings. Most studies involve

bias; however, minimizing sources of bias is important. There are different types of bias:

- Design Bias:
  - Effects of industry: To support a randomized controlled trial is expensive for universities and institutions. Many randomized controlled trials are supported by industry. Funding bodies play a major role in the selection of researchers and study subjects (Meshikhes, 2015).
  - Blinding: Surgeon and patient blinding may not be possible, but blinding of outcome assessors and data analysts is feasible.
  - Randomization: The randomization is the best way to minimize bias by distributing known and unknown prognostic variables uniformly between treatment groups. For surgical trials, randomization can be difficult because of surgeon or patient preferences.
  - Procedural bias: Procedural bias is the pressure applied to patients, forcing them to complete their responses quickly (e. g. fill the questionnaire).
- Sampling Bias:
  - Selection bias: Patient groups differ in characteristics and therefore have different prognoses after surgery (Schulz et al., 2010).
  - Information bias: When information is collected differently between two groups, the conclusion of the association will be affected.
  - Attrition bias: If the patients lost to follow-up (withdrawal, nonresponse) in one group are different than the other patients group, the characteristics of groups would change. Therefore, the final group characteristics will be different than the original group.
- Data Collection Bias
  - Patient related
    - Poor compliance (reject randomization)

        - Rarity of the condition
    - Analysis Bias
        - Poor statistics
    - Publication bias
        - Several studies have reported the evidence of publication bias against negative results (Hopewell et al., 2009; Lee et al., 2008; Turner et al., 2008). However, the cause of this bias is not clear (Jones et al., 2013; Rennie and Flanagin, 1992). To impede publication bias, many journals follow the International Committee of Medical Journal Editors recommendations, which require registration of prospective trials involving human participants in a public trials registry at or before the time of first patient enrollment (International Committee of Medical Journal Editors, 2016). Nevertheless, in the study of Jones CW et al (Jones et al., 2013) including trials with at least 500 participants, the authors found that 29% of registered studies were unpublished. Non-publication was more common among trials that received industry funding than those that did not.
        - Conflict of interest: Financial conflict of interest was found to incline authors towards describing positive findings (Okike et al., 2007).
    - Dissemination Bias: The data of the study can be misrepresented (intentionally or unintentionally) which will lead to distortion of the research evidence (Bassler et al., 2016).
- **Confounding:** A remote variable that is independently associated with both the dependent (effect) and independent (cause) variables and inaccurately amplifies or minimizes the apparent relationship between variables is called confounding.

External validity is another important issue. It is the process of deciding whether the findings of internally valid clinical studies can be generalized to a specific patient. The individual patient characteristics play an important role in the outcomes, as may surgical expertise/experience.

EBM is not restricted to randomized trials and meta-analyses. EBM aims to use the most appropriate study design to answer the specific question with maximal validity. Although randomized controlled trials are preferred because of less bias and confounding, it is not easy to perform a randomized controlled trial for a rare disease, such as ulnar club hand. Case-reports still have some value in improving patient care. As a striking example, the tragic side effects of thalidomide were first reported by McBride in a case-report (McBride WG, 1961).

Integration of the Best Evidence with Clinical Expertise and Patient Values (Haynes et al., 2002; Karlsson et al., 2011; Szabo and MacDermid, 2009)

Once evidence has been collected, reviewed, analyzed, and adjusted to the clinical question at hand, a clinical decision can be made. Even in one of the initial articles about EBM, Sackett et al (1996) emphasized the concept of individualized care in following sentences: "Evidence based medicine is not a "cookbook". It requires a bottom up approach that integrates the best external evidence with individual clinical expertise and patients' choice. It cannot result in slavish, cookbook approaches to individual patient care. External clinical evidence can inform, but can never replace, individual clinical expertise, and it is this expertise that decides whether the external evidence applies to the individual patient at all and, if so, how it should be integrated into a clinical decision."

Self-evaluation (Karlsson et al., 2011; Sackett et al., 2000)

The final step of EBM approach is self-evaluation of decision making. The self-evaluation process will help us to realize the errors and to fill the gaps throughout the EBM steps. Moreover, by continuously performing this step, we acquire feedbacks to improve our EBM approach technique for the upcoming clinical questions. For self-evaluation there are questions classified for every step of EBM approach.

- **Asking a Focused Question:** Are my questions focused and answerable? Are they well-formulated? Do I have a working

method to save my questions for later answering? Am I modeling the asking of questions for my learners?

- **Finding the Best Evidence:** Do I know the best resources for seeking current evidence? Am I searching from a wide variety of resources? Do I have access to these resources? Am I becoming more efficient in my searching?
- **Critical Appraisal of the Evidence:** Am I critically appraising the evidence? Am I looking for the validity of the studies? Am I checking the grade of the studies and trying to determine strength of recommendation?
- **Integration of the best evidence with clinical expertise and patient values:** Am I integrating the best available evidence with clinical state and patient values? Can I accurately and efficiently adjust my findings to fit my unique patient?

PRISMA Methodology

The reporting quality of a publication is of utmost importance. The publication must allow the readers to analyze and reproduce the work. In a recent paper of Post et al (2014), the authors emphasized that higher methodological and reporting standards are needed in hand and wrist surgery. They claimed that some excellent randomized controlled trials might have received relatively poor quality scores because of poor reporting. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is the methodology to guide the authors to report systematic reviews and meta-analyses in an understandable and transparent way.

The PRISMA statement consists of a checklist and flow diagram (Moher et al., 2009). The 27 item checklist includes the title, abstract, methods, results, discussion and funding (Table 2). The four-phase flow diagram illustrates the flow of information through the different phases of a systematic review (Table 3). It outlines identification of records in the literature searches, the number of studies included and excluded, and the reasons for exclusions.

Table 2 PRISMA 2009 Checklist

Section/topic	#	Checklist item
TITLE		
Title	1	Identify the report as a systematic review, meta-analysis, or both.
ABSTRACT		
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.
INTRODUCTION		
Rationale	3	Describe the rationale for the review in the context of what is already known.
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).
METHODS		
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis.

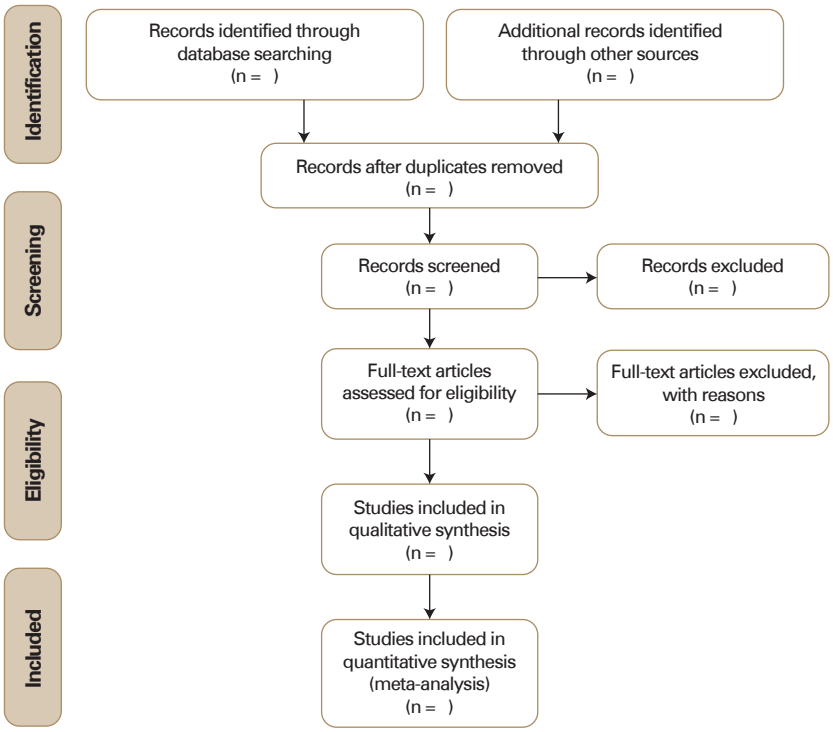
>>>

Section/topic	#	Checklist item
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.
RESULTS		
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.
Synthesis of results	21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).
DISCUSSION		
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.
FUNDING		
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: www.prisma-statement.org.

Table 2 PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097
For more information, visit www.prisma-statement.org.

Industrial Considerations

The healthcare industry is one of the world's largest and fastest-growing industries. As we mentioned in the beginning, this potential highly advertised market, is open to considerable bias which may lead us to use expensive implants and products. Sticking to evidence-based approach is a wise way to reduce bias. There are concerns that the evidence-based approach can be hijacked by insurance companies to promote cost-cutting. The specialist dealing with problems of the hand must build a medically-based, humanistic, and ethical evidence-based hand surgery system before someone else does.

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1.2 Hand Outcome Measurements

A Systematic Review of Performance-Based Outcome Measures and Patient-Reported Outcome Measures

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Introduction

In the last two decades, outcome assessment in hand surgery and hand therapy has shifted from focusing on disability/symptoms (e.g. measuring ranges of motion, muscle strength and sensation) to activity and participation (e.g. activities of daily living) (Schoneveld et al., 2009). Recently, performance based outcome measures (PBOMs) along with patient-reported outcome measures (PROMs) are being collected for outcome evaluation of hand problems.

Performance based outcome measures mainly aim to assess what someone is able to do in a standardized environment (Wittink et al., 2003). The main performance based outcome measures in hand care are evalautions of manual dexterity or strength. Patient-reported outcome measures aim to capture the patients' own perspective of their health/illness and the effect of interventions

(Fitzpatric et al., 1998). Over recent years huge numbers of patient-reported outcome measures has been developed. They have a spectrum that ranges from evaluating symptoms, functional capacity, health status and quality of life to quality and effect of treatment (Peláez-Ballestas, 2012).

The responsibility of the clinician is to select the evidence based instrument(s) that best addresses the patient's condition in full and the impact of treatment. This is not easy. Outcome measures should reflect a comprehensive understanding of the disease or injury and the effect of that disease or injury to the patient's ability to perform activities and participation. In addition it should give an insight into the benefits and harms associated with treatment (Bryant and Fernandes, 2011). The ability of an outcome measure to improve decision-making in clinic also relies on the psychometric strength of the instrument (Lohr, 2002).

The aim of this systematic review is to investigate the methodological quality using the Consensus-based standards for the selection of health measurement instruments (COSMIN) checklist of published performance based outcome measures and patient reported outcome measures in the field of hand injuries or hand disorders and to make recommendations for the selection of appropriate outcome measures.

Methods

Review protocol

The protocol was developed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards (Moher et al., 2010).

Literature Search Strategy

We performed a literature search on 26.06.16 to identify all published studies describing development or evaluation measurement properties of outcome measures measuring functional status of hand conditioned patients. A computerized bibliographic database of PubMed from 01.01.1980 to 26.06. 2016 was searched. We used a search filter developed by Terwee et al., (2009). Search steps

were combined using the Boolean operators 'OR' and 'AND'.

1# Construct search

2# Population search

3# Instrument search

4# #1 AND #2 AND #3 AND filter for measurement properties.

5 # #4 NOT exclusion filter

Subsequently, the names of the outcome measures were used in a complementary search in the entire database to identify additional studies of the measurement properties of the hand outcome measures. The names of the outcome measures referenced from the review articles (Schoneveld et al., 2009; van de Ven-Stevens et al., 2009; Weinstock-Zlotnick and Mehta, 2016; Yancosek and Howell, 2009). Reference lists of the articles and reviews were also searched to identify additional relevant studies. (See supplement for full search strategy)

The inclusion criteria were: the study was written in English; they were published in peer-reviewed journals; they include at least one psychometric (measurement) property of an outcome measure; they included at least one outcome measure designed for use in a clinical setting; and they were a full-text original articles.

The exclusion criteria were: comments; letters; editorial guidelines; conference reports; reviews; and studies on patients with neurological problems or studies on children.

The measurement properties of the patient reported outcome measures used in hand conditions were studied by Kleinlugtenbelt et al., for patients with distal radius fractures (Kleinlugtenbelt et al., 2016). So we have mainly focused on performance based outcome measures in this chapter and we report the results of the study Kleinlugtenbelt et al.

Article selection

The results of database searches were imported into End Note X7. Two independent reviewers (both author) assessed titles, abstracts and full-text articles (where appropriate) for eligibility. We included all the articles with at least one description of measurement

properties of an outcome measurement. Discrepancies were discussed to reach consensus.

Assessment of the quality of the studies

First descriptive variables of the studies like authors, year, study sample, gender and mean age (SD or range) were collected. Then the methodological quality of included studies was evaluated according to the COSMIN 4-point checklist.

In this review we made two adaptations clarifying the quality scorings in the COSMIN checklist; since the majority of the included studies either did not indicate the number of missing items or did not indicate how missing items were handled, we decided to exclude these items from the quality ratings (Elvrum et al., 2016); and criterion validity was defined as "the degree to which the scores of a HR-PRO instrument are an adequate reflection of a "gold standard""(Terwee et al., 2007). The criterion used should be considered as a reasonable "gold standard". A Delphi Panel reached a consensus that no gold standards exist for HR-PRO instruments. We applied this to the performance based outcome measures (McDowell, 2006; Mokkink et al., 2010). According to the COSMIN checklist there should be clearly defined hypotheses and the studies should test the magnitude and direction of the correlation between any two or more tested instruments.

Quality Criteria For Measurement Properties:

We independently extracted the data and performed the quality assessments. Disagreement between the two reviewers was resolved by discussion until agreement was reached.

The quality of the measurement properties was critiqued using the tool of Terwee et al., (2007). These criteria consist of positive (+), intermediate (?), negative (-) or no information available (0) for each measurement property. The definitions of the measurement properties and interpretability are given in Table 1. For example, reliability is considered positive (+) where the ICC or weighted Kappa value is 0.70; criterion validity is considered positive where there are convincing arguments that the gold standard is "gold" and the correlation value is ≥0.70.

Table 1 Quality criteria for measurement properties adapted from Terwee et al., (2007)

Property	Rating	Quality Criteria
Reliability		
Internal consistency	+	(Sub)scale unidimensional AND Cronbach's alpha(s) ≥0.70
	?	Dimensionality not known OR Cronbach's alpha not determined
	-	(Sub)scale not unidimensional OR Cronbach's alpha(s) <0.70
Reliability	+	ICC/weighted Kappa ≥0.70 OR Pearson's *r* ≥0.80
	?	Neither ICC/weighted Kappa, nor Pearson's *r* determined
	-	ICC/weighted Kappa <0.70 OR Pearson's *r* <0.80
Measurement error	+	MIC > SDC OR MIC outside the LOA
	?	MIC not defined
	-	MIC ≤ SDC OR MIC equals or inside the LOA
Validity		
Content validity	+	A clear description is provided of the measurement aim, the target population, the concept(s) being measured, and the item selection. Target population and experts in the field were involved in the development process
	?	Not enough information available
	-	No clear description is provided of the measurement aim, the target population, the concept(s) being measured, and the item selection, OR target population and experts in the field were not involved in the developmental process
Construct validity		
Structural validity	+	Factors should explain ≥50% of the variance
	?	Explained variance not mentioned
	-	Factors explain <50% of the variance
Hypothesis testing	+	Correlations with instruments measuring the same construct ≥0.50 OR ≥75% of the results are in accordance with the hypotheses AND correlations with related constructs are higher than with unrelated constructs
	?	Solely correlations determined with unrelated constructs
	-	Correlations with instruments measuring the same construct <0.50 OR <75% of the results are in accordance with the hypotheses AND correlations with related constructs are lower than with unrelated constructs
Cross-cultural validity	+	No differences in factor structure OR no important DIF between language versions
	?	Multiple group factor analysis not applied AND DIF not assessed
	-	Differences in factor structure OR important DIF between language versions
Criterion validity	+	Convincing arguments that gold standard is "gold" AND correlation with gold standard ≥0.70

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Property	Rating	Quality Criteria
	?	No convincing arguments that gold standard is "gold" OR doubtful design or methods
	-	Correlation with gold standard <0.70 despite adequate design and method
Responsiveness		
Responsiveness	+	Correlation with changes on instruments measuring the same construct ≥0.50 OR at least 75% of the results are in accordance with the hypotheses OR AUC ≥0.70 AND correlations with changes in related constructs are higher than with unrelated constructs
	?	Solely correlations determined with unrelated constructs
	-	Correlation with changes on instruments measuring the same construct <0.50 OR < 75% of the results are in accordance with the hypotheses OR AUC <0.70 AND correlations with changes in related constructs are higher than with unrelated constructs

+=positive rating; ?=indeterminate rating; -=negative rating; ICC=intraclass correlation coefficient; MIC=minimal important change; SDC=smallest detectable change; LOA=limits of agreement, DIF=differential item functioning

Levels of evidence of the measurement properties of the instruments

To synthesize the evidence a "best-evidence synthesis" was performed; for each performance based instrument the level of evidence was determined by combining the results of different studies (Kleinlugtenbelt et al., 2016). As proposed by the Cochrane Back Review Group, the levels of evidence were "strong," "moderate," "limited," "conflicting," or "unknown" (Table 2). (Furlan et al., 2009; Van Tulder et al., 2003) We defined the best-rated instruments as those which had a "+++" (strongly positive) in at least one measurement property or a "+" or "++" in at least three measurement properties according to the data synthesis. (Liu et al., 2016)

The quality criteria and Levels of evidence for the overall quality of the patient reported outcome measurement properties are based on the study of Kleinlugtenbelt et al., (2016).

Table 2 Levels of evidence for the overall quality of the measurement properties, based on the Cochrane Back Review Group (2003)

Level	Rating	Criteria
Strong	+++ or ---	Consistent findings in multiple studies of good methodological quality
		OR in one study of excellent methodological quality
Moderate	++ or --	Consistent findings in multiple studies of fair methodological quality
		OR in one study of good methodological quality
Limited	+ or -	One study of fair methodological quality
Conflicting	±	Conflicting findings
Unknown	?	Only studies of poor methodological quality

+=positive results, ?=indeterminate results, -=negative results.

Results

Included Studies

The selection process for all the studies is shown in Figure 1. A total of 638 studies were identified. After screening the title and abstracts 484 articles were excluded. The remaining 154 were screened with the full text; 97 studies were excluded. Thus 57 studies were analyzed in this review.

The included hand dexterity tests were the: Functional Dexterity Test; Purdue Pegboard Test; Grooved Pegboard Test; Nine Hole Peg Test; Rosenbuch Test of Finger Dexterity; Box and Block Test; Minnesota Manual Dexterity Test; O'Conor Functional Dexterity Test; Test evaluant la performance des Membres superieurs des Personnes Agees-Tempa; Southampton Assessment Procedure; Sollerman Hand Function Test; Sequential Occupational Therapy Dexterity Assessment; Jebsen Taylor Hand Function Test; Arthritis Hand Function Test; Moberg Pick Up Test; O'Neill Hand Function Assessment; and NK Hand Dexterity Test. The Bennet Hand Tool Dexterity Test, Crawford Small Parts Dexterity Test, Greenseid & McCormack Test and Minnesota Rate of Manipulation Tests were excluded from our review because of unknown psychometric properties. The characteristics, clinical utility, target population and scoring of the performance based outcome measures included in this review are reported in Table 3 (Bear-Lehman

and Abreu, 1989; Greenseid and McCormack, 1968).

Papers reporting on the Tekdyne Hand Dynamometer, Jamar Hydrolic Hand Dynamometer, BTE Work Simulator, Baseline Hydraulic Dynamometer, Sphygmomanometer, Computerized Jamar Dynamometer, Rolyan Hydraulic Dynamometer, BTE- Primus Grip Tool, Dexter Hand Dynamometer, DynEx Dynamometer, Lode Hand Grip Dynamometer, Takei Digital Non-static Handle Dynamometer, Biometrics E-LINK EP9 Electronic Dynamometer, MicroFET 4 hand-grip Dynamometer, Grip Ball Dynamometer, J-tech Pinch Gauge, NK Pinch Gauge, Jamar Electronic Pinch Gauge, B&L Engineering Pinch Gauge, Digitalized Pinch Dynamometer, and Digital Strain Gauge Torsion Dynamometer (MIE) were included for assessment of evaluation methods of grip strength.

The Patient-Rated Wrist Evaluation (PRWE), Disabilities of Arm, Shoulder and Hand (DASH), Michigan Hand Questionnaire (MHQ), Short Form-36 (SF36), Patient Evaluation Measure (PEM), Arthritis Impact Measurement Scale, Brigham and Women's Hospital Carpal Tunnel Questionnaire (BWH-CTQ), International Osteoporosis Foundation Wrist Fracture Questionnaire, Patient Focused Wrist Outcome Instrument, Tampa Scale of Kinesophobia, Catastrophizing Subscale of the Coping Strategies Questionnaire and the Self-Efficacy Scale were the patient rated outcome measures included in the study of Kleinlugtenbelt et al., The study characteristics of the patient reported outcome measures described in the article of Kleinlugtenbelt et al., are shown in Table 4 (Kleinlugtenbelt et al., 2016).

Overall results

In the 57 studies we identified 38 instruments, including 17 performance based measurements and 21 methods to evaluate grip strength. The study populations ranged from 20 to 703 subjects, with ages ranging from 12 to 89 years.

Thirty-three of the 57 studies were published after 2000. Most studies (54%) evaluated more than one measurement property

and most of them evaluated reliability (mostly test re-test reliability) and hypothesis testing. Construct validity, structural validty, criterion validity and responsiveness were not evaluated in any of the studies.

Of the hand dexterity tests the Purdue Pegboard Test, Sequential Occupational Therapy Dexterity Assessment and Arthritis Hand Function Test and of the grip strength assessment methods the Jamar Hydrolic Hand Dynamometer and B&L Engineering Pinch Gauge" have been studied the most. However, the methodological quality of these studies is low (Tables 5 and 6).

Quality of the Included Studies

The quality of included studies can be found in Tables 7 and 8. The methodological quality of the existing studies ranged from poor to excellent, with few being good or excellent.

Studies on performance-based measures

There were 17 studies that analyzed the measurement properties of performance-based measures. Test retest reliability and hypothesis testing were the most commonly reported measurement properties. Internal consistency and content validity were reported in two and three studies, respectively. But the methodological quality of those studies was poor (Table 7).

Of the studies reporting on reliability, one study was excellent, one was good, eight were fair and 26 were poor. An inadequate sample size was the main reason for a poor or fair grading. For hypothesis testing three studies were good, eight were fair and nine were poor. The main weaknesses lay in inadequate sample sizes and a lack of adequate hypotheses. All three studies reporting content validity were poor as they did not assess all relevant items for the study population.

For the studies examining the quality of the hand dexterity tests only the Functional Dexterity Test was graded as excellent for test-retest reliability.

Among 21 studies relating to grip strength measurement sys-

tems 12 studies reported test re-test reliability, 15 studies reported hypothesis testing, no studies reported inter-rater reliability, five studies reported intra-rater reliability and 12 studies reported inter instrument reliability. Only one study reported measurement eror. The qualities of the studies were poor to excellent. Inadequate sample size was the main reasons for the studies being only fair or poor. The quality of most studies was only fair for hypothesis testing because they did not formulate any hypotheses in their studies (Table 8).

The studies on the BTE-primus Grip Tool had excellent measurement properties for test-retest reliability and hypotheses testing and those on the DynEx Dynamometer had excellent measurement properties for test-retest reliability, hypotheses testing and interrater reliability.

Studies on patient-reported outcome measures (PROM)

Kleinlugtenbelt et al., included 19 studies evaluating 12 PROMS. Most studies (80%) evaluated more than one measurement property. None of the studies evaluated structural validity or criterion validity. Of all patient reported outcome measures, the PRWE has been studied the most, followed by the DASH. (Table 9,10) (Kleinlugtenbelt et al., 2016)

Level of evidence of the measurement properties for performance based outcome measures

A summary of level of evidence of the measurement properties for performance based outcome measueres and grip strength evaluation methods is provided in tables 9 and 10. The best rated instruments with a "+++" in one measurement property or "+"/"++" in at least three measurement properties are the Functional Dexterity Test, the Jamar Hydrolic Hand Dynamometer, the BTE- primus Grip Tool, the DynEx Dynamometer, the B&L Engineering Pinch Gauge. (Table 11,12)

Kleinlugtenbelt et al., reported the highest levels of evidence for the PRWE and DASH (table 13)(Kleinlugtenbelt et al., 2016). Overall studies on PROMs performed better than studies on PBOMs.

Discussion

Although none of the instruments was tested for all measurement properties described in the COSMIN checklist, this systematic review recommends seven out of 49 hand instruments. The best evidence for assessing hand dexterity is for the Functional Dexterity Test whereas the Jamar Hydrolic Hand Dynamometer, the BTE- primus Grip Tool, the DynEx Dynamometer, the B&L Engineering Pinch Gauge have the best evidence for grip strength measurement. The PRWE and DASH have the best evidence amongst patient reported outcome measures. A combination of these measurements would be useful for assessing hand function.

Most of the studies included in this review were rated as "fair" or "poor" based on the COSMIN checklist. The main reason for this rating were the small sample sizes. In every COSMIN checklist box, there is an item related to the sample size requirements (Mokkink et al., 2010). To receive a "fair" rating for this item, a study has to have at least 30 participants; in many studies included in this review the sample size was less than 30. Some studies included in this review reported that the sample size requirement was determined by a statistical analysis (MacDermid et al., 1994). Although those articles emphasized that the required sample size was chosen in order to achieve the minimum acceptable reliability or validity in our review we rated the quality of that item according the COSMIN checklist. However, it should be kept in mind that the COSMIN checklist was originally developed to assess studies for PROMs. Considering the differences in instrument characteristics and study designs between studies on PBOMs and studies on PROMs, the sample size criteria may need some adjustment. Although it is difficult to conduct a PBOM design with a large sample size it appears clear from this review that the sample size of PBOMs should be enlarged in future studies (Schoneveld et al., 2009).

One another important reason is for rating the quality of the items as 'fair' or 'poor' is the absence of adequate hypotheses formulated a priori and or vague or unformulated hypotheses.

Another reason for a low rating on the COSMIN checklist were reporting p values instead of ICC or Pearson or Spearman correlations for reliability.

According the results of this review and the study of Kleinlugtenbelt et al., (2016) neither the PBOMs nor PROMs support all of the measurement properties with strong levels of evidence. Van de Ven-Stevens et al., (2009) also mentioned in their review that none of the instruments had a positive rating for all the clinimetric properties. According to the best evidence synthesis we rated the Functional Dexterity Test as having the best evidence for the PBOMs. However there is only one article about the psychometric properties of the Functional Dexterity Test that evaluates the test retest reliability. Consequently, evidence on the other psychometric properties of the Functional Dexterity Test are unknown. It was a surprise that the psychometric properties of the Jebsen Taylor Hand Function Test have been examined in only one article. The Jebsen Taylor Hand Function Test is the most widely used test in the literature for assessing hand dexterity; most of the time it is considered as the ‘‘gold-standard’ (Jebsen et al., 1969; van de Ven-Stevens et al., 2009). Further studies on the psychometric properties of the Jebsen Taylor Hand Function test are necessary.

To our knowledge, this is the only study that evaluates the measurement properties of PBOMs according to the COSMIN checklist. Previous reviews have described a variety of PBOMa but in those studies the methodological quality of the clinimetric studies was not taken into account. In his narrative review of dexterity assessments Yancosek and Howell noted that the Minesota Rate of Manipulation, Purdue Pegboard Test, and Box and Block Test demonstrated solid psychometric properties through evidence from more than five Level 2b studies. The Box and Block Test and Minesota Rate of Manipulation are therefore recommended as assessments of choice to evaluate manual dexterity, and the Purdue Pegboard is recommended to assess fine finger dexterity”. This is contradictory to our finding. Some studies included in that review were not included in this review because the population of those studies had neurological problems (Yancosek and Howell, 2009).

The sample sizes of the other studies were less than 30 so rated only as fair in our review. Corresponding to our review, Schoneveld et al., (2009) described the Functional Dexterity Test as the highest rated hand dexterity test.

A standardised method is needed to enable more consistent measurement of grip and pinch strength for better assessment of hand strength (Roberts et al., 2011). We believe this is the only systematic review of grip strength measurement that has used the COSMIN checklist. For grip strength measurement systems the Jamar Hydraulic Hand Dynamometer, the BTE- primus Grip Tool and the DynEx Dynamometer are the tests with the best evidence measurement methods. The Jamar Hydraulic Hand Dynamometer is the most widely cited method in the literature and accepted as the gold standard. The BL pinch and Digitalized Pinch Dynamometer have moderate inter-rater and inter-instrument reliability and strong hypothesis testing properties. The, Primus, DynEx Dynamometer has the best level of evidence. For pinch the B&L Engineering Pinch Gauge, has strong levels of evidence for hypothesis testing. According to King (2013): "to determine whether measurements recorded by different dynamometers can be compared on an equitable basis within the clinic and whether readings from one dynamometer can be appropriately compared with norms established by a different dynamometer, inter-instrument reliability should be evaluated". Although inter-instrument reliability is not one of the criteria in the COSMIN checklist most grip strength studies have evaluated the inter-instrumental study so we have added it as a criterion.

In our study the measurement properties of patient reported outcome measures are taken from to the results of Kleinlugtenbelt et al., (2016). Although it is a study designed for distal radius fractures it is the only one, to our knowledge, that has used the COSMIN checklist to systematically review the methodological quality of studies on PROMs. Kleinlugtenbelt et al., mentioned in their study that "for the PRWE, there is moderate evidence supporting good reliability, content validity, hypotheses testing and responsiveness. The DASH showed at best moderate evidence for good

responsiveness and limited evidence for good hypothesis testing and reliability." These findings parallel Kim's systematic review (Kim et al., 2013).

According to the best-evidence synthesis, PBOMs do not have as much positive evidence for their measurement properties as PROMs. But it is clear that PBOMs are valuable to assess objectively what patients actually do (Dobson et al., 2012). PROMs mostly reflect patients' abilities to perform different tasks, whilst PBOMs only focus on specific tasks. PBOMs mostly evaluate ability whereas PROMs mostly evaluate disability. Although there is little evidence of the high quality in the current PBOMs they appear to be valuable instruments .

The aim of our study was to analyze the measurement properties of the articles not the instruments. We believe the results of our study should be interepreted as showing that the Functional Dexterity Test, Jamar Hydrolic Hand Dynamometer, BTE- primus Grip Tool, DynEx Dynamometer, B&L Engineering Pinch Gauge, PRWE and DASH instruments have best methodological quality. Since they have the best methodological quality papers they currently provide the best outcome measurements for assessment of patients with hand problems. The results of our study also imply the need for higher quality papers in order to properly assess in detail the measurement properties of all other instruments.

There are limitations to this study. This review mainly focused on adult performance based and patient reported outcome measures; paediatric and geriatric assessment tools were excluded from the study, as were studies on adults with neurological problems. Another limitation was the difficulty in distinguishing between poor study reporting and poor methodology in some studies. This may have affected the rating of the quality of outcome measures.

In this systematic review we identified seven outcome measures assessing hand function where aspects of reliability and validity have been studied. For assessing patients with hand problems we recommend the Functional Dexterity Test, Jamar Hydrolic Hand Dynamometer, BTE- primus Grip Tool, DynEx Dynamometer,

B&L Engineering Pinch Gauge, PRWE and DASH instruments. The instruments identified in this systematic review can be useful in clinical settings for hand therapists and hand surgeons. Further good quality studies are needed in order to assess further the psychometric properties of performance-based and patient reported outcome measures for the hand.

Figure 1 PRISMA Flow Diagram

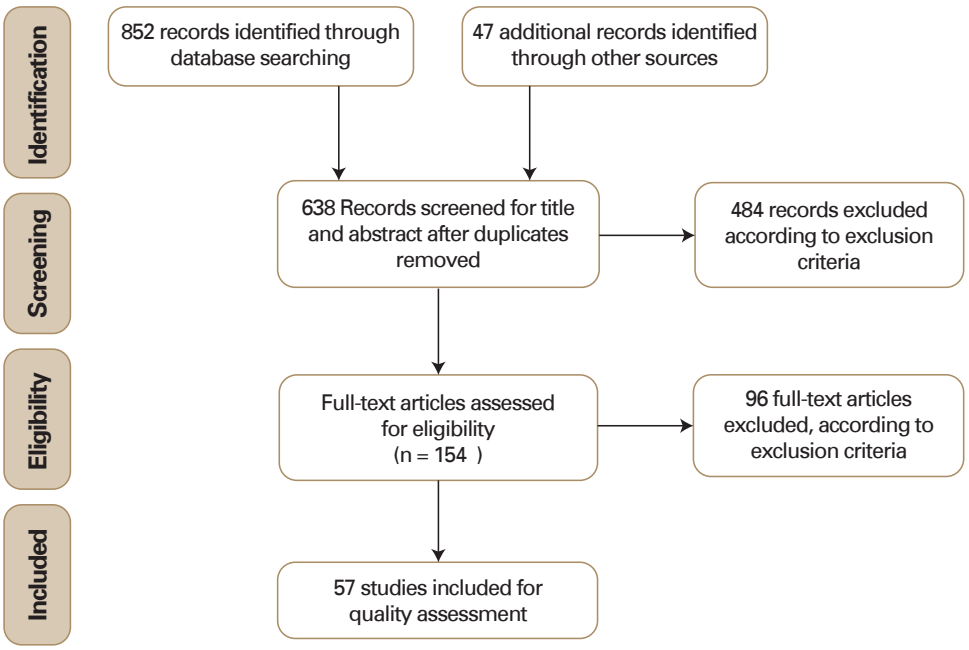

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Table 3 The characteristics, clinical utility, target population and scoring of the performance based outcome measures

Instrument	Abbreviation	Purpose	Assess Bilateral Hand Use	Target Population	Range of Scores
Functional Dexterity Test (Aaron and Jansen, 2003)	FDT	To assess the ability to use hand for daily tasks	N	All types of hand injuries	Movement Times (sec) converted into functional score
Purdue Pegboard Test (Tiffin and Asher, 1948)	PPT	To assess fine manual dexterity	Y	All types of hand injuries	Movement Times (sec)
Grooved Pegboard Test (Bryden and Roy, 2005)	GPT	To assess manual dexterity and eye hand coordination	N	Originally for neurologic and cognitive disorders	Movement Times (sec)
Nine Hole Peg Test (Mathiowetz et al., 1985)	NHPT	To assess finger dexterity	N	Physically impaired person	Movement Times (sec)
Rosenbuch Test of Finger Dexterity (Stein and Yerxa, 1990)	RTFD	To assess fine dexterity	N	All types of hand injuries	Movement Times (sec)
Box and Block Test (Mathiowetz et al., 1985)	BBT	To assess manual dexterity	N	Physically impaired person	Number of blocks displaced in 60 sec.
Minnesota Manual Dexterity Test (Desrosiers et al., 1997)	MMDT	To assess manual dexterity	Y	Testing workers in occupations	Movement Times (sec)
O'Cconor Functional Dexterity Test (Gloss and Wardle, 1981)	OFDT	To assess manipulation of small objects	N	All types of hand injuries	Movement Times (sec)
Test evaluant la performance des Membres superieurs des Personnes Agees (Desrosiers et al., 1994)	TEMPA	To assess upper extremity performance in ADL	Y	Upper extremity injured	Time of tasks in seconds, functional rating, task analysis

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Instrument	Abbreviation	Purpose	Assess Bilateral Hand Use	Target Population	Range of Scores
South Hampton Assessment Procedure (Light et al., 2002)	SHAP	To assess hand function rather than dexterity	Y	Prosthetic Hand Function	Functional score
Sollerman Hand Function Test(O'Connor et al., 1999)	SHFT	To assess hand function in ADL	Y	Physically impaired person	Five point Score
Sequential Occupational Therapy Dexterity Assessment (van Lankveld et al., 1996)	SODA	To assess manual dexterity	Y	All types of hand injuries	3 point ability score, 3 point effort score, VAS score
Jebsen Taylor Hand Function Test (Jebsen et al., 1969)	JTHFT	To assess patient's functional capacities	Y	All types of hand injuries	Movement Times (sec)
Arthritis Hand function Test (Backman et al., 1991)	AHFT	To assess hand function	Y	Rheumatoid Arthritis	mmHg, kg, time number of lifted cans, mL poured water
Moberg Pick Up Test (Ng et al., 1999)	MPUT	To assess functional sensibility of the hand	N	Hand injuries with sensory deficits	Movement Times (sec)
O'neil Hand Function Assessment (O'Neill, 1995)	OHFA	To measure performance of the hand	N	All types of hand injuries	Movement Times (sec)
NK Hand Dexterity Test (Turgeon et al., 1999)	NKHDT	To assess hand dexterity	N	All types of hand injuries	Movement Times (sec)

Table 4 Study characteristics of the patient reported outcome measures based on Kleinlugtenbelt(Kleinlugtenbelt et al., 2016)

Measurement Instrument	Study	n	Mean Age (range or sd)	Gender Male (%)	Country	Language
Patient-Rated Wrist Evaluation	Gabl et al (Gabl et al., 2007)	133	62 (19 to 92)	27	Austria	German
	Hemelaers et al Hemelaers et al., 2008)	44	56 (15)	36	Switzerland	German
	Macdermid et al., (MacDermid et al., 1998)	36/101	45 (10) / 50 (16)	33 / 31	Canada	English
	Macdermid et al (MacDermid et al., 2000)	59	53 (18)	37	Canada	English
	Wilcke et al., (Wilcke et al., 2009)	99	58 (18)	20	Sweden	Swedish
	Lovgren et al., (Lövgren and Hellström, 2012)	16	52 (12)	19	Sweden	Swedish
	Mehta et al., (Mehta et al., 2012)	50	46 (14)	56	India	Hindi
	Kim et al., (Kim and Kang, 2013)	63	56 (19 to 83)	27	Rep. korea	Korean
	Schonnemann et al., (Schonnemann et al., 2013)	60/29	55 (19 to 86)	27	Denmark	Danish
	Walenkamp et al., (Walenkamp et al., 2015)	102	59 (48 to 66)	30	Netherlands	Dutch
Disabilities of Arm, Shoulder and Hand	Macdermid et al., (MacDermid et al., 2000)	59	53 (18)	37	Canada	English
	Westphal et al., (Westphal et al., 2001)	107	59 (17 to 84)	27	Germany	German
	Westphal et al., (Westphal, 2007)	72	60 (16)	29	Germany	German
	Lovgren et al., (Lövgren and Hellström, 2012)	16	52 (12)	19	Sweden	Swedish
Michigan Hand Questionnaire	Kotsis et al., (Kotsis et al., 2007)	47 / 37	48 (17) / 51(16)	32 / 38	USA	English
	Shauver et al., (Shauver and Chung, 2009)	51	50 (19 to 83)	37	USA	English
	Waljee et al., (Waljee et al., 2011)	128	61 (9)	27	USA/UK	English
Short Form-36	Amadio et al., (Amadio et al., 1996)	21	57 (14 to 84)	14	USA	English
	Macdermid et al., (MacDermid et al., 2000)	59	53 (18)	37	Canada	English
Patient Evaluation Measure	Forward et al., (Forward et al., 2007)	200	54 (24 to 80)	36	UK	English
Arthritis Impact Measurement Scale2	Amadio et al., (Amadio et al., 1996)	21	57 (14 to 84)	14	USA	English

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Measurement Instrument	Study	n	Mean Age (range or sd)	Gender Male (%)	Country	Language
Brigham and Women's Hospital Carpal Tunnel Questionnaire	Amadio et al., (Amadio et al., 1996)	21	57 (14 to 84)	14	USA	English
International Osteoporosis Foundation Wrist Fracture Questionnaire	Lips et al., (Lips et al., 1999)	105	63 (8)	12	UK/NL/ITA/BE	English/ Dutch/ Italian
Patient Focused Wrist Outcome Instrument	Bialocerkowski et al (Bialocerkowski et al., 2003)	26	62 (22 to 84)	15	Australia	English
Tampa Scale of Kinesophobia	Lovgren et al., (Lövgren and Hellström, 2012)	16	52 (12)	19	Sweden	Swedish
Catastrophizing Subscale of the Coping Strategies Questionnaire	Lovgren et al., (Lövgren and Hellström, 2012)	16	52 (12)	19	Sweden	Swedish
Self-efficacy Scale	Lovgren et al., (Lövgren and Hellström, 2012)	16	52 (12)	19	Sweden	Swedish

Table 5 Study characteristics of performace based measurements

Instrument	Author	Year	n	Study Sample	Gender	Mean Age
Functional Dexterity Test	Sartorio et al., (Sartorio et al., 2013)	2013	698	Healthy subjects	309 F 389 M	43±17
Purdue Pegboard Test	Buddenberg et al., (Buddenberg and Davis, 2000)	2000	47	Students	%70 F %30M	26
	Amirjani et al (Amirjani et al., 2011)	2011	312	190 subjects with Carpal Tunnel Syndrome 122 Healthy subjects	232 F 140 M	20-89 years
	Desrosiers et al (Desrosiers et al., 1995)	1995	360	Healthy older adults	-	60-89
	Shahar et al., (Shahar et al., 1998)	1998	97	54 post traumatic hand injury patients 43 healthy subjects	-	38.35
Grooved Pegboard Test	Ruff et al., (Ruff and Parker, 1993)	1993	360	Healthy subjects	120 F 120 M	12-50
Nine Hole Peg Test	Grice et al., (Grice et al., 2003)	2003	703	Healthy subjects	389 F, 314 M	21-71+
	Mathiowtez et al (Mathiowetz et al., 1985)	1985	618	Students, healthy subjects	310 F, 310 M	20-94
Rosenbuch Test of Finger Dexterity	Stein et al., (Stein and Yerxa, 1990)	1990	74	64 healthy subjects 10 subjects with disabilities affecting fine dexterity	39F 35 M	20-60 years
Box and Block Test	Mathiowetz et al., (Mathiowetz et al., 1985)	1985	628	Healthy subjects	318 F 310 M	20-94
	Desrosiers et al., (Desrosiers et al., 1994)	1994	104	Healthy subjects Older adults with sensorimotor impairment	62F 42 M	74.4
Minnesota Manual Dexterity Test	Desrosiers et al., (Desrosiers et al., 1997)	1997	264	Healthy older adults	144 F, 133 M	74.3±7.2

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Instrument	Author	Year	n	Study Sample	Gender	Mean Age
O'connor Functional Dexterity Test	Gloss at al. (Gloss and Wardle, 1981)	1981	96	Adults with permanent upper extremity impairment	18 F, 78 M	-
TEMPA	Umraw et al., (Umraw et al., 2004)	2004	20	Burn patients	%25 F %75 M	42.3
	Desrosiers et al., (Desrosiers et al., 1994)	1994	104	Older adults with different types of upper limb impairment	62F, 42 M	74.4±7.4
South Hampton Assessment Procedure	Light et al., (Light et al., 2002)	2002	24	Healthy students	-	18-25
Sollerman Hand Function Test	O'Connor et al., (O'Connor et al., 1999)	1999	25	Rheumatoid arthritis patients	14 F 11 M	70±7.7
	Weng et al., (Weng et al., 2010)	2010	12	Burn patients	5 F, 7 M	45.1±13.3
Sequential Occupational Therapy Dexterity Assessment	Massy Westroop et al., (Massy-Westropp et al., 2004)	2004	62	Rheumatoid arthritis patients	45 F, 17 M	65
	O'Connor et al., (O'Connor et al., 1999)	1999	25	Rheumatoid arthritis patients	14 F, 11 M	70
	vanLankveld et al., (van Lankveld et al., 1996)	1996	109	Rheumatoid arthritis patients	F/M 6/4	54.5±15
Jebsen Taylor Hand Function Test	Sears et al., (Sears and Chung, 2010)	2010	111	Adults with upper extremity impairment	-	-

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Instrument	Author	Year	n	Study Sample	Gender	Mean Age
Arthritis Hand Function Test	Poole et al., (Poole et al., 2000)	2000	20	Systemic Sclerosis patients	20 F	50.33±12.05
	Backman et al., (Backman and Mackie, 1997)	1997	26	Osteoarthritis patients	23 F 3 M	67
	Backman et al., (Backman et al., 1991)	1991	20	Rheumatoid arthritis patients	13 F 7 M	60.5±7.5
	Backman et al., (Backman and Mackie, 1995)	1995	30	Osteoarthritis and Rheumatoid arthritis patients	21 F, 9 M	57.5
Moberg Pick Up Test	Ng et al., (Ng et al., 1999)	1999	100	Healthy subjects	47 F, 53 M	11-77
	Amirjani et al., (Amirjani et al., 2011)	2011	278	162 subjects with Carpal Tunnel Syndrome 116 Healthy subjects	Carpal Tunnel Syndrome Subjects (120F, 42M) Healthy subjects (87F, 29M)	Carpal Tunnel Syndrome Subjects (20-89) Healthy subjects (20-86)
O'neil Hand Function Assessment	O'neill et al., (O'Neill, 1995)	1995	28	Healthy subjects	-	-
NK Hand Dexterity Test	Turgeon et al., (Turgeon et al., 1999)	1999	37	Healthy subjects	24 F 13 M	29±9
	Mac Dermid et al., (MacDermid and Mule, 2001)	2001	50	40 subjects with upper extremity disability 10 healthy subjects	25 F, 25 M	39.7

Table 6 Study characteristics of handgrip strength measurement systems

Instrument	Author	Year	n	Study Sample	Gender	Mean Age
Tekdyne Hand Dynamometer	Stephens et al., (Stephens et al., 1996)	1996	78	48 Healthy subjects 39 subjects with carpal Tunnel surgery	-	20-75
Jamar Hydrolic Hand Dynamometer	Smidt et al., (Smidt et al., 2002)	2002	50	50 subjects with lateral epicondylitis	%40 F, %60 M	47±11
	Peolsson et al., (Peolsson et al., 2001)	2001	45	32 Healthy subjects 13 subjects with cervical radiculopathy	24 F, 5M 6F, 6M	29±11 50±12
	Amaral et al., (Amaral et al., 2012)	2012	18	Healthy subjects	10 F, 8M	20.0♂1.3
	Mathiowetz et al., (Mathiowetz et al., 1984)	1984	27	Healthy subjects	27F	25
	Bohannon et al., (Bohannon and Schaubert, 2005)	2005	21	Healthy elderly	17 F, 4 M	75±5.9
	Lindstrom-Hazel et al., (Lindstrom-Hazel et al., 2009)	2009	73	Healthy subjects	-	-
	Mac Dermid et al., (MacDermid et al., 1994)	1994	38	Subjects with cumulative trauma disorder	-	41±14
	Hamilton et al., (Hamilton et al., 1994)	1994	33	Healthy subjects	16 F, 17 M	20-51
BTE Work Simulator	Beaton et al., (Beaton et al., 1995)	1995	14	Healthy subjects	-	20-46
Baseline Hydraulic Dynamometer	Mathiowetz et al., (Mathiowetz et al., 2000)	2000	80	Healthy subjects	40 F, 40 M	20-55
Sphygmomanometer	Hamilton et al., (Hamilton et al., 1992)	1992	29	Healthy subjects	29 F	29±4.9

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Instrument	Author	Year	n	Study Sample	Gender	Mean Age
Computerized Jamar Dynamometer	Niebuhr et al., (Niebuhr et al., 1994)	1994	33	Healthy subjects	28F, 5 M	24.4±5.4
	Kıng et al., (King, 2013)	2013	40	Healthy subjects	20 F, 20 M	20-50
	Svens et al (Svens and Lee, 2005)	2005	46	Healthy subjects	46 F	29.7
Rolyan Hydraulic Dynamometer	Mathiowetz et al., (Mathiowetz, 2002)	2002	60	Healthy subjects	30 F, 30 M	37.8
BTE- primus Grip Tool	Shechtman et al., (Shechtman et al., 2003)	2003	180	Healthy subjects	100F, 80 M	18-49
Dexter Hand Dynamometer	Brown et al., (Brown et al., 2000)	2000	30	Healthy subjects	22F, 8M	43±12.3
	Bellaca et al., (Bellace et al., 2000)	2000	62	Healthy subjects	-	18-50
DynEx Dynamometer	Shechtman et al., (Shechtman et al., 2005)	2005	100	Healthy subjects	50 F, 50 M	23.5±3.47
Lode hand grip dynamometer	Schreuders et al., (Schreuders et al., 2003)	2003	33	Subjects with hand injuries	20 F, 13 M	36±13.7
Takei digital, non-static handle dynamometer	Amaral et al (Amaral et al., 2012)	2012	18	Healthy subjects	10 F, 8M	20.0ƺ1.3
Biometrics E-LINK EP9 electronic dynamometer	Allen et al (Allen and Barnett, 2011)	2011	48	Healthy subjects	42F, 7M	18-25
MicroFET 4 hand-grip dynamometer	Bohannon et al., (Bohannon, 2006)	2006	30	Healthy subjects	16 F, 14M	38ƺ15.16
Grip ball Dynamometer	Chkeir et al., (Chkeir et al., 2012)	2012	16	Healthy subjects	6 F, 10 M	-
J-tech pinch gauge	Mac Dermid et al., (MacDermid et al., 2001)	2001	40	Subjects with hand injuries	19 F, 21 M	32

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Instrument	Author	Year	n	Study Sample	Gender	Mean Age
NK pinch gauge	Mac Dermid et al., (MacDermid et al., 2001)	2001	40	Subjects with hand injuries	19 F, 21 M	32
Jamar electronic pinch gauge	King et al., (King, 2013)	2013	40	Healthy subjects	20 F, 20 M	20-50
B&L Engineering Pinch Gauge	Lindstrom-Hazel et al., (Lindstrom-Hazel et al., 2009)	2009	73	Healthy subjects	-	-
	Mac Dermid et al., (MacDermid et al., 1994)	1994	37	Subjects with cumulative trauma disorder	-	41±14
	Mathiowetz et al., (Mathiowetz et al., 1984)	1984	27	Healthy subjects	27F	25
	Mac Dermid et al., (MacDermid et al., 2001)	2001	40	Subjects with hand injuries	19 F, 21 M	32
	Mathiowetz et al., (Mathiowetz et al., 2000)	2000	80	Healthy subjects	40 F, 40 M	20-55
Digitalized Pinch Dynamometer	Shin et al., (Shin et al., 2012)	2012	30	Healthy subjects	7F, 23 M	27.8
Digital strain gauge torsion dynamometer (MIE)	Miller et al., (Miller and Jerosch-Herold, 2013)	2013	36	Subjects with osteoarthritis of carpometacarpal joint	%68F, %32M	63±8.3

Table 7 The quality of of the studies for performance based outcome measures

Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Functional Dexterity Test	Sartorio et al., (Sartorio et al., 2013)	Test-retest reliability	324	ICC=0.92	+	Excellent	-
Purdue Pegboard Test	Buddenberg et al., (Buddenberg and Davis, 2000)	Test-retest reliability	47	ICC:0.51	-	Fair	Moderate sample size (30-49)
	Amirjani et al., (Amirjani et al., 2011)	Test-retest reliability	51	ICC:0.97	+	Good	Good sample size (50-99)
		Hypotheses testing	312	Correlation between PPT and Levine Self Assessment Questionnaire (r= -0.19 young, r=-0.20 middle aged, r=-0.33 elderly)	-	Good	Expected direction of the correlations or differences NOT stated
	Desrosiers et al., (Desrosiers et al., 1995)	Test-retest reliability	35	ICC:0.84	+	Fair	Moderate sample size (30-49)
	Shahar et al., (Shahar et al., 1998)	Hypotheses testing	54	Correlation between PPT and FDT (r=0.51dominant hand, r= 0.79 non dominant hand)	+	Fair	Hypotheses vague or not formulated but possible to deduce what was expected
Grooved Pegboard Test	Ruff et al., (Ruff and Parker, 1993)	Test-retest reliability	110	r= 0.72 Dominant hand r=0.74 non-dominant hand	-	Fair	Unclear if patients were stable
		Measurement error	55	SEM 6.6-6.8	?	Fair	Time interval NOT stated
Nine Hole Pegg Test	Grice et al., (Grice et al., 2003)	Test-retest reliability	25	r:0.49 rigth hand r:044 left hand	-	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	25	r:0.98 rigth hand r:0.99 left hand	+	Poor	Small sample size (< 30 per analysis)
	Mathiowtez et al., (Mathiowetz et al., 1985)	Test-retest reliability	26	r:0.69 rigth hand r:0.43 left hand	-	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	26	r:0.99 rigth hand r:0.99 left hand	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	26	Correlation between NHPT and PPT (r=-0.61 rigth hand, r=-0.53left hand)	+	Poor	Small sample size (< 30 per analysis)

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Rosenbuch Test of Finger Dexterity	Stein et al., (Stein and Yerxa, 1990)	Internal consistency	74	Coefficient α=0.93 Dominant hand Coefficient α=0.87non- Dominant hand Coefficient α=0.96 dysfunctional hand	+	Poor	Factor analysis NOT performed and no reference to another study
		Test-retest reliability	13	r:0.93	+	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	10	r=0.97	+	Poor	Small sample size (< 30 per analysis)
		Content validity		%100 agreement of the expert comitee	+	Poor	NOT assessed if all items are relevant for the study population OR target population not involved
Box and Block Test	Mathiowetz et al., (Mathiowetz et al., 1985)	Interrater reliability	27	Rho= 1 rigth hand Rho=0.99 left hand	+	Poor	Small sample size (< 30 per analysis)
	Desrosiers et al., (Desrosiers et al., 1994)	Test-retest reliability	35	ICC:0.90 rigth hand able bodies ICC:0.89 left hand able bodies ICC:0.97 rigth hand subjects with impairment ICC:0.96 left hand subjects with impairment	+	Fair	Moderate sample size (30-49)
		Hypotheses testing	104	Correlation between BBT and Functional Autonomy Measurement System (*r*=-0.47 rigth hand, *r*=-0.51 left hand)with Action Research Arm test(*r*=-0.80 rigth hand, *r*=-0.82left hand)	-	Good	Expected magnitude of the correlations or differences NOT stated
Minnesota Manual Dexterity Test	Desrosiers et al., (Desrosiers et al., 1997)	Test-retest reliability	35	ICC=-0.88 rigth hand ICC= -0.83 left hand ICC= 0.79 turning	+	Fair	Moderate sample size (30-49)
		Hypotheses testing	44	Correlation between MMDT and PPT(*r*=-0.64 rigth hand, *r*=-0.67 left hand, *r*=-0.63 turning) with BBT (*r*=-0.63 rigth hand, *r*=-0.67 left hand)	+	Fair	Moderate sample size (30-49)
O'connor Functional Dexterity Test	Gloss et al., (Gloss and Wardle, 1981)	Hypotheses testing	96	Correlation between OFDT and disability rating (*r*=0.69), with ADL subscale (*r*=0.88)	+	Fair	Hypotheses vague or not formulated but possible to deduce what was expected

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
TEMPA	Umraw et al., (Umraw et al., 2004)	Hypotheses testing	20	Correlation between TEMPA and Michigan Hand Outcomes Questionnaire (r=0.68)	+	Poor	Small sample size (< 30 per analysis)
	Desrosiers et al., (Desrosiers et al., 1994)	Hypotheses testing	104	Correlation between TEMPA and Action Research Arm Test Spearman correlation (r=-0.90-0.95), with BBT (r=0.73-0.78)	+	Good	Expected magnitude of the correlations or differences NOT stated
South Hampton Assessment Procedure	Light et al., (Light et al., 2002)	Test-retest reliability	18	Annova Test F value=0.39	?	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	24	Annova Test F value=2.65	?	Poor	Small sample size (< 30 per analysis)
		Content validity	24	Demostrated by a peer panel	?	Poor	Small sample size (< 30 per analysis)
Sollerman Hand Function Test	O'Connor et al., (O'Connor et al., 1999)	Interrater reliability	8	ICC:0.98	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	25	Correlation between Sollerman and SODA (r=0.79)	+	Poor	Small sample size (< 30 per analysis)
	Weng et al., (Weng et al., 2010)	Test-retest reliability	12	ICC:0.98	+	Poor	Small sample size (< 30 per analysis)
		Interrater Reliability	12	ICC:0.98	+	Poor	Small sample size (< 30 per analysis)
		Intra-rater reliability	12	ICC=0.98	+	Poor	Small sample size (<30)
		Hypotheses testing	12	Correlation between Sollerman and Total Range of Motion (r=0.68), with Grasp strength (r=0.52), with pinch strength (r=0.50)	+	Poor	Small sample size (< 30 per analysis)

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Sequential Occupational Therapy Dexterity Assessment	Massy Westroop et al., (Massy-Westropp et al., 2004)	Test-retest reliability	11	ICC:0.89	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	62	Correlation between SODA and Physical Function Scale of AUSCAN (r=0.81)	+	Fair	Hypotheses vague or not formulated but possible to deduce what was expected
	O'Connor et al., (O'Connor et al., 1999)	Interrater reliability	8	ICC:0.98	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	25	Correlation between SODA and SHFT (r=0.79)	+	Poor	Small sample size (< 30 per analysis)
	van Lankveld et al., (van Lankveld et al., 1996)	Test-retest reliability	22	Pearson correlation (r=0.93)	+	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	6	Kendall's coefficent of concordance W= 0.78	?	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	109	Correlation between SODA and duration of disease (r=0.21), with general level of disease activity as assessed with DAS (r=0.34), with grip strength (r=0.49),with the range of motion of wrist and fingers (r=-0.49 and 0.53)	-	Fair	Hypotheses vague or not formulated but possible to deduce what was expected
		Internal consistency	109	Alpha=0.91	+	Poor	Factor analysis NOT performed and no reference to another study
Jebsen Taylor Hand Function Test	Sears et al., (Sears and Chung, 2010)	Hypotheses testing	111	Correlation between JTHFT and Michigan Hand Outcomes Questionnaire (r=0.10-0.30 for rheumatoid artritis, r=0.56 for carpal tunnel syndrome patients)	_	Fair	Hypotheses vague or not ormulated but possible to deduce what was expected
		Responsiveness	111	Correlation between JTHFT and Michigan Hand Outcomes Questionnaire (AUC=0.52 for rheumatoid artritis, AUC=0.59 for distal Radius, AUC=0.66 carpal tunnel syndrome, AUC=0.58 CMC arthritis patients)	-	Fair	Unclear whether the criterion used can be considered an adequate gold standard

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Arthritis Hand Function Test	Poole et al., (Poole et al., 2000)	Test-retest reliability	20	ICC=0.80 to 0.97	+	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	20	ICC=0.99 to 1	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	20	Correlation between AHFT and Arthritis Impact Measurement Scale (r=-0.45-0.69)	-	Poor	Small sample size (< 30 per analysis)
	Backman et al., (Backman and Mackie, 1997)	Test-retest reliability	26	ICC=0.74to 0.96	+	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	26	ICC=0.99	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	26	Correlation between AHFT and Self reported physical ADLs (r=0.40-0.75 rigth hand, r=0.08 left hand) with Arthritis Impact Measurement Scale (r=0.71)	-	Poor	Small sample size (< 30 per analysis)
	Backman et al., (Backman et al., 1991)	Test-retest reliability	20	ICC=0.53to 0.95	-	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	20	ICC=0.89 to 1	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	20	Correlation between AHFT and JTHFT (r=0.63 rigth hand, 0.08 left hand), with Arthritis Impact Measurement Scale (r= 0.71)	_	Poor	Small sample size (< 30 per analysis)
	Backman et al., (Backman and Mackie, 1995)	Interrater reliability	30	r=0.45- 0.99	-	Fair	Moderate sample size (30-49)
Moberg Pick Up Test	Ng et al., (Ng et al., 1999)	Interrater reliability	14	r=0.60	-	Poor	Small sample size (< 30 per analysis)
	Amirjani et al., (Amirjani et al., 2011)	Test-retest Reliability	46	ICC=0.91	+	Fair	Moderate sample size (30-49)

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
O'neil Hand Function Assessment	O'neill et al., (O'Neill, 1995)	Test-retest reliability	22	r=0.82	+	Poor	Small sample size (< 30 per analysis)
		Interrater reliability	28	r=0.96 -0.99	+	Poor	Small sample size (< 30 per analysis)
		Content validity	55 OT	Through the methodology of a questionnaire, rank-ordering of tasks under these 7 grip classifications was performed by the therapists	+	Poor	NOT assessed if all items are relevant for the study population OR target population not involved
		Hypotheses testing	28	Correlation between OHFT and grip strength (*r*= 0.37), with pain (*r* 0.09), and with range of movement: finger flexion (*r* 0.18), finger extension (0.38), and thumb flexion (*r* 0.58); with the Nine-Hole Peg Test r=0.04 – 0.38	-	Poor	Small sample size (< 30 per analysis)
NK Hand Dexterity Test	Turgeon et al., (Turgeon et al., 1999)	Test-retest reliability	37	ICC=0.53- 0.86	-	Fair	Moderate sample size (30-49)
	Mac Dermid et al., (MacDermid and Mule, 2001)	Hypotheses testing	50	Correlation between NK and JTHFT (*r*=0.47-0.87)	-	Fair	Hypotheses vague or not formulated but possible to deduce what was expected

Table 8 The quality of of the studies of hand grip strength measurement systems

Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Tekdyne Hand Dynamometer	Stephens et al., (Stephens et al., 1996)	Test-retest reliability	30	ICC=0.97 dominant hand, 0.97 nondominant hand	+	Fair	Moderate sample size (30-49)
		Hypotheses testing	30	Correlation between Tekdyne Hand Dynamometer and Jamar Hydrolic Hand Dynamometer r=0.88	?	Fair	Moderate sample size (30-49)
		Measurement Eror	30	SEM=0.2	+	Fair	Moderate sample size (30-49)
Jamar Hydrolic Hand Dynamometer	Smidt et al., (Smidt et al., 2002)	Interrater reliability	50	ICC=0.72-0.98	+	Good	Good sample size (50-99)
	Peolsson et al., (Peolsson et al., 2001)	Intra-rater reliability	13	ICC=0.94-0.98	+	Poor	Small sample size (< 30 per analysis)
		Interrater Reliability	32	ICC=0.98 (rigth and left hand), r=0.85 (right index grip), r= 0.86 (left index grip)	+	Fair	Moderate sample size (30-49)
	Amaral et al., (Amaral et al., 2012)	Inter instrument reliability	18	ICC>0.80	+	Poor	Small sample size (< 30 per analysis)
	Mathiowetz et al., (Mathiowetz et al., 1984)	Test-retest Reliability	27	r>0.80	+	Poor	Small sample size (< 30 per analysis)
		Interrater Reliability	27	r>0.97	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	27	±5 %accuracy	?	Poor	Small sample size (< 30 per analysis)
	Bohannon et al., (Bohannon and Schaubert, 2005)	Test-retest Reliability	21	ICC=0.95 for rigth hand, 0.91 for left hand	+	Poor	Small sample size (< 30 per analysis)
	Lindstrom-Hazel et al., (Lindstrom-Hazel et al., 2009)	Interrater Reliability	73	ICC=0.99	+	Good	Good sample size (50-99)
	Mac Dermid et al., (MacDermid et al., 1994)	Interrater Reliability	38	ICC>0.85	+	Fair	Moderate sample size (30-49)
	Hamilton et al., (Hamilton et al., 1994)	Test-retest Reliability	33	ICC>0.93	+	Fair	Moderate sample size (30-49)

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
BTE Work Simulator	Beaton et al., (Beaton et al., 1995)	Hypotheses testing	14	Correlation between BTE Work Simulator and Jamar Hydrolic Hand Dynamometer r=0.87	+	Poor	Small sample size (< 30 per analysis)
Baseline Hydraulic Dynamometer	Mathiowetz et al., (Mathiowetz et al., 2000)	Inter instrument reliability	80	ICC>0.99	+	Good	Good sample size (50-99)
		Hypotheses testing	80	Correlation between Baseline Hydraulic Dynamometer and Jamar Hydrolic Hand Dynamometer r=0.99	+	Good	Good sample size (50-99)
Sphygmomanometer	Hamilton et al., (Hamilton et al., 1992)	Test-retest reliability	29	ICC=0.75	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	29	Correlation between Sphygmomanometer and Jamar Hydrolic Hand Dynamometer r=0.75	+	Poor	Small sample size (< 30 per analysis)
Computerized Jamar Dynamometer	Niebuhr et al., (Niebuhr et al., 1994)	Test-retest reliability	33	ICC=0.80-0.90	+	Fair	Moderate sample size (30-49)
	King et al. (King, 2013)	Inter instrument reliability	40	ICC=0.61 for men, 0.73 for women	-	Fair	Moderate sample size (30-49)
	Svens et al. (Svens and Lee, 2005)	Inra instrument reliability	23	ICC=0.99	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	23	Correlation between Computerized Jamar jamar and certified standard weights r=0.99	+	Poor	Small sample size (< 30 per analysis)
Rolyan Hydraulic Dynamometer	Mathiowetz et al., (Mathiowetz, 2002)	Inter instrument reliability	60	ICC=0.90 to =0.97	+	Good	Good sample size (50-99)
		Hypotheses testing	60	Correlation between Rolyan Hydraulic Dynamometer and Jamar Hydrolic Hand Dynamometer r=0.99	+	Good	Good sample size (50-99)
BTE- primus Grip Tool	Shechtman et al., (Shechtman et al., 2003)	Test-retest reliability	180	r=0.97 to 0.98	+	Excellent	
		Hypotheses testing	180	Correlation between BTE- primus Grip Tool and Jamar Hydrolic Hand Dynamometer r=0.95 to 0.96	+	Excellent	

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Dexter Hand Evaluation System	Brown et al., (Brown et al., 2000)	Interrater reliability	30	ICC= 0.89	+	Fair	Moderate sample size (30-49)
		Intrarater Reliability	30	ICC= 0.98-0.99	+	Fair	Moderate sample size (30-49)
		Hypotheses testing	30	P>0.55 (Annova)	?	Fair	Moderate sample size (30-49)
	Bellaca et al., (Bellace et al., 2000)	Hypotheses testing	62	Correlation between Dexter Hand Evaluation System and Jamar Hydrolic Hand Dynamometer r=0.99 dominant hand, to 0.98 non dominant hand	+	Fair	Hypotheses vague or not formulated but possible to deduce what was expected
DynEx Dynamometer	Shechtman et al., (Shechtman et al., 2005)	Test-retest reliability	100	ICC=0.98 (human subjects), ICC= 0.99 (known weigths)	+	Excellent	
		Interrater reliability	100	r= 1	+	Excellent	
		Hypotheses testing	100	Correlation between DynEx Dynamometer and Jamar Hydrolic Hand Dynamometer r= 0.98 (right and left Excellent hand)	+	Excellent	
Lode hand grip dynamometer	Schreuders et al., (Schreuders et al., 2003)	Measurement eror	33	SEM=4-29 N	?	Fair	Moderate sample size (30-49)
		Intrarater Reliability	33	ICC= 0.82 to 0.97	+	Fair	Moderate sample size (30-49)
		Interrater Reliability	33	ICC=0.82 to 0.97	+	Fair	Moderate sample size (30-49)
Takei digital, non-static handle dynamometer	Amaral et al., (Amaral et al., 2012)	Inter instrument reliability	18	ICC>0.8	+	Poor	Small sample size (< 30 per analysis)
Biometrics E-LINK EP9 electronic dynamometer	Allen et al., (Allen and Barnett, 2011)	Test-retest reliability	48	r = 0.99 rigth hand r = 0.98 left hand	+	Fair	Moderate sample size (30-49)
		Hypothesis Testing	48	r = 0.983; 0.986	+	Fair	Moderate sample size (30-49)

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
MicroFET 4 hand-grip dynamometer	Bohannon et al., (Bohannon, 2006)	Test-retest reliability	30	ICC>0.97	+	Fair	Moderate sample size (30-49)
Grip ball Dynamometer	Chkeir et al., (Chkeir et al., 2012)	Intrarater Reliability	16	ICC=0.95-0.98	+	Poor	Small sample size (< 30 per analysis)
		Hypothesis Testing	16	Correlation between Grip ball Dynamometer and Jamar Hydrolic Hand Dynamometer r=0.88	+	Poor	Small sample size (< 30 per analysis)
J-tech pinch gauge	Mac Dermid et al., (MacDermid et al., 2001)	Inter instrument reliability	40	ICC>0.90 for ptients, ICC>0.80 for asymptomatic group	+	Fair	Moderate sample size (30-49)
NK pinch gauge	Mac Dermid et al. (MacDermid et al., 2001)	Inter instrument reliability	40	ICC>0.90 for ptients, ICC>0.80 for asymptomatic group	+	Fair	Moderate sample size (30-49)
Jamar electronic pinch gauge	King et al., (King, 2013)	Inter instrument reliability	42	ICC=0.28 for men, 0.52 for women	-	Fair	Moderate sample size (30-49)
B&L Engineering Pinch Gauge	Lindstrom-Hazel et al., (Lindstrom-Hazel et al., 2009)	Interrater Reliability	73	ICC= 0.94	+	Good	Good sample size (50-99)
	Mac Dermid et al., (MacDermid et al., 1994)	Interrater Reliability	37	ICC>0.87	+	Fair	Moderate sample size (30-49)
	Mathiowetz et al., (Mathiowetz et al., 1984)	Test-retest Reliability	27	r>0.80	+	Poor	Small sample size (< 30 per analysis)
		Interrater Reliability	27	r>0.97	+	Poor	Small sample size (< 30 per analysis)
		Hypotheses testing	27	±1 %accuracy	?	Poor	Small sample size (< 30 per analysis)
	Mac Dermid et al., (MacDermid et al., 2001)	Inter instrument reliability	40	ICC>0.90 for aptients, ICC>0.80 for aspymthomatic group	+	Fair	Moderate sample size (30-49)
	Mathiowetz et al., (Mathiowetz et al., 2000)	Hypotheses testing	80	Correlation between B&L Engineering Pinch Gauge and Baseline pinch gauge r=0.99	+	Good	Good sample size (50-99)

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Outcome measure	Author	Evaluated measurement property	n	Results	Terwee Quality Rating	COSMIN Quality Rating	COSMIN 'Worst score' item
Digitalized Pinch Dynamometer	Shin et al., (Shin et al., 2012)	Inter instrument reliability	30	ICC=0.70-0.87	+	Fair	Moderate sample size (30-49)
		Interrater Reliability	30	ICC= 0.87-0.88	+	Fair	Moderate sample size (30-49)
		Intra-rater Reliability	30	ICC= 0.79-0.93	+	Fair	Moderate sample size (30-49)
Digital strain gauge torsion dynamometer (MIE)	Miller at al. (Miller and Jerosch-Herold, 2013)	Test-retest Reliability	36	ICC>0.90	+	Fair	Moderate sample size (30-49)
		Measurement Eror	36	SEM= 0.60	?	Fair	Moderate sample size (30-49)

Table 9 Summary of methodological quality of the studies on measurement properties of the PRWE and DASH based on Kleinlugtenbelt(Kleinlugtenbelt et al., 2016)

	PRWE (Gabl et al., 2007)	PRWE (Hemelaers et al., 2008)	PRWE (MacDermid et al., 1998)	PRWE (MacDermid et al., 2000)	PRWE (Wilcke et al., 2009)	PRWE (Lövgren and Hellström, 2012)	PRWE (Mehta et al., 2012)	PRWE (Schönnemann et al., 2013)	PRWE (Kim and Kang, 2013)	PRWE (Walenkamp et al., 2015)	DASH (MacDermid et al., 2000)	DASH (Westphal et al., 2001)	DASH (Westphal, 2007)	DASH (Lövgren and Hellström, 2012)
Generalisability	Fair	Fair	Fair	Poor	Fair	Excel	Poor	Fair	Fair	Fair	Poor	Fair	Good	Excel
Internal Consistency	Poor	Poor			Fair	Poor	Poor	Poor	Poor	Poor		Poor	Poor	Poor
Reliability		Fair	Poor		Fair	Poor	Fair	Poor	Fair				Fair	Poor
Measurement error									Fair	Poor				
Content Validity			Fair					Good						
Structural Validity														
Hypotheses testing		Fair			Good		Fair	Fair	Poor			Fair		
Cross-cultural					Fair		Poor	Poor	Poor					
Criterion Validity														
Responsiveness			Fair	Fair	Fair		Fair	Fair	Poor		Fair		Fair	
Interpretability					Poor				Poor		Poor	Poor		

Table 10 Summary of methodological quality of the studies on measurement properties of the other measurement instruments based on Kleinlugtenbelt(Kleinlugtenbelt et al., 2016)

	MHQ (Kotsis et al., 2007)	MHQ (Shauver and Chung, 2009)	MHQ (Shauver and Chung, 2009)	SF-36 (MacDermid et al., 2000)	SF-36 (Amadio et al., 1996)	PEM (Forward et al., 2007)	IOF (Lips et al., 1999)	PFW (Bialocerkowski et al., 2003)	AIMS2 (Amadio et al., 1996)	BWH-CTQ (Amadio et al., 1996)	TSK (Lövgren and Hellström, 2012)	CAT (Lövgren and Hellström, 2012)	SES (Lövgren and Hellström, 2012)
Generalisability	Fair	Fair	Poor	Poor	Fair	Poor	Fair	Fair	Fair	Fair	Excellent	Excellent	Excellent
Internal Consistency						Poor	Poor				Poor	Poor	Poor
Reliability							Poor				Poor	Poor	Poor
Measurement error													
Content Validity													
Structural Validity													
Hypotheses testing						Poor		Poor					
Cross-cultural													
Criterion Validity													
Responsiveness	Fair	Fair	Fair	Fair	Poor		Fair	Poor	Poor	Poor			
Interpretability		Fair											

Table 11 A summary of level of evidence of the measurement properties for performance based outcome measueres

		Measurement Property										
		Reliability				Validity						
		Internal consistency	Intrarater	Interrater	Test-retest	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
FDT	Level of evidence				Strong							
	Rating				+++							
	Reference				Sartorio et al., (Sartorio et al., 2013)							
PPT	Level of evidence				Conflicting					Conflicting		
	Rating				±					±		
	Reference				Buddenberg et al. (Buddenberg and Davis, 2000) Amirjani et al (Amirjani et al., 2011) Desrosiers et al. (Desrosiers et al., 1995)					Amirjani et al (Amirjani et al., 2011) Shahar et al. (Shahar et al., 1998)		
GPT	Level of evidence				Limited	Conflicting						
	Rating				-	±						
	Reference				Ruff et al., (Ruff and Parker, 1993)	Ruff et al. (Ruff and Parker, 1993)						

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		Measurement Property									
		Reliability				Validity					
		Internal consistency	Intrarater	Interrater	Test-retest	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
NHPT	Level of evidence			Unknown	Unknown					Unknown		
	Rating			?	?					?		
	Reference			Grice et al., (Grice et al., 2003) Mathiowtez et al., (Mathiowetz et al., 1985)	Grice et al., (Grice et al., 2003) Mathiowtez et al., (Mathiowetz et al., 1985)					Mathiowtez et al., (Mathiowetz et al., 1985)		
RTFD	Level of evidence	Unknown		Unknown	Unknown		Unknown					
	Rating	?		?	?		?					
	Reference	Stein et al. (Stein and Yerxa, 1990)		Stein et al. (Stein and Yerxa, 1990)	Stein et al. (Stein and Yerxa, 1990)		Stein et al. (Stein and Yerxa, 1990)					
BBT	Level of evidence			Unknown	Limited					Moderate		
	Rating			?	+					--		
	Reference			Mathiowetz et al., (Mathiowetz et al., 1985)	Desrosiers et al., (Desrosiers et al., 1994)					Desrosiers et al., (Desrosiers et al., 1994)		
MMDT	Level of evidence				Limited					Limited		
	Rating				+					+		
	Reference				Desrosiers et al., (Desrosiers et al., 1997)					Desrosiers et al., (Desrosiers et al., 1997)		

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		Measurement Property										
		Reliability				Validity						
		Internal consistency	Intrarater	Interrater	Test-retest	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
OFDT	Level of evidence									Limited		
	Rating									+		
	Reference									Gloss at al (Gloss and Wardle, 1981)		
TEMPA	Level of evidence									Moderate		
	Rating									++		
	Reference									Desrosiers et al., (Desrosiers et al., 1994) Umraw et al., (Umraw et al., 2004)		
SHAP	Level of evidence			Unknown	Unknown		Unknown					
	Rating			?	?		?					
	Reference			Light et al., (Light et al., 2002)	Light et al., (Light et al., 2002)		Light et al., (Light et al., 2002)					

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		Measurement Property										
		Reliability				Validity						
		Internal consistency	Intrarater	Interrater	Test-retest	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
SHFT	Level of evidence		Unknown	Unknown	Unknown					Unknown		
	Rating		?	?	?					?		
	Reference		Weng et al., (Weng et al., 2010)	O'Connor et al., (O'Connor et al., 1999) Weng et al., (Weng et al., 2010)	Weng et al., (Weng et al., 2010)					O'Connor et al., (O'Connor et al., 1999) Weng et al., (Weng et al., 2010)		
SODA	Level of evidence	Unknown		Unknown	Unknown					Conflicting		
	Rating	?		?	?					±		
	Reference	van Lankveld et al., (van Lankveld et al., 1996)		van Lankveld et al., (van Lankveld et al., 1996)	Massy Westroop et al., (Massy-Westropp et al., 2004) van Lankveld et al., (van Lankveld et al., 1996)					Massy Westroop et al., (Massy-Westropp et al., 2004) O'Connor et al., (O'Connor et al., 1999) van Lankveld et al., (van Lankveld et al., 1996)		

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	Measurement Property										
	Reliability				Validity						
		Internal consistency	Intrarater	Interrater	Test-retest	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
JTHFT	Level of evidence									Limited		Limited
	Rating									-		-
	Reference									Sears et al. (Sears and Chung, 2010)		Sears et al., (Sears and Chung, 2010)
AHFT	Level of evidence			Conflicting	Unknown					Unknown		
	Rating			±	?					?		
	Reference			Poole et al., (Poole et al., 2000) Backman and Mackie et al., (Backman and Mackie, 1997) Backman and Mackie et al., (Backman et al., 1991) Backman and Mackie et al., (Backman and Mackie, 1995)	Poole et al., (Poole et al., 2000) Backman and Mackie et al., (Backman and Mackie, 1997) Backman and Mackie et al., (Backman et al., 1991)					Poole et al., (Poole et al., 2000) Backman and Mackie et al., (Backman and Mackie, 1997) Backman and Mackie et al., (Backman et al., 1991)		

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	Measurement Property										
	Reliability				Validity						
		Internal consistency	Intrarater	Interrater	Test-retest	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
MPUT	Level of evidence			Unknown	Limited							
	Rating			?	+							
	Reference			Ng et al., (Ng et al., 1999)	Amirjani et al., (Amirjani et al., 2011)							
OHFA	Level of evidence			Unknown	Unknown		Unknown			Unknown		
	Rating			?	?		?			?		
	Reference			O'neill et al., (O'Neill, 1995)	O'neill et al., (O'Neill, 1995)		O'neill et al., (O'Neill, 1995)			O'neill et al., (O'Neill, 1995)		
NK	Level of evidence				Limited					Limited		
	Rating				-					-		
	Reference				Turgeon et al., (Turgeon et al., 1999)					Mac Dermid et al., (MacDermid et al., 2001)		

Table 12 A summary of level of evidence of the measurement properties for grip strength evaluation methods

		Measurement Property										
		Reliability					Validity					
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
Tekdyne Hand Dynamometer	Level of evidence				Limited		Conflicting				Limited		
	Rating				+		±				+		
	Reference				Stephens et al., (Stephens et al., 1996)		Stephens et al., (Stephens et al., 1996)				Stephens et al.(Stephens et al., 1996)		
Jamar Hydrolic Hand Dynamometer	Level of evidence	Unknown	Strong	Limited	Unknown						Unknown		
	Rating	?	+++	+	?						?		
	Reference	Peolsson et al., (Peolsson et al., 2001)	Smidt et al., (Smidt et al., 2002) Peolsson et al., (Peolsson et al., 2001) Mathiowetz et al., (Mathiowetz et al., 1984) Lindstrom-Hazel et al., (Lindstrom-Hazel et al., 2009) Mac Dermid et al., (MacDermid et al., 1994)	Mathiowetz et al., (Mathiowetz et al., 1984) Bohannon et al., (Bohannon and Schaubert, 2005) Hamilton et al., (Hamilton et al., 1994)	Amaral et al., (Amaral et al., 2012)					Mathiowetz et al., (Mathiowetz et al., 1984)		

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		Measurement Property												
		Reliability						Validity						
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument		Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
BTE Work Simulator	Level of evidence											Unknown		
	Rating											?		
	Reference											Beaton et al., (Beaton et al., 1995)		
Baseline Hydraulic Dynamometer	Level of evidence					Moderate						Moderate		
	Rating					++						++		
	Reference					Mathiowetz et al., (Mathiowetz et al., 2000)						Mathiowetz et al., (Mathiowetz et al., 2000)		
Sphygmomanometer	Level of evidence				Unknown							Unknown		
	Rating				?							?		
	Reference				Hamilton et al., (Hamilton et al., 1992)							Hamilton et al., (Hamilton et al., 1992)		
Computerized Jamar Dynamometer	Level of evidence				Limited	Uk/Limited						Limited		
	Rating				+	?/-						+		
	Reference				Niebuhr et al., (Niebuhr et al., 1994)	Svens et al., (Svens and Lee, 2005) Kıng et al. (King, 2013)						Svens et al. (Svens and Lee, 2005)		

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		Measurement Property											
		Reliability					Validity						
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
Rolyan Hydraulic Dynamometer	Level of evidence					Moderate					Moderate		
	Rating					+					+		
	Reference					Mathiowetz et al., (Mathiowetz, 2002)					Mathiowetz et al., (Mathiowetz, 2002)		
BTE- primus Grip Tool	Level of evidence				Strong						Strong		
	Rating				+++						+++		
	Reference				Shechtman et al., (Shechtman et al., 2003)						Shechtman et al., (Shechtman et al., 2003)		
Dexter Hand Evaluation System	Level of evidence	Limited	Limited								Moderate		
	Rating	+	+								++		
	Reference	Brown et al., (Brown et al., 2000)	Brown et al., (Brown et al., 2000)								Brown et al., (Brown et al., 2000) Bellaca et al., (Bellace et al., 2000)		

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		Measurement Property										
		Reliability					Validity					
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
DynEx Dynamometer	Level of evidence			Strong	Strong						Strong		
	Rating			+++	+++						+++		
	Reference			Shechtman et al., (Shechtman et al., 2005)	Shechtman et al., (Shechtman et al., 2005)						Shechtman et al., (Shechtman et al., 2005)		
Lode hand grip dynamometer	Level of evidence		Limited	Limited			Conflicting						
	Rating		+	+			±						
	Reference		Schreuders et al., (Schreuders et al., 2003)	Schreuders et al., (Schreuders et al., 2003)			Schreuders et al., (Schreuders et al., 2003)						
Takei digital,non-static handle dynamometer	Level of evidence					Unknown							
	Rating					?							
	Reference					Amaral et al., (Amaral et al., 2012)							
Biometrics E-LINK EP9 electronic dynamometer	Level of evidence				Limited						Limited		
	Rating				+						+		
	Reference				Allen et al., (Allen and Barnett, 2011)						Allen et al., (Allen and Barnett, 2011)		

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		Measurement Property											
		Reliability					Validity						
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
MicroFET 4 hand-grip dynamometer	Level of evidence				Limited								
	Rating				+								
	Reference				Bohannon et al., (Bohannon, 2006)								
Grip ball Dynamometer	Level of evidence		Unknown								Unknown		
	Rating		?								?		
	Reference		Chkeir et al., (Chkeir et al., 2012)								Chkeir et al., (Chkeir et al., 2012)		
J-tech pinch gauge	Level of evidence					Limited							
	Rating					+							
	Reference					Mac Dermid et al., (MacDermid et al., 2001)							
NK pinch gauge	Level of evidence					Limited							
	Rating					+							
	Reference					Mac Dermid et al., (MacDermid et al., 2001)							

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		Measurement Property										
		Reliability					Validity					
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
Jamar electronic pinch gauge	Level of evidence					Limited							
	Rating					-							
	Reference					King et al., (King, 2013)							
B&L Engineering Pinch Gauge	Level of evidence			Modarate	Unknown	Limited					Strong		
	Rating			++	?	+					+++		
	Reference			Lindstrom-Hazel et al., (Lindstrom-Hazel et al., 2009) Mathiowetz et al., (Mathiowetz et al., 1984) Mac Dermid et al., (MacDermid et al., 1994)	Mathiowetz et al., (Mathiowetz et al., 1984)	Mac Dermid et al., (MacDermid et al., 2001)					Mathiowetz et al., (Mathiowetz et al., 1984) Mathiowetz et al., (Mathiowetz et al., 2000)		
Digitalized Pinch Dynamometer	Level of evidence	Limited		Limited		Limited							
	Rating	+		+		+							
	Reference	Shin et al., (Shin et al., 2012)		Shin et al., (Shin et al., 2012)		Shin et al., (Shin et al., 2012)							

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		Measurement Property												
		Reliability					Validity							
		Internal consistency	Intra rater	Inter Rater	Test-retest	Inter-intra instrument	Measurement error	Content	Construct	Structural validity	Hypotheses testing	Criterion	Responsiveness
Digital strain gauge torsion dynamometer (MIE)	Level of evidence				Limited		Conflicting							
	Rating				+		±							
	Reference				Miller et al. (Miller and Jerosch-Herold, 2013)		Miller at al. (Miller and Jerosch-Herold, 2013)							

Table 13 Ratings of measurement properties and interpretability of measurement instruments with level of evidence based on Kleinlugtenbelt(Kleinlugtenbelt et al., 2016)

	PRWE (Gabl et al., 2007; Hemelaers et al., 2008; Kim and Kang, 2013; Lövgren and Hellström, 2012; MacDermid et al., 2000; MacDermid et al., 1998; Mehta et al., 2012; Schönnemann et al., 2013; Walenkamp et al., 2015; Wilcke et al., 2009)	DASH (Lövgren and Hellström, 2012; MacDermid et al., 2000; Westphal et al., 2007; Westphal et al., 2001)	MHQ (Kotsis et al., 2007; Shauver and Chung, 2009; Waljee et al., 2011)	SF-36 (Amadio et al., 1996; MacDermid et al., 2000)	PEM (Forward et al., 2007)	AIMS2 (Amadio et al., 1996)	-BWH-CTQ (Amadio et al., 1996)	PFW (Bialocerkowski et al., 2003)	IOF (Lips et al., 1999)	TSK (Lövgren and Hellström, 2012)	CAT (Lövgren and Hellström, 2012)	SES (Lövgren and Hellström, 2012)
Reliability												
Internal Consistency	+	?		?		?		?	?	?	?	?
Cronbach's alpha	0.89 to 0.97	0.93 to 0.98		0.94		0.96		0.68 to 0.82	0.88 to 0.97	0.79 to 0.95		
Reliability	++	+				?		?	?	?		
Intraclass correlation cofficient	0.81 to 0.97	0.78 to 0.95				NA		0.81 to 0.84	0.85 to 0.89	0.57 to 0.86		
Measurement error	+											
Smallest detectable change	4.4 to 11.0											
Validity												
Content Validity	++											
Structural validity												
Hypotheses testing	++	+		?				?				
Comparator instrument	DASH	Gartland		NA				NA				
Cross-cultural	+											

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SES **(Lövgren and Hellström, 2012)**									
CAT **(Lövgren and Hellström, 2012)**									
TSK **(Lövgren and Hellström, 2012)**									
PFW **(Bialocerkowski et al., 2003)**									
IOF **(Lips et al., 1999)**									
-BWH-CTQ (Amadio et al., 1996)									
AIMS2 **(Amadio et al., 1996)**									
PEM **(Forward et al., 2007)**									
SF-36 **(Amadio et al., 1996; MacDermid et al., 2000)**									
MHQ (Kotsis et al., 2007; Shauver and Chung, 2009; Waljee et al., 2011)									
DASH **(Lövgren and Hellström, 2012; MacDermid et al., 2000; Westphal, 2007; Westphal et al., 2001)**									
PRWE **(Gabl et al., 2007; Hemelaers et al., 2008; Kim and Kang, 2013; Lövgren and Hellström, 2012; MacDermid et al., 2000; MacDermid et al., 1998; Mehta et al., 2012; Schönnemann et al., 2013; Walenkamp et al., 2015; Wilcke et al., 2009)**									
Criterion validity									
Responsiveness									
Responsiveness	++		++	++	+	?	?	+	?
Standardised response mean	NA		NA	NA	NA	NA	NA	NA	NA
INTERPRETABILITY									
Interpretability	?								
Minimal important change	11.5								

Abbreviations	Full name
PRWE	Patient-Rated Wrist Evaluation
DASH	Disabilities of Arm, Shoulder and Hand
MHQ	Michigan hand Questionnaire
SF-36	Short Form-36
PEM	Patient Evaluation Measure
AIMS2	Arthritis Impact Measurement Scale
BWH-CTQ	Brigham and Women's Hospital Carpal Tunnel Questionnaire
IOF-WFQ	International Osteoporosis Foundation Wrist Fracture Questionnaire
PFW	Patient Focused wrist outcome Instrument
TSK	Tampa Scale of Kinesophobia
CAT	Catastrophizing Subscale of the Coping Strategies Questionnaire
SES	Self-Efficacy Scale
FDT	Functional Dexterity Test
PPT	Purdue Pegboard Test
GPT	Grooved Pegboard Test
NHPT	Nine Hole Peg Test
RTFD	Rosenbuch Test of Finger Dexterity
BBT	Box and Block Test
MMDT	Minnesota Manual Dexterity Test
OFDT	O'Cconor Functional Dexterity Test
TEMPA	Test evaluant la performance des Membres superieurs des Personnes Agees
SHAP	South Hampton Assessment Procedure
SHFT	Sollerman Hand Function Test
SODA	Sequential Occupational Therapy Dexterity Assessment
JTHFT	Jebsen Taylor Hand Function Test
AHFT	Arthritis Hand function Test
MPUT	Moberg Pick Up Test
OHFA	O'neil Hand Function Assessment
NKHDT	NK Hand Dexterity Test

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CHAPTER 2

CONGENITAL HAND PROBLEMS

2.1 Congenital Hand Surgery

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Introduction

This chapter considers some, but not all, of the more common congenital hand and upper limb anomaly presentations. By no means is the chapter intended to be exhaustive of all conditions.

There is some controversy as to whether trigger thumb is a congenital or acquired condition. Indeed, most now refer to it as paediatric trigger thumb. Nevertheless, as will be seen, the evidence is perhaps less than fully compelling and it remains a subject for which an alternative to surgery may be reasonably considered. It is included to seek evidence for and against operative and non-operative treatments.

Syndactyly, along with polydactyly, is one of the two most common congenital hand presentations. This review of evidence based medicine deals with simple and complex syndactylies alone, seeking evidence for the benefit of one skin incision method over another; and whether there is any substantial evidence which indicates that the use or not of skin grafting is superior.

Thumb polydactyly is common, more so in the Asian races. The aim of surgery, as with all thumb reconstructions, is to create a thumb of adequate size and shape, stability and motion, and strength. At times, there is a conflict between some of these parameters, particularly stability and motion. Techniques to obtain optimal results and the methods used to assess outcomes are considered in this sub-chapter.

Radial longitudinal deficiencies have long fascinated the congenital hand and upper limb surgeon. Three sub-chapters deal with reconstruction of the hypoplastic thumb; pollicisation of the index finger to replace an absent or severely hypoplastic thumb; and the methods of dealing with hypoplasia or aplasia of the radius. As with many congenital conditions, normal function and appearance are often beyond our best efforts.

There are a number of problems relating to the assessment of function in children presenting with congenital hand and upper limb anomalies (CAHUL), not the least being the small number of cases presenting to any one individual surgeon or department. This chapter considers the evidence which is present in the literature to determine whether any methods of management are superior to others.

TRIGGER THUMB

Jihyeung KIM, Goo Hyun BAEK

Introduction

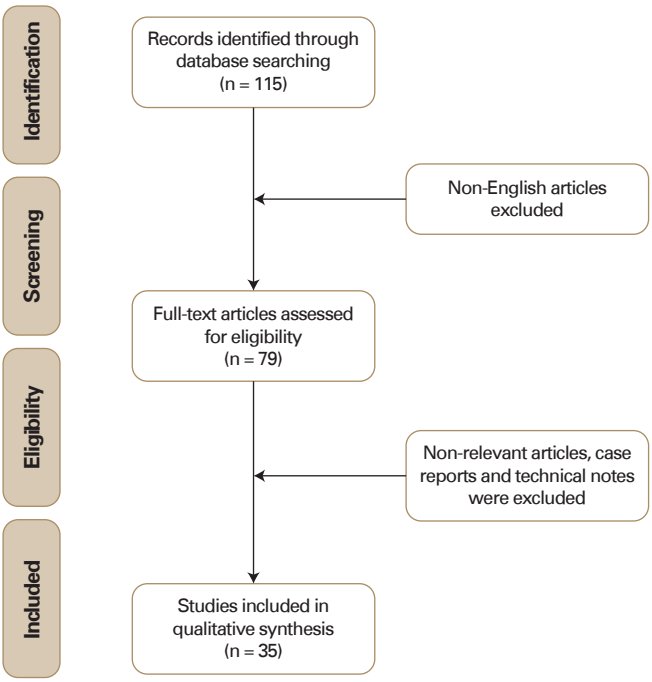
Paediatric trigger thumb is a stenosing condition of the flexor pollicis longus (FPL) tendon under the A1 pulley and exhibits triggering, flexion deformity of the thumb interphalangeal (IP) joint, or snapping movement of the thumb. The incidence has been estimated as 0.5-3.3 cases per 1,000 live births (Ger et al., 1991; Kikuchi and Ogino, 2006; Rodgers and Waters, 1994). There is a higher incidence of trigger thumb in the Hispanic population, and lower incidence among blacks (Ashford and Bidic, 2009).

Patients most commonly presented at the age of 2 years (Baek et al., 2008; Dinham and Meggitt, 1974; Marek et al., 2011; Slakey and Hennrikus, 1996; Tan et al., 2002), and approximately 25-33% of patients showed bilateral involvement (Baek et al., 2008; Dinham and Meggitt, 1974; Marek et al., 2011). The right and left sides are equally affected in the unilateral cases, and boys and girls are equally affected (Ashford and Bidic, 2009; Dinham and Meggitt, 1974; Tan et al., 2002).

Systematic Review

We conducted an online systematic literature search in accordance with the PRISMA statement. We searched for articles using PubMed and medical subject headings (MeSHs) used were “trigger thumb” and “child”. We assessed the titles and abstracts of all retrieved articles for suitability for inclusion in the review using the following criteria; (1) studies for human children in English, (2) randomized trials, uncontrolled comparative trials, or case series of pediatric trigger thumb. Case reports and technical notes were excluded in this review. Figure 1 is a flowchart of included articles.

Figure 1 Flowchart of search results



Results

Etiology

There have been controversies as to whether it is a congenital or acquired condition. In 1974, Dinham and Meggitt reported that there were 19 patients who had trigger thumb at birth among the 105 patients. However, several neonatal survey studies supported the contention that pediatric trigger thumb is an acquired condition. There were no cases with congenitally trigger digits or Notta's nodules in the neonatal survey of the 1,046 infants (Rodgers and Waters, 1994). Likewise, there were also no cases with trigger thumb among 4,719 newborns (Slakey and Hennrikus, 1996). In a consecutive series of 7,700 neonates, there were no cases with paediatric trigger thumb at birth, and 35 trigger thumbs developed during follow-up (Moon et al., 2001). Kikuchi and Ogino (2006) examined 1,116 babies born at their institution within 14 days after birth and trigger thumb was not identified in any patient at

birth. Tan et al., (2002) reported that the onset of trigger thumb ranged from 3 months to 10.2 years. Currently, it is widely accepted as an acquired condition; the diagnosis has been changed from "congenital trigger thumb" to "pediatric trigger thumb". Buchman et al., (1999) reported the findings of transmission electron microscopic examinations of the tendon sheath and the tendon nodule. They observed large amounts of mature collagen and fibroblasts but detected no degenerative or inflammatory changes in the tendon or sheath. They concluded that those findings do not support an infectious, inflammatory, or degenerative aetiology.

Natural History

There are several reports which described the natural history of pediatric trigger thumb (Table 1).

Table 1 Natural history of the pediatric trigger thumb

Authors	Duration of observation	Spontaneous resolution rate
Dinham and Meggitt	More than 6 months	12%
Mulpruek and Prichasuk	3 months	24%
Dunsmuir and Sherlock		49%
Baek et al.	Minimum 2 years	63%
Baek and Lee	Minimum 5 years	76%

In 1956, Wilks stated that "in mild cases there is often spontaneous improvement". Dinham and Meggitt (1974) retrospectively reviewed 105 patients with trigger thumb. In this study, 8 (31%) resolved spontaneously among 26 patients with trigger thumb presented at birth, and 13 (12%) resolved spontaneously during at least 6 months of observation among 107 patients with trigger thumb first noticed between the age of 6 to 30 months. Mulpruek and Prichasuk (1998) reported that 10 patients (24%) had spontaneous recovery within 3 months of their initial visit among 42 children with trigger thumb. Dunsmuir and Sherlock (2000) reported a rate of spontaneous recovery of 49% in children with trigger thumb. Spontaneous recovery occurred more commonly in children over 12 months old. In the first prospective observational study of paediatric trigger thumb, Baek et al., (2008) reported that

45 (63%) out of 71 trigger thumbs resolved spontaneously. The median time from the initial visit to resolution was 48 months. Although resolution was not observed in the remaining 26 thumbs, flexion deformities improved in 23 (88%) thumbs. Baek and Lee (2011) also reported a 76% spontaneous resolution rate among the patients with a minimum of five years follow-up.

Management

Although there is still controversy in the treatment of paediatric trigger thumb, treatment modalities have changed from operative treatment only to simple observation or conservative treatment combined with operative treatment. In 1974, Dinham and Meggitt asserted that operative treatment should be performed before the age of four years to prevent the creation of residual flexion deformities. However, Skov et al., (1990) concluded that the risk of residual flexion deformity was no higher following operations conducted in patients who were more than three years old. Han et al., (2010) reported that the surgical treatment with A1 pulley release for those children over 5 years of age resulted in successful resolution of trigger thumb and satisfactory clinical outcome in all patients. These studies support initial non-operative treatment regardless of age. Chalise et al., (2013) compared the results of conservative and surgical treatments for trigger thumb in children. The overall success rate was 72% following conservative treatment. Following surgical treatment it was 92% with a recurrence rate of 8% and wound infection rate of 4%. They concluded that trying conservative methods to get a higher chance of recovery is reasonable before elective surgery because the surgery was not urgent and postponing surgery did not interfere with the result. Farr et al., (2014) performed a systematic review of open surgery versus non-operative treatments for paediatric trigger thumb. In the review, full IP joint motion without residual triggering was achieved in 95% of all children undergoing surgery, in 67% of children treated with continuous splinting, and 55% after passive stretching. They concluded that open surgery resulted in more reliable and rapid outcomes compared with non-operative treatment.

Conservative managements

Conservative treatments of paediatric trigger thumb include splinting or stretching exercises (Table 2) (Forlin et al., 2012; Jung et al., 2012; Koh et al., 2012; Lee et al., 2006; Nemoto et al., 1996; Watanabe et al., 2001).

Table 2 The results of conservative treatments

Authors	Level of evidence	Methods	Improvement	Full recovery
Nemoto et al.	Level IV	Splinting		73%
Watanabe et al.	Level IV	Stretching	97%	41%
Lee et al.	Level III	Splinting	71%	
Jung et al.	Level III	Stretching	97%	
Koh et al.	Level III	Splinting		92%
Forlin et al.	Level IV	Stretching	77%	54%

Nemoto et al., (1996) described night time IP joint extension splinting in 40 trigger thumbs. The duration of splint application ranged from 1 to 30 months, with a mean of 10 months. Although the success rate was 73%, eight patients who did not tolerate splinting were excluded from the analysis of the success rate. Watanabe et al., (2001) reported 58 thumbs in 46 children treated with passive extension exercises performed by their mothers. Although 56 thumbs (97%) out of 58 thumbs showed a satisfactory result, only 24 thumbs (41%) showed complete recovery. Jung et al., (2012) reported the outcome of passive stretching exercise 10-20 times per day. In this study, 34 thumbs (97%) out of 35 thumbs showed improvement of the grade of trigger thumb severity. Forlin et al., (2012) presented the outcome of stretching exercises in 13 thumbs of 11 children. Ten thumbs (77%) showed satisfactory results; the mean time taken from diagnosis to clinical improvement was 21 months. Lee et al., (2006) compared the results of extension splinting and simple observation. The splint was applied all day for 6 to 12 weeks and then changed to night splinting. The response rate (cured or improved) was 71% in the splint group and 23% in the observation group. Koh et al., (2012) also compared the outcomes of splinting and simple observation in 64 patients with

trigger thumb. In the splint group, 92% of the patients experienced complete symptom relief within 22 months, whereas 60% resolved completely within 59 months in the observation group.

Surgical managements

Surgical release of the A1 pulley is a safe and effective treatment option (Table 3).

Table 3 The results of surgical treatments

Authors	Level of evidence	Techniques	Number of thumbs	Success rate	Complications or Recurrence
Skov et al.	Therapeutic IV	Open	47	100%	
McAdams et al.	Therapeutic IV	Open	30		No recurrence of triggering or nodules and no functional deficit
Li et al.	Therapeutic IV	Open	7	100%	
Kuo and Rayan	Therapeutic IV	Open	20	95%	5 thumbs had an average of 12° less active IP joint motion without flexion contracture.
Han et al.	Therapeutic IV	Open	31	100%	
Leung et al.	Therapeutic IV	Open	209	95%	Residual flexion deformity (4%)
Marek et al.	Therapeutic IV	Open	217	100%	Four thumbs had minor complications (superficial infection and wound dehiscenece).
Eamsobhana et al.	Therapeutic IV	Open	21	95%	One thumb had recurrent triggering after 60 months.
Wang and Lin	Therapeutic IV	Percutaneous	40	90%	
Ruiz-Iban et al.	Therapeutic IV	Percutaneous	27	96%	One thumb relapsed and required subsequent open surgery.
Sevencan et al.	Therapeutic IV	Percutaneous	31	97%	Recurrence was seen in 1 thumb at postoperative 3 weeks.
Masquijo et al.	Therapeutic II	Percutaneous	20	70%	
Wang and Lin	Therapeutic III	Percutaneous	40	90%	
		Open	32	100%	

Ger et al., (1991) reviewed 41 patients with 53 trigger thumbs and concluded that all patients eventually required surgical release of the FPL tendon. Tan et al., (2002) reported surgical outcomes of 59 children who underwent surgery. The outcome was good with a recurrence rate of 1.4% and a wound infection rate of 2.8%. Marek et al., (2011) retrospectively reviewed 173 patients with 217 thumbs who underwent surgical treatment. There were no major complications or recurrences identified although five thumbs (2.3%) developed minor skin complications. McAdams et al., (2002) re-examined 30 thumbs in 21 patients who underwent a release of the A1 pulley and reported that there was no recurrence of triggering or nodules and no functional deficit. Because all patients who had a longitudinal incision had concerns about the scar appearance, they recommended a transverse incision for A1 pulley release. Likewise, Leung et al., (2011) reported that more than 95% of the operated thumbs with a transverse incision acquired a good range of movement with a scarcely apparent scar. Van Loveren and van der Biezen (2007) claimed that the division of just the A1 pulley at the metacarpal head was sufficient to relieve triggering in only 3 (19%) of the 16 thumbs. The stenosis was found to be more distal to the classic A1 pulley in 11 thumbs (69%), and a separate annular pulley was found in two thumbs (13%). They suggested that a separate pulley system or more distal stenotic lesion, if present, should be released to allow for free FPL excursion. Eamsobhana et al., (2014) and Kuo and Rayan (2010) asserted that release of 50% of the oblique pulley can be needed in patients who were not corrected after A1 pulley release. Although several authors suggested percutaneous release for trigger thumb (Ruiz-Iban et al., 2006; Sevencan et al., 2010; Wang and Lin, 2004; Wang and Lin, 2005), Masquijo et al., (2014) did not recommend percutaneous release because of the risk of iatrogenic neurovascular injury or incomplete release of the A1 pulley.

Discussion

A number of studies have supported the contention that the paediatric trigger thumb is an acquired condition (Kikuchi and Ogino,

2006; Moon et al., 2001; Rodgers and Waters, 1994; Slakey and Hennrikus, 1996; Tan et al., 2002). The spontaneous resolution rate has been reported as 12-76% in the studies of the natural history of this condition (Baek et al., 2008; Baek and Lee, 2011; Dinham and Meggitt, 1974; Dunsmuir and Sherlock, 2000; Mulpruek and Prichasuk, 1998). However, the pathogenesis of paediatric trigger thumb and the process of resolution have not been verified. In addition, the prognostic factors of paediatric trigger thumb have not been revealed. Although the flexion deformity of the IP joint is the characteristic finding in patients with paediatric trigger thumb, hyperextension of the metacarpophalangeal (MCP) joint is frequently observed. Li et al., (2009) presented volar plate advancement in addition to the A1 pulley release to correct the hyperextension tendency of the MCP joint. Because it can be a compensatory deformity of the IP joint flexion, there remains doubt about whether we should correct the hyperextension tendency.

The outcome of the conservative treatments, such as splinting and stretching exercises, have shown excellent results in the many studies (Forlin et al., 2012; Jung et al., 2012; Koh et al., 2012; Lee et al., 2006; Nemoto et al., 1996; Watanabe et al., 2001). However, the compliance with these conservative managements and their effects on the relationship between child and parents should be evaluated in future research. Furthermore, high-quality randomized trials or prospective studies seem to be needed to assess whether these conservative treatments can indeed decrease the duration of the condition.

It is indisputable from the preceding reports of surgical results that A1 pulley release is a safe and effective management for paediatric trigger thumb. However, when considering the natural history of this condition, it is clear that all patients do not need surgical treatment. As there is evidence that delaying surgery until over 5 years of age results in no residual deformity of the IP joint (Han et al., 2010), it is reasonable to suggest simple observation or conservative treatment as a first line treatment option for paediatric trigger thumb. The duration of conservative treatment has not been established. It may be influenced by several factors, such

as medical expenses, insurance system, economic status, cultural background, patience of parents, and functional discomfort of the patients. Therefore, it is appropriate to provide sufficient information about the natural history of pediatric trigger thumb and the success rate of each treatment option to the parents.

KEY POINTS

- Paediatric trigger thumb appears to be an acquired condition
- Surgical release of the A1 pulley is safe and effective
- Conservative treatment - observation, splinting and stretching - results in correction in a significant number of cases
- Delay of surgery until 5 years of age, minimally, does not compromise correction of deformity

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SYNDACTYLY

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Introduction

Syndactyly release is one of the most common procedures in congenital hand surgery. The aim is to create an adequate neo-commissure, and to separate the fingers to allow independent function. Different palmar and dorsal flaps have been proposed to create an anatomic, aesthetic web and to reduce the risk of secondary distal migration of the web known as web creep. The surface area of the separated fingers is greater than that of the syndactylised fingers. Traditionally this lack of skin has been addressed with skin grafts, which are time consuming to perform and can be associated with complications including hyperpigmentation, hair growth and graft failure. In addition to worsening web creep, contracture of scars and grafts can lead to deformity of the fingers, especially during growth, and reduced range of motion. Graftless techniques have been described to overcome these complications and to reduce operating time.

We conducted a systematic review of the literature to evaluate the evidence for the different techniques and outcome measures utilised. Although the majority of authors include different types of syndactyly in their series, we aimed to focus on simple and complex congenital syndactyly. The treatment of complicated syndactylies or syndactylies with associated hand malformations is beyond the scope of this paper because it is more often associated with abnormal bony fusions which inherently make soft tissue coverage more complex.

Methods

Literature Search

This systematic review was registered on PROSPERO (registration number CRD42016041962) and performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analysis

(PRISMA) method (Moher et al., 2009). We included original articles treating patients with complete or incomplete, simple or complex congenital hand syndactyly, who had follow up data after surgical intervention. Original articles reporting outcomes of surgery for heterogenous types of syndactyly were included if the majority of the patients were treated for simple or complicated syndactyly. Case reports, editorials, opinions, comments and articles about non-congenital syndactyly (e.g. burns, trauma related), complicated syndactyly, syndactyly associated with syndromes such as Apert's or Poland's syndrome, syndactyly of the feet and patients without follow-up data and languages other than English were excluded.

Nine databases were searched on 7th July 2016 by two reviewers (AW and KM), using the following search terms: syndactyly (and synonyms), hand (and synonyms). The databases searched for this review include MEDLINE (1946-present) on Ovid platform; Embase (1974-present) on Ovid platform; PreMEDLINE on Ovid platform; the Cochrane collection (including the Cochrane Database of Systematic Reviews 2005 to present, ACP Journal Club 1991 to present, Database of Abstracts of Reviews of Effects, Cochrane Central Register of Controlled Trials (CENTRAL), the Cochrane Methodology Register, Health Technology Assessment, NHS Economic Evaluation Database) on Ovid platform; PubMed; CINAHL Complete on EBSCO platform; Scopus; and Web of Science. An additional hand search was performed on Google scholar and in Clinical Trial registers (clinicaltrials.gov; clinicaltrialsregister.eu; anzctr.org.au; apps.who.int/trialsearch). All full-text articles were assessed for eligibility by the two reviewers (AW and KM). If there was disagreement, a third reviewer (DS) decided on inclusion or exclusion.

Assessment of the level of evidence and methodological quality

The classification of study design and level of evidence developed by Jovell and Narvarro-Rubio (1995) was used to determine the quality of the evidence for the included studies and to generate the strength of recommendation. Two reviewers (AW, KM) independently assessed the quality of each study using the Coleman Methodology Score (CMS) system. A perfect score of 100

would represent a study design that largely avoids the influence of chance, various biases, and confounding factors. If scores were not consistent, a consensus score was determined for each study (Coleman et al., 2000).

Data extraction

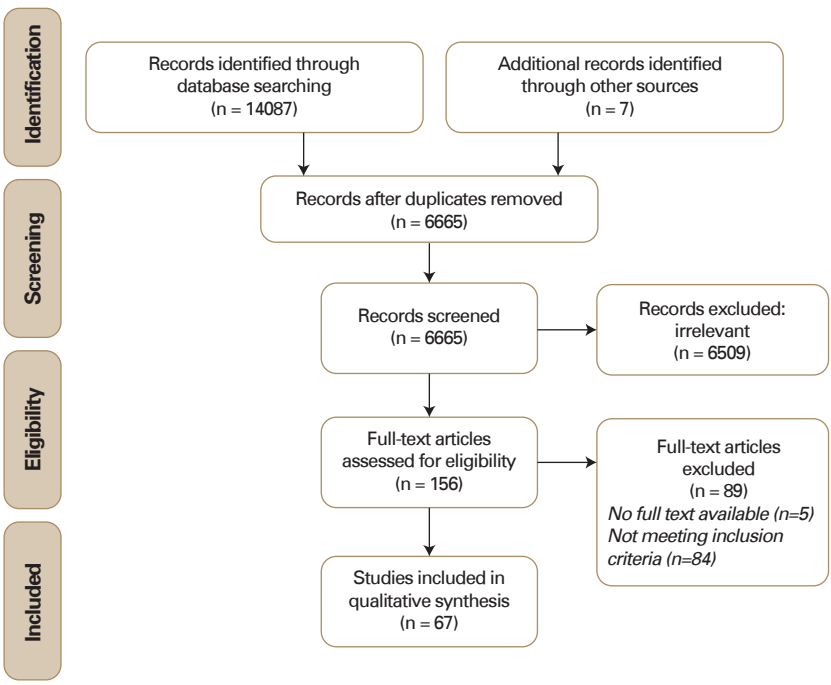
The reported age at surgery, duration of follow-up, number of treated webs, types of syndactyly and different surgical techniques were extracted from the data. The outcome measures used to assess the results of surgery and complications encountered were recorded from all studies included in the review.

Results

Literature search

The search strategy identified 14,094 publications. Based on title and abstract screening, 156 articles were selected for full-text assessment. From these, 67 articles that met the inclusion criteria were included for analysis (Figure 1).

Figure 1 Flowchart illustrating the selection of trials included in the systematic review



Study characteristics

The study characteristics are shown in Table 1. Of the 67 articles, 64 were retrospective, non-controlled, clinical series or retrospective, descriptive studies, with a level of evidence of VIII, which is rated "poor". The remaining three articles were retrospective cohort studies with a level of evidence VI, which is rated "fair".

The quality assessment using the 100 point CMS reached a mean of 36 (range 13 – 66). In part A of the CMS (maximum score 60), which assesses the study characteristics, (study size, length of follow-up, number of different procedures included in each reported outcome, type of study, diagnostic certainty, description of surgical procedure, description of postoperative rehabilitation) the mean score obtained (out of 60) was 30 (range 11 – 45). Part B, which analyses outcome criteria, the procedure for measuring outcomes and the description of the selection process, achieved a mean score of 6 (range 0 – 27).

Of all analysed studies, 25 (37%) reported a heterogeneous group of syndactylies, including complicated, trauma or burn related, adult or toe syndactyly. These different subgroups were not separated out in their results.

Table 1 Study characteristics

Author	Level of Evidence	n	Age at surgery, months (range)	Mean follow-up, months (range)	CMS part A	CMS part B	CMS total
Aydın and Özden, 2004	VIII Poor	19	132 (12 - 252)	36 (12 - 60)	35	0	35
Barabas and Pickford, 2014	VIII Poor	144	13 (3 - 48)	60 (16 - 78)	35	19	54
Brennen and Fogarty, 2004	VIII Poor	9	n/s (24 - 180)	n/s (6 - 32)	30	0	30
Brown, 1977	VIII Poor	76	n/s (n/s)	n/s (n/s)	30	2	32
Bulic, 2013	VIII Poor	26	112 (22 - 197)	74 (13 - 124)	32	18	50
Chapmann et al., 1987	VIII Poor	11	88 (24 - 204)	n/s (n/s)	19	5	24
Colville, 1989	VIII Poor	57	n/s (n/s)	>24 (n/s)	42	0	42
Cortez et al., 2014	VIII Poor	35	73.7 (16 - 204)	23,6 (12 - 108)	11	11	22
Cronin, 1956	VIII Poor	50	>15 (n/s)	n/s (n/s)	22	2	24
D'Arcangelo et al., 1996	VIII Poor	65	n/s (9 - 120)	>96 (n/s)	45	5	50
De Smet et al., 1998	VIII Poor	50	32 (3 - 156)	n/s (n/s)	37	11	48
Deunk et al., 2003	VIII Poor	34	42 (12 - 192)	252 (144 - 408)	19	10	29
Duteille et al., 2016	VIII Poor	40	67.8 (22 - 101)	41.6 (6 - 81)	14	4	28
Ebskov et al., 1966	VIII Poor	208	n/s (<12 - >120)	n/s (n/s)	13	0	13
Ekerot, 1996	VIII Poor	17	20 (9 - 119)	25.7 (9 - 47)	32	0	32

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Author	Level of Evidence	n	Age at surgery, months (range)	Mean follow-up, months (range)	CMS part A	CMS part B	CMS total
Ekerot, 1999	VIII Poor	76	40.6 (4 - 1280)	n/s (n/s)	15	0	15
Emmett, 1963	VIII Poor	26	60 (n/s)	n/s (n/s)	27	0	27
Gao et al., 2011	VIII Poor	17	n/s (3 - 59)	26 (23 - 35)	35	4	39
Golash and Watson, 2000	VIII Poor	38	n/s (n/s)	38 (2 - 84)	29	5	34
Goldfarb et al., 2012	VIII Poor	25	12 (4 - 34)	108 (24 - 324)	14	22	36
Greuse and Coessens, 2001	VIII Poor	25	14 (3 - 70)	22 (12 - 44)	36	5	31
Gudushauri and Tvaliashvili, 1991	VIII Poor	60	(5 - 360)	n/s (n/s)	25	0	25
Hsu et al., 2010	VIII Poor	28	13 (4 - 204)	50.4 (12 - 102)	39	15	54
Jose et al., 2010	VIII Poor	221	32.4 (6 - 156)	24 (6 - 48)	45	10	55
Karakaoğlan et al., 1993	VIII Poor	25	52.8 (24 - 168)	n/s (6 - 36)	19	0	19
Karameşe et al., 2016	VIII Poor	16	n/s (36 - 60)	24 (n/s)	35	18	53
Keret and Ger, 1987	VIII Poor	58	27 (6 - 87)	48 (3 - 108)	42	0	42
Kettelkamp and Flatt, 1961	VIII Poor	69	n/s (n/s)	n/s (n/s)	25	0	25
Killian and Neimkin, 1985	VIII Poor	17	56.4 (12 - 336)	n/s (13 - 20)	30	2	32
Liu et al., 2015	VIII Poor	24	30 (18 - 96)	28 (15 - 48)	39	7	46
Lumenta, et al., 2010	VIII Poor	26	52.8 (7 - 180)	138 (60 - 420).	39	22	61
Lundkvist and Barfred, 1991	VIII Poor	18	n/s (n/s)	62.4 (12 - 120)	20	0	20
Mallet et al., 2013	VI Fair	59	16 (n/s)	68 (n/s)	42	9	51
Matsumine et al., 2011	VIII Poor	12	n/s (12 - 66)	24 (n/s)	22	0	22
Mei et al., 2015	VIII Poor	12	n/s (31.2 - 54)	16 (12 - 27)	32	13	45
Mercer et al., 1992	VIII Poor	25	52.8 (24 - 96)	n/s (8 - 36)	12	5	17
Mericli et al., 2015	VIII Poor	138	24 (n/s)	31.2 (n/s)	45	5	50
Moss and Foucher, 1990	VIII Poor	49	n/s (24 - 540)	n/s (12 - 48)	29	0	29
Nakamura et al., 1989	VIII Poor	14	12 (n/s)	23 (n/s)	22	5	27
Ni et al., 2015	VIII Poor	116	26 (8 - 84)	50.4 (n/s)	45	19	64
Niranjan et al., 2005	VIII Poor	25	28.3 (4 - 108)	n/s (24 - 144)	39	12	51
Niranjan and De Carpentier, 1990	VIII Poor	17	n/s (10 - 156)	n/s (5 - 12)	30	0	30
Nylen, 1957	VIII Poor	44	n/s (6 - 180)	n/s (n/s)	37	0	37
Percival and Sykes, 1989	VIII Poor	218	54 (n/s)	n/s (n/s)	28	5	33
Posch et al., 1981	VIII Poor	558	n/s (n/s)	60 (12 - 264)	33	12	45
Saeed et al., 2015	VI Fair	50	17.3 (26 - 205)	17.3 (3 - 36)	27	10	37
Savacı et al., 1998	VIII Poor	14	n/s (8 - 192)	n/s (1 - 4)	30	0	30
Sawabe et al., 2005	VIII Poor	6	10.8 (10 - 12)	n/s (12 - 34)	32	0	32
Schulstad and Skoglund, 1977	VIII Poor	34	n/s (60 - 120)	n/s (9 - 132)	31	9	40
Segura-Castillo et al., 2003	VIII Poor	4	17.5 (7-24)	12 (n/s)	22	0	22
Shevtsov and Danilkin, 2008	VIII Poor	40	n/s (n/s)	n/s (n/s)	19	0	19
Sherif, 1998	VIII Poor	21	n/s (6 - 204)	n/s (6 - 24)	34	0	34
Sommerkamp et al., 1992	VIII Poor	23	21 (2 - 89)	13.9 (2 - 33)	36	0	36
Sugihara et al., 1991	VIII Poor	6	(10 - 16)	n/s (36 - 72)	25	5	30
Tadiparthi et al., 2009	VIII Poor	9	55.2 (12 - 180)	36 (5 - 60)	35	5	40
Teoh and Lee, 2004	VIII Poor	22	n/s (7 - 300)	33.7 (20 - 46)	39	10	49
Toledo and Ger, 1979	VIII Poor	97	18 (n/s)	168 (24 - 456)	23	12	35

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Author	Level of Evidence	n	Age at surgery, months (range)	Mean follow-up, months (range)	CMS part A	CMS part B	CMS total
Tuma et al., 1999	VIII Poor	37	58 (8 - 252)	11 (4 - 60)	24	7	31
van der Biezen and Bloem, 1992	VIII Poor	10	12 (n/s)	30 (n/s)	35	0	35
Vekris et al., 2010	VIII Poor	131	(4 - 264)	138 (6 - 216)	35	7	42
Widerberg et al., 2015	VIII Poor	29	28 (11 - 128)	192 (>120)	39	27	66
Withey et al., 2001	VI Fair	31	14.3 (n/s)	100.2 (n/s)	35	13	48
Wyard et al., 1978	VIII Poor	66	18 (n/s)	168 (12 - 264)	20	9	29
Xu et al., 2003	VIII Poor	58	n/s (n/s)	n/s (36 - 192)	32	0	32
Yamashita et al., 2015	VIII Poor	8	42 (10 - 276)	n/s (n/s)	15	0	15
Yao et al., 1996	VIII Poor	8	(24 - 156)	n/s (2 - 18)	20	0	20
Zoltie et al., 1989	VIII Poor	14	54 (18 - 216)	19 (12-25)	32	2	34

n = number of webs, CMS = Coleman methodology score, n/s = not stated or unclear.

Statistical Methods

Evaluation of the data was conducted with an independent statistician. The outcome measures that have been reported in the studies varied greatly so they did not allow for comparison of the results of different procedures.

Surgical techniques

A variety of surgical procedures for the creation of the interdigital web were described in the retrieved articles. These procedures may be broadly grouped into four categories. The first group, which comprised the majority of the studies, used a dorsal transposition flap, which can be either rectangular, or have a modified design (38 studies). One study reported on a volar transposition flap (Jose et al., 2010) with the aim of achieving better aesthetic results and reducing scars on the dorsum of the hand. The second group, used volar and dorsal interdigitating triangular flaps (19 studies) based on the technique of Cronin (1956). Island flaps were the third subgroup classification. These are either based on a dorsal metacarpal artery (Aydın and Özden, 2004; Colville, 1989; Hsu et al., 2010; Liu et al., 2015; Magdi Sherif, 1998; Segura-Castillo et al., 2003; Teoh and Lee, 2004) or raised from the syndactyly web with a random subcutaneous pedicle (Brennen and Fogarty, 2004; Savacıet al., 1999; Tadiparthi et al., 2009; Yamashita et al., 2016; Yao et al., 1997). A fourth group used simple or composite Z-plasties, which were only applicable in minor simple incomplete syndac-

tylies (Chapman et al., 1987; Shevtsov and Danilkin, 2008). Six authors reported on the results of a variety of techniques in their studies; three articles did not specify clearly the techniques that were employed.

The most commonly used technique (47 (70%) papers) for separation of the syndactylised fingers was a zig-zag incision (Cronin, 1956). Four authors reported using curved incisions, two rectangular interdigitating incisions and three used Z-plasties to break up the scar for the finger separation. Five authors used straight incisions. Three papers reported on use of distraction prior to syndactyly release via an external distraction device (Gudushauri and Tvaliashvili, 1991; Mei et al., 2015; Shevtsov and Danilkin, 2008). In nine studies the type of incision used for finger separation is not specified or is unclear.

Twenty-five authors reported using only full thickness skin grafts (FTSG), two used only split thickness skin grafts (STSG) and 11 used both in order to cover remaining raw areas after syndactyly release and flap insertion. Duteille et al., (2016) compared the results of using a combination of a dermal substitute (Matriderm®) and STSG with FTSG. Donor sites for STSG were either the thigh or buttocks, but in most of the studies the area was not specified. Donor sites for FTSG were the groin or cubital fossa, forearm, or not mentioned. One study reported the use of FTSG from the submalleolar region of the foot (Zoltie et al., 1989).

A number of articles describing techniques without the use of skin grafts were identified. These procedures may be grouped into three categories. The first group (four studies) are techniques for minor simple incomplete syndactylies (Brennen and Fogarty, 2004; Matsumine et al., 2011; Tadiparthi et al., 2009; Yao et al., 1997). The second group are techniques that manage to obtain closure of all wounds without the use of skin grafts by using specific flaps to reconstruct the web space (ten studies). Skin is recruited from adjacent areas and in general, this is from the dorsum of the hand (Aydın and Özden, 2004; Ekerot, 1999; Gao et al., 2011; Mallet et al., 2013; Matsumine et al., 2011; Niranjan et al., 2005; Niranjan and De Carpentier, 1990; Savacı et al., 1999; Segura-Castillo et

al., 2003; Widerberg et al., 2016). Some techniques (seven studies) report concomitant removal of subcutaneous fat of the separated fingers to allow for closure without use of grafts, which is also referred to as "defatting" (Ekerot, 1996; Greuse and Coessens, 2001; Hsu et al., 2010; Liu et al., 2015; Magdi Sherif, 1998; Ni et al., 2015; Teoh and Lee, 2004). The third type of "graftless" techniques (three studies) leave the remaining surfaces open for healing by secondary intention, also called "open finger technique" (Greuse and Coessens, 2001; Jose et al., 2010; Withey et al., 2001). In their description, Withey at al. modified the interdigitating zig-zag incisions to multiple triangular flaps with a narrower base to avoid secondary straightening and therefore contracture of the resulting scar.

For separation of the osseous-fused distal phalanges in complex syndactylies, 14 studies emphasized the importance of reconstruction of the nail fold by using one of the several variants of pulp flaps. Nine studies specifically referred to Buck-Gramcko's technique (Buck-Gramcko, 1988), two studies to Lundkvist's design (Lundkvist and Barfred, 1991), and two authors mentioned similar techniques without specifying further. Sugihara et al., suggest the use of proximally based rectangular transposition flaps (Sugihara et al., 1991). Sommerkamp described a 94% rate of good results in reconstruction of 34 fingertips with composite grafts from the instep area of the foot.

Outcomes

We reviewed the outcome measures employed in the 67 papers. Specifically we focused our review on web creep, scar appearance, pigmentation, range of motion (ROM) and complications (infection and revision surgery).

Web creep

Web creep was recorded as an outcome measure in 46 of the papers reviewed. The wide range of methods utilised in order to define web creep is demonstrated in Table 2.

Table 2 Assessment of Web Creep

Author	Percentage n (%)	Direct Measurement n - cm	Withey Score * Grade (Gr): n	Ratio ** Grade (Gr): n	D'Arcangelo Criterion ***	Re-operation n (%)
Barabas and Pickford, 2014	6/144 (4)		Gr 1: 3/6 Gr 2: 3/6			
Brown, 1977	14/76 (19)	10/76 - 0.5 cm				
D'Arcangelo et al., 1996					Simple: Good 30/36, Fair 3/36, Poor 3/36. Complex: Good 21/29, Fair 7/29, Poor 1/29	4/65 (6)
De Smet et al., 1998	13/50 (26)			Gr 1: 23/50 Gr 2: 14/50, Gr3: 11/50 Gr4: 2/50		2/50 (4)
Deunk et al., 2003						6/34 (18)
Duteille et al., 2016			FTSG Group: 0.8 (0 – 3) FTSG, Matriderm Group: 1.2 (0 – 3)			
Ekerot, 1996						3/17 (18)
Ekerot, 1999						5/76 (7)
Emmett, 1963						5/60 (8)
Goldfarb et al., 2012		.				6/25 (24)
Greuse and Coessens, 2001		1/25 – 1 cm				1/25 (4)
Hsu et al., 2010		1/28 - 0.5 cm				1/28 (4)
Jose et al., 2010	12/221 (5)					7/221 (3)
Karameşe et al., 2016			Gr 1: 1/16			
Keret and Ger, 1987						1/58 (2)
Lumenta et al., 2010			Gr 0: 13/26, Gr 1: 11/26, Gr 2: 2/26, Gr 3 & 4: 0			3/26 (12)
Mallet et al., 2013	10/59 (17)		Gr 2: 10			5/59 (8)
Mei et al., 2015	3/12 (25)		Gr 0: 9/12, Gr 1: 3/12			
Mercer et al., 1992						16/21 (76)
Mericli et al., 2015	12/138 (9)					10/138 (7)

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Author	Percentage n (%)	Direct Measurement n - cm	Withey Score * Grade (Gr): n	Ratio ** Grade (Gr): n	D'Arcangelo Criterion ***	Re-operation n (%)
Ni et al., 2015					Good (98) - height and width webs, Fair (16), Poor (2)	
Niranjan et al., 2005						4/25 (16)
Nylen et al., 1957						2/28 (7)
Percival and Sykes, 1989	48/218 (22)					37/218 (17)
Saeed et al., 2015	4/50 (8)					
Toledo and Ger, 1979		53/176 <1 cm, 4/176 >1 cm				53/176 (30)
Vekris et al., 2010						7/131 (5)
Widerberg et al., 2015			Gr 1: 22/29, Gr 2: 7/29			2/29 (7)
Withey et al., 2001			Closed: Gr 0: 7/19, Gr 1: 9/19 Gr 2: 1/19, Gr 3: 2/19, Gr 4: 0/19 Open: Gr 0: 4/12, Gr1: 6/12, Gr 2: 2/12, Gr & 3: 0/12			Closed: 5/12 (42) Open: 0

n = number of webs

* Withey Grading System (Withey et al., 2001) 0 = normal and soft web, 1 = no web creep, thickening of web from scarring, 2 = creep of the web to 1/3 the distance between the base of the web and PIPJ crease, 3 = creep of the web 2/3 of the distance between the base of web and PIPJ web crease, 4 = creep of the web to the PIPJ crease

** Ratio (De Smet, 1998): Web Localisation in full extension and abduction: Gr 1 Normal < 1/5 to of distance MCP to tip, Gr 2 1/5-1/4 distance, Gr 3 1/4-1/3, Gr 4 >1/3

*** D'Arcangelo Criterion (D'Arcangelo et al., 1996). Good: if height and width of web was close to normal, Fair: if the height and width of web 50-75% of normal, Poor: if height and width of web <50%

A measurement in centimetres was reported in four studies (Brown, 1977; Greuse and Coessens, 2001; Hsu et al., 2010; Toledo and Ger, 1979). Nine papers reported web creep in a percentage of their cases without specifying any degree of web creep (Barabas and Pickford, 2014; Brown, 1977; De Smet, 1998; Jose et al., 2010; Mallet et al., 2013; Mei et al., 2015; Mericilli et al., 2015; Percival et al., 1989; Saeed et al., 2015). The score described by Withey (2001) was the measurement chosen in eight papers (Bara-

bas and Pickford, 2014; De Smet et al., 1998; Duteille et al., 2016; Karameşe et al., 2016; Lumenta et al., 2010; Mallet et al., 2013; Mei et al., 2015; Widerberg et al., 2016; Withey et al., 2001). This scoring system graded the degree of web creep based on the extent of migration from the palmar metacarpophalangeal (MCP) joint creases to the proximal interphalangeal (PIP) joint creases. The degree of web creep was divided into thirds for this grading system. De Smet (1998) also described a ratio of web creep, defining grade one as less than one-fifth of the distance from the MCP to the tip of the digit and grade four as greater than one-third of the distance. D'Arcangelo provided a descriptive criterion for web creep: Good, Fair and Poor. The web spaces were declared to be good if the height and width of the web was close to normal; fair if the height and width of the web was 50-75% of normal and poor if the height and width were less than 50%. This assessment tool was used in two of the articles reviewed (D'Arcangelo, 1996; Ni et al., 2015). Reoperation was a common marker (21 papers) of web creep recurrence. However, the clinical criteria on which the indication for further surgery was based were not always clearly described. Two different approaches to the assessment of web creep included radiographic monitoring by Vekris et al., (2010) and clinical photography by Niranjan et al., (2005). The method employed in 17 papers was not specified or was unclear.

Range of motion

ROM was reported in 17 papers; a variety of methods measuring ROM were described. Some papers recorded ROM as a measure of pulp to palm distance (cm) (Posch et al., 1981; Schulstad and Skoglund, 1977), others reported a percentage loss (Brown, 1977), and in two papers ROM was reported in degrees for the individual joints (Deunk et al., 2003; Widerberg et al., 2016). A composite or total ROM was reported in three papers (Goldfarb et al., 2012; Mei et al., 2015; Ni et al., 2015). A descriptive term was utilised as an outcome measure in four papers (Vekris et al., 2010; Xu et al., 2009; Yamashita et al., 2016; Yao et al., 1997). The ROM was not specified or was unclear in 38 papers.

Scar assessment

The appearance of any scars was evaluated in 32 (48%) of the articles reviewed. Descriptive qualities of the scar, e.g. contracture (Brown, 1977; Cronin, 1956; D'Arcangelo et al., 1996; Karacaoğlan et al., 1993; Nylen, 1957; Toledo and Ger, 1979), keloid (Liu et al., 2015) or hypertrophic scarring (Magdi Sherif, 1998; Mercer et al., 1992; Zoltie et al., 1989) were used as assessment tools. Generalised terminology, e.g. "acceptable" and "satisfactory", was employed by six articles (Emmett, 1963; Gudushauri and Tvaliashvili, 1991; Niranjan and De Carpentier, 1990; Savacı et al., 1999; Vekris et al., 2010; Wyard et al., 1978). In six of the papers (Goldfarb et al., 2012; Karameşe et al., 2016; Lumenta et al., 2010; Mei et al., 2015; Ni et al., 2015; Widerberg et al., 2016), published since 2010, the Vancouver Scar Scale (VSS) was used to assess the scar quality. This is a standardised scale that describes several aspects of the scar (pigmentation, pliability, height, vascularity, itching and pain). One study (Duteille et al., 2016) used the Observer Scar Assessment Scale to quantify scar properties.

Pigmentation of the skin is a problem that can be encountered particularly when skin grafts have been used. Fourteen articles (not including the studies that employed the VSS) commented on pigmentation of the resulting tissue (Deunk et al., 2016, Duteille et al., 2016, Ekerot et al., 1996, Gao et al., 2011, Karameşe et al., 2016, Kettelkamp and Flatt 1961, Keret and Ger 1987, Lumenta et al., 2016, Mallet et al., 2013, Nakamura et al., 1989, Nylen et al., 1952, Schulstad et al., 1977, Toledo and Ger 1979, Wyard et al., 1978). Nine of these articles made reference to a proportion of the study candidates having increased pigmentation or hyperpigmentation of the scar. Hair growth was an outcome measure discussed in seven articles reviewed (Brown, 1977; Deunk et al., 2003; Ebskov and Zachariae, 1966; Lumenta et al., 2010; Mallet et al., 2013; Toledo and Ger, 1979; Vekris et al., 2010).

Nail fold reconstruction

Two studies reported on the outcomes of nail fold reconstruction. Bulic (2013) recommended the use of Buck-Gramcko flaps in complete complex syndactylies, whilst reserving the traditional zig-zag

and FTSG closure for cases of complete simple syndactylies. These conclusions were drawn from his comparative study in 84 fingertips. He proposed a four-grade scale to assess the aesthetic outcome of the fingertip following syndactyly release based on the quality of the lateral nail fold, nail plate definition, symmetry and pulp fullness. Golash and Watson (2000) describe cosmetically pleasing fingertips, with a rounded contour and an adequate pulp pad in 75 fingertips using Buck-Gramcko flaps. One flap was completely lost and six had tip necrosis. If scarring, e.g. from previous syndactyly releases on adjacent fingers was present, the planning of flaps of adequate length for nail fold reconstruction was impaired.

Complications

Two types of complications were noted in the literature: infection and revision surgery. Infection was reported in 31 papers. Eighteen papers reported no infections. Barabas and Pickford (2014) reported a 2.8% incidence of infection, which resolved with antibiotic treatment with no adverse outcomes. A higher rate of infection (11.4%) was reported in the study by Cortez et al., (2014). Graft loss was a consequence of infection that was reported in six cases in the paper by Ebskov et al., in 1996. Niranjan et al., (2005) reported three cases of delayed healing as a result of infection. Vekris et al., (2010) and Withey et al., (2001) identified infection as the reason for revision surgery in four and one case(s) respectively. A pin site infection rate of 16%, which resolved with antibiotic treatment, was reported in a study utilising distraction techniques with external fixation (Mei et al., 2015).

Revision surgery was a definitive endpoint that was used as an outcome measure in 42 of the papers reviewed. Thirty one papers identified revision surgery occurring in a proportion of the patients reviewed. Eleven remaining papers stated that further or revision surgery was not required. The reasons for reoperation varied from web creep (Barabas and Pickford, 2014; Ekerot, 1996; Hsu et al., 2010; Mallet et al., 2013; Niranjan et al., 2005; Toledo and Ger, 1979) to scar contracture (Karacaoğlan et al., 1993; Keret and Ger, 1987). Golash and Watson (2000), Jose et al., (2010) and Nylen et al., (2015) sighted a variety of reasons for

revision surgery. However, the specific criteria and measurements used to determine the indications for revision (both for web creep and infection) were inconsistent.

Discussion

This systematic review has found that the available literature on outcomes of surgical syndactyly release consists mainly of retrospective, non-controlled descriptive series and a few retrospective cohort studies. The level of evidence is predominantly poor and does not support recommendations in favour of any particular surgical technique. Nevertheless, most authors seem to agree that incisions separating the syndactylised fingers should be either zigzagged or in a geometric configuration that avoids straight lines in order to reduce the potential for contracture or deviation. Pulp flaps to reconstruct the nail folds potentially achieve better results than skin grafts in cases with bony fusion of the distal phalanges (Bulic, 2013). In recent years, techniques avoiding the use of skin graft, thus decreasing operating time and the potential complications associated with grafts, have been published in increasing numbers. In order to allow for closure without grafts, reduction of subcutaneous fat and recruitment of skin from an area beyond the syndactylised fingers is required, predominantly from the dorsum of the hand, to allow for direct closure. A variety of geometric shapes and designs are described. These techniques might not be suitable for the treatment of complicated syndactylies, but they are an appropriate approach for simple and many cases of complex syndactylies. To allow small raw areas to heal by secondary intention, which has been described as "open finger techniques", seemed not to result in significant higher scarring (Greuse and Coessens, 2001; Jose et al., 2010; Withey et al., 2001) and also reduce the necessity for skin grafts. Other approaches to overcome the deficiency of skin, without relying on grafts, have been attempted. These include pre-expansion or distraction techniques, but they often require several stages and have the potential for additional complications associated with external or internal devices (d'Arcangelo and Maffulli, 1996; Gudushauri and Tvaliashvili, 1991; Işık et al., 1996; Mei et al., 2015; Ogawa et al., 1989; Shevtsov and Danilkin, 2008).

At the outset of the study, we aimed to limit our review to simple and complex syndactyly and excluded complicated cases. However, the vast majority of the literature reported a mixture of the varying types of syndactyly. Although, these subgroup types were frequently reported in the methods sections of these papers, they were often not identified in the results sections. This lack of differentiation between the groups was one of the problems encountered when comparing various surgical techniques.

The outcome measures described to determine the success of surgery for syndactyly are highly variable and do not allow for comparison of results between different authors. The absence of sensitive and reliable outcome measures is reflected in the low scores obtained by almost all studies for these criteria in part B of the CMS. Early studies of syndactyly often provided case-specific results of surgery, and in later years postoperative assessment was structured on the basis of variable evaluation criteria.

Recurrent or persisting webbing, i.e. web creep, is probably the most important outcome measure and was used in four papers identified by this review to assess the results of syndactyly surgery. A variety of methods have been reported to measure web creep. Evaluation of web creep is dependent on finger position, the reference points of measurement, as well as the participation by the child. Tonkin et al., (2015) quantified web creep utilising a ratio of measurements based on anatomical landmarks and two perpendicular lines drawn from the midpoint of the web to the finger axis. The fingers were held in abduction for these measurements to be performed. A web index is calculated and may be compared with the web index over a period of time to determine whether web creep had occurred. Withey et al., (2001) developed a grading system that assigned the level of web creep into thirds. This is a simple method but it lacks both intra- and inter-observer reliability. Photographic and radiographic measurements have also been employed to measure web creep.

Other outcome measures that have been reported include range of motion, scar assessment, nail fold and complications.

Reoperation rates as a primary outcome measure of surgery is problematic as there are no consistent or comparable indicators. Attempts to establish outcome assessment systems for congenital hand differences in the paediatric population have been made for radial polydactyly (Al-Qattan, 2016; de Kraker et al., 2016; Dijkman et al., 2016; Tonkin, 2016). However no standardized, reliable and validated outcome measure for syndactyly has been adopted.

Congenital hand difference research suffers from small numbers and variability in clinical presentation. Ideally, future research would compare "graftless" techniques with those using skin grafts for simple complete syndactyly in a multi-centre randomised controlled trial. If a standardised set of outcome measures were subsequently employed, the benefits of the varying surgical techniques could be determined better.

KEY POINTS

- Incisions separating the syndactylised fingers should be either zig-zagged or in a geometric configuration that avoids straight lines in order to reduce the potential for contracture or deviation.
- Pulp flaps to reconstruct the nail folds potentially achieve better results than skin grafts in cases with bony fusion of the distal phalanges.
- Techniques avoiding the use of skin graft, thus decreasing operating time and the potential complications associated with grafts might not be suitable for the treatment of complicated syndactylies, but they are an appropriate approach for simple and many cases of complex syndactylies.

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THUMB POLYDACTYLY

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Introduction

Thumb polydactyly (also preaxial or radial polydactyly) refers to one of the most common congenital upper limb anomalies (CULA) with patients having excess of parts on the radial side of at least one limb. A Dutch anatomist and alchemist, Theodor Kerckring, already described the difference in the 17th century. Preaxial polydactyly can be separated into five types according genetic literature: thumb polydactyly; polydactyly of a triphalangeal thumb; polydactyly of an index finger; polysyndactyly and hallux polydactyly (Orioli and Castilla, 1999). For this chapter, the focus we will be directed toward the treatment of thumb polydactyly, and polydactyly with a triphalangeal thumb, classified in the OMT classification as a malformation, under failure of axis formation/differentiation of the hand plate in the radial-ulnar axis (Tonkin and Oberg, 2015). Thumb polydactyly mostly occurs as an isolated and sporadic anomaly, however, in the Online Mendelian Inheritance in Man ('OMIM') database it is mentioned as part of over 125 distinct syndromes and phenotypical associations, including Holt-Oram syndrome, Townes-Brocks syndrome, and Fanconi's anaemia. In our population, cases were associated with craniofacial syndrome, Greig cephalosynpolydacyly, Nager, Klippel-Feil and VACTERL. In the Human Phenotype Ontology (HPO) database, preaxial hand polydactyly as a patient's feature is related to 59 different diagnose\s. Therefore, multidisciplinary knowledge on phenotypes and syndromes is to our opinion mandatory to treat these patients with a high quality of care.

The incidence of thumb polydactyly is estimated to be 0.3 – 3.6 per 1,000 live births and 1.6 – 10.7 per 1,000 in the general population (Ekblom et al., 2010; Goldfarb et al., 2015), with males twice as often affected as females. Variability in incidence is based on the population studied and the definition used for thumb polydactyly. It is believed that the incidence of thumb polydactyly with

or without a triphalangeal component is highest in people of Asian descent. Thumb polydactyly represents up to 90% of all polydactyly cases in a Chinese population (Leung et al., 1982).

To structure the spectrum in thumb polydactyly, with or without a triphalangeal component, several classifications have been introduced based on the level of duplication and/or morphologic patterns (Chung et al., 2013; Wassel, 1969; Zuidam et al., 2008), simplifying the communication between specialists for clinical decision-making and/or research purposes. When choosing a morphologic classification to rank or group a phenotype of thumb polydactyly, the outcome will be influenced inevitably. Moreover, when adding non-classifiable phenotypes to certain subgroups this could influence outcomes based on bias in morphological differences.

With regard to outcome, focus is nowadays increasingly on evaluating patient outcome measures based on the framework for evaluating the impact of disability on a person's overall functioning, the International Classification for Functioning, Disability and Health (The ICF Framework, (Dahl, 2002)). The outcome assessments developed in thumb polydactyly are numerous (Cheng et al., 1984; Dobyns et al., 1985; JSSH, 2006; Larsen and Nicolai, 2005; Ogino et al., 1996; Tada et al., 1983; Tuch et al., 1977; Wood, 1978), and the conclusion on the outcome of treatment of thumb polydactyly may vary considerably, dependant on the outcome assessment used.

The difference is easily detected, leading to functional and aesthetic concern with the parents, and if not treated, to aesthetic concern of the affected child, depending of course on cultural differences. Most parents or patients will pursue surgery for restoring functional anatomy, however, affected by abnormal embryological development of osseous structures and soft tissues, normal aesthetic and functional results are not to be expected. Results on functionality and aesthetics with regard to manual ability, participation and quality of life in patients with thumb polydactyly are scarce.

Methods

For this systematic review for the treatment of radial polydactyly, the PRISMA guidelines were followed.

Search strategy

Embase and Medline (OvidSP) were searched for eligible articles. The search strategy used is attached as appendix 1 and was performed in March 2017. Original research articles on the outcome of the treatment of radial polydactyly in the English language were included (n=217). Additional articles found by own search were added to the analysis (n=2). For further analysis see flow diagram 1. Articles exclusively on techniques of surgery (n=19), genetics of radial polydactyly (n=13), case reports on rare polydactyly cases (n=27) and general radial polydactyly reports (n=16) were excluded. Moreover, reviews on general thumb or congenital hand (n=12), commentaries (n=1), and articles not involving hand or human polydactyly (n=21), were also excluded.

Inclusion of articles was done by both authors and was based on screening of title and abstract. A subsequent exclusion of articles was done during full-text reading, when articles did not fulfil the aforementioned inclusion criteria.

The classification of study design and level of evidence developed should be used to determine the quality of the evidence for the included studies and to generate the strength of recommendation. However, since only a few studies have been performed reporting outcome on radial polydactyly, it was not possible to perform the comparison of the different procedures according to the afore mentioned guidelines. Therefore, a review is given on the different subsets of the treatment of radial polydactyly.

Classification

In order to structure the variable phenotypic presentation, thumb polydactyly cases can be categorized using different types of classification systems. In choosing a classification system, later evaluation of the results of the different types of thumb polydactyly is influenced by this choice.

Since soft tissue anomalies are harder to visualize, most classification systems are based on osseous configuration, which can be shown using x-rays. These classification systems play an important role in communication between specialists, in the evaluation of treatment outcomes, and in supporting clinical decision-making. However, in using the osseous based classification systems, one should not overlook the additional soft tissue differences.

The most widely used system for thumb polydactyly is the Wassel classification (Wassel, 1969). Seven types of osseous configurations are described: types I-VI represent distal-to-proximal levels of thumb polydactyly, while type VII represents thumb polydactyly with a triphalangeal component. The three most common types of radial polydactyly are type IV (30% - 46%), type II (9% - 25%) and type VII (7% - 32%), with varying occurrence across different case series, e.g. areas in the world.

This classification is easy to apply, but the clinical relevance is limited by the inability to classify surgically important features of radial polydactyly (e.g., diverging components or hypoplasia), features that influence outcome. This has led to the introduction of many alternative classification systems, such as the Rotterdam classification (Zuidam et al., 2008), integrating elements of the Wassel (Wassel, 1969), Buck-Gramcko (Buck-Gramcko, 2002), and Upton (Upton and Shoen, 2000) classification, into an all-embracing classification system for thumb polydactyly including triphalangeal components and triplications.

However, the major disadvantage of the Rotterdam classification is the more extensive possibilities to classify, making it questionable if it can be used with an equal reliability and consistency in the daily congenital hand clinic as with the Wassel classification. In a study, incorporating patients from two large European congenital hand units (Hamburg and Rotterdam), the occurrence of the different types of thumb polydactyly were investigated, evaluating a total of 520 available X-rays from both units from the period 1980-2012. Both the Wassel and Rotterdam classification were applied. A comparative historical cohort was extracted from literature, pooling

1723 eligible cases of thumb polydactyly to describe the frequency of the different types reported in literature. A large part (40%) of the studied population could not be classified using the Wassel classification, compared to 6% studied in literature. However, all study cases could be classified using the Rotterdam classification. All the unclassifiable cases had aberrant components: triphalangeal, deviating and hypoplastic. This implies that the Rotterdam classification is more suited for describing the entire spectrum of thumb polydactyly and guidance in surgical treatment.

Reliability was tested using a test-retest, showing a good overall intraobserver and fair interobserver reliability (K ranging .83 - .87 and .65 - .70 respectively) for both classification systems. No significant relation was found between reliability and years of experience. This indicates both systems are reliable regardless of the experience of the person implementing the classification system.

According to these results, the Rotterdam classification is best suited for research purposes, even if an inexperienced observer performs analysis. The Rotterdam classification is the base for clear and type-specific description in treatment and its outcome. However, for daily practice in non-research environment, the use might be too time consuming.

Outcome Assessment

Several outcome assessment systems have been published describing the results of the treatment of thumb polydactyly. These systems consist of a variety of domains: 1) *function* with range of motion, joint stability, mal-alignment, strength, first web and/or overall function; 2) *aesthetics* with evaluation of the nail, pulp, size, scar, prominence and overall appearance; and 3) *subjective evaluation* with pain and patient satisfaction. Recently, ten outcome assessment schemes have been evaluated on reliability and validity, followed by an analysis how to optimize the best available outcome assessment system, based on long-term follow up data from an international population with thumb polydactyly (Dijkman et al., 2014). The ten outcome assessment schemes were used to evaluate

the outcome of 37 patients with 41 thumb polydactylies by at least 2 examiners. The interobserver variability was highest in the JSSH scoring system (JSSH, 2006), also showing superior correlations for function and aesthetics with both examiner- and patient- rated visual analogue scale scores. After recommending this scoring system for evaluating outcome in thumb polydactyly, it was clinically weighted, performing a linear regression analysis on multicentre data of 121 patients with thumb polydactyly type II, IV and VII. The JSSH score was adjusted with the following steps: 1) the pulp/nail item in the JSSH system was separated since it might influence outcome differently; 2) the balance between the functional, aesthetic and patient-reported domains was established adding more value to the latter two; 3) regression analysis incorporating all items from the JSSH system; 4) redistribution of 30 instead of 20 points according to their impact on overall outcome based on the regression analysis; 5) redefining cut-off values. The item weighted and cut-off values represent clinical practice with therefore less need to compare the result with the unaffected contralateral hand. Especially, since a normal outcome is not to be expected.

For future research on outcome of polydactyly, it is important to choose an outcome assessment tool that is easily used and facilitates comparison and interpretation worldwide. Furthermore, be aware of the fact that in selecting an outcome assessment system you can make your results look better or worse. The weighted system (Dijkman et al., 2016) therefore addresses to the influence of the items that need to be graded and the options given, with a higher sensitivity as a result.

In addition to the already existing outcome assessment systems, the question on ability and participation still remains: are we asking the right questions to our patients? Or are we focussing on what they can, instead of can not do?

Controversy in Surgical Treatment

Thumb polydactyly is seen as a relative simple difference as it is a more common CULA, however, its treatment can be very complex. The aim of surgical intervention in thumb polydactyly is to obtain

a functional thumb, without instability and deviation, and is also aesthetically pleasing. Except for the abnormal osseous structure with joint incongruence, the flexor and extensor tendons can have aberrant insertions, influencing the line of pull with regard to future deviations. In addition, aberrant and intricate connections may exist between flexors and extensors, affecting thumb movement. In the more proximal polydactyly types, intrinsic muscles might be hypoplastic or absent. In most cases, the thumb is inadequate in size, width and nail development compared to the non-involved opposite side in unilateral cases. However, it is difficult to address to these latter hypoplastic features when reconstructing a thumb polydactyly.

Taking into account all the features of reconstruction in thumb polydactyly surgical approaches have been refined over the years. Different techniques to treat thumb polydactyly can be identified.

Although the evidence is limited to case-series and literature describing surgical technique is extensive, consensus exists on a number of issues:

1) ablation of one thumb only without reconstruction of the remaining thumb is an insufficient approach, leading to revision surgery (Miura, 1982; Tada et al., 1983; Tonkin and Bulstrode, 2007; Townsend et al., 1994);
2) correct as much as possible during the first procedure, since secondary procedures can only improve 'poor' initial results to 'average' final results (Andrew and Sykes, 1988; Tada et al., 1983; Townsend et al., 1994);
3) 20% of radial polydactyly cases will need secondary procedures (Ogino et al., 1996; Patel et al., 2014), with joint deviation and instability being the most common reasons for revision surgery (Andrew and Sykes, 1988; Patel et al., 2014; Tada et al., 1983).

Despite this consensus, the effects of many other preoperative, perioperative, and surgery-related factors on postoperative outcome are still controversial:

a) the influence of the range of motion preoperatively on postoperative range of motion (Dobyns et al., 1985);

b) influence of the aberrant muscle insertions on postoperative range of motion (Tonkin, 2012);

c) factors influencing postoperative stability and alignment and influence on range of motion when addressing to instable joints (Horii et al., 1997; Ogino et al., 1996; Tonkin, 2012);

d) preoperative factors and postoperative results affecting strength of the thumb (Patel et al., 2014);

e) age at first operation with early (Cabrera Gonzalez et al., 2013; Cooney et al., 2004; Iwasawa et al., 2008; Tada et al., 1983) versus late after growth of anatomic structures (Cheng et al., 1984; Goffin et al., 1990; Goldfarb, 2006; Marks and Bayne, 1978; Wassel, 1969);

f) surgical resection and reconstruction versus the Bilhaut procedure with their specific advantages and drawbacks (Dijkman et al., 2016; Naasan and Page, 1994; Tonkin, 2012; Tonkin and Bulstrode, 2007; Townsend et al., 1994);

g) relation of experience of the surgeon and volume operated (Ogino et al., 1996).

For the purpose of this chapter, we will discuss the data available on outcome of resection and reconstruction, and on the Bilhaut procedure.

Resection and Reconstruction

The most versatile and widely applied surgical treatment for thumb polydactyly is the resection and reconstruction technique. The majority of cases can be treated using this technique, indicated whenever one of the extra thumbs is better developed than the other (floating-type thumb polydactyly excepted). In most cases, the ulnar thumb is better developed and the radial thumb is resected. Resection of the radial thumb has the added benefit of preserving the ulnar collateral ligament, playing a key role in stabilizing the MCPJ during pinch grip and prehension. Furthermore, the scar will be situated dorsally or on the radial side of the remaining thumb, not impeding with sensation of the ulnar sided pulp of the thumb. Several techniques have been described

to improve appearance and function as attention to pulp size and girth (Dautel and Perrin, 2015), separate techniques for type III reconstruction (Horii et al., 2009), support of collateral ligaments in type IV (Engelhardt et al., 2013), and rebalancing of tendons (Xu et al., 2014).

When analysing literature on the long-term outcome of thumb polydactyly treatment, only few reports are found with overall outcome (Ogino et al., 1999; Patel et al., 2014; Stutz et al., 2014) and one only on thumb size and appearance (Goldfarb et al., 2008).

In a recently published thesis, an extensive analysis was performed on the outcome of surgically treated thumb polydactyly (Dijkman, 2016). The outcomes measured, the outcome assessment scoring system used, and the type of thumb polydactyly studied was not comparable in the four mentioned evaluations, therefore, analysis according to the PRISMA guidelines was not possible. Therefore, a review of the outcomes is outlined.

Ogino (Ogino et al., 1996) evaluated 113 thumbs with a follow-up of more than one year and morphologically classified the thumb polydactyly according a modified Wassel classification. The postoperative assessment was performed using the Tada scoring system (Tada et al., 1983). Subjective assessment resulted in 88% satisfaction with the functional and aesthetic results. The objective assessment revealed good outcome in 86%, with no excellent outcome in 113 thumbs. The factors influencing objective outcome in surgery were: 1) reconstruction in Wassel type III, V and VI; 2) in case of triphalangeal thumbs polydactyly, with unsatisfactory results when retaining the triphalangeal part; 3) removal of the ulnar digit; 4) period of surgery (more satisfaction when more experienced).

The congenital hand group in the Texas Scottish Rite Hospital (Stutz et al., 2014) reviewed types II, III, IV and V thumb polydactyly with a long-term follow up of more than 10 years. Type VII or atypical thumb polydactylies were excluded from the analysis. Forty-one patients were included for analysis with a total of 43 thumbs. Average age at follow up was 18 years (range 12-31)

with a mean follow up of 17 years (range 11-30). The Tada score (Tada et al., 1983) was used as outcome measure, with additional strength measurements, compared to the non-involved side. The Tada score gives good-fair-poor results, after combining the numerical value given to three categories. An additional DASH questionnaire and PedsQL were administered to evaluated patient related outcomes. Average Tada score at final follow up was 4.1, with 79% good results. The tripod pinch was significantly worse than the non-involved hand. Average DASH and PedsQL score were respectively 5 and 87 (for parents and patients). No analysis regarding factors influencing outcome were given.

Patel (Patel et al., 2014) evaluated 42 thumbs after being treated for Wassel type IV thumb polydactyly with a mean follow up time of 79 months (range 13 months – 18 years). Thirty-nine patients were available for analysis using the JSSH scoring (JSSH, 2006; Tada et al., 1983) with 5% of patients being excellent, 51% good, 36% fair and 8% poor. Additional analysis was performed as previously mentioned, adding radial abduction at the CMC joint, pinch and grip strengths, thumb size measurements, and patient and clinician assessment of appearance and function, compared as a percentage to the normal collateral thumbs. When incorporating this scale, 59% good results were found with less excellent and poor results (2.5%). No analysis was performed regarding the factors that would influence fair or poor results.

In a report on long-term outcome in a thesis dedicated to thumb polydactyly (Dijkman, 2016), 114 thumbs with type II, IV and type IV with a triphalangeal component were evaluated after a minimal follow up of 2 years, using the previously mentioned weighted score, called the Rotterdam outcome score for thumb polydactyly (Dijkman et al., 2016). Twenty patients (18%) were evaluated after multiple surgeries. Mean age at follow up was 9.1 years and time to follow up was 7.8 years. Overall outcome was similar between the different thumb polydactyly types with an average Rotterdam outcome score of 21 points (out of 30) in the single surgery group compared to the multiple surgery group of 17 points. Patients operated before an age of 1 year had less favour-

able outcomes than patients operated after an age of two. This difference was not found in patients operated between the age of 1 and 2 years. Furthermore, overall outcome and patient reported outcome was significantly better when the surgery was performed primarily or supervised by a dedicated congenital hand surgeon. The main reason for reoperation were instability and deviation in the 20 multiple surgery cases.

Overall, the majority of patients will have good results (51% - 86%), with only a few patients having excellent results. However, comparison between the mentioned studies is difficult because the evaluation was performed using different outcome assessment systems. Two studies reported improved results when dedicated congenital hand surgeons perform treatment.

The Bilhaut procedure

While radial polydactyly typically presents with one better developed and one less developed thumb, some cases will present where both thumbs are of approximately the same size and shape. In this case a Bilhaut procedure (Bilhaut, 1889) may be indicated. The Bilhaut procedure was originally described for radial polydactyly type I, but is nowadays also applied for types II-IV, and VII. Moreover, some find it particularly well suited for the 'diamond-shaped' type IV radial polydactyly cases. However, in using this technique, several risks are involved with regard to joint stiffness, marked broadness, and scarring of the nail and pulp. Several techniques have been introduced to overcome the drawbacks as mentioned (Abid et al., 2010; Baek et al., 2007; Iwasawa et al., 2008; Samson et al., 2004). In a matched comparative study, the Bilhaut procedure was compared with the resection and reconstruction technique (Dijkman et al., 2016). In a cohort of 116 eligible cases with thumb polydactyly, 8 patients underwent the Bilhaut procedure and were matched with 32 resection and reconstruction cases. The MCP joint stability in the Rotterdam outcome score (Dijkman et al., 2014) was significantly better after the Bilhaut procedure, with similar outcomes for the remaining functional items. Aesthetic items, appearance domain sub score and overall

clinician reported score for appearance, were significantly worse for the Bilhaut procedure. Regarding strength, the tip pinch was significantly weaker, with tripod- and key-pinch showing a same trend. Pulp circumference and nail width were significantly larger compared to the unaffected side in the Bilhaut technique. These results underline the increased MCP joint stability and thumb size after the Bilhaut procedure. However, these advantages do not result in stronger thumbs. Regarding aesthetic outcome, if using the Bilhaut procedure, attention should be given to reconstruction of the nail and nail wall.

Evaluating the reported outcome in thumb polydactyly according to current standard is a challenge due to the different tools used. In classifying thumb polydactyly, most will choose the Wassel classification. But since not all thumb polydactylies can be classified according this osseous anatomy based classification, authors choose to modify it, all in a different manner. In this way, it is not definite what the different types of thumb polydactyly are, or which patients were grouped in what type of difference. As a result, the base for being able to compare results of different types of thumb polydactyly is undefined, leading to incomparable evaluations of patient groups. When using the Rotterdam classification for polydactyly, all cases could be classified and is proposed as an all-embracing system to classify thumb polydactyly (Dijkman et al., 2014). The second step in evaluating outcome is choosing the right outcome assessment system, since reported results in the treatment of thumb polydactyly are dependent on the available tools used (Dijkman et al., 2014). To be able to report valid and generalizable outcomes, the importance of the different items in assessment schemes should be weighted carefully, defined by careful statistical analysis as is performed for the modified JSSH outcome measure (Dijkman et al., 2016).

In an era of value-based health care, evaluating surgical result is the first step, followed by patient related outcome measures such as manual ability, participation and quality of life. The reduced strength in thumb polydactyly patients does not influence their manual ability. However, the current questionnaires available for

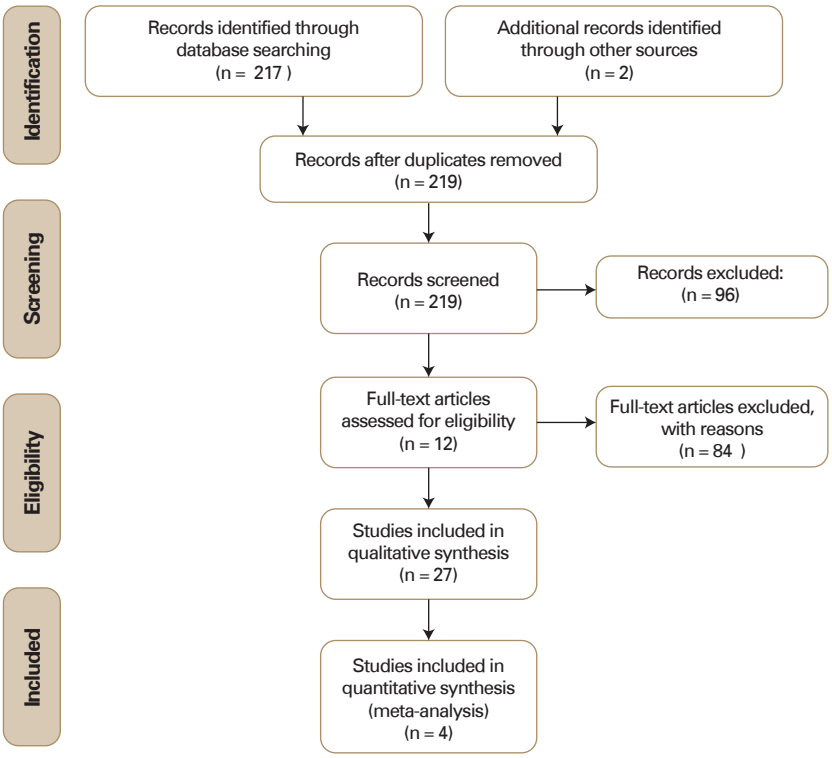
CULA are not specific and sensitive for the detection of activities that patients with for instance thumb polydactyly, are not able to perform. Are we asking the right questions? And do we need these results in shared-decision making?

Most importantly, the primary operation for children with thumb polydactyly is the major one, not performing surgery before one year of age, correcting all differences and avoiding revision surgery. It is advised to perform this type of surgery by or under supervision of experienced congenital hand surgeons.

Appendix 1

(((polydactyly/de OR (polydactyl* OR polysyndactyl* OR hyperdactyl*):ab,ti) AND (thumb/de OR (thumb* OR pollex OR radial OR preaxial* OR (pre NEXT/1 axial*)):ab,ti)) OR ('Holt Oram syndrome'/de OR 'acrocallosal syndrome'/de OR 'syndrome VATER'/de OR 'poland syndrome'/de OR 'Fanconi anemia'/de OR (((atriodigital OR 'heart hand' OR 'hand heart') NEAR/3 syndrome*) OR (holt NEAR/3 (Oram OR oran)) OR ((greig OR acrocallosal OR 'acro callosal') NEAR/3 syndrome*) OR ((vater OR vacterl) NEAR/3 (syndrome* OR association*)) OR (poland* NEAR/3 (syndrome* OR syndactyl* OR symbrachidactyl*)) OR (Fanconi* NEAR/3 anemia*) OR ((thumb* OR pollex) NEAR/3 (duplicat* OR triplicat* OR extra* OR addition* OR triphalangial* OR accessor* OR supernumerar* OR 'super numerary'))):ab,ti)) AND ('surgery'/exp OR surgery:lnk OR (surg* OR operati* OR remov* OR resect* OR reconstruct OR postoperat*):ab,ti) AND (hand/exp OR 'hand surgery'/exp OR 'hand malformation'/de OR (hand* OR thumb* OR finger* OR pollex):ab,ti) NOT ([Conference Abstract]/lim OR [Letter]/lim OR [Note]/lim OR [Editorial]/lim) AND [english]/lim AND (child/exp OR adolescent/exp OR adolescence/exp OR 'child behavior'/de OR 'child parent relation'/de OR pediatrics/exp OR childhood/exp OR 'child nutrition'/de OR 'infant nutrition'/exp OR 'child welfare'/de OR 'child abuse'/de OR 'child advocacy'/de OR 'child development'/de OR 'child growth'/de OR 'child health'/de OR 'child health care'/exp OR 'child care'/exp OR 'childhood disease'/exp OR 'child death'/de OR 'child psychiatry'/de OR 'child psychology'/de OR 'pediatric ward'/de OR 'pediatric hospital'/de OR 'pediatric anesthesia'/de OR 'pediatric intensive care unit'/de OR 'neonatal intensive care unit'/de OR (adolescen* OR preadolescen* OR infan* OR newborn* OR (new NEXT/1 born*) OR baby OR babies OR neonat* OR child* OR kid OR kids OR toddler* OR teen* OR boy* OR girl* OR minors OR underag* OR (under NEXT/1 (age* OR aging)) OR juvenil* OR youth* OR kindergar* OR puber* OR pubescen* OR prepubescen* OR prepubert* OR pediatric* OR paediatric* OR school* OR preschool* OR highschool*):ab,ti)

Diagram 1



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097
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RECONSTRUCTION FOR CONGENITAL THUMB HYPOPLASIA

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Introduction

Congenital thumb hypoplasia is a failure of formation or differentiation in the radial-ulnar axis of the hand plate and can occur as an isolated entity or in the context of radial longitudinal deficiency (Oberg et al., 2010). Several classification systems are in use to describe the anomalies in bones, joints and soft tissues of the thumb which serve as a guideline in the management of the hypoplastic thumb (Blauth, 1967; Buck-Gramcko, 2002; Manske and McCarroll, 1992; Müller, 1937; Tonkin, 2014). In order to provide the hand with the best functioning thumb, the choices for surgical reconstruction of the hypoplastic parts are usually made for thumbs that have an adequate carpometacarpal (CMC) joint. Management of these cases involves one or more of the following procedures: release of the first web space, stabilisation of the metacarpophalangeal (MP) joint, opposition plasty using most often the flexor digitorum superficialis (FDS) or abductor digiti minimi (ADM), and extrinsic tendon reconstruction, as appropriate. (Guero, 2008; Tonkin, 2011). Surgical approaches vary amongst different surgeons working in the field of congenital hand surgery. For the measurement of post-operative outcomes for children with congenital thumb anomalies, a number of assessment protocols with different parameters are used (Dijkman et al., 2016; Molenaar et al., 2008). This systematic review of the literature aims to: identify the different surgical techniques that have been used for reconstruction of the hypoplastic thumb; report the different measurement parameters used; and assess the reported outcomes.

Material and Methods

Selection of studies for assessment

This systematic review was registered on PROSPERO (registration number CRD42016042648) and performed according to the Pre-

ferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) method (Moher et al., 2009). Articles were included in the systematic review based on the following criteria: the study population included patients with isolated congenital thumb hypoplasia or in association with radial dysplasia, who underwent surgical reconstruction of the thumb and who had follow up data. Studies in all languages were considered for inclusion. Exclusion criteria were studies on patients with thumb hypoplasia that did not require surgical treatment, or for whom pollicization was indicated. Studies without follow up data, case reports on two or fewer patients, editorials, opinions, and comments were also excluded from analysis.

Search strategy

A systematic search of nine databases was performed on the 11th of July 2016 by two reviewers (JAS and KM), using a combination of the following key terms: thumb; thumbs; pollex; pollux; digit; dig; ray; phalanx; phalange; hypoplasia; hypoplastic; underdeveloped; deficient; deficiency; dysplasia. The databases searched for this review included PubMed, Medline, Embase, Premedline, AMED, CENTRAL (including Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, Cochrane Central Register of Controlled Trials, Cochrane Methodology Register, Health Technology Assessment, NHS Economic Evaluation Database), CINAHL Complete, SCOPUS, and Web of Science. An additional hand search was performed on Google scholar and in Clinical Trial registers (clinicaltrials.gov; clinicaltrialsregister.eu; anzctr.org.au; apps.who.int/trialsearch). Titles and abstracts were screened for relevancy and eligibility by two reviewers independently (JAS and KM). Differences were discussed between the reviewers, and the opinion of a third researcher (MAT) was sought when consensus could not be reached.

Level of evidence, methodology and statistics

To classify level of evidence, a classification system developed by Jovell and Navarro-Rubio (1995) was used. This system holds nine levels of evidence based on study design, and assigns strength

from good to poor for each level. To assess the methodological quality, the Coleman Methodology Score (CMS) was applied to each individual article. This method consists of part A (CMS A), with a value of 60 points, and part B (CMS B) with a value of 40 points. A perfect score of 100 would represent a study design that largely avoids the influence of chance, various biases, and confounding factors (Coleman et al., 2000). For each individual study, a consensus score was determined by two authors (JAS and KM). Where possible, a meta-analysis was considered for the comparison of groups.

Data extraction

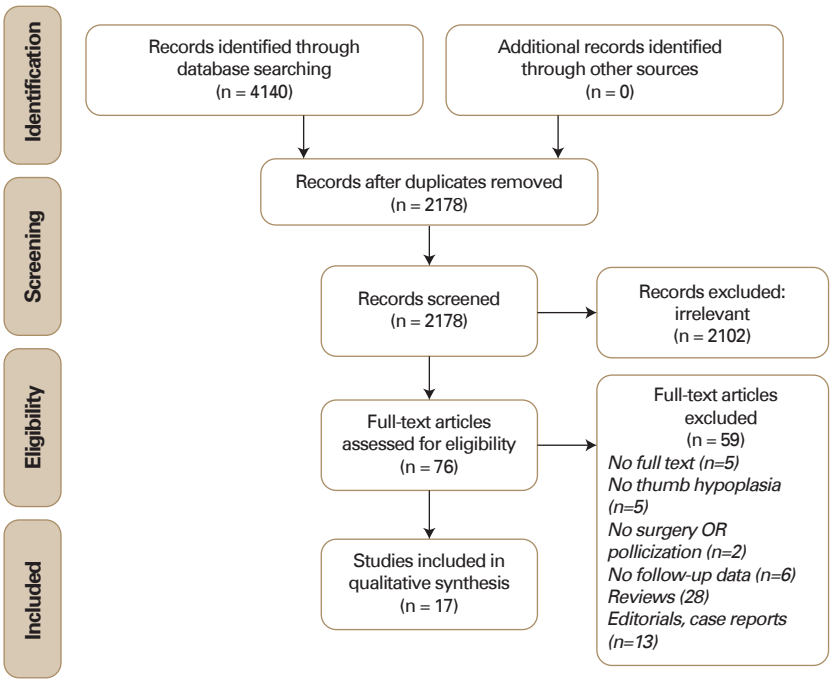
The following data was extracted from the articles: study and patient characteristics; surgical technique; surgical outcomes; and postoperative care. Surgical outcomes were sub-classified in: objective parameters, including strength, range of motion (ROM), alignment, stability, size, and contour; subjective parameters, including appearance, satisfaction, and pain; functional measurements; and complications.

Results

Literature search

The search strategy identified 2178 unique publications. Based on title and abstract screening, 76 articles were selected for full-text assessment. Seventeen articles that met the inclusion criteria were included for analysis (Figure 1). Languages included English (Abdel-Ghani and Amro, 2004; Christen and Dautel, 2013; de Kraker et al., 2016; Fitch et al., 1984; Graham and Louis, 1998; Lister, 1991; Manske and McCarroll, 1978; Neviaser, 1979; Ogino and Ishii, 1995; Ogino et al., 1986; Shibata et al., 2012; Smith et al., 2012; Upton and Taghinia, 2008; Vuillermin et al., 2016; Yoon and Jones, 2015), French (Oberlin and Gilbert, 1984) and Spanish (Vergara Amador, 2008).

Figure 1 Flowchart illustrating the selection of studies included in the systematic review



Study and patient characteristics

Study characteristics are shown in Table 1. The level of evidence of the included articles ranged from VI to IX, which equals a "poor" strength in 13 articles and a "fair" strength in four articles according to the identified classification system (Jovell and Navarro-Rubio, 1995). The total Coleman Methodology Score ranged from 10 (Fitch et al., 1984) to 68 (de Kraker et al., 2016). The mean age at time of surgery was 57.4 months (range 8 – 360 months) and the mean follow-up period was 45.9 months (range 2 – 264 months). Classification systems according to Blauth (1967) or a modification by Manske and McCarroll (1992) were used to grade patients. The analysed studies showed a heterogeneous study population. Five studies included all grades of thumb hypoplasia and described outcomes of pollicization as well as outcomes of reconstruction (Abdel-Ghani and Amro, 2004; Shibata et al., 2012; Upton and Taghinia, 2008; Vergara Amador, 2008; Yoon

and Jones, 2015). Four studies included patients with grade II and IIIA, according to the modified Blauth's classification by Manske and McCarroll (1992), that underwent reconstruction (Christen and Dautel, 2013; de Kraker et al., 2016; Ogino and Ishii, 1995; Ogino et al., 1986). Two studies reported their results of patients with grade IIIA exclusively (Graham and Louis, 1998; Neviaser, 1979) and one study included grade II thumbs only (Smith et al., 2012). Lister (1991) reported outcomes of his patients with pollex abductus. In contrast, de Kraker et al., (2016) excluded patients with pollex abductus in patients with grade II and IIIA hypoplasia. Fitch et al., (1984) reported outcomes of three cases with an anomalous connection between the flexor pollicis longus (FPL) and extensor pollicis longus (EPL). Two studies analysed all ADM transfers in patients with radial dysplasia and associated anomalies (Manske and McCarroll, 1978; Oberlin and Gilbert, 1984).

Table 1 Study characteristics

	LOE	Total Patients in study (n)	Patients with reconstruction (n)	Mean age at surgery in months (range)	Mean FU in months (range)	CMSA	CMS B	CMS total
Abdel-Ghani and Amro, 2004	VIII	82	9	37 (8 - 120)	36.8 (31 - 50)	20	7	27
Christen and Dautel, 2013	VIII	18	18	63 (22 - 180)	45 (n/a)	35	4	39
de Kraker et al., 2016	VI	27	21	n/a	n/a (24 - n/a)	39	29	68
Fitch et al., 1984	IX	3	3	100 (72 - 144)	n/a (0 - 24)	8	2	10
Graham and Louis, 1998	VIII	14	14	62 (12-144)	53 (5 - 156)	13	10	23
Lister, 1991	VIII	20	11	13 (n/a)	20 (2 - 60)	22	13	35
Manske and McCarroll, 1978	VIII	21	15	59 (18 -120)	37 (5 - 68)	32	5	37
Neviaser, 1979	VIII	10	10	n/a (12 - 132)	n/a (24 - 60)	17	0	17
Oberlin and Gilbert, 1984	VIII	14	8	36 (18 - 84)	15 (3 - 42)	17	2	19

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	LOE	Total Patients in study (n)	Patients with reconstruction (n)	Mean age at surgery in months (range)	Mean FU in months (range)	CMSA	CMS B	CMS total
Ogino and Ishii, 1995	VIII	18	18	78 (12 - 360)	37.2 (12 - 96)	32	2	34
Ogino et al., 1986	VIII	10	10	84 (16 - 360)	46.4 (12 - 96)	32	0	32
Shibata et al., 2012	VIII	18	13	59 (13 - 99)	90 (18 - 179)	25	2	27
Smith et al., 2012	VIII	49	45	67.2 (8 - 204)	40.8 (6 - 109.2)	32	17	49
Upton and Taghinia., 2008	VI	14	6	24 (n/a)	n/a (12 - 264)	25	4	29
Vergara Amador, 2008	VIII	22	5	n/a	28 (12 - 60)	23	12	35
Vuillermin et al., 2016	VI	40	40	58.8 (24 - 144)	91.2 (24 - 192)	29	27	56
Yoon and Jones, 2015	VI	38	13	62.6 (48 - 120)	56.4 (12 - 168)	30	20	50

LOE: Level of Evidence
CMS: Coleman Score

Surgical technique

The identified articles reported different techniques for opposition plasty, web space release, joint stabilisation and management of extrinsic anomalies (Table 2).

Table 2 Surgical techniques used for different parts of reconstruction

	Opposition plasty	First web space release	MPJ Stabilisation	Extrinsic anomalies
Abdel-Ghani and Amro, 2004	FDS IV OR ADM1	Z-plasty OR Double opposing Z-plasty with Y-V advancement	FDS IV	Release of FPL-EPL interconnections
Christen and Dautel, 2013	FDS IV	Kite flap with closing of the donor site using a Dufourmentel island flap OR 4-flap Z-plasty. To keep web space open: omega-shaped K-wire between MC1 and MC2	FDS IV	-

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	Opposition plasty	First web space release	MPJ Stabilisation	Extrinsic anomalies
de Kraker et al., 2016	FDS IV	5-flap Z-plasty OR transposition flap from the radio-dorsal side of dig II.	FDS IV	Extrinsic tendons were present and normal
Fitch et al., 1984	ADM1	Technique not described	Arthrodesis	Release of FPL-EPL interconnections
Graham and Louis, 1998	Technique not described. In general avoided	Technique not described	Capsular reefing. UCL reconstruction via capsular advancement OR palmaris longus tendon graft	Release of FPL-EPL interconnections. FPL path release and reorientation of tendon insertions
Lister, 1991	FDS IV + FDS III	Different local flaps	FSD IV AND pinning	Reconstruction
Manske and McCarroll, 1978	ADM3	-	Imbrication and suture of tendon slip to the ulnar capsule	-
Neviaser, 1979	ADM2	Z-plasty OR local advancement flap AND derotation of MP1	Intra-articular ankylosis AND K wire	Reconstruction
Oberlin and Gilbert, 1984	ADM2	Z-plasty	Temporary pinning	-
Ogino and Ishii, 1995	ADM3	Z-plasty with release of m. interosseous and adductor pollicis OR rotation flap	Free tendon graft	-
Ogino et al., 1986	ADM3	Z-plasty OR rotation flap	EIP adductor plasty	-
Shibata et al., 2012	ADM4	-	-	-
Smith et al., 2012	FDS OR ADM2 (based on MPJ stability)	Z-plasty	Type IIA: FDS IV. Type IIB: chondrodesis and K-wire	-
Upton and Taghinia., 2008	ADM4	-	Collateral ligament reconstruction, technique not described	-

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	Opposition plasty	First web space release	MPJ Stabilisation	Extrinsic anomalies
Vergara Amador, 2008	FDS IV	-	FDS IV	Reconstruction
Vuillermin et al., 2016	FDS IV	4-flap z-plasty AND release of the first dorsal compartment fascia.	FDS IV	IPJ arthrodesis in association with the opposition plasty
Yoon and Jones, 2015	FDS IV	4-flap Z plasty OR full-thickness skin graft	FDS IV	-

1 Technique not described
2 Technique according to Huber
3 Modified technique
4 ADM pedicled myocutaneous flap

To create opposition, transposition of the ADM was performed in seven articles (Fitch et al., 1984; Manske and McCarroll, 1978; Neviaser, 1979; Oberlin and Gilbert, 1984; Ogino and Ishii, 1995; Ogino et al., 1986; Smith et al., 2012). Ogino's group performed the ADM transfer alone or in combination with an adductor plasty using the extensor indicis proprius (EIP) (Ogino and Ishii, 1995; Ogino et al., 1986). The FDS obtained from the ring finger was used for opposition plasty in six articles (Christen and Dautel, 2013; de Kraker et al., 2016; Lister, 1991; Vergara Amador, 2008; Vuillermin et al., 2016; Yoon and Jones, 2015). Two articles performed opposition plasty using both FDS and ADM (Abdel-Ghani and Amro, 2004; Smith et al., 2012). Smith et al., (2012) based their choice for opposition plasty on stability of the MP joint and transferred the FDS in patients with unilateral instability and used the ADM in combination with chondrodesis in patients with bilateral instability. Abdel-Ghani and Amro (2004) performed only one ADM transfer in their patient group but did not state their reasons for using this transfer in this particular patient. Graham and Louis (1998) tried to avoid opposition plasty by performing simple releases and reorientation of tendon insertions, but opposition plasty with an undescribed donor tendon was performed in 57% of their patients. A total of six articles reported their reasons for selecting a specific opposition plasty (de Kraker et al., 2016; Lister, 1991; Smith et al., 2012; Upton and Taghinia, 2008; Vuill-

ermin et al., 2016; Yoon and Jones, 2015). For ADM opposition plasty four different surgical techniques were used: the original technique described by Huber in 1921 (Neviaser, 1979; Oberlin and Gilbert, 1984; Smith et al., 2012); a modification with partial detachment of the origin (Manske and McCarroll, 1978); a modification involving transfer of the origin to the palmaris longus tendon or the flexor retinaculum (Ogino et al., 1986); or the transfer of a pedicled myocutaneous flap (Smith et al., 2012; Upton and Taghinia, 2008).

For web space release, a Z-plasty using 2, 4 or 5 flaps was the most commonly described, alongside with the use of other reorientation flaps. Six studies did not make a statement about web space deepening, or did not report their technique. MP joint stabilisation was described in 16 of the identified articles and was performed via ulnar collateral ligament (UCL) reconstruction, radial collateral ligament (RCL) reconstruction, or both using FDS IV or palmaris longus, capsular advancement, temporary joint fusion with K-wires, or definitive arthrodesis or chondrodesis. Management of extrinsic anomalies was described in eight studies and included release of anomalous interconnections (Abdel-Ghani and Amro, 2004; Fitch et al., 1984; Graham and Louis, 1998; Lister, 1991), or reconstruction using EIP (Lister, 1991; Neviaser, 1979; Ogino and Ishii, 1995; Ogino et al., 1986; Vergara Amador, 2008). Postoperative care was reported in 11 articles and a dressing, splint or cast was used for immobilisation. The mean duration of immobilisation was 4.9 weeks (range 3 – 7).

Surgical outcomes

The surgical outcomes that have been used include: objective parameters (strength, ROM, alignment, stability, sensibility, size, contour); subjective parameters (appearance, satisfaction, pain); functional measurements and complications. Not every study used every measurement parameter to assess surgical outcomes. Details of the different objective and subjective outcome parameters collected by each article are shown in Tables 3 – 6. Complications and reoperations are shown in Table 7. Four studies considered

preoperative measurements and compared them postoperatively (Fitch et al., 1984; Ogino and Ishii, 1995; Ogino et al., 1986; Yoon and Jones, 2015). Other studies recruited the patient group postoperatively and compared outcomes with age-related normal values (de Kraker et al., 2016; Vuillermin et al., 2016) or compared outcomes to a control group of hypoplastic thumbs without surgery (de Kraker et al., 2016).

Strength

Table 3 summarises strength outcomes after reconstruction. Five studies reported outcome measurements for strength (de Kraker et al., 2016; Ogino and Ishii, 1995; Shibata et al., 2012; Upton and Taghinia, 2008; Vuillermin et al., 2016).

Table 3 Strength outcomes (by percentage of normal or compared to the opposite hand)

	Grip	Tip pinch	Lateral/ Key pinch	Tripod pinch	Pulp pinch	Opposition
de Kraker et al., 2016 *	46	46	44	42	-	66
Ogino and Ishii, 1995 **	-	56	-	-	-	-
Shibata et al., 2012 **	-	-	125	-	100	-
Upton and Taghinia., 2008*	-	-	40	-		-
Vuillermin et al., 2016 *	46	-	49	48	-	-

* % of normal
** % of opposite hand

De Kraker et al., (2016) measured grip, pinch and tripod pinch strength using an electronic dynamometer. Thumb opposition and palmar abduction strength were measured using the Rotterdam Instrinsic Hand Myometer. The measurements were performed by one independent researcher and a mean of three measurements was collected. Outcomes were compared with normative data obtained by a group in the same centre (Molenaar et al., 2008), and between operated and non-operated groups. De Kraker et al., (2016) found a significant difference in opposition strength between op-

erated (72% of normal) and non-operated grade II thumbs (33% of normal) and a significantly greater pinch strength, and key pinch strength in operated grade II thumbs compared to operated grade IIIA thumbs. Ogino et al., (1986) measured pinch function prior to surgery and described an overall improvement of pinch function postoperatively, without providing data. Ogino and Ishii (1995) measured pinch strength in a subgroup of 5 patients and compared their results to the normal, opposite hand. The mean pinch strength in this group was 2.3 kg (range 0.9 – 4.0 kg), with a mean percentage of 56% (range 23% – 90%) when comparing to the opposite side. Shibata et al., (2012) compared pulp pinch and key pinch of the reconstructed thumbs to the opposite hand. They found an equivalent pulp pinch and a key pinch of 125%, compared to the opposite hand. However, all patients had thumb hypoplasia of a different degree on the opposite hand and the actual method of obtaining the measurements was not described. Upton and Taghinia (2008) used a standard pinch meter to measure key pinch strength between thumb and index finger and found no difference in strength of the myocutaneous flap group compared to patients who received the ADM transfer described by Huber (1921). They found a decrease in strength of 40%, when comparing their results to age-matched hands in their practice. Vuillermin et al., (2016) measured grip, lateral pinch and tripod pinch and compared their results with age-related and sex-matched normative data. The actual method of obtaining measurements was not stated. One patient achieved tripod pinch strength greater than the mean of normal values. All other patients achieved grip, key, and tripod pinch strengths that were less than normal. Vuillermin et al., (2016) described a non-significant increase in grip strength when the surgical side was the dominant extremity ($P = 0.052$). Two studies stated that there was either improvement of strength in all patients (Manske and McCarroll, 1978), or that there was no weakness in pinch strength found in their patient group (Neviaser, 1979). One study classified pinch strength into three grades: no pinch; lateral pinch or pulp to pulp pinch (Vergara Amador, 2008). However, these three studies did not collect actual data and did not report on the measuring method.

Range of Motion

Table 4 provides an overview of the outcomes of postoperative ROM. ROM of the MP joint or interphalangeal (IP) joint was measured in six studies and expressed in degrees (Christen and Dautel, 2013; de Kraker et al., 2016; Fitch et al., 1984; Graham and Louis, 1998; Lister, 1991; Vuillermin et al., 2016).

Table 4 Range of motion outcomes

	Mean thumb ROM (°)		Thumb opposition				Mean thumb abduction (°)		Retro-position (cm)
	MPJ	IPJ	Little finger (%)	Ring finger (%)	Middle finger (%)	Kapandji (0-10)	Radial	Palmar	
Abdel-Ghani and Amro, 2004	-	-	89	-	11*	-	-	-	-
Christen and Dautel, 2013	43	21	-	-	-	6	-	-	-
de Kraker et al., 2016	41	14	-	-	-	7.8	39	43	1
Fitch et al., 1984	-	48	-	-	-	-	-	-	-
Graham and Louis, 1998	-	20*	-	-	-	-	-	-	-
Lister, 1991	-	21	-	-	-	-	-	-	-
Neviaser, 1979	-	-	100	-	-	-	-	-	-
Oberlin and Gilbert, 1984	-	-	100	-	-	-	-	-	-
Ogino and Ishii, 1995	-	-	83	11	6	-	-	-	-
Ogino et al., 1986	-	-	89	11	-	-	-	-	-
Shibata et al., 2012	-	-	67	33	-	-	-	-	-
Smith et al., 2012	-	-	20	67	13	-	-	-	-
Vergara Amador, 2008	-	-	60	23	7	-	-	-	-
Vuillermin et al., 2016	17	51	-	-	-	8	-	-	-
Yoon and Jones, 2015	-	-	85	15	-	-	-	-	-

* Postoperative improvement in degrees

Only de Kraker et al., (2016) and Vuillermin et al., (2016) provided details of their actual method of measuring range of motion. Vuillermin et al., (2016) measured MP joint and IP joint flexion and extension of the thumb from a neutral position, but did not define if the thumb was assessed in his resting position or measured from a corrected neutral position. De Kraker et al., (2016) measured active and passive ROM. MP joint and IP joint flexion and extension, together with radial abduction, were measured with a conventional goniometer. Palmar abduction was measured using the pollexograph (de Kraker et al., 2009) and thumb retroposition was measured as the distance in centimetres from table to tip of the thumb. De Kraker (2016) found that ROM in their patient group was reduced compared to normal, but IP joint flexion and extension in the operated thumbs was reduced most remarkably. Fitch et al., (1984) reported three cases with lack of IP joint flexion preoperatively, and found a mean postoperative improvement of 48° after releasing extrinsic tendon interconnections. Graham and Louis (1998) stated that an improvement of ROM was seen in all patients by a mean of 20°, but did not report the actual range of motion in their patient group. Lister (1991) reported only the ROM of his patients with poor IP joint flexion postoperatively and did not describe the outcomes of the other patients in his group. Upton and Taghinia (2008) stated that ROM in MP joint and IP joint was limited in 50% of their patients, but no measurements were displayed and the measuring method was not described. Thumb opposition was measured in eleven studies, using either the Kapandji score (Christen and Dautel, 2013; de Kraker et al., 2016; Vuillermin et al., 2016), a modified Kapandji score (Yoon and Jones, 2015), or a description of the ability to perform opposition to the little, ring or middle finger (Abdel-Ghani and Amro, 2004; Neviaser, 1979; Oberlin and Gilbert, 1984; Ogino and Ishii, 1995; Ogino et al., 1986; Shibata et al., 2012; Smith et al., 2012; Vergara Amador, 2008). Yoon and Jones (2015) compared preoperative and postoperative results for opposition and described improvement of opposition in all patients. Manske and McCarroll (1978) stated that all the transferred muscles contracted and pulled the thumb into opposition, but did not provide any further details. Oberlin and Gilbert (1984) measured antepulsion in degrees, but did not describe the outcomes of reconstruction and pollicization groups separately.

Alignment

Two authors included patients with pollex abductus and described an abnormal abduction deformity of the resting thumb (Graham and Louis, 1998; Lister, 1991). However, postoperative alignment was not described and no measurements were recorded. Lister (1991) described operative pinning of the MP joint in the "correct alignment", but did not obtain actual measurements for alignment. No further studies in this analysis measured the alignment of the thumb in its resting position. None of the articles commenting on alignment described the use of radiological imaging for that purpose.

Stability

Table 5 shows an overview of the outcomes of the studies assessing stability of the CMC, MP and IP joints.

Table 5 Stability (% of patients who underwent stabilisation)

Author	Stability					
	CMC joint		MPJ		IPJ	
	Stable	Unstable	Stable	Unstable	Stable	Unstable
Abdel-Ghani and Amro, 2004	-	-	71	29	-	-
Christen and Dautel, 2013	-	-	82	18*	-	-
de Kraker et al., 2016	95	5	86	14*	95	5
Graham and Louis, 1998	-	-	86	14**	-	-
Lister, 1991	-	-	100	0	-	-
Manske and McCarroll, 1978	-	-	82	18	-	-
Neviaser, 1979	-	-	100*	0	-	-
Ogino and Ishii, 1995	-	-	79	21	-	-
Ogino et al., 1986	-	-	67	33	-	-
Smith et al., 2012	-	-	82	18***	-	-

* Unstable when deviation >30°
** Deviation of approximately 20°
*** Unstable when deviation > 20°

Of all papers that have used stability in their assessment of outcomes, two studies provided a definition for MP joint instability (de Kraker et al., 2016; Smith et al., 2012). Smith et al., (2012) defined unilateral instability on the ulnar side (grade IIA) or bilateral instability (grade IIB) and considered the MP joint unstable when deviation was more than 20°. De Kraker et al., (2016) determined MP joint instability when a deviation greater than 30° was measured. However, both articles did not state if this outcome parameter represents ulnar deviation, radial deviation, or the total arc of both. Other papers reporting on MP joint stability did not provide an exact definition of stability and which degree of deviation was considered unstable. The methods used to measure stability were described by two studies (de Kraker et al., 2016; Graham and Louis, 1998). De Kraker et al., (2016) measured stability of the thumb manually in a neutral position and in 30° flexion, but did not specify whether stability of the thumb was measured from its resting position or from a corrected neutral position. Graham and Louis (1998) performed radially directed stress on the MP joint to test UCL integrity and compared the outcomes to the contralateral side. When comparing to the contralateral side, a greater deviation of approximately 20° was seen in 14% of their reconstructed thumbs (Graham and Louis, 1998). Two articles described improvement of stability relative to the preoperative status in respectively 94% and 100% of the patients who had MP joint stabilisation (Christen and Dautel, 2013; Neviaser, 1979). Ogino's group described in two studies a radial deviation of the MP joint when pinching in 17% (Ogino and Ishii, 1995) and 33% (Ogino et al., 1986). Of the papers reporting on stability, de Kraker et al., (2016) was the only one that provided outcomes for CMC joint and IP joint stability. CMC joint instability was defined by a positive dorsal shift test and was found in one patient (5%). IP joint instability, defined by more than 5° deviation, was also found in one patient (5%).

Sensibility, thumb size and contour

De Kraker et al., (2016) measured sensibility in children using the Shape-Texture Index (STI) for tactile gnosis and two-point discrimination. In adults, the Semmes-Weinstein monofilament test

was used. The overall results in these groups showed that sensibility was normal in 89% of the thumbs. Abdel Ghani and Amro (2004) assessed sensibility through physical examination and no skin abnormalities were noticed in his patient group. Other analysed articles did not assess sensibility. None of the identified studies assessed thumb size or contour.

Subjective parameters

Subjective parameters are shown in Table 6. Twelve studies reported on patient or parent satisfaction.

Table 6 Subjective measurements

	Assessment method	Scale	Appearance	Function	Overall
Abdel-Ghani and Amro, 2004	Not specified	Not specified	+	+	100% satisfied
Christen and Dautel, 2013	Questionnaire	"Completely satisfied"; "very satisfied"; "satisfied"; "not satisfied"	+	+	"Completely" or "very satisfied": 39% "satisfied": 61%
de Kraker et al., 2016	Visual analogue scale	0 (very poor/ugly) to 10 (very good/ beautiful)	7.0	6.7	-
Graham and Louis, 1998	Visual analogue scale	Not specified	+	+	Highest grade (excellent): 100%
Manske and McCarroll, 1978	Not specified	Not specified	Improvement in 100%	-	-
Ogino and Ishii, 1995	Questionnaire	Not specified	+	+	100% satisfied
Ogino et al., 1986	Not specified	Not specified	+	+	100% satisfied
Shibata et al., 2012	Not specified	Not specified	Improvement in 100%	-	-
Upton and Taghinia., 2008	Not specified	Not specified	Improvement in 100%	-	-
Vergara Amador, 2008	Questionnaire	"Poor"; "fair"; "good"	"Good": 100%	-	-
Vuillermin et al., 2016	Questionnaire*	0 to 100 (highest level of function)	-	90	-
Yoon and Jones, 2015	Questionnaire	Not specified	+	+	Improvement in 100%

+ Included in assessment
- Excluded from assessment
* Paediatric Outcomes Data Collection Instrument questionnaires

Seven studies stated their assessment method (Christen and Dautel, 2013; de Kraker et al., 2016; Graham and Louis, 1998; Ogino and Ishii, 1995; Vergara Amador, 2008; Vuillermin et al., 2016; Yoon and Jones, 2015). The majority of patients were satisfied, or stated to be satisfied with the improvement of the appearance and function of the reconstructed thumb. One study compared satisfaction between parents and their children and found no significant differences (de Kraker et al., 2016). Vuillermin et al., (2016) employed the Paediatric Outcomes Data Collection Instrument (PODCI) questionnaire, which uses different scales to measure outcomes for upper extremity, transfer and basic mobility, sports and physical function, pain and comfort, happiness, and global function. No other written assessment methods for function were utilized in the analysed studies. None of the authors assessed pain.

Complications and reoperations

Complications and reoperations were described in nine studies (Table 7).

Table 7 Number of postoperative complications and reoperations (from total)

	Complications	Reoperations
Christen and Dautel, 2013	2 (18)	0 (18)
de Kraker et al., 2016	1 (21)	2 (21)
Graham and Louis, 1998	-	1 (14)
Neviaser, 1979	0 (10)	-
Ogino and Ishii, 1995	0 (18)	-
Smith et al., 2012	3 (49)	6 (49)
Upton and Taghinia., 2008	0 (14)	-
Vuillermin et al., 2016	-	5 (40)
Yoon and Jones, 2015	0 (38)	-

Complications involved a residual clinodactyly (Christen and Dautel, 2013), wound healing problems (de Kraker et al., 2016) and Smith et al., (2012) reported infection, tip necrosis, and flexion contracture in 6% of their patients. Other studies made a general comment that no complications were seen in their patients (Graham and Louis, 1998; Neviaser, 1979; Ogino and Ishii, 1995;

Yoon and Jones, 2015). The studies utilizing a pedicled flap for opposition plasty reported flap survival in 100% of the patients (Shibata et al., 2012; Upton and Taghinia, 2008).

Secondary surgery was performed in 14 patients in four studies (de Kraker et al., 2016; Graham and Louis, 1998; Smith et al., 2012; Vuillermin et al., 2016). De Kraker et al., (2016) described re-operations in two patients (10%) due to wound healing problems (5%) and insufficient tension and stability of the reconstructed thumb (5%). Six patients (12%) of Smith et al., (2012) required secondary surgery, including releases of recurrent first web contractures (6%), MP joint stabilisation (4%) and a correction of pollex abductus (2%). Vuillermin et al., (2016) described five reoperations (13%) involving RCL reconstructions due to persistent MP joint instability (8%), a resection of an accessory ossicle at the distal scaphoid, and an additional EIP transfer due to muscular imbalance (Vuillermin et al., 2016). Graham and Louis (1998) described one patient that underwent an additional deepening of the first web space.

Discussion

Current available literature on reconstruction of the hypoplastic thumb consists largely of uncontrolled, retrospective descriptive studies with a low level of evidence. Identified studies showed large variations in inclusion criteria, inducing heterogeneous study populations outlining the results of patients with different grades of thumb hypoplasia. Additionally, the definition for different grades might not have been used consistently. For example, de Kraker et al., (2016) included thumb hypoplasia grade II and IIIA (which by Manske's modification of Blauth's classification are distinguished by extensive extrinsic deficiency), but subsequently excluded patients with pollex abductus.

With regards to the surgical techniques, a number of different procedures are described for each part of the reconstruction. Characteristics of the hypoplastic parts to be reconstructed vary amongst each individual patient, which implies that there is no standard procedure that can be applied for the reconstruction of all hypoplastic thumbs. Analysed studies suggested that the choice for

a particular surgical approach is based on the preoperative measurements, with MP joint stability being the most important parameter. We believe that intraoperative findings and the surgeon's experience and preference also contribute to that decision. For opposition plasty, one benefit of utilizing the ADM is the creation of bulk to the thenar eminence, hereby improving the appearance in comparison with an FDS transfer. However, the tendon is too short to reconstruct the UCL and RCL, which is an advantage of the FDS transfer. This raises the question as to whether surgeons should adapt their method of opposition plasty according to an intraoperative assessment of the degree of radial and ulnar instability of the MP joint, and the quality of local tissues.

In the analysed studies, the methods to measure surgical outcomes varied largely. Furthermore, we found a great variation in the quality of reporting assessment methods and results. This questions the value of the reported outcomes, as the results of individual studies cannot easily be compared. Recently, there has been more interest in obtaining standardised measurement methods for the assessment of the paediatric hand (de Kraker et al., 2016; Dijkman et al., 2016; Engelhardt et al., 2016; Tonkin, 2016). However, validated tests to measure surgical outcomes for children with thumb hypoplasia are not yet available. It would seem logical to evaluate success of surgery by comparing preoperative and postoperative measurements, and by comparing postoperative outcomes with age-related normal values. Currently, paediatric normal values are only obtained for patients from the age of three to fourteen (Engelhardt et al., 2016), four to twelve (de Kraker et al., 2009; Molenaar et al., 2011; Molenaar et al., 2010) and six to twelve (Mathiowetz et al., 1986). However, the preferred age to perform reconstruction is during the first and second year of life. Clinical examination in this age category is more difficult, and this raises the question as to which measurements are applicable in this group of patients and how reliable these measurements are. The fact that there is no standard surgical procedure and no standard measurement method available is reflected in the variety of the different classification systems in use (Tonkin, 2014).

In conclusion, the poor study quality, the number of different surgical approaches and the lack of standardised measurement methods used in the identified studies do not allow us to compare results and make recommendations that can change our practice. For the choice of the appropriate surgical technique, an accurate assessment of the deficient structures requiring reconstruction is needed. The intraoperative assessment might eventually define the final decision for the method of reconstruction. The establishment of a valid, age-related assessment method for thumb hypoplasia which considers preoperative measurements and includes intraoperative findings would be a valuable contribution for the future.

KEY POINTS

- For the choice of the appropriate surgical technique, an accurate assessment of the deficient structures requiring reconstruction is needed.
- Currently, grading and assessment systems are inconsistently used. The intraoperative assessment might eventually define the final decision for the method of reconstruction.
- The establishment of a grading system that includes preoperative assessment and intraoperative findings would allow one to assess the success of surgery and compare similar patients from different studies.

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POLLICISATION FOR THUMB HYPOPLASIA AND APLASIA

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Introduction

For most surgeons, the indication for pollicisation in children with thumb hypoplasia is the absence of a thumb carpometacarpal joint (Blauth grades 3-5, Manske grades 3B, 4 and 5 and Tonkin grades 3A, 3B, 4 and 5) (Blauth, 1967; Buck-Gramcko, 1971; Manske and McCarroll, 1992; Tonkin, 2014). Several technical modifications have been proposed to optimise the function of the pollicised thumb over time. Nonetheless, the broad surgical principles (Buck-Gramcko, 1971; Ceulemans et al., 2010) in pollicisation surgery involve:

i. Planning of the skin incision to create an adequate first web-space
ii. Transposition of the index finger on its neurovascular pedicle
iii. Skeletal readjustment (metacarpal shortening and head rotation) to create a neo-trapezium and basal trapeziometacarpal joint
iv. Intrinsic and extrinsic musculotendinous transfers and rebalancing

Outcome measures have historically involved consideration of range of motion, strength, composite function, dexterity, cosmesis, sensibility and satisfaction. However, modifications of surgical technique, the heterogeneity of surgical candidates and the lack of standardised data collection make critical evaluation of pollicisation outcomes difficult. Moreover, functional assessment is confounded by co-existent congenital anomalies, and age-appropriate testing is challenging in paediatric populations. The purpose of this systematic review is to synthesise the results of index digit pollicisation for reconstruction of the congenitally absent or hypoplastic thumb.

Methods

Inclusion criteria

This systematic review was performed in accordance with the PRISMA statement (Moher et al., 2009). Articles were included in the study based on the following criteria:

i. The studied population included patients with congenital thumb hypoplasia or aplasia NOT patients with post-traumatic thumb injuries or amputations
ii. The results were published as a full report in English

Exclusion criteria

Abstracts, case reports, conference presentations, review articles, editorials and expert opinions were excluded from the report.

Literature search strategy

Electronic searches were performed using Ovid Medline and Pubmed from their date of inception to September 2016. To identify all studies, "pollicisation" or "pollicization" were searched as either key words or MeSH terms. The reference lists of all retrieved articles were reviewed for further identification of potentially relevant studies. All identified articles were systematically assessed using the inclusion and exclusion criteria.

Outcome measurement

In cases of pollicisation for congenital thumb hypoplasia or aplasia, the outcome of this evaluation included the post-operative assessment of:

i. Thumb mobility
ii. Strength (grip and pinch)
iii. Functional outcomes measured by scoring systems
iv. Bony union between the head and base of the index finger (new carpometacarpal joint)
v. Sensation of the pollicised index finger
vi. Post-operative complications

vii. Revision surgery rates

viii. Subjective parent/caretaker satisfaction levels (function and cosmesis)

Assessment of level of evidence and methodological quality

One reviewer independently assessed the methodological quality of each study using the Coleman methodology score system (Coleman et al., 2000).

Results

Literature search

A total of 538 articles were identified through the aforementioned search strategy. After exclusion of duplicate or irrelevant references, 33 potentially relevant studies were retrieved. Detailed evaluation of these texts yielded 27 studies that are included in this systematic review (Figure 1).

Figure 1 Search strategy

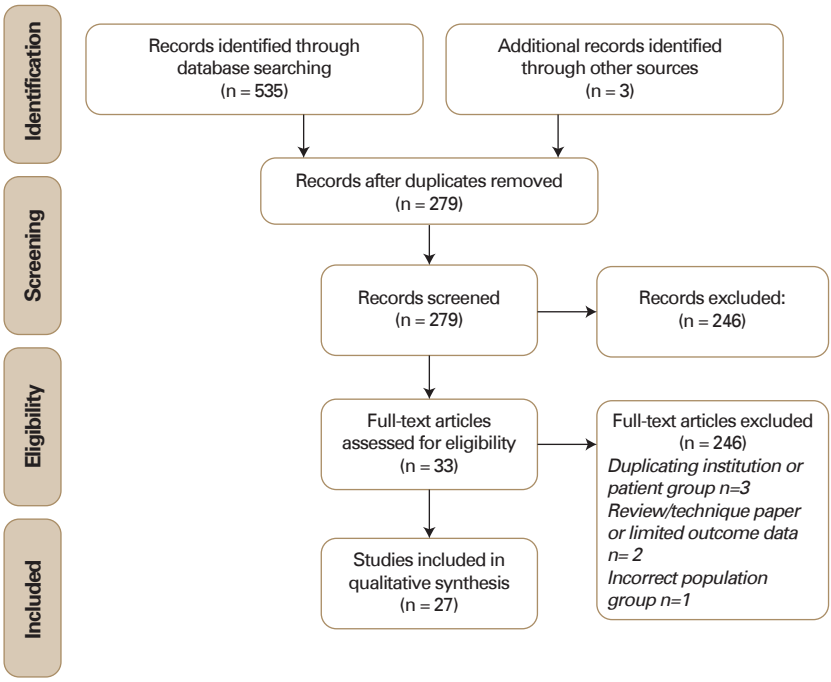

Table 1 summarises key features of included studies.

Table 1 Summary of studies investigating pollicisation outcomes

Author	Patients (n)	Pollicisation procedures (n)	Mean age of surgery (months)	Mean follow-up (years)	Coleman methodology score	
					Individual	Total
Strugarek-Lecoanet et al., 2016	14	23	19	8.2	4, 5, 10, 0, 5, 5, 0	29
Mas et al., 2016	22	22	34	6.4	4, 5, 10, 0, 5, 5, 5	29
Tonkin et al., 2015	35	42	34	5.7	7, 5, 10, 0, 5, 5, 0	32
Trist et al., 2015	36	46	22	8	7, 5, 10, 0, 5, 5, 0	32
Lightdale-Miric et al., 2015	8	10	40	8.2	0, 5, 10, 0, 5, 5, 10	35
Zlotolow et al., 2014	35	42	23	3.4	7, 5, 10, 0, 5, 5, 0	32
Tan and Tu, 2013*	15	15	23	5.7	0, 5, 10, 0, 5, 5, 0	25
de Kraker et al., 2013	24	30	43	9.4	4, 5,10, 0, 5, 5, 0	29
Netscher et al., 2013	18	22	-	5.3	4, 5, 10, 0, 5, 5, 0	29
Lochner et al., 2012	74	85	48	**	10, 5, 10, 0, 5, 5, 0	35
Al-Qattan, 2012	16	17	22	5	0, 5, 10, 0, 5, 5, 0	25
Vekris et al., 2011	18	21	41	9	4, 5, 10, 0, 5, 5, 0	29
Ceulemans et al., 2010	17	24	12	4.4	4, 5,10, 0, 5, 5, 0	29
Hildegunde et al., 2009	15	19	36	4.5	0, 5, 10, 0, 5, 5, 10	35
Goldfarb et al., 2009	64	73	46	5.5	10, 5, 10, 0, 5, 5, 0	35
Aliu et al., 2008	5	7	23	9.1	0, 5, 10, 0, 5, 5, 0	25
Goldfarb et al., 2007	26	31	-	3.4	4,5,10, 0, 5, 5, 0	29
Staines et al., 2005	10	12	28	2.8	0, 5, 10, 0, 5, 5, 0	25
Abdel-Ghani and Amro, 2004*	16	17	18	3.2	0, 5, 10, 0, 5, 5, 0	25
Clark et al., 1998	11	15	84	27	0, 5, 10, 0, 5, 5, 0	25
Manske et al., 1992	23	28	48	8	4, 5, 10, 0, 5, 5, 0	29
Kozin et al., 1992	10	14	84	9	0, 5, 10, 0, 5, 5, 0	25
Sykes et al., 1991	22	30	62	6.8	4, 5, 10, 0, 5, 5, 0	29
Roper and Turnbull, 1986	9	9	60	5	0, 5, 10, 0, 5, 5, 0	25
Manske and McCarroll, 1985	33	40	67	6.2	4, 5 10, 0, 5, 5, 0	29
Egloff and Verdan, 1983	14	14	-	8	0, 5, 10, 0, 5, 5, 0	25
Buck-Gramcko, 1971	73	100	***	****	10, 5, 10, 0, 5, 5, 0	35

* Only cohort of patients undergoing pollicisation included
** At least 2 years follow up
*** Age range: 11 weeks -12 years
**** Follow up range: from less than 1 year to 12 years

Mobility

Tables 2-4 outline studies that reported mobility outcomes after pollicisation, sub-categorised by population case-mix (isolated thumb hypoplasia or aplasia only, patients with thumb hypoplasia or aplasia and additional forearm or hand anomalies, and mixed groups). Thumb opposition to the little finger ranged from 62-100%, ring finger ranged from 17-29% and middle finger ranged from 7-21% of cases across mixed study populations (Table 2).

In patients with isolated thumb hypoplasia or aplasia (Table 3), thumb metacarphophalangeal (MP) joint and interphalangeal (IP) joint range of movement ranged from 38-70° and 35-43° respectively after surgery.

In patients with thumb hypoplasia or aplasia and other forearm or hand anomalies, thumb MP and IP joint range of motion ranged from 17-85° and from 19-44° respectively after surgery (Table 4).

Two studies statistically compared mobility in patients with isolated thumb hypoplasia or aplasia with and without additional forearm or hand anomalies (Table 5).

Table 2 Thumb mobility outcomes in pollicisation cases (included data represents study populations with both isolated thumb hypoplasia or aplasia cases and patients with additional forearm or hand anomalies)

	"New" thumb range of motion (°)		Total thumb active motion (°)	Thumb opposition (%)			Thumb abduction (°)			Thumb retropulsion (mm)
Study	MP	IP		Little finger	Ring finger	Middle finger	Radial	Palmar	Unspecified	
Tonkin et al. (2015)	26	26	-	62	17	21	43	44	-	7
Vekris et al. (2011)	55*	34*	145	85	10	5	-	-	-	-
Abdel-Ghani and Amro (2004)	-	-	-	-	-	-	-	-	>40**	-
Manske et al. (1992)	42	25	98	-	-	-	-	-	-	-
Kozin et al., (1992)	93*	38*	-	64	29	7	-	-	62	-
Roper and Turnbull (1986)	-	-	-	100	-	-	44	53	-	-

* Extrapolated from study
** 88% of patients had thumb abduction >40degrees

Table 3 Mobility outcomes in pollicisation cases classified by isolated thumb hypoplasia or aplasia cases only

Study	"New" thumb range of motion (°)		Total thumb active motion (°)	Thumb abduction (°)			Thumb retropulsion (mm)
	MP	IP		Radial	Palmar	Unspecified	
Tonkin et al., (2015)	38	35	-	48	37	-	13
Al-Qattan (2012)	60	35	-	-	-	-	-
Vekris et al., (2011)	70	43	145	-	-	-	-
Staines et al., (2005)	-	-	89	-	-	-	-
Manske et al., (1992)	65	41	146	-	-	-	-
Egloff and Verdan (1983)	42	35	-	-	-	-	-

Table 4 Mobility outcomes in pollicisation cases in patients with thumb hypoplasia or aplasia and additional forearm or hand anomalies (*extrapolated from study)

Study	"New" thumb range of motion (°)		Total thumb active motion (°)	Thumb abduction (°)			Thumb retropulsion (mm)
	MP	IP		Radial	Palmar	Unspecified	
Tonkin et al., (2015)	17	19	-	42	39	-	0
Tan and Tu (2013)	-	-	74	-	-	-	-
de Kraker et al., (2013)	51*	26*	-	48	38	-	14
Vekris et al., (2011)	35	22	96	-	-	-	-
Manske et al., (1992)	29	17	69	-	-	-	-
Kozin et al., (1992)	85	44	-	-	-	50	-

Table 5 Range of motion and strength in thumb hypoplasia or aplasia cases with and without forearm anomalies (% - proportion of age related normal values)

Study	Variable	Thumb hypoplasia/aplasia		P-value
		No other forearm/ hand anomalies	Additional forearm or hand anomalies	
Tonkin et al. (2015)	ROM - MP joint (°)	38	17	0.002
	ROM - IP joint (°)	35	19	0.009
	% Grip	40	6	<0.001
	% Lateral pinch	30	9	0.005
	% Tip pinch	52	22	0.006
Manske et al., (1992)	ROM - MP joint (°)	65	29	0.006
	ROM - IP joint (°)	41	26	0.002
	% Grip	31	15	0.005
	% Lateral pinch	38	14	<0.001
	% Tip pinch	44	16	<0.001

Strength

Tables 6 and 7 summarise strength outcomes after pollicisation. In patients with isolated thumb hypoplasia or aplasia, mean grip strength ranged from 29-40%, lateral/key pinch from 25-38%, tip pinch from 44-52% and tripod pinch from 31-35% as a proportion of age related normal values after surgery (Table 6).

In patients with isolated thumb hypoplasia or aplasia, grip strength ranged from 55-60% of the other hand (Table 7). In patients with thumb hypoplasia or aplasia and other congenital forearm or hand anomalies, mean grip strength ranged from 6-45%, lateral/key pinch from 9-14%, tip pinch from 16-54% and tripod pinch from 16-46% of age related normal values. Two studies statistically compared strength outcomes in patients with thumb hypoplasia or aplasia cases with and without additional forearm or hand anomalies (Table 5). Two studies reported increases in grip strength in cohorts of patients assessed over a three to five year period (Aliu et al., 2008; Tonkin et al., 2015).

Table 6 Strength (by percentage of age-related normal values) in varied pollicisation cohorts

Study	Case mix	Grip	Lateral / key pinch	Tip pinch	Tripod pinch
		*% of normal**			
Tonkin et al., (2015)	Mixed	20	18	34	-
	Isolated hypoplasia/aplasia	40	30	52	-
	Additional anomalies	6	9	22	-
de Kraker et al., (2013)	Mild radial longitudinal deficiency	45	-	54	46
	Severe radial longitudinal deficiency	17	-	19	15
Netscher et al., (2013)	Isolated hypoplasia / aplasia	29	27	-	31
Staines et al., (2005)	Isolated hypoplasia / aplasia	36	25	-	32
Clark et al., (1998)	Mixed	43**	41**	41**	-
Manske et al., (1992)	Mixed	21	22	26	23
	Isolated hypoplasia / aplasia	31	38	44	35
	Additional conditions	15	14	16	16

* Age related normal values
** Extrapolated data

Table 7 Strength (by percentage of contralateral side) in varied pollicisation cohorts

Study	Case mix	Grip	Lateral / key pinch	Tip pinch	Tripod pinch
			*% of normal**		
Netscher et al., (2013)	Isolated hypoplasia/aplasia	60	44	-	47
Al-Qattan (2012)	Isolated hypoplasia / aplasia	55	-	45	-
Vekris et al., (2011)	Mixed	76	60	56	-
Clark et al., (1998)	Mixed	43**	39**	43**	-
Kozin et al., (1992)	Mixed	67	60	-	39
Roper and Turnbull (1986)	Mixed	63	-	56	-

**Extrapolated data

Functional Outcomes

Percival Score

The Percival score is a composite pollicisation-specific measure of pinch strength and accuracy, opposition, grasp, mobility, sensation and cosmesis (Percival et al., 1991). Six studies reported Percival scores after pollicisation (Table 8). 54-95% of reported patients achieved a "good" or "excellent" result, as defined by Percival score categories.

Table 8 Percival scores

Study	Case Mix	Percival (% of total patients)			
		Excellent	Good	Fair	Poor
Mas et al., (2016)	Mixed	9	54	23	14
Vekris et al., (2011)	Mixed	75	19	0	6
Ceulemans et al., (2010)	Mixed	5	49	23	23
Hildegunde et al., (2009)	Mixed	37	58	5	0
Clark et al., (1998)	Mixed	40	20	13	27
Sykes et al., (1991)	Mixed	33	40	17	13
	Isolated hypoplasia / aplasia	48	42	5	5
	Associated anomalies	0	33	45	22

Jebsen Test

The Jebsen test is a validated timed assessment of fine and gross motor hand function using simulated activities of daily living (Jebsen et al., 1969). Two studies compared Jebsen test scores (as a proportion of normal values) in children with thumb hypoplasia or aplasia with and without other forearm or hand anomalies (Table 9). For mixed study populations, mean Jebsen test times ranged from 122-173% of normal values. Two other studies assessed results from Jebsen test subcategories. Netscher et al., (2013) reported a longer time taken in seconds (s) for small object manipulation (12s vs 7s, p=0.021), simulated feeding (47s vs 11s, p=0.013) and large light object lifting (7s vs 4s, p<0.001) in pollicised patients compared to age-matched controls. Staines et al., (2005) reported a longer time taken for page turning (23.9s vs 13.9s, p=0.031), checker stack (13.6s vs 6.4s, p=0.016) and light lifting (26.9s vs 7.7s, p=0.016) in pollicised patients compared to the contra-lateral hand.

Table 9 Jebsen test results - comparative analysis by patient groups

Study	Case mix	Jebsen test % normal	P-value
Tonkin et al., (2015)	Mixed	173	
	Isolated hypoplasia / aplasia	136*	0.001
	Additional forearm anomalies	205*	
Manske et al., (1992)	Mixed	122	
	Isolated hypoplasia / aplasia	101*	0.007
	Additional forearm or hand anomalies	133*	

* P-values comparing isolated hypoplasia / aplasia and additional forearm or hand anomaly groups

Sensibility

There were no studies that reported changes in sensibility in the pollicised index fingers attributable to the pollicisation procedure. De Kraker et al., (2013) reported one case of diminished light touch in a patient, which was explained by the presence of an underdeveloped neurovascular bundle observed during surgery.

Bony union

Three studies formally assessed union and trapezial instability in the new trapeziometacarpal joint (Table 10). Non-union rates between the head and based on metacarpal ranged from 15-39%. Clinical or radiographic trapezial instability was reported in 15-43% of cases.

Table 10 Fixation, bone union, physeal arrest and trapezial instability in pollicisation cases

	Fixation method*	Non-union*	Union*	Physeal arrest (index metacarpal)	Trapezial instability in non-union cases **
		N (%)	N (%)	N (%)	N (%)
Strugarek-Lecoanet et al., (2016)	Kirschner wires	9/23 (39)	14/23 (61)	0/23 (0)	3/9 (33)
Trist et al., (2015)	Kirschner wire, non-absorbable suture and bone graft	7/46 (15)	39/46 (85)	-	3/7 (43)
Lochner et al., (2012)	Kirschner wires	20/85 (24)	65/85 (76)	21/85 (25)	3/20 (15)

* Between head and base of index metacarpal
** Clinical or radiographic

Peri- and post-operative complications

Five studies formally reported complication outcomes (Table 11). The rates of skin flap necrosis or infection varied from 1-18%. The incidence of salvageable venous congestion or iatrogenic arterial injury ranged from 3-7%. Three cases of loss of the pollicised digit were reported.

Table 11 Post-operative complications

	Skin necrosis	Infection	Salvageable venous congestion	Salvageable arterial or unspecified vascular injury	Loss of pollicised digit
	N (%)	N (%)	N (%)	N (%)	N (%)
Hildegunde et al., (2009)	1/19 (5.2)	-	-	-	-
Goldfarb et al., (2009)	4/73 (5.5)	1/73 (1.4)	2/73 (2.7)	-	1/73 (1.4)
Abdel-Ghani and Amro (2004)	3/17 (17.6)			1/17 (5.9)	1/17 (5.9)
Clark et al., (1998)	-	-	-	1/15 (6.7)	-
Buck-Gramcko (1971)	-	-	-	12/460* (2.6)	1/460* (0.2)

* N=460 from Buck-Gramcko (1991)

Revision surgery

Seven studies reported rates of revision surgical procedures after index finger pollicisation (Table 12). Across all studies, the rates of revision surgery varied from 5-65%. The rates of scar contracture release ranged from 4-21%, bone shortening or spike excision from 7-17%, extensor tendon imbrication or shortening from 5-15%, joint arthrodesis from 6-10% and opponensplasty from 13-50%.

Table 12 Rates of revision surgery after primary pollicisation

	Scar contracture release / revision	Excision of bone spike / bone shortening	Extensor tendon imbrication / shortening	Arthrodesis	Opponensplasty	Other	Total revision procedures
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Vekris et al., (2011)	-	1/21 (4.8)	-	-	-	-	1 (4.8)
Hildegunde et al., (2009)	-	-	1/19 (5.3)	-	-	1/19 (5.3)	2 (10.6)
Goldfarb et al., (2009)	3/73 (4.1)	-	11/73 (15.1)	4/73 (5.5)	19/73 (26)	-	37 (50.7)

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	Scar contracture release / revision	Excision of bone spike / bone shortening	Extensor tendon imbrication / shortening	Arthrodesis	Opponensplasty	Other	Total revision procedures
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Staines et al., (2005)	-	-	-	-	6/12 (50)	-	6 (8.2)
Sykes et al., (1991)	4/30 (13.3)	5/30 (16.7)	-	-	4/30 (13.3)	-	13 (43.3)
Manske and McCarroll (1985)	-	-	4/40 (10)	4/40 (10)	18/40 (45)	-	26 (65)
Egloff and Verdan (1983)	3/14 (21.4)	1/14 (7.1)	-	-	-	2/14 (14.3)	6 (42.9)

Parent satisfaction

Table 13 highlights parent satisfaction after pollicisation surgery. Regardless of the assessment method, the majority of parents were satisfied with functional and cosmetic outcomes after pollicisation surgery.

Table 13 Parent / care-taker satisfaction (function, cosmesis, overall) after pollicisation surgery

	Assessment method	Scale	Cosmesis	Function	Overall
Tonkin et al., (2015)	Questionnaire	"Excellent", "good", "fair" and "poor"	94% (excellent or good)	77% (excellent or good)	-
de Kraker et al., (2013)	Visual analogue scale	0 (very poor/ ugly) to 10 (very good/beautiful)	7.2	7.5	-
Netscher et al., (2013)	Questionnaire	1 (best) to 5 (worst)	2.1	2.2	-
Al-Qattan (2012)	Questionnaire	"Satisfied", "somewhat satisfied" or "not satisfied"	-	-	100% satisfied
Vekris et al., (2011)	Questionnaire	1 (worst) to 10 (best)	-	-	8.6
Ceulemans et al., (2010)	Visual analogue scale	1 (worst) to 10 (best)	-	-	7.6

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	Assessment method	Scale	Cosmesis	Function	Overall
Aliu et al., (2008)	Questionnaire	1 (best) to 5 (worst)	-	-	58% (1)
Goldfarb et al., (2007)	Visual analogue scale	1 (worst) to 10 (best)	7.3	-	-
Staines et al., (2005)	Questionnaire	1 (best) to 5 (worst)	58% (1 or 2)	67% (1 or 2)	
Abdel-Ghani and Amro (2004)	Not specified	Not specified	-	-	100% satisfied
Manske et al., (1992)	Not specified	Not specified	96% satisfied	-	-
Roper and Turnbull (1986)	Not specified	Not specified	100% satisfied	-	-

Discussion

Although pollicisation surgery for hypoplastic or aplastic thumbs was popularised almost fifty years ago (Buck-Gramcko, 1971), the lack of consensus outcome measures precludes analysis of different techniques across studies (Tonkin et al., 2015; Zlotolow et al., 2014). The comparative analysis of outcomes is further complicated by different study methodologies, the heterogeneity of study populations (age, severity of disease and co-existing disorders) as well as the lack of availability of raw data sets (Tonkin et al., 2015). Few studies adequately subcategorised and statistically compared their population groups. Most studied cohorts mixed children with isolated thumb hypoplasia or aplasia cases with patients who had additional congenital abnormalities like radial dysplasia. The studies conducted by Manske et al., (1992) and Tonkin et al., (2015), included in this review, affirm the significant differences in range of motion, strength and composite function in patients with isolated thumb hypoplasia/aplasia as against those with additional congenital abnormalities.

In this review, decreased mobility, strength and functional performance was observed in children undergoing pollicisation for thumb hypoplasia or aplasia, compared to age-matched normal values or non-operated contralateral hands. In patients with isolated thumb hypoplasia/aplasia, mean grip strength approximated

one-quarter to half of normal strength values across all studies (Al-Qattan, 2012; Egloff and Verdan, 1983; Manske et al., 1992; Staines et al., 2005; Tonkin et al., 2015; Vekris et al., 2011). Grip, lateral/key, tip and tripod pinch strengths for patients with additional forearm or hand abnormalities, were more heterogeneous, ranging from 6-54% (of normal values) (de Kraker et al., 2013; Egloff and Verdan, 1983; Manske et al., 1992; Tan and Tu, 2013; Tonkin et al., 2015; Vekris et al., 2011). The use of contralateral hand function as a denominator for pollicisation outcomes in unilateral cases is contentious. In unilateral pollicisation cases, studies have demonstrated that the opposite, seemingly clinically normal hand may not function at the same level of strength and dexterity as age-matched normal hands (Aliu et al., 2008; Lightdale-Miric et al., 2015; Manske et al., 1992; Netscher et al., 2013). Consequently, the grip strength range of 55-60% (as a proportion of the contralateral hand) reported in this review, may over-estimate functional outcomes after pollicisation.

Despite their functional limitations, the majority of parents were satisfied with the aesthetic and functional outcomes. More objectively, the vast majority of patients (54-95%) achieved a "good" or "excellent" result, as defined by Percival score categories (Ceulemans et al., 2010; Clark et al., 1998; Hildegunde et al., 2009; Mas et al., 2016; Sykes et al., 1991; Vekris et al., 2011). Significant post-operative complications were rare and although revision surgery rates varied from 5-65% (Ceulemans et al., 2010; Clark et al., 1998; Egloff and Verdan, 1983; Goldfarb et al., 2009; Hildegunde et al., 2009; Manske and McCarroll, 1985; Mas et al., 2016; Staines et al., 2005; Sykes et al., 1991; Vekris et al., 2011), specific evidence-based indications or outcome measures for these procedures cannot be ascertained from the existing literature.

This review failed to demonstrate a consistent relationship between the incidence of non-union between the head and base of the transposed index finger and subsequent trapezial instability (radiographic or clinical) across studies (Lochner et al., 2012; Strugarek-Lecoanet et al., 2016; Trist et al., 2015). Despite the theoretical argument that bony union between the new trapezium

and retained base of index metacarpal should increase stability, it is unclear whether union of the trapezium to the metacarpal base is necessary. Buck-Gramcko (1971) initially suggested that fibrous union between the head and base of index finger may be sufficient.

Larger longitudinal studies are required to understand the functional changes that occur as children with pollicised hands grow, mature and adapt. Prospective and pooled databases are necessary to better investigate the impacts of surgical techniques (metacarpal excision amount, stabilisation methods for new trapeziometacarpal joint, intrinsic muscle transfer, flexor or extensor tendon shortening) and rehabilitation protocols on pollicisation outcomes. The impact of rehabilitation protocols on pollicisation outcomes has not been investigated in the literature, and this is important given the neuroplasticity and adaptive ability of paediatric patients (Lightdale-Miric et al., 2015). Finally, the development of consensus outcome measures, stratified according to hypoplasia severity and other congenital anomalies like radial dysplasia, is necessary to streamline future research.

KEY POINTS

- The literature pertaining to outcomes following surgery fails to adequately assess pre-operative differences.
- Pollicisation in a four- fingered hand with minimal forearm anomaly provides a superior result to that obtained when pollicisation is performed in a limb with a significant forearm radial deficiency.
- The development of consensus outcome measures, which include pre-operative degrees of digit and forearm involvement, is necessary to determine individual efficacy of specific surgical techniques.

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RADIAL DYSPLASIA

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Introduction

Radial dysplasia is a disfiguring, and potentially disabling, congenital limb anomaly (Figure 1). The entire upper limb may be involved, although the defect is most evident in the forearm and hand (Goldfarb et al., 2002). Affected children suffer a variable degree of hypoplasia or absence of the pre-axial skeleton and soft tissues, in particular their thumb, radius and dorso-radial soft tissues. The hand is usually radially deviated and subluxed off the distal ulna, and there is no true wrist (radio-carpal) joint in types III and IV radial dysplasia (Bayne and Klug, 1987).

Figure 1 Child with radial dysplasia (before treatment)

The incidence in whole-population studies is 1:6,000 – 1:8,000 live birth (Ekblom et al., 2010; Giele et al., 2001; Koskimies et al., 2011). This is significantly higher than the classical estimates of 1:30,000 – 1:100,000, derived from specialist clinic referrals, which may have missed patients referred elsewhere, treated locally or not treated at all (Lamb, 1977). The same whole-population studies report perinatal mortality approaching 30%, presumably from associated anomalies, reducing the prevalence to about 1:10,000 of the general population.

Known causes include spontaneous mutations, teratogenic drugs and syndromes such as Holt-Oram, VACTERL or Fanconi anemia, although fewer than 30% of patients receive a confirmed genetic diagnosis (Pakkasjarvi et al., 2013). The commoner genetic

causes are summarized in Table 1. Associated syndromic malformations include cardiac, renal and vertebral malformations and blood dyscrasias; as these may be asymptomatic at referral, most centres screen for these routinely.

Table 1 Genetics of syndromic radial dysplasia

Syndrome	Phenotype OMIM	Gene	Gene OMIM	Location	Inheritance	Incidence
VACTERL association	192350	Unknown	-	-	Unknown	1:10,000 to
VACTERL-X	314390	ZIC3	300265	Xq26.3	XLR	1:40,000
		FANCB	300515	Xp22.2	XLR	
VACTERL-H	276950	PTEN	601728	10q23.31	AR	
	608406	Unknown	-	-	Unknown	
Holt-Oram	142900	TBX5	601620	12q24.21	AD	1:100,000
Thrombocytopenia-Absent Radius (TAR)	274000	RBM8A	605313	1q21.1	AR	<1:100,000
Fanconi anemia		18 FA or FA-like genes:				1:160,000
	227650	FANCA	607139	16q24.3	AR	
	300514	FANCB	300515	Xp22.2	XLR	
	227645	FANCC	613899	9q22.32	AR	
	605724	FANCD1 (BRCA2)	600185	13q13.1	AR	
	227646	FANCD2	613984	3p25.3	AR	
	600901	FANCE	613976	6p21.31	AR	
	603467	FANCF	613897	11p14.3	AR	
	614082	FANCG	602956	9p13.3	AR	
	609053	FANCI	611360	15q26.1	AR	
	609054	FANCJ (BRIP1)	605882	17q23.2	AR	
	614083	FANCL	608111	2p16.1	AR	
		FANCM	609644	14q21.2	AR	
	610832	FANCN (PALB2)	610355	16p12.2	AR	
	613390	FANCO (RAD51C)	602774	17q22	AR	
	613951	FANCP (SLX4)	613278	16p13.3	AR	
	615272	FANCQ (XPF)	133520	16p13.12	AR	
		FANCS (BRCA1)	113705	17q21.31	AR	
	616435	FANCT	610538	1q32.1	AR	
Townes-Brocks	107480	SALL1	602218	16q12.1	AD	1:250,000
Baller-Gerold	218600	RECQL4	603780	8q24.3	AR	1:75,000 to
Rothmund-Thompson	268400					<1:1,000,000
RAPADILINO	266280					
Duane-radial ray (aka Okihiro)	607323	SALL4	607343	20q13.2	AD	Unknown (very rare)
IVIC	147750					
LADD	149730	FGFR2	176943	10q26.13	AD	Unknown
		FGFR3	134934	4p16.3	AD	(very rare)
		FGF10	602115	5p12	AD	

Sources: http://ghr.nlm.nih.gov/ (accessed 19/1/2016)
http://omim.org/ (accessed 19/1/2016)
AD – autosomal dominant; AR – autosomal recessive; XLR – X-linked recessive

The best treatment for radial dysplasia remains unclear, with several opposing approaches currently advocated as optimal. Treatment options, by increasing intervention, include conservative treatment (Bora et al., 1981; Ekblom et al., 2014; Heikel, 1959; Kotwal et al., 2012), isolated soft-tissue release (Vuillermin et al., 2015), repositioning the carpus on the distal ulna by centralization (Lamb, 1977; Sayre, 1894) or radialization (Buck-Gramcko, 1985), and radial substitution with imported tissue, such as microvascular transfer of the second toe (Vilkki, 1998) or proximal fibular epiphysis. The commonest of these approaches globally, involves soft tissue distraction (Kessler, 1989), followed by some form of surgical centralization or radialization with adjunctive tendon transfers to reposition and rebalance the hand. However, whether treated operatively or not, these patients suffer poor forearm growth, which may be worsened by surgery, and many have some degree of recurrent radial "wrist" deviation (Dana et al., 2012; de Jong et al., 2012; Goldfarb et al., 2002; Manske et al., 2014).

Systematic Review

Search strategy

We searched Medline and Embase via OvidSP (all fields), PUBMED (all fields), The Cochrane Database of Systematic Reviews and the Cochrane Central Register of Controlled Trials (searched 2 December 2016). The trial registries ClinicalTrials.gov and the WHO International Clinical Trials Portal (http://apps.who.int/trialsearch/Default.aspx) were also searched, to identify unpublished trials (searched 2 December 2016). The search strategy in Table 2 was developed to retrieve all studies and reviews of outcomes following surgical or conservative management of radial dysplasia.

Table 2 Search strategy (OvidSP – Medline and Embase)

#	Searches	Results
1	"Radial dysplasia"	133
2	"Radial aplasia"	256
3	"Radial longitudinal deficiency"	105
4	"Radial club hand"	192

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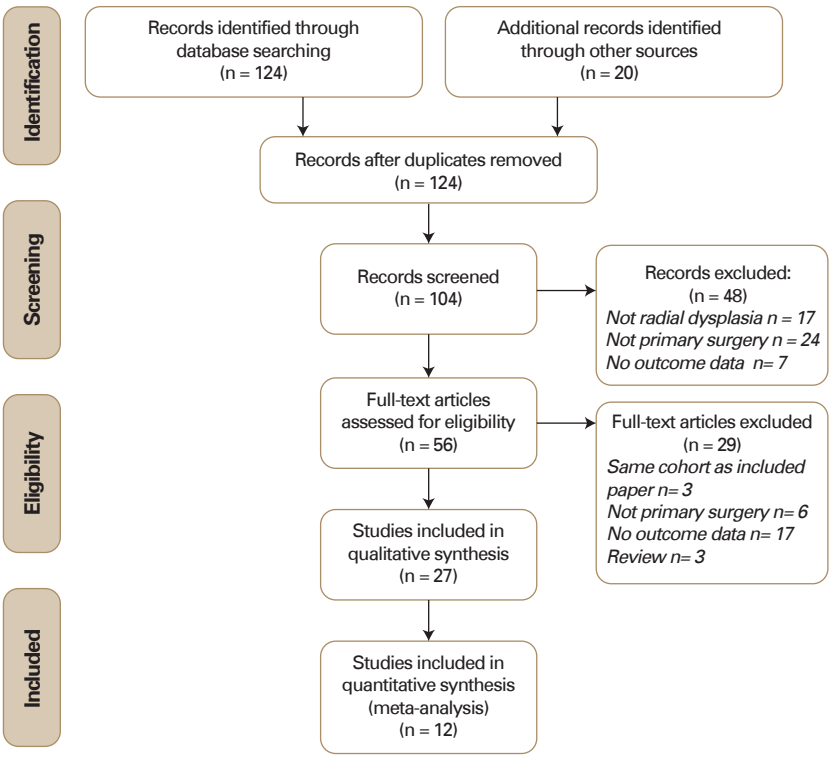
#	Searches	Results
5	"Radial clubhand"	61
6	1 or 2 or 3 or 4 or 5	700
7	Outcome	3150902
8	6 and 7	100
9	Remove duplicates from 8	74

Searches were not limited by date, language or publication status. Search results were independently screened for relevance by two authors (GM and BS). Full-text articles were retrieved via the Bodleian Library (Oxford, UK) and British Library (London, UK). Disagreements on study eligibility were resolved by consensus, with reference to a third author if required. Study selection is outlined in Figure 2. The study protocol was prospectively registered with the PROSPERO database (http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016036665).

Figure 2 PRISMA study flow diagram



All studies reporting patient outcomes after any form of surgical treatment or conservative management for radial dysplasia were included. Studies reporting outcomes in both adult and paediatric populations were included. Interventional and observational studies were included. Studies without quantified follow-up data after treatment were excluded. Studies with follow-up longer than 9 years were included in the meta-analysis: data from clinically homogenous series were pooled by operative technique. For studies included in the meta-analysis, the outcome measures were hand-forearm angle (HFA), ulnar length and "wrist" total active motion (all at final follow-up), and change in HFA from pre-op to final follow-up. Included papers were screened to ensure all relevant primary studies were included.

Data collection and analysis

Studies were assessed for risk of bias using the GRADE criteria for observational studies. Two authors (GM and BS) independently extracted data on the number, disease severity and treatment of study participants, and the mean and standard deviation (SD) for pre- and post-operative HFA, ulnar length and "wrist" total active motion. For studies with missing data, the corresponding author was contacted to request this. Where the range was reported instead of the standard deviation, the SD was estimated using the range rule: SD = (Maximum – Minimum)/4.

Length of follow-up is important in pediatric hand surgery, with the final result only apparent at skeletal maturity. We therefore restricted our meta-analysis to the 12 papers with an average follow-up longer than 9 years, which are likely to have included a minimum of two major growth spurts. Studies were grouped by operative technique for the meta-analysis. For change in HFA, mean differences (MD) and 95% confidence intervals (CI) were calculated for each trial. Ulnar length and "wrist" total active motion were infrequently reported pre-operatively, so the mean and standard deviation of the last follow-up was calculated. Two authors (GM and BS) assessed the participants, interventions and outcomes for clinical heterogeneity. Due to the variety of trial

methodologies and treatment regimens used, trial data were pooled using the random-effect model. The low methodological quality of the original studies limits meaningful statistical comparison of the different surgical techniques they reported. We did not, therefore, calculate significance levels, and have presented the results in narrative form. Statistical advice was provided by the King's College London Research Support Team.

Results

We identified 104 studies, of which data were extracted from twenty-seven; twelve were included in the data synthesis. Figure 2 summarizes the review process. Of the studies in the data synthesis, five were retrospective cohort studies, reporting the outcome of more than one treatment approach, and seven were case series, reporting the outcome of a single treatment approach. No randomized studies were found. With one exception (Kotwal et al., 2012) (n=446); all were small (n=35 or fewer). The methodological quality was low or very low under the GRADE criteria for all papers.

Table 3 summarizes the data synthesis results. Many centres use both centralization and radialization, and choose between them according to the intra-operative soft tissue quality. We therefore calculated the combined results of centralization or radialization after soft-tissue distraction, along with the results for the individual techniques.

Table 3 Long term results of treatment, by modality (>9 years follow-up)

Technique	N = Limbs (patients)	Mean follow-up, years	Change in HFA° (MD, 95% CI)	Final results (mean +/- StDv)		
				HFA°	UL, cm	"wrist" AROM°
Conservative	147 (109)	14.1	19.0 (13.8, 24.2)	83.8 ±24.0	16.1 predicted	61.0 ±26.3
Centralization	103 (75)	15.3	-34.4 (-46.1, -22.7)	27.6 ±23.4	12.2 ±2.9	34.4 ±25.0
SD & Stabilization of which:	356 (283)	13.5	-58.0 (-71.7, -44.3)	12.6 ±16.8	12.9 ±3.0	40.8 ±24.4
SD & Centralization	21 (19)	11.1	-71.4 (-93.2, -49.5)	16.7 ±20.1	11.5 ±2.2	25.4 ±18.2

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Technique	N = Limbs (patients)	Mean follow-up, years	Change in HFA° (MD, 95% CI)	Final results (mean +/- StDv)		
				HFA°	UL, cm	"wrist" AROM°
SD & Radialization	26 (25)	11.0	-49.1 (-63.2, -35.4)	16.5 ±22.5	13.6 ±3.1	46.3 ±29.3
Soft-tissue release & bilobed flap	18 (16)	9.2	-24.0 (-34.6, -13.4)	64 ±13.3	-	73
SD and Microvascular 2nd MTPj transfer	19 (18)	11.0	-33.7 (-46.2, -21.2)	27.9 ±14.4	15.4 ±2.5	83.2 ±21.9

Key: n = number of; HFA = Hand-Forearm angle; UL = Ulnar length; AROM = active range of motion; SD = soft tissue distraction; 2nd MTPj = second metatarso-phalangeal joint, MD = mean difference.

The HFA of conservatively treated (i.e un-operated) patients worsened during childhood, from 66° to 84°. "Wrist" active motion, at 61°, was better than for most surgically treated patients. The ulnar length of conservatively treated patients was not reported in the meta-analysed studies. In studies of conservatively treated children with shorter follow-up, Heikel (1959) observed ulnar length was half to three-quarters of normal, whilst Sestero predicted growth of 16cm by age 15 (Sestero et al., 2006). Oishi and colleagues' technique of isolated soft-tissue release with a bilobed skin flap gave only a slight improvement in HFA, to 64°, but preserved 73° of "wrist" movement (Vuillermin et al., 2015).

When compared to conservatively treated patients, soft tissue distraction with either centralization or radialization achieved the best HFA correction, to a final result of 16° radial deviation. It is noteworthy that centralized patients had a greater HFA deformity to start with, so although the final HFA was the same, centralized patients had a larger improvement in HFA, changing by 71°, than radialized patients, who improved by 49°. Radialization maintained better "wrist" movement (46°) and ulnar length (13.6cm) than centralization (25° and 11.5cm).

Vilkki's series of microvascular 2nd metatarso-phalangeal (MTP) joint transfer reported better "wrist" movement (83°) and ulnar length (15.4cm) than other surgical techniques, at the cost of a smaller improvement in HFA (28°) (Vilkki, 2008); this is not surprising, as it is the only technique in this data synthesis which imports a true joint to the "wrist". It should be noted that this

paper recorded the HFA after "gentle stretching" of the hand, to measure the "radial tightness". The HFA in this series is therefore not directly comparable with other series, which measured the unstretched HFA, as described by Manske (Manske et al., 1981).

Finally, it is worth noting that whether treated conservatively or surgically, and regardless of the treatment approach, all studies reporting multiple follow-up time points observed increasing radial deviation with growth.

Discussion

This is the first systematic review of treatment outcomes for radial dysplasia. Our findings suggest that, over the medium to long term, soft-tissue distraction and a stabilization procedure (centralization or radialization) provides substantial correction of the HFA when compared to conservative treatment, at the cost of some loss of "wrist" motion, and possibly of ulnar length. Although both centralization and radialization reached the same final HFA, centralized patients had achieved a much larger change in HFA, from a more radially deviated starting point. This selection bias may be due to surgeons choosing between centralization and radialization based on the intra-operative quality of the dorso-radial muscle mass and other soft tissues, reserving centralization for the worse affected cases. Microvascular 2nd MTP joint transfer also provides a noticeable improvement in HFA, and improves "wrist" motion over conservative treatment, whilst maintaining ulnar length. Isolated soft-tissue release plus a bilobed flap offered only minimal improvement in HFA, but preserved "wrist" motion.

These findings provide support for current surgical practice, but they leave a number of important questions unanswered. These include the management of the soft tissues, and the ideal donor for microvascular reconstruction; are two short axial bones with a true joint (2nd MTP joint) better, or is a long bone such as the proximal fibula better, even without a joint?

There are several limitations to this study. The absence of randomized studies in the primary literature means that we cannot confidently ascribe differences in outcome to the techniques used, rather than to intrinsic differences between the patient groups. The scope for error is magnified as even for a named procedure (e.g. cen-

tralization), there is no standardization of the actual surgical technique between surgeons or centres globally. This is similarly true for named outcomes, which may have multiple different measurement techniques. Radiographic measurements are prone to errors of rotation and projection/magnification, as well as being dependent on the age and ossification stage of the child. Radiographic angles may also be affected by how co-operative an awake child is, and by muscle relaxant if measured intra-operatively. The detail of this information is seldom reported clearly. Clinical measurements of range of motion are also limited, as on their own they do not clarify how useful or stable such movement is. Finally, the lack of a validated core outcome set, generated with patient involvement, means that we have little idea from the literature which outcomes truly matter to patients, although two relevant and related outcome sets are under development (ICHOM congenital hand group; Murphy et al.).

These limitations mean that we must be cautious in our interpretation of these data. Nonetheless, they provide our current benchmark for comparing treatments, and the baseline for future research. Given the need for follow-up to skeletal maturity, and the relatively low numbers of patients seen annually even by national specialist centres, it is likely to be some time before we have large, methodologically robust studies to inform us; this review highlights the urgent need for this evidence to inform our practice.

KEY POINTS

- In both treated and untreated cohorts, the HFA worsens during growth.
- Centralization and Radialization provide comparably good HFA correction.
- Radialization preserves more ulnar length and “wrist” motion than centralization.
- Microvascular 2nd MTP joint transfer provides slightly better “wrist” motion and ulnar length, but less HFA correction, compared to radialization.

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Discussion

Although there are a number of large studies suggesting that the condition of trigger thumb is not present at birth, the relatively low incidence of the condition in the whole population has prevented an absolute determination that trigger thumb is an acquired condition. The evidence which has been accumulated tends to suggest that it is. Studies larger than that of even Ogino, assessing newborns for the presence of trigger thumb, are required to establish this beyond doubt.

Another interesting observation, which requires larger epidemiological studies to provide proof, is the apparently increased incidence of thumb MCP joint hyperextension accompanying trigger thumb. Intuitively, this is logical, as hyperextension of the proximal joint decreases the sheath diameter and increases the rigidity at the level of the A1 pulley.

Is there evidence for the success of non-surgical treatment? Undoubtedly, a percentage of trigger thumbs will spontaneously resolve, with or without massaging, exercises and splinting. A multi-centre trial, in which no treatment is provided following presentation, with a follow-up period of perhaps three years, may answer this question. There is evidence that there is no detrimental effect to delayed surgical treatment, at least up to the age of 5. However, a percentage of parents will prefer that the less than perfect thumb, in their eyes, is treated earlier if spontaneous correction does not occur within a short time period. Furthermore, the non-operative treatment of stretching and splinting, as against observation alone, may be demanding on both child and parent and may not be acceptable in many communities. Evidence does exist for the successful resolution of trigger thumbs following surgery. Complications, although uncommon and usually minor, do exist. Evidence in the literature for success following surgery is satisfactory.

The disabilities associated with the presence of simple and complex syndactylies, relate to the loss of spread (abduction) of the affected fingers and the lack of individual digit motion. For those complex syndactylies between digits of significant length differ-

ence (particularly those involving the fourth web), deviation and instability of joints may result.

Separation of digits to obtain abduction, independent motion and to avoid deformity is well accepted, at least in the hand, if not the foot. The complications are web creep, excessive scarring, deviation and instability of joints and diminished motion, particularly of the distal interphalangeal joints when there is a complex joining of distal phalanges. Nail and nail fold deformity is likely in this last group.

Common sense and surgical principles have dictated the use of zig-zag incisions as against straight line incisions in the digits themselves. No prospective controlled study demonstrates a superiority of multiple, acutely angled digital flaps over the raising of flaps which are fewer in number and having a larger angle at the apex. Although there is some preference for pulp flaps over skin grafts to reconstruct nail folds, controlled studies providing absolute evidence are lacking.

The presence or absence of web creep post-operatively is used to determine whether the pattern of web flap elevation and the connection between the incisions of web flaps and those of digital flaps play any role in this phenomenon. Regrettably, in spite of many publications dedicated to this topic, we await a consistently reliable and reproducible method of measuring the position of the web. Whether creep occurs or not post-operatively is dependent upon reliable documentation of position of the web at the end of the procedure. Only with this information and with a reliable and reproducible method of measuring change in web position can the presence of web creep be precisely detailed. Without this precision, those advocating particular incisions as being superior to others in the prevention of web creep still lack the support of evidence-based medicine.

All agree that skin grafts tend to pigment, some donor sites more than others, and some skin types and skin colours more than others. Furthermore, the use of hair-bearing skin in full-thickness skin grafts creates an obvious problem. Loss of the skin graft, par-

ticularly if infection ensues, may lead to increased scarring, the phenomenon of web creep and digit deviation. A number of studies espouse the benefits of avoiding skin grafting through transposition of skin from areas of redundant skin to areas lacking skin, significant defatting, tight closure or loose closure with gaps. Many document their own complications and some attempt to make comparisons between techniques. However, a double-blind prospective study with adequate numbers, beginning with similar cases and with outcome measurements at five years, remains wanting.

Some use the rate of revision surgery as an indicator of complications. Regrettably, there are no definitive or consistent parameters which determine whether or not revision surgery should be performed or not. One surgeon's rate of revision surgery may seem superior to that of another, but the indications for each may differ. This, and a lack of continuity of long term care prevents any conclusions based on the incidence of revision surgery.

The authors of the section referring to "Thumb polydactyly" emphasise the need for collaborative efforts to deliver a consistently reliable pre-operative classification and post-operative assessment scale.

The Wassell classification of thumb duplication is used by most. This is in spite of its reliance on the radiological assessment of an immature skeleton and its failure to provide information of soft tissue anomalies and joint deviation, stability and motion.

Furthermore, the literature contains an abundance of error, in which a common proximal phalangeal epiphysis in the most prevalent type IV duplication, has been copied from one publication to others. Nevertheless, we all know what we are talking about and it is reasonable to continue to use it, at least for types I to VI. (The presence of triphalangism of one, or other, or of both thumbs is best added as additional information to the appropriate type eg. type IV with triphalangism of the radial thumb).

However, greater pre-operative detail is necessary to guide our best surgical efforts to the attention of the soft tissue and joint

problems described in the sub-chapter. The Rotterdam classification may be used in conjunction with the Wassell classification to assist in this endeavour, although the only "fair" inter-observer reliability is of concern. It would appear that more work is needed, particularly to better direct specific techniques to specific problems, some of which only become precisely defined at surgery, and to compare the outcomes of these techniques in like populations.

The JSSH post-operative assessment has been shown by the Rotterdam group to be the most reliable. It has been modified by them and others to improve the application of the scale to better reflect outcomes. The validity of these modifications rests with the application of regression analysis. Of some concern is the down grading of the "joint deviation" parameter by this method, which many, including the authors of this sub-chapter and the chapter author, consider to be a main indicator of the failure to adequately attend to the skeletal alignment and deforming soft tissue forces.

The authors have effectively conveyed the difficulty of applying PRISMA principles to the disparate assessment methods of pre- and post-operative status used in the literature. Their timely review does suggest (perhaps prove) that invariably (except perhaps in the case of a small floating extra digit), some reconstruction of the digit to be retained, is necessary; that secondary surgery remains common; and that those undergoing secondary surgery, are less likely to obtain as good a result as those in which "all" corrections are made at the initial surgery. The studies, which are not directly comparable because of differing assessment methods, also suggest that the experienced surgeon is more likely to obtain a superior result. One well-structured case series indicated that surgery before the age of 12 months gave less favourable outcomes.

Assessment of surgical results for the management of thumb hypoplasia and aplasia is compromised by: the relatively small number of cases treated by any one surgeon or any one department; the lack of precision in pre-operative documentation; adequate time of post-operative follow-up; and consistently reliable and reproducible methods of measurement of function. The age of

the child prior to the performance of surgery, be it reconstruction or pollicisation, prevents the application of many of the measurement parameters which may be applicable to older children and to many of the functional tests which have become popular amongst therapists and surgeons. This surgery is usually performed from adjacent to the age of 12 months to 24 months or thereabouts. Some cases are treated at an older age according to the time of presentation or the presence of other more important medical problems. However, even for the supposedly objective measurements of joint deviation, joint instability and passive joint motion, there has been no study which has confirmed the reliability and reproducibility of such measurements, even if performed when the child is under general anaesthetic at the time of surgery.

Therefore, we rely on pre-operative gradings. These too are lacking in precision and consistency. All pre-operative gradings of classical thumb hypoplasia are based on the grades of Blauth. Attempts to sub-classify within grades are well-described. However, these sub-classifications are not consistently defined. It would be appropriate to agree upon a pre-operative grading system which all would use. The balance must be between splitting into too many groups such that numbers are too small; and lumping within too few groups such that differences in pre-operative status are lost. Agreement would allow better comparison of outcomes using different techniques, as we would be more likely to be comparing patients with a similar pre-operative status.

Another problem compounds a lack of documentation of the pre-operative circumstances. If, for instance, one wishes to compare the efficacy of a particular method of collateral ligament reconstruction, an improvement from 60 degrees of instability to 31 degrees of instability would indicate a failure according to current normal measurement parameters. However, the improvement regardless of whatever surgical technique is utilised, is more effective than another surgical technique which may have improved the instability from 35 degrees to 29 degrees, even though the latter is now within, but at the extreme of, a normal parameter. Current assessment protocols would favour the latter procedure as superior.

Even post-operative assessment at an older age is problematic. Assessment of final results against age-related normal values tends to negate the wide variation of differences between individuals. However, the opposite hand and thumb is very commonly affected and comparison against this may be a comparison of two abnormalities rather than against a normal circumstance. There is no realistic answer to this problem, although the inclusion of very large numbers assists in diminishing the factor of individual variation.

There is adequate evidence supporting the intuitively obvious observation that pollicisation of a stiff, deformed and underdeveloped index finger results in a poorer thumb than the pollicisation of a near-normal index finger. The former is more likely to be associated with a radial longitudinal deficiency with an unsupported wrist, another obvious, confounding factor. Vilkki's pre-operative grading of radial longitudinal deficiency, although most appropriately directed towards the differing pre-operative circumstances of those with a forearm longitudinal deficiency, includes an assessment of the thumbs. It is beneficial in attempting to sub-classify like with like, so that the efficacy of the surgical procedures takes the pre-operative status into closer consideration. Only then, and with the accumulation of multi-centred information, will we be in a position to decide whether, for instance, bone union between the new trapezium and the index finger metacarpal base is a desirable component of pollicisation.

The published evidence suggests that pre-operative distraction for Bayne type 3 and 4 radial longitudinal deficiencies is effective when followed by a stabilisation procedure, be this with the ulna supporting the carpus on its radial side (radialisation) or supporting the centre of the carpus (centralisation). The literature has also been able to substantiate that the natural growth of the ulna is to about 60 percent of its normal growth. Following premature physeal closure of the distal ulna as a complication of surgery, this is closer to 40 percent. The contention that stability is more important than wrist motion or vice versa has not been established.

The methods of measurement of the hand-forearm angle are

not standardised, so differences are difficult to affirm. Furthermore, this measurement does not take into account displacement between the ulna and the carpus in either the radio-ulnar plane or the dorso-ventral plane.

A review of Heikel's work from the 1950s does not show any significant improvement in function of those children undergoing surgery. More recent studies suggest that function is improved following successful surgery. Subjective assessments are all complicated by the perception of appearance, be this by patient, medical or paramedical staff, parents and/or carers.

The transfer of vascularised bone with a growth potential to replace the absent radius has obvious advantages. Vilkki's pre-operative grading helps us to consider the outcomes of surgery by comparing cases with a similar pre-operative status. The lack of numbers, however, compromises this effort.

Conclusion

The detailed discussion within the text of each sub-topic should be read in conjunction with the discussion by the chapter author which precedes this conclusion section. It should be clear that the subject of congenital hand surgery suffers from a lack of evidence-based medicine, a consequence of a deficiency of numbers and a deficiency of random, blinded, prospective, comparative studies, when considering the efficacy of specific treatments. However, we must take into consideration the realities of treating children in the numbers in which they present. As surgeons, we are taught surgical principles and practice of surgical techniques; we read the experience of others in the literature; we learn from our own experiences and compare these with those of others.

Most studies reflect an experience of a particular technique and, although based on sound surgical principles, do not satisfy the criteria demanded by evidence-based medicine. This lack of evidence-based medicine should not undermine the necessity to continue with a common sense and collaboratively approved approach to the management of these problems, based upon the surgical principles, teaching and experience referred to above. It

remains worthwhile to review and report our own experiences, even if the conclusions we reach are less than substantial.

Future advancement requires broader collaboration amongst those working in the field, with multi-centre accumulation and combination of cases and experience.

A feature common to those sub-chapters reviewing techniques used to achieve outcomes, following surgery for thumb duplication, thumb hypoplasia and radial deficiency, is the difficulty of pre-operative assessment. Undoubtedly, agreement on pre-operative grading is necessary for a determination of efficacy of management and a comparison of surgical outcomes. The reliability and reproducibility of pre-operative measurements made in the first 24 months of life need to be established and confirmed, so that the pre-operative status may be incorporated into the post-operative assessment.

Post-operative assessments may best utilise measurements of the opposite, normal limb, if such is available, and provide the optimal comparison for any one child. Age-related normal population values are a useful alternative. Those which have been established should be more widely available to all, preferably available within one text relating to assessment of objective hand measurements in children.

It is reasonable to attempt to achieve consensus on an all-inclusive assessment, including objective measurements, of children's hand function according to age. From this exhaustive set of parameters, it is then logical to choose those parameters which are relevant for measurement for each specific condition. An assessment system for one particular condition may be entirely inappropriate for another if it skews the overall result by including measurement of parameters which are normal in that condition.

Hopefully, the benefit of this evidence-based review of some specific congenital conditions will add impetus to those working to improve guidelines to more accurately determine optimal treatment protocols.

CHAPTER 3

BONE AND JOINT

3.1 Management of Common Hand Fractures: The Evidence

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Metacarpal Shaft Fractures
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Fracture subluxations/dislocations of the base of the middle phalanx
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Summary and Introduction

In this chapter, we have collated the best quality evidence that is currently available on management of several common hand fractures:

- Phalangeal shaft fractures
- Bennett's fractures
- Condylar fractures

- Bony mallet injuries
- Fracture/dislocations of little finger (5th) carpometacarpal joint
- Fractures of the little finger (5th) metacarpal neck
- Metacarpal shaft fractures
- Fracture/dislocations of the base of the middle phalanx

General Methods

Unless otherwise stated in the text, a similar search and review method was used for each of the sub-chapters.

For each topic a simple search strategy using the multipurpose field was developed, combining free text and index field searching. EPub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid Medline(R) (1946 to Present) and EMBASE (1974 to Date) databases were simultaneously searched using the search criteria. No electronic language or other restrictions were applied unless otherwise specified. Search results were de-duplicated electronically before being exported to reference manager software for reviewing.

All articles were screened by title, abstract and if necessary full-text against a predetermined list of criteria in line with the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Liberati et al., 2009), sequentially excluding those articles that did not describe in-vivo, human results of the treatment of the topic of interest. Depending on the quality of available literature some topics considered only comparative studies, whilst other topics including case series. Non-English language full texts and conference abstracts were excluded. Any duplicates not identified by the electronic search were removed manually. The reference lists for included articles were searched for eligible articles and these were added if appropriate.

The exact search strategy, date of search and specific criteria for inclusion are listed separately for each topic.

PHALANGEAL SHAFT FRACTURES

Robert SAVAGE

Methods

The objective of this process was to identify and review studies concerning the treatment of phalangeal shaft fractures. The search strategy is described in Table 3.1.1.

Table 3.1.1 Search Strategy (Completed 27th December 2016)

#	Search Term (.mp)	Number of Returned Articles
1	Phalanx	13714
2	Phalangeal	6372
3	Phalanges	7830
4	#1 OR #2 OR #3	22752
5	Shaft	37384
6	Diaphysis	11804
7	#5 OR #6	48090
8	#4 AND #7	498
9	Fracture	481078
10	Injury	1931819
11	#9 OR #10	2276412
12	#8 AND #11	190
13	De-duplicate #12	137

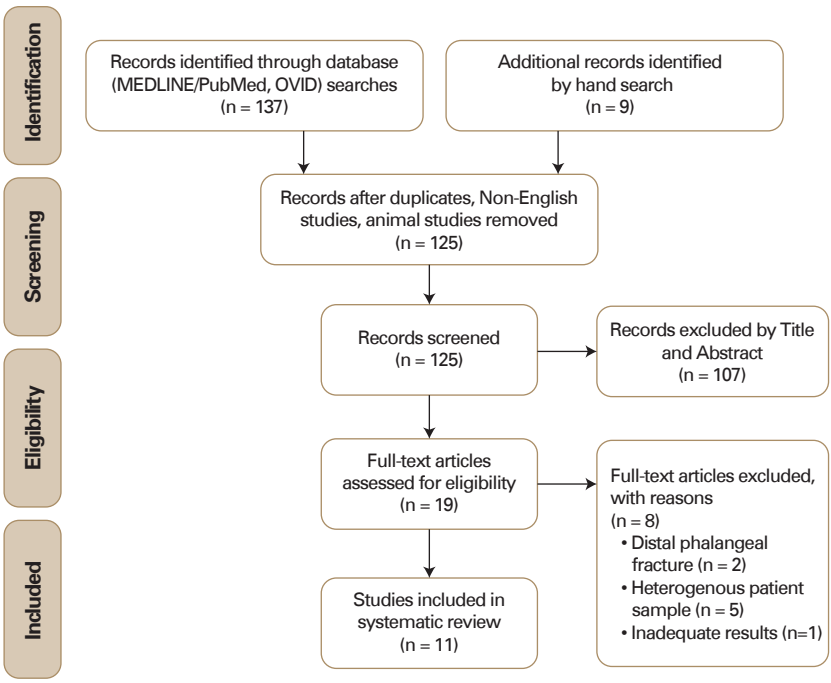
Articles reporting results in a heterogenous sample of phalangeal fractures (e.g. inclusive of base, neck and condylar fractures) but where the results were collectively reported, were excluded.

Results

A total of 137 articles were identified and subjected to title and abstract review. Of these, 117 articles were rejected following review of the title and abstract, on the basis of not describing a series of cases treated by a certain method and including outcome measures.

Therefore, 19 articles were obtained and reviewed in full-text. A further eight articles were rejected on the same principals as the original assessment. Detailed reasons for rejection were incomplete or indecipherable results, non-homogeneous fracture types, inclusion of non-unions or distal phalangeal fractures: we elected to focus on middle and proximal phalanx shaft fractures. There were very few reports of fractures involving joints (Figure 2.1).

Figure 2.1 PRISMA flowchart depicting the selection process. From Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6:e1000097. For more information, visit www.prisma-statement.org.



During review of the selected papers some extra references were found which did not appear to have been located by the original search: nine such articles were requested but seven were excluded on the same principals as stated above.

The final report is based on the 11 publications; it is interesting to note that five of these publications were by the same author and the other six by different authors for each paper. Ten papers reported operative treatment and only one reported non-operative treatment.

Each paper provided a good description of the technique used to fix the fractures, including post-operative management and were a good guide to treatment.

Two of the treatments described, differential pitch K-wires (and intraosseous tension bands, which was not reported due to exclu-

sion criteria) have probably been superseded by small lag screws to achieve inter-fragmentary compression in oblique or spiral fractures.

Transverse or short oblique fractures were treated with either intraosseous wire loops or longitudinal K-wires either crossing or not crossing an adjacent joint. All reports of open fixation aimed for early mobilisation. Union of fractures did not give cause for concern.

Table 2.2 Treatment types

Treatment Type	Number of fractures treated
AO screws	38
AO plate	37
Circlage wires	15
K-wire crossing DIP joint	22
K-wire crossing MP joint	40
K-wire sparing MP and PIP joint	35
K-wire and Lister Loop	10
Differential pitch k-wire	11
Intramedullary wire	21
Intraosseous wire loop	38
MUA and buddy	92
Total	369

Table 2.3 Fracture types

Fracture Type	Numbers of fractures treated
Oblique or spiral	41
Transverse or short oblique	171
Base of proximal phalanx	92
Not stated	37

Table 2.4 Publications and Conclusions

Author	Study	Conclusion
Al-Qattan and Al-Zahrani (2008)	A prospective study of 15 cases of long oblique or spiral fractures of proximal phalanx, treated with cerclage wires	All fractures united. Full movement (>260°) in 12 patients, 5-15° fixed flexion at PIP J in 3 cases. One prominent wire removed. No infection, CRPS, loss of fracture position, wire migration or extrusion. Return to work 8 weeks (7-11). An acceptable method for treating these fractures.

Author	Study	Conclusion
Al-Qattan (2008)	A prospective study of 22 cases of middle phalanx transverse and short oblique fractures and associated industrial accident and extensor tendon injury, treated with a k-wire crossing the DIP J and the fracture.	All clinical union, 12 radiological union (10 lost to follow up prior to final radiographs). Full movement at PIP and MP J, mean 33° (10-70°) at DIP J. Return to work 14 (12-20) weeks. No infection, CRPS, fracture displacement, rotation or malunion.
Al-Qattan (2008)	78 industrial injuries with displaced unstable transverse fractures of proximal phalanges. 40 treated with closed reduction and K-wiring that crossed the MPJ, 38 with open reduction and interosseous loop wire fixation. 10 in each group were compound	All fractures united. Final range of movement (TAM) was graded, excellent > 240°, good 220-239°, fair 180-219°, poor < 180°. For intraosseous wires the results were excellent 39%, good 42%, fair 8%, poor 11%. For K-wires the results were excellent 13%, good 50%, fair 25%, poor 13%. Thus movement was better for intraosseous wires (19% fair and poor, against 38% for K-wires). Return to work 15 (12-30) weeks for K-wires, 14 (11-26) for interosseous wires. Complications for K-wires were fracture re-displacement 2, CRPS 1, rotational malalignment 1, infection 2, wire migration 5 - versus respectively 3,0,0,0,1 for intraosseous wires.
Al-Qattan (2011)	35 male industrial workers with displaced unstable transverse proximal phalanx fractures, treated with a K-wire that spared the PIPj and MPj	All fractures united. Final range of movement (TAM) was graded, excellent > 240°, good 220-239°, fair 180-219°, poor < 180°. The results were excellent 43%, good 29%, fair 14%, poor 14%. Complications were fracture re-displacement 0, CRPS 0, rotational malalignment 0, infection 4, wire migration 0
Al-Qattan et al., (2013)	Describes the use of the Diaphyseal Axis –Metacarpal Angle (DHA) in a series of 92 base of proximal phalanx fractures in children – and treatment with MUA and buddy taping	The DHA was described; the normal value in uninjured fingers was 177-180°. The majority of fractures were manipulated over a pencil. The mean pre-reduction angle was 156° (132-156°) and post-reduction angle 177° (169-180°). All children returned to an excellent result i.e. union, full range of movement, no deformity, and normal function.

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Author	Study	Conclusion
Dhamangaonkar and Patankar (2014)	13 patients with 15 transverse or short oblique middle phalanx fractures were treated with joint sparing, buried, intramedullary K-wires.	All fractures united. Final range of movement (TAM) was graded, excellent > 240°, good 220-239°, fair 180-219°, poor < 180°. Results, excellent 10, good 3, fair 1, poor 1. 3 patients with tendon injury of which 2 had an excellent result. No infection, delayed wound healing, or persistent pain
Ford et al., (1987)	38 oblique fractures of condyles, shafts or bases of proximal and middle phalanges, treated with 1.5 or 2.0 mm AO screws	TAM > 220° 24 cases, 180-219° 8 cases, <180° 2 cases. AVN condyle 1, screws loosening 4. Aching and cold intolerance 38 but resolved by one year.
Itadera et al., (2011)	6 patients and 6 fingers – 5 transverse and 1 oblique fracture. Description of a hand-made curved K-wire inserted to one side of the tendon sheath into the proximal phalanx	All fractures united. Malunion in 4 cases, 5°, 10°, 20°, 20° TAM, 255, 250, 230, 210, 200, 190° A small series achieving good movement but with some radiological deformity
Thomas et al., (2015)	10 patients with open transverse fractures of proximal phalanx, treated with a Lister loop and oblique K-wire (they name this 'Theta fixation')	All fractures united. Belsky score used. 90% excellent, 10% good. Radiological union in 6.1 weeks. All returned to the same work at a mean of 11.3 weeks.
Page and Stern (1998)	Retrospective review of 109 fractures of metacarpals and phalanges (37) treated with AO mini titanium plates and screws.	Final range of movement (TAM) was graded, excellent > 240°, good 220-239°, fair 180-219°, poor < 180°. Phalangeal fractures: fair and poor 89% of 37 fractures. Metacarpals: excellent and good 76%
Zach (2015)	Short report letter. Description of a differential pitch threaded K-wire, (like a Herbert screw), for 11 closed transverse and short oblique proximal phalanx fractures.	All fractures united. Belsky score used. 10 excellent, 1 good

Outcome Measures

The 11 papers focused on range of movement as the primary outcome measure. Total active movement (TAM) was used widely, and this became one of the criteria for selecting the papers, as less structured outcome measures gave no clear information on method of measurement. However, the TAM score was not used con-

sistently: usually authors graded the results as excellent, good, fair and poor, each representing a range of angles, but excellent was graded variously as > 195°, > 220°, > 240° and > 250°: the poor category was, at its most generous < 65°, but typically < 180°.

Some of the papers reported complications such as infection, wound healing, shift of implants, CRPS, mal-union etc. but a consistent list was not evident.

Discussion

The author of this section was surprised by the small number of publications on phalangeal shaft fractures when considering the numbers of such fractures that are treated by all of us on a weekly basis. There was only one report of manipulation of fractures, which appears to demonstrate the general tendency of authors to write and journals to publish on matters which appear novel, complex and arguably interesting.

Given the comments on outcome measures it would be hard to make definite recommendations based on the papers reviewed, but the limited data did suggest more complications of stiffness from plate fixation of phalangeal fractures, and k-wires that cross and immobilise joints.

In future research and publications, assessment of phalangeal shaft fracture treatment could be greatly improved by using a consistent set of outcome measures. Broadly, this would include range of movement, time to clinical union and return of function, pain, deformity, complications and requirement for secondary treatment.

Some authors have given attention to defined fracture types but comparison of case series could be improved by restricting fracture types to categories with similarity such as oblique and spiral, transverse and short oblique, and not including other fracture types in the same publication, such as peri-articular or basal fractures.

The very low number of publications on fracture treatments offers ample scope for future comparative studies of non-operative and operative treatments.

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2. Al-Qattan MM. K-wire fixation for extraarticular transverse/short oblique fractures of the shaft of the middle phalanx associated with extensor tendon injury. J Hand Surg Eur. 2008, 33: 561-5.
3. Al-Qattan MM. Displaced unstable transverse fractures of the shaft of the proximal phalanx of the fingers in industrial workers: Reduction and k-wire fixation leaving the metacarpophalangeal and proximal interphalangeal joints free. J Hand Surg Eur. 2011, 36: 577-83.
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BENNETT'S FRACTURES

Gray EDWARDS, Grey GIDDINS

Methods

A systematic search of PubMed, the Cochrane library and the Current Controlled Trials Register for studies reporting the treatment of Bennett's fractures was performed. No restrictions were set on the search. A structured search was performed using the following search string: (Bennett OR Bennett's OR thumb metacarpal base OR first metacarpal base) AND (Fracture OR Fractures).

From the initial search results, inclusion and exclusion criteria were applied to the studies identified. Inclusion required a description of the method employed, follow up of at least one year, adult patients only, a minimum of five patients in the study and recorded clinical and/or radiographic outcome measures. Full text copies of those that met the inclusion criteria were obtained. The quality of the studies was assessed using a validated method, the Coleman scoring system (Coleman et al., 2000).

Data extracted included study design, numbers of patients, mean final follow up time, treatment (s) utilised- and clinical, functional and radiological outcomes. The outcome measures were the presence of pain at follow up, return to employment, the presence of radiographic osteoarthritis and complications of treatment.

The last search was performed on 30/10/2016.

Results

A total of 183 references were identified in the literature search. Following title and abstract review 106 references were excluded and the full text of 77 articles obtained (Table 3.1). Thirty-eight studies that underwent full text review were excluded, six of which could not be obtained.

Thus 39 studies including 1505 patients underwent formal analysis, a list of which is shown in the appendix. Two hundred and forty-four were lost to follow up leaving 1261 patients (Table 3.2).

The studies were broadly divided in to those that evaluated surgi-

cal methods of treatment and those that evaluated non-surgical methods of treatment for comparison. Twelve different treatment modalities were described in the studies included in this review (Table 3.3).

Table 3.1 Flow chart demonstrating study selection

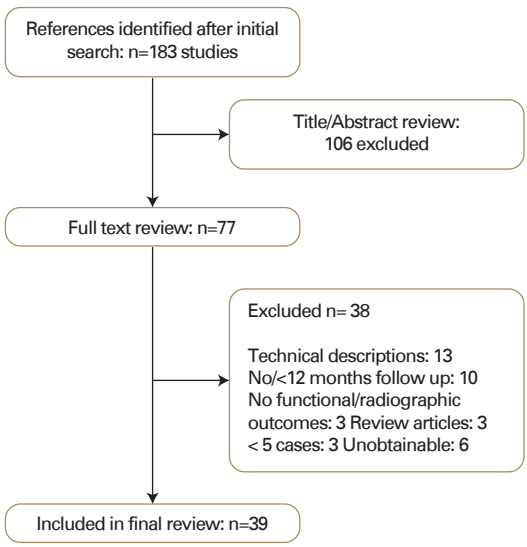

Table 3.2 Overview of Studies

Treatment	Numbers of patients reviewed in these studies	Mean final assessment time (years)
Non-surgical	431	9.0 (2-26.4)
Surgical	830	4.3 (1.2-11.5)
Total	1261	

Table 3.3 Treatments used in studies

Treatment	Numbers of patients treated
None/Early mobilisation	18
Elastoplast	2
Splint	40
POP-No manipulation	94
MUA & POP 1-6 weeks	332
MUA, K-wire and POP	405
ORIF(Using Plate/Wires/Screw)	406
Tension band wiring	56
Suture loop	8

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Treatment	Numbers of patients treated
External fixation	56
Traction outrigger	59
Arthroscopically assisted ORIF	11
Not described	18
Total	1505

POP-Plaster of Paris
MUA-Manipulation under anaesthetic
ORIF-Open reduction and internal fixation

Table 3.4 Patient outcomes

Outcome (Available number of patient data)	Non-surgical*	Surgical**
Pain at final review (n=695)	75 (224)	108 (471)
Return to Work (n=495)	120 (122)	371 (373)
OA at final review (n=839)	99 (299)	182 (540)
Complications (n=977)	Pressure sores: 2 (287)	Prominent metalwork: 56 Superficial infection: 10 Nerve injury: 8 Revision surgery: 4 Unspecified: 8 Adverse reaction to implant: 2 Deep infection: 2 Malunion: 3 Patient factors: 1 Secondary displacement: 1 Total: 95 (690)

* Non surgical methods: Early mobilisation/Elastoplast/Splint/POP/MUA & POP
** Surgical methods: MUA & K-wire/ORIF/Tension band wiring/Suture loop/External fixation/ Traction outrigger

Within the studies, many different outcome measures were used to assess pain and function including the Visual Analogue Scale (VAS), Disabilities of the Arm, Shoulder and Hand (DASH) and measurements of hand movements. Furthermore, some studies did not describe all of the desired outcome measurements. Unfortunately, due to this variation in reporting of data a formal meta-synthesis was not possible and simple binary categories were created to assess the presence of pain, return to work, presence of osteoarthritis at final review and complications of treatment

The presence of pain at final review was reported for 792 patients, however 97 of these used a DASH score; these were all surgical studies and are not included in this analysis as the presence of pain could not be established solely on the basis of a DASH score. This left 695 patients for analysis. Seventy-five of 224 (33%) patients treated non-surgically reported pain at final review (mean time 12.0, range 6-26.4 years), compared with 108 of 471 (23%) of those treated surgically (mean time 4.2, range 2.2-10.7 years) (Chi-Squared test, $X^2 = 8.179$; P=<0.0042).

Data regarding return to employment were available for 495 patients. One hundred and twenty of 122 (98%) patients treated non-surgically had returned to work at final review (mean 10.8, range 2-26.4 years), compared with 371 of 373 (99%) of those treated surgically (mean 4.0, range 1.2-11.5 years) (X^2=0.359; P=0.5492).

At final review osteoarthritis was reported radiographically in 839 patients. Ninety-nine of 299 (33%) patients treated non-surgically had osteoarthritis at final review (mean 7.9, range 2-26.4 years), compared with 182 of 540 (33%) patients treated surgically (mean 4.1, range 1.16-11.5 years) (X^2=0.01; P=0.9219).

Data regarding complications of treatment were available for 977 patients. Two of 287 (<1%) of patients treated non-surgically had complications opposed to 95 of 690 (13%) patients who underwent surgery; 56 patients of this group relate to prominent metalwork due to tension band wiring (X^2=37.28; P=0.0001).

Discussion

The findings of this study support the premise that following a Bennetts fracture, patients are more likely to experience pain if they are treated non-surgically and more likely to have complications of treatment with a surgical method. No significant differences in radiographic arthritis at final follow up or return to work between non-operative and operative treatment were observed. The variety in methods of reporting pain in the studies as well as the paucity of the use of validated outcome measures makes the strength of the evidence for the presence of pain poor. Furthermore, the difference between the mean time of final review in non-surgical and surgical

studies casts doubt on a fair comparison. Due to large numbers and the more straightforward manner of assessing and reporting the radiological presence of osteoarthritis and complications of treatment, these present fair evidence for the figures presented, however they may still be open to bias of self-reporting.

There were 12 separate methods of treatment included in this study with several other methods being described in the literature. This supports the argument that no one treatment method is superior to another. The most frequently employed treatments are manipulation under anaesthetic (MUA) and plaster of Paris (POP), MUA and K wiring and open reduction and internal fixation (ORIF). Within the current literature appropriate fracture classification, reduction techniques and quality of reduction are rarely given; in addition several different techniques of K-wiring and ORIF are presented, making direct comparison challenging.

It has been suggested in the literature that fractures of the metacarpal base should be reduced to within 1mm to reduce the risk of radiographic arthritis, but this is not shown conclusively to prevent long term symptomatic arthritis (Kjaer-Petersen *et al.*, 1990; Thurston e Dempsey, 1993; Oosterbos e De Boer, 1995). This may be due in part due to the inaccuracy with the use of fluoroscopy which has an error of 1-2mm(Augé e Velázquez, 2000; Mehta *et al.*, 2000). More recent publication on the use of arthroscopic assisted fixation shows promise, but numbers are small and follow up short (Pomares *et al.*, 2016).

In summary, there is currently no high quality evidence to guide us to the optimal treatment method for a Bennett's fracture. The data from this review suggest that surgical treatment results in less pain but a higher rate of complications when compared to non-surgical methods. However, given the poor quality of data this may not be applicable to all fracture types. There is no clear evidence that operative treatment is better than non-operative treatment. Provided a good reduction of the fracture is achieved and maintained until bone union it is likely that a good outcome will be achieved. One or more randomised control trials comparing non-surgical or surgical treatments are required to advance the treatment of this common injury.

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7. Thurston AJ, Dempsey SM. Bennett's fracture: a medium to long-term review. Aust N Z J Surg. 1993, 63: 120-3.

Appendices

Study type	Reference:
Non-operative	Blazkova, L. Problem of the diagnosis & therapy of Bennett's fractures. Acta Chir Orthop Traumatol Cech. 1958, 25: 462-6.
Non-operative	Spangberg, O, Thoren, L. Bennett's Fracture. A method of treatment with oblique traction. J Bone Joint Surg Br. 1963, 45: 732-6.
Non-operative	Griffiths, JC. Fractures at the base of the first metacarpal bone. J Bone Joint Surg Br. 1964, 46: 712-9.
Non-operative	Ziffko, B, Matuschka, H. Bennett's dislocation fractures - conservative treatment. Hefte Unfallheilkd. 1980, 141: 85-92.
Non-operative	Wang, ZB. Duck-shaped wire fixation splint for treatment of Bennett's fracture. Zhonghua Wai Ke Za Zhi. 1981, 19: 467-9.
Non-operative	Livesley, PJ. The conservative management of Bennett's fracture-dislocation: a 26-year follow-up. J Hand Surg Br. 1990, 15: 291-4.
Non-operative	Oosterbos, CJ, de Boer, HH. Non operative treatment of Bennett's fracture: A 13 year follow up. J Orthop Trauma. 1995, 9: 23-27.
Non-operative	Milosević, I, Sudjić, V, Bumbasirević, V, Lesić, A, Damjanović, G, Bumbasirević, M. Nonoperative treatment of fractures of the base of the first metacarpal bone--Bennett fracture. Acta Chir Iugosl. 2005, 52: 67-71.
Operative	Thoren, L. A new method of extension treatment in Bennett's fracture. Acta Chir Scand. 1956, 30: 485-93.
Operative	Sommer, J. Bennett's fracture. A follow-up Study of Bennett's fracture treated with Moberg-Gedda Osteosynthesis. Nord Med. 1963, 19: 1367-9.
Operative	Fisher, E. Bennett's fracture in general practice. Med J Aust. 1976, 27:434-8.
Operative	Stromberg, L. Compression fixation of bennett's fracture. Acta Orthop Scand. 1977, 48: 586-91.
Operative	Tourne, Y, Moutet, F, Lebrun, C, Massart, P, Butel, J. The value of compression screws in Bennett fractures. Apropos of a series of 44 case reports. Rev Chir Orthop Reparatrice Appar Mot. 1988, 74: 153-5.
Operative	van Niekerk, JL, Ouwens, R. Fractures of the base of the first metacarpal bone: results of surgical treatment. Injury. 1989, 20: 359-62.
Operative	Móricz, O, Bíró, V, Vámhidy, L. Results of surgical management of Bennett fractures. Magy Traumatol Orthop Helyreallito Seb. 1990, 33: 273-5.
Operative	Timmenga, EJ, Blokhuis, TJ, Maas, M, Raaijmakers, EL. Long-term evaluation of Bennett's fracture. A comparison between open and closed reduction. J Hand Surg Br. 1994, 19: 373-7.
Operative	Brazier, J, Moughabghab, M, Migaud, H, Fontaine, C, Elia, A, Tillie, B. Articular fractures of the base of the first metacarpal. Comparative study of direct osteosynthesis and closed pinning. Ann Chir Main Memb Super. 1996, 15: 91-9.
Operative	Pelto-Vasenius, K, Hirvensalo, E, Rokkanen, P. Absorbable pins in the treatment of hand fractures. Ann Chir Gynaecol. 1996, 85: 353-8.
Operative	Brüske, J, Bednarski, M, Niedźwiedź, Z, Zyluk, A, Grzeszewski, S. The results of operative treatment of fractures of the thumb metacarpal base. Acta Orthop Belg. 2001, 67: 368-73.
Operative	Lutz, M, Sailer, R, Zimmermann, R, Gabl, M, Ulmer, H, Pechlaner, S. Closed reduction transarticular Kirschner wire fixation versus open reduction internal fixation in the treatment of Bennett's fracture dislocation. J Hand Surg Br. 2003, 28: 142-7.

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Study type	Reference:
Operative	Demir, E, Unglaub, F, Wittemann, M, Germann, G, Sauerbier, M. Surgically treated intraarticular fractures of the trapeziometacarpal joint -- a clinical and radiological outcome study. Unfallchirurg. 2006, 109: 13-21.
Operative	Sawaizumi, T, Nanno, M, Nanbu, A, Ito, H. Percutaneous leverage pinning in the treatment of Bennett's fracture. J Orthop Sci. 2005, 10: 27-31.
Operative	Bennani, A, Zizah, S, Benabid, M et al., The intermetacarpal double pinning in the surgical treatment of Bennett fracture (report of 24 cases). Chir Main. 2012, 31: 157-62.
Operative	Greeven, AP, Alta, TD, Scholtens, RE, de Heer, P, van der Linden, FM. Closed reduction intermetacarpal Kirschner wire fixation in the treatment of unstable fractures of the base of the first metacarpal. Injury. 2012, 43: 246-51.
Operative	Leclère, FM, Jenzer, A, Husler, R et al., 7-year follow-up after open reduction and internal screw fixation in Bennett fractures. Arch Orthop Trauma Surg. 2012, 132: 1045-51.
Operative	Zhang, X, Shao, X, Zhang, Z, Wen, S, Sun, J, Wang, B. Treatment of a Bennett fracture using tension band wiring. J Hand Surg Am. 2012, 37: 427-33.
Operative	Pavić, R, Malović, M. Operative treatment of Bennett's fracture. Coll Antropol. 2013, 37:169-74.
Operative	Uludag, S, Ataker, Y, Seyahi, A, Tetik, O, Gudemez, E. Early rehabilitation after stable osteosynthesis of intra-articular fractures of the metacarpal base of the thumb. J Hand Surg Eur. 2015, 40:370-3.
Operative	Adi, M, Miyamoto, H, Taleb, C et al., Percutaneous fixation of first metacarpal base fractures using locked k-wires: a series of 14 cases. Tech Hand Up Extrem Surg. 2014, 18: 77-81.
Operative	Li, Z, Guo, Y, Tian, W, Tian, G. Closed reduction external fixator fixation versus open reduction internal fixation in the patients with Bennett fracture dislocation. Chin Med J (Engl). 2014, 127: 3902-5.
Operative	Middleton, SD, McNiven, N, Griffin, EJ, Anakwe, RE, Oliver, CW. Long term patient reported outcomes following Bennett's fractures. Bone Joint J. 2015, 97-B: 1004-1006.
Operative	Pomares, G. et al., Bennett fracture: Arthroscopically assisted percutaneous screw fixation versus open surgery: Functional and radiological outcomes. Orthop Traumatol Surg Res. 2016, 102: 357-61.
Combined study	Gedda, KO. Studies on Bennett's fracture; anatomy, roentgenology, and therapy. Acta Chir Scand Suppl. 1954, 193: 1-114.
Combined study	Sälgeback, S, Eiken, O, Carstam, N, Ohlsson, NM. A study of Bennett's fracture. Special reference to fixation by percutaneous pinning. Scand J Plast Reconstr Surg. 1971, 5: 142-8.
Combined study	Lemberger U. Long-term results of treatment of Bennett fractures. Handchirurgie. 1980, 12: 245-6.
Combined study	Cannon, SR, Dowd, GS, Williams, DH, Scott, JM. A long-term study following Bennett's fracture. J Hand Surg Br. 1986, 11: 426-31.
Combined study	Kjaer-Petersen, K, Langhoff, O, Andersen, K. Bennett's fracture. J Hand Surg Br. 1990, 15: 58-61.
Combined study	Thurston, AJ, Dempsey, SM. Bennett's fracture: a medium to long-term review. Aust N Z J Surg. 1993, 63: 120-3.
Combined study	Surzur, P, Rigault, M, Charissoux, JL, Mabit, C, Arnaud, JP. Recent fractures of the base of the 1st metacarpal bone. A study of a series of 138 cases. Ann Chir Main Memb Super. 1994, 13: 122-34.

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CONDYLAR FRACTURES

David J. SHEWRING

Introduction

Condylar fractures of the phalanges are relatively common. Most of these fractures will require stabilisation since the oblique fracture pattern of the typical condylar fracture renders them inherently unstable (Weiss and Hastings, 1993; Shewring et al., 2015). Mal-union will result in deformity and articular incongruity with the possibility of late osteoarthrosis. Displaced condylar fractures will require open reduction and internal fixation. If there is marked displacement then there will be significant soft tissue disruption, with tearing of the periostium which will herald instability.

If the fracture presents in an un-displaced position and non-operative treatment is initially embarked upon, close monitoring with weekly radiographs will be required, as these fractures will frequently displace.

Methods

The objective of this process was to identify and review all studies concerning the treatment of fractures of the phalangeal condyles. The search strategy is described in Table 4.1.

Articles reporting heterogenous series of phalangeal fractures (e.g. inclusive of base, neck and condylar fractures) but where the results were collectively reported were excluded, as were animal studies, those relating to the foot and case reports. Inclusion required a description of the method employed, a minimum of five patients in the study and recorded clinical or radiographic outcome measures. Full text copies of those that met the inclusion criteria were obtained (Figure 4.1). The quality of the studies was assessed using the Coleman scoring system (Coleman *et al.*, 2000).

Data extracted included study design, numbers of patients, mean final follow up time, treatment(s) utilised and clinical, functional and radiological outcomes. The outcome measures were range of movement of the affected joint and complications of treatment.

Applying the Coleman methodological quality score to the in-

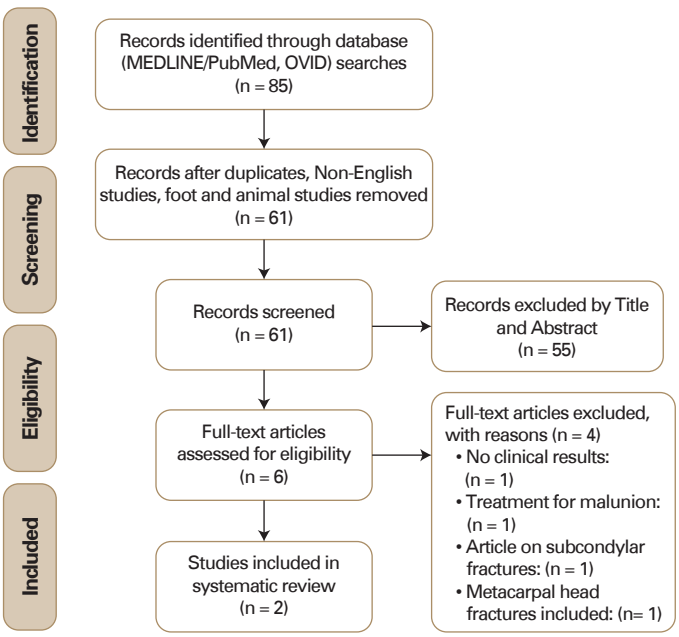
cluded studies, the mean Coleman score was 48.5 (range 38 – 59). Included studies gave good descriptions of any surgical interventions that were involved. Outcome measures were also defined and follow-up timings were clearly stated in the text.

Studies differed in their study size and numbers of intervention. The detailed Coleman methodological analysis of the included studies are summarised in Table 4.2.

Table 4.1 Search strategy phalangeal condyle fractures (Completed 9th November 2016)

#	Search Term (.mp)	Number of Returned Articles
1	Condyle	33826
2	Condylar	16178
3	Phalanx	13714
4	Phalangeal	6372
5	Fracture	481078
6	Injury	1931819
7	#1 OR #2	40779
8	#3 OR #4	18292
9	#7 AND #8	204
10	#5 OR #6	2276412
11	#9 AND #10	129
12	De-duplicate #11	84

Figure 4.1 PRISMA flowchart depicting selection process



Results

A total of 85 articles were identified and subject to title and abstract review. Upon review, 79 studies were excluded on the title and abstract alone; six articles were deemed eligible for full-text assessment. Of these, three were rejected on the basis that they contained no clinical results, were reporting on the results of treatment for malunion or related to sub-condylar rather than condylar fractures (Figure 4.1).

No randomised controlled trials or any other type of comparative studies were identified in the search.

In total, two studies were included, registering a total of 112 patients.

Outcome Measures

The two papers used simple outcome measures, range of movement, radiological assessments and occurrence of complications (Table 4.4).

Table 4.2. Modified Coleman Methodological Analysis scores for included studies

Coleman Criteria	Shewring	Weiss & Hastings
1. Study size - Number of patients (N)	4	0
2. Mean follow-up	0	3
3. Percentage of patients with follow-up (radiographic and clinical)	5	5
4. Number of interventions per group	10	0
5. Type of study	10	0
6. Diagnostic certainty	5	5
7. Description of surgical technique	5	5
8. Description of postoperative rehabilitation	5	5
Part B: 1. Outcome criteria		
Outcome measures clearly defined?	2	2
Timing of outcome assessment clear?	2	2
Use of outcome criteria with reported good reliability?	3	3
Use of outcome with good sensitivity?	3	3

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Coleman Criteria	Shewring	Weiss & Hastings
Part B: 2. Procedure for assessing outcomes		
Subjects recruited	5	5
Independent investigator (2 radiographic / 2 clinical)	0	0
Written assessment	0	0
Patient centred data collected	0	0
Part B: 3. Description of subject selection process		
Selection criteria reported and unbiased	0	0
Recruitment rate reported and >80%	0	0
Eligible subjects not included in the study satisfactorily accounted for	0	0
Total	**59**	**38**

Table 4.3 Treatments used in studies

Treatment	Numbers of patients treated
Splintage	9
Splintage then ORIF	10
ORIF: K-wires	21
ORIF Loop wire	1
ORIF: Lag screw	77
ORIF: Lag screw + K-wire	4
Total	112

ORIF-Open reduction and internal fixation

Table 4.4 Patient complications

	Splintage n = 14	ORIF (K-wires) n = 21	ORIF (lag screw) n = 87
Complications (n=17)	Loss of position: 10	Loss of fixation: 4	Loss of fixation: 1 Infection: 1

Discussion

Despite condylar fractures being relatively common, there is a dearth of published material with regard to their management. There were no comparative studies; one of the two papers analysed is a retrospective case series. There is general agreement that these fractures tend to be unstable and so non-operative management, even when such fractures are undisplaced, is difficult. There is also general agreement that when displaced, such fractures should be operatively stabilised. Methods used for this include a single lag screw (Weiss and Hastings, 1993; Shewring et al., 2015; Tan et al., 2011), K-wires inserted using open and closed techniques, and a combination of a screw with a K-wire (Weiss and Hastings, 1993). What is unknown is which methods of fixation will yield the best results. There is no clear evidence that one method is superior to another, although the papers from Weiss and Hastings (1993) as well as Shewring et al (2015) contained examples of fractures treated with K-wires in which loss of fixation occurred.

To advance our knowledge of the management of these fractures there is a need for a randomised controlled trial comparing the use a single lag screw to stabilise the fracture with treatment using K-wires.

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BONY MALLET INJURIES

Ryan W. TRICKETT

Introduction

Mallet fingers are a common problem presenting to hand surgeons world-wide, comprising 9.3% of all tendon or ligament injuries (de Jong et al., 2014). Otherwise known as "baseball finger" or "dropped finger", an injury to the extensor apparatus of the distal interphalangeal (DIP) joint was first described in the 1880s by Segond and then by Shoening (Botero et al., 2016). Injuries can occur to tendon alone or the dorsal surface of the distal phalanx, both resulting in a defunctioning of the extensor apparatus and the classic appearance of loss of active extension at the DIP joint. The pathoanatomy remains disputed. Initially an axial load to the distal joint can be followed by either a hyper-flexion (Lange and Engber, 1983; Moss and Steingold, 1983) or hyper-extension force (Botero et al., 2016). Knowledge of the terminal extensor tendon anatomy and the history of injury in the majority of encountered patients would suggest that a hyperflexion force is the likely mechanism in most patients.

Conservative treatment for tendinous mallet injuries has been practised for many years and yields reliable results (Abouna and Brown, 1968; Brooksbank et al., 2014; Hallberg and Lindholm, 1960; Shankar and Goring, 1992; Stack, 1968; Stack, 1986). However, questions remain about the significance of bony mallet injuries, and whether these require alternative treatment.

Bony mallet injuries represent an injury to the extensor apparatus but also potentially compromise the stability of the DIP joint. Of particular interest are those injuries that lead to subluxation or frank dislocation of the joint. Classification systems demonstrating the potential risk of subluxation have been described (Doyle, 1999; Wehbe and Schneider, 1984) but only recently has dynamic testing been considered as a useful decision making tool (Giddins, 2016). Although understanding the risk of instability of the DIP joint, the optimal treatment for these injuries remains unknown.

Methods

Search Strategy

The objective was to identify and review comparative studies concerning the treatment of mallet finger injuries, including both tendinous and bony injuries. A simple search strategy using the multipurpose field was developed, combining free text and index field searching using a single term "mallet finger". Both tendinous and bony mallet injuries were included due to the overall lack of high quality evidence, particularly comparative trials. The search strategy is described in Table 5.1.

Table 5.1 Search Strategy (Completed 27th December 2016)

#	Search Term (.mp)	Number of Returned Articles
1	Mallet Finger	705
2	De-duplicate (1)	429

Selection Criteria and Assessment of Methodological Quality

Types of Studies

Simple case reports and case series dominated the published literature concerning both tendinous and bony mallet fingers. The majority of these articles reported results in heterogeneous groups of patients, including both types of injury as well as open injuries. Case series and non-comparative reports of techniques were excluded from full review.

Randomised controlled trials (RCTs), pseudo-randomised controlled trials (PRCTs) and comparative observational study designs were included.

Assessment of Methodological Quality of Included Studies

Included articles were considered for their methodological quality using the modified Coleman methodological score (Coleman et al., 2000). This considers study design as well as the reporting of validated outcome measurements. It has been shown to have an excellent reliability (Tallon et al., 2001).

Results

A total of 429 articles were identified by the search (Table 5.2). Two additional articles not identified in the original search were added (Lucchina et al., 2010; Okafor et al., 1997) after reviewing an included article reference list.

After removal of duplicates, non-human and non-English language papers, a total of 298 titles and abstracts were reviewed before full-text review of 26 articles and an additional five "systematic reviews". During review of the systematic reviews, an article previously excluded on the basis of the title and abstract (Maitra and Dorani, 1993) was subsequently included for full text review. This article reported the results of a comparative observational study.

Overall, the 16 included studies were of variable quality with a mean modified Coleman score of 61.3 (range 37 to 87). There were six randomised controlled trials (Gruber et al., 2014; O'Brien and Bailey, 2011; Pike et al., 2010; Saito and Kihara, 2016; Tocco et al., 2013; Warren et al., 1988) all comparing differing designs of splints except for Gruber et al., (2014) who looked at the duration of splinting. The methodology of these studies was predictably better than the non-randomised studies; with a mean modified Coleman score of 78.8 (range 56 to 87). Despite using a randomised methodology the study by Warren et al., (1988) reported pooled results using the criteria defined by Abouna and Brown (1968). This made further conclusions based upon this study difficult to interpret. Two other non-randomised studies also compared splinting regimens (Kinninmonth and Holburn, 1986; Maitra and Dorani, 1993).

There were no randomised trials comparing surgery and splinting for any type of mallet injury. Six observational studies compared surgical intervention and splinting but all were open to bias due to participant selection and non-randomisation (Auchincloss,

1982; Clement and Wray, 1986; Lubahn, 1989; Niechajev, 1985; Stern and Kastrup, 1988; Wehbe and Schneider, 1984). Four studies looked specifically at treatment for bony mallet injuries; two compared surgery and splinting (Lubahn, 1989; Wehbe and Schneider, 1984). However details concerning specific treatment protocol were lacking and neither independently assessed patient important results. Two others reported the results of different surgical techniques (Acar et al., 2015; Lucchina et al., 2010) but did not demonstrate superiority of one technique over another.

Summary data for the included studies is shown in Table 5.3.

Figure 5.1 PRISMA flowchart depicting the selection process.From Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6:e1000097. For more information, visit www.prisma-statement.org.

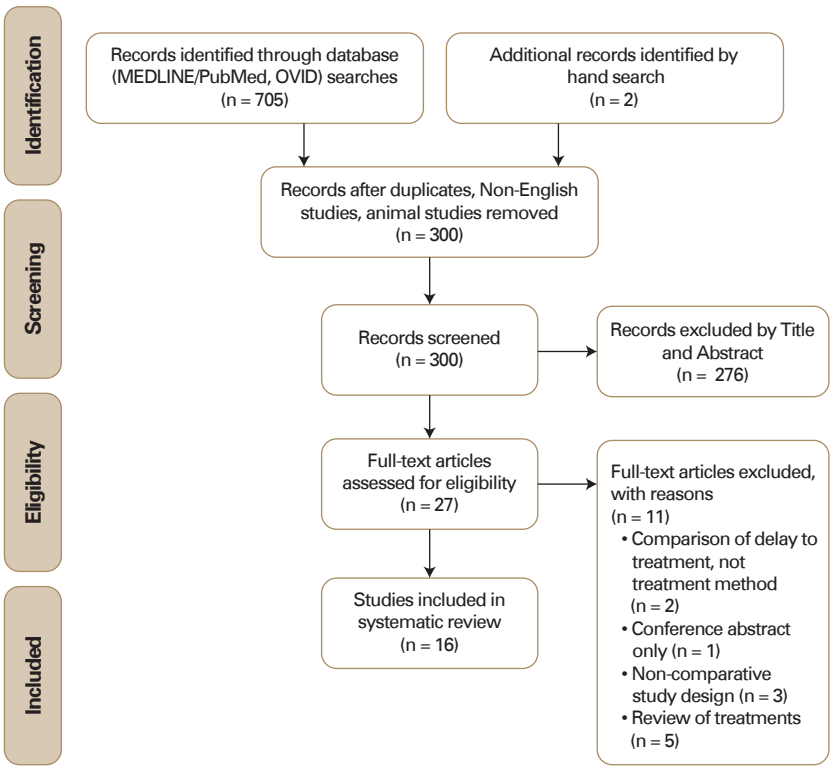

Table 5.2 Modified Coleman methodological score for included studies

Coleman Criteria	Acar et al., (2015)	Auchincloss (1982)	Clement and Wray (1986)	Gruber et al., (2014)	Kinninmonth and Holburn (1986)	Lubahn (1989)	Lucchina et al., (2010)	Maitra and Dorani (1993)	Niechajev (1985)	O'Brien and Bailey (2011)	Pike et al., (2010)	Saito and Kihara (2016)	Stern and Kastrup (1988)	Tocco et al., (2013)	Warren et al., (1988)	Wehbe and Schneider (1984)
1. Study size - Number of patients (N)	0	4	4	4	4	0	4	4	10	4	4	4	10	4	7	4
2. Mean follow-up	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
3. Percentage of patients with follow-up (radiographic and clinical)	3	3	5	5	5	5	5	5	5	5	5	5	5	5	5	0
4. Number of interventions per group	10	10	10	10	10	10	10	10	5	10	10	10	0	10	10	10
5. Type of study	0	10	0	15	15	0	0	15	0	15	15	15	0	15	10	0
6. Diagnostic certainty	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
7. Description of surgical technique	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
8. Description of postoperative rehabilitation	5	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Part B: 1. Outcome criteria																
Outcome measures clearly defined?	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Timing of outcome assessment clear?	2	0	0	2	2	2	2	2	2	2	2	2	0	2	2	2
Use of outcome criteria with reported good reliability?	3	0	2	2	0	0	2	0	2	2	2	2	0	2	0	2
Use of outcome with good sensitivity?	3	0	2	2	0	0	2	0	2	2	2	2	0	2	0	2
Part B: 2. Procedure for assessing outcomes																
Subjects recruited	5	5	0	5	0	5	5	5	5	5	5	5	0	5	5	5
Independent investigator (2 radiographic / 2 clinical)	0	0	0	0	0	0	0	0	0	2	4	2	0	2	0	0
Written assessment	3	0	0	3	0	0	0	0	0	0	3	3	0	3	0	0
Patient centred data collected	3	3	3	3	3	0	0	3	0	3	3	3	0	3	0	3
Part B: 3. Description of subject selection process																
Selection criteria reported and unbiased	0	0	0	5	0	5	0	0	0	5	5	5	0	5	0	0
Recruitment rate reported and >80%	5	5	0	5	5	5	0	0	0	0	5	5	5	5	0	0
Eligible subjects not included in the study satisfactorily accounted for	0	0	0	5	0	5	0	0	0	5	5	5	0	5	0	0
Total	**54**	**52**	**43**	**83**	**61**	**54**	**47**	**61**	**51**	**77**	**87**	**85**	**37**	**85**	**56**	**48**

Table 5.3 Summary data for the included studies

Author (Year)	Country	n	Mean age	Study Type	Group 1	Group 2	Group 3	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Acar et al., (2015)	Turkey	32	28 (1) 32 (2)	Retrospective cohort	Open hook plate (n = 13)	Ishiguro technique (n = 19)		19 months	Full extension, full flexion, no pain = Excellent 0-10° extensor lag, full flexion, no pain = Good 10-25° extensor lag, any flexion loss, no pain = Fair >25° extensor lag or persistent pain = Poor (Crawford 1984) VAS DASH Return to work DIP arthritis	Open surgery took longer but required fewer fluoroscopic images Open surgery had a quicker time to bone healing Return to work was quicker in the open surgery group Extensor lag comparable (Open 3°, SD 4; Perc 4°, SD 4) DIP flexion comparable (Open 64°, SD 6; Perc 61°, SD 8) VAS comparable (Open 0; Perc 0.6) Less articular incongruity with open surgery Complications: 3 nail deformity in open (all 3 further surgery to remove the plate), 1 in percutaneous	Percutaneous wiring offers faster surgery with less chance of revision surgery. Otherwise results are similar although open surgery has a shorter (non-significant) time to return to work.	54
Auchincloss (1982)	UK	41	43.3 (1) 39.1 (2)	PCT	Pryor and Howard splint (similar design to Stack) (n = 22)	Percutaneous transarticular K-wire (n = 19)		15.8 months	No pain/deformity & Full ROM = Good Residual extensor lag but improved from presentation by 10° & full flexion = Improved No significant change in extensor lag or reduced flexion = Unchanged (Stark, Boyes, Wilson 1962) Subjective patient assessment of treatment acceptability, result and function	9 lost to follow up Similar results between splint and transarticular K-wiring Patients with a delay > 1 week until treatment had poorer results 2 infection in wiring group	Few patients have significant disability regardless of treatment method. A delay in treatment however does risk a poorer result.	52
Clement and Wray (1986)	UK	47	?	Retrospective cohort	Stack splint	Operative reinsertion		?	Extensor lag Total active movement Cold intolerance	Surgery: Lag 10°; flexion 50° Splint: Lag 15°; flexion 50° No difference in lag between fracture and tendinous injury (10°) Many experienced cold intolerance and pain but no difference between surgery and splint	No observable difference between surgery and splint but a full RCT recommended	43

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Author (Year)	Country	n	Mean age	Study Type	Group 1	Group 2	Group 3	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Gruber et al., (2014)	USA	51	50	PRCT	Night splinting (n = 25)	No night splinting (n = 26)		10 to 12 weeks	Extensor lag DASH Satisfaction	No difference in extensor lag (no night 16°, SD 12; night 11°, SD 11) No difference in DASH (no night 9.4, SD 12; night 8.1, SD 8.5) No difference in satisfaction (no night 8.5, SD 2.2; night 8.0, SD 2.9) Greater age and presentation of lag correlated with greater lag after treatment Extensor lag did not correlate with satisfaction or DASH score	No benefit to additional night splinting once the standard course of daytime splinting has been completed	83
Kinninmonth and Holburn (1986)	UK	54	?	PCT	Perforated splint (n = 27)	Traditional splint (n= = 27)		12 months	Extensor lag Failure of treatment Complications Compliance	Splint technique was easier to master in the perforated group Splint failures were more common in the standard group, requiring a change to the perforated splint 89% perforated splint patients have lag <5° 67% standard splint patients have lag <5°	Perforated mallet splint is better tolerated and thus offers more consistent results	61
Lubahn (1989)	USA	30	27.6 (1) 31.3 (2)	Retrospective cohort	Surgery (n = 11)	Splint (n = 19)		17 weeks and 21 weeks	Extensor lag Dorsal prominence Complications	Surgery: 0-20° lag; ROM 55° Splint: 20-30° lag; ROM 35° Significant dorsal prominence in splint group in those who had joint subluxation or fragment larger than 1/3 of joint 1 infection in surgery group; 1 dorsal skin loss in splint group	Surgery offered a better functional and cosmetic result than splinting	54
Lucchina et al., (2010)	Switzerland/ USA	58	42 (1) 36 (2) 36 (3)	Retrospective cohort	Extension block pinning (n = 20)	K-wire joysticks (n = 22)	Open reduction (n = 16)	21.3 months (1) 19.2 months (2) 22 months (3)	Extensor lag Range of movement Time to union Complications Time off work	Extension block: extensor lag 5°; flexion 58° Joysticks: extensor lag 2°; flexion 72° Open reduction: extensor lag 5°; flexion 55° 2 complications in each of extension block and open reduction groups; no complications for joystick group	All 3 procedures give similar results in terms of range of movement and union Open reduction allows a faster return to work	47

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Author (Year)	Country	n	Mean age	Study Type	Group 1	Group 2	Group 3	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Maitra and Dorani (1993)	UK	60	44.5	PRCT	Trial splint	Stack splint		9 weeks	Time off work Opinion about splint Complications Abouna & Brown	Trial: 11 Success; 6 Improved; 13 Failure Stack: 10 Success; 6 Improved; 14 Failure Complications more likely with Stack splint (33% versus 6.6%) Similar patient opinion of both	A DIY aluminium splint (Trial splint) can be useful where Stack splint does not fit well in preventing skin complications Results are otherwise equivocal	61
Niechajev (1985)	Japan	150	?	Retrospective cohort	Aluminium splint	Pull out suture		3 years	Extensor lag Flexion Discomfort	Majority of the patients followed-up to 3 years had no complaints (75/92) Surgery reserved for worse injuries (larger fracture, or subluxation of joint) Splint had improved extensor lag and flexion High proportion of no lag (64/92) and full flexion (82/92) with splint	Untreated fractures yielded universally (subjective) poor results As diagnostic and treatment groups were dissimilar the results are hard to interpret	51
O'Brien and Bailey (2011)	USA	64	37.6	PRCT	Stack splint (n = 21)	Dorsal aluminium splint (n = 21)	Custom splint (n = 22)	20 weeks	Extensor lag Range of movement Patient satisfaction (/5) VAS Pain Complications	Stack splint: 1.5° extensor lag (SD 4.1), 4.5 satisfaction, 0.6 VAS, 64.4° active ROM Aluminium: 1.2° extensor lag (SD 4.1), 3.8 satisfaction, 1.1 VAS, 59.1 active ROM Custom: 5.2° extensor lag (SD 8.2), 3.9 satisfaction, 1.2 VAS, 62.7 active ROM No significant differences in any outcome measures Complications favoured custom splint Increasing age associated with worse extensor lag	Majority of injuries managed successfully Custom made splint had fewer complications which could lead to treatment failure and should therefore be favoured	77

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Author (Year)	Country	n	Mean age	Study Type	Group 1	Group 2	Group 3	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Pike et al., (2010)	USA	87	43 (1) 44 (2) 42 (3)	PRCT	Dorsal aluminium splint (n = 26)	Volar aluminium splint (n = 27)	Custom splint (n = 24)	24 weeks (radiographs week 12)	Extensor lag (radiographic and clinical) Michigan Hand Questionnaire Complications	Dorsal aluminium: 6.7° (SD 15) radiographic lag; 6° (SD 6.5) clinical lag; 80 MHQ. Volar aluminium: 4° (SD 10.7) radiographic lag; 5° (SD 5.3) clinical lag; 80 MHQ. Custom: 5° (SD 17.1) radiographic lag; 7° (SD 7.5) clinical lag; 79 MHQ. Increasing age correlated with extensor lag Complications similar	Radiographic lag accounts for variation of individuals compared to their normal side ("normal" lag varied from -10° to 24°) Slightly underpowered study	87
Saito and Kihara (2016)	Japan	44	43 (1) 41 (2)	PRCT	2-step orthosis	Standard splint		16 weeks	Extensor lag Flexion VAS Pain Abouna and Brown	2-step: 8° (SD 4.5) extensor lag; 53° (SD 10.9) flexion; 1.4 (SD 0.6) VAS Pain Standard: 16° (SD 6.9) extensor lag; 47° (SD 7.6) flexion; 1.2 (SD 1.0) VAS Pain	A 2-step orthosis, initially immobilising the PIP joint in 30° flexion, appears to have a beneficial effect on extensor lag compared to standard splinting	85
Stern and Kastrup (1988)	USA	123	36	Retrospective cohort	Splint	Splint then surgery	Surgery	?	Extensor lag Flexion Complications	Splint: 8° extensor lag; 44° flexion Splint/surgery: 3° extensor lag; 51° flexion Surgery: 7° extensor lag; 49° flexion	Heterogenous cohort Splinting associated with a lower complication rate compared to surgery Outcomes otherwise equivocal therefore splinting favoured	37

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Author (Year)	Country	n	Mean age	Study Type	Group 1	Group 2	Group 3	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Tocco et al., (2013)	USA	57	47.1 (1) 42.7 (2)	PRCT	Custom splint	QuickCast		100 days (1) 107 days (2)	Extensor lag Active flexion Oedema (ring sizer unit) VAS (Satisfaction & Pain) Complications	Custom: 9° (SD 9) extensor lag; 0.8 oedema; 0 VAS Pain; -4.2° (SD 11.4) active flexion deficit QuickCast: 4° (SD 4) extensor lag; 0.6 oedema; 0.4 VAS; -6° (SD 12.3) active flexion deficit	No significant difference between splint designs in extensor lag QuickCast reduced oedema better than a custom splint	85
Warren et al., (1988)	UK	116	46.1	PCT	Stack splint (n = 58)	Abouna splint (n = 49)		10 weeks	0-5° extension loss & no stiffness & full active ROM = Success 6-15° & no stiffness with normal flexion = Improved >15° & stiffness or impaired flexion = Failure (Abouna and Brown 1968)	Worse results with increasing age Similar results between splint designs Patients preferred the Stack splint	Mallet fingers can be resolved or significantly improved in the majority of cases.	56
Wehbe and Schneider (1984)	USA	44	30.11	Retrospective cohort	Splint (n = 35)	Surgery (n = 9)		3.25 years	Extensor lag Flexion arc Complications Functional impairment (subjective)	Full follow-up for 21 injuries Surgery: 4 patients < 10° extensor lag; 2 patients 10-30° extensor lag Splint: 11 patients < 10° extensor lag; 4 patients 10-30° extensor lag	Surgical treatment was challenging and did not obviously offer benefits over conservative measures	48

Discussion

The published literature does not currently support the use of one treatment over another for the treatment of mallet injuries to the fingers. Overall, the quality of evidence is poor. Often sample populations are heterogeneous and include both tendinous and bony mallet injuries. It seems from the pathoanatomy that the two injuries may be dissimilar in mechanism and, understandably, an articular component is likely to lead to a poorer outcome than a pure soft tissue injury. Thus, it is inappropriate to report results of these differing injuries together.

Whilst there is a wealth of case series concerning the conservative treatment of tendinous mallet injuries the evidence base is poor. The included studies here (Kinninmonth and Holburn, 1986; Maitra and Dorani, 1993; O'Brien and Bailey, 2011; Pike et al., 2010; Saito and Kihara, 2016; Tocco et al., 2013; Warren et al., 1988) suggest that the results of splinting are universally good with regards to extensor lag and flexion movement. Furthermore there appears to be no significant difference between splint designs, although, as discussed, the description of splints and subsequent data is too heterogeneous to allow any meaningful meta-analysis. Previous systematic reviews have reached similar conclusions (Handoll and Vaghela, 2004; Valdes et al., 2015).

The role of surgery is uncertain. It is possible that splinting is insufficient to adequately maintain articular reduction in bony mallet injuries where there has been significant subluxation of the DIP joint.

Auchincloss (1982), Clement and Wray (1986), Stern and Kastrup (1988) and Wehbe and Schneider (1984) all compared surgical intervention and splinting. All found that the results were equivalent between the groups and that surgery could be challenging. None preferred surgery for most cases but recommended splinting for the majority of injuries.

Lubahn (1989) favoured open surgical treatment of bony mallet fractures to restore the articular surface anatomically, suggesting that this gave better functional and cosmetic results. In this small

series there was no use of a validated patient reported measure of either function or cosmesis.

Niechajev (1985) reported results using a pull-through suture and splints. However, the groups described in the paper varied and there were no set protocols for treatment of each group. This makes analysis of the results impossible. One useful conclusion was that untreated bony mallet injuries had universally poor results.

Acar et al., (2015) showed favourable results using both percutaneous wires inserted using the Ishiguro technique (Ishiguro et al., 1997; Ishiguro et al., 1999) and open reduction using a hook plate. Whilst there were no significant differences in outcome between the groups, the authors did note an increased rate of revision surgery (for plate removal) in the open reduction group. This conflicted with previous evidence from Lucchina et al., (2010) who showed that two of the three described surgical techniques (Ishiguro and open reduction) had similar rates of nail or soft tissue irritation, whilst the "K-wire as joystick" had no complications.

Finally, Gruber et al., (2014) looked at the duration of splinting, comparing a standard course of daytime splinting to a standard course of daytime splinting (6 to 8 weeks) with additional splinting at night for a further 4 weeks. They demonstrated no difference in extensor lag or patient reported outcome in the night splinting group.

Conclusions

Despite the huge range of splinting and surgical techniques, with varying rehabilitation regimens, there is no clear consensus regarding the optimal treatment for mallet injuries. Conservative methods continue to be safe and yield predictably good results in the majority of patients. In the modern era of patient important outcomes, it is no longer sufficient to base decision making around the degree of extensor lag or surgeons preferred technique. Further studies that seek to determine the optimal treatment for these common injuries will need to focus on patient reported outcomes and functional measurements and demonstrate a clear benefit in order to consider a paradigm shift from conservative to surgical management.

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MANAGEMENT OF FRACTURE DISLOCATIONS OF THE LITTLE FINGER (5TH) CARPO-METACARPAL JOINT

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Introduction

Fracture dislocations of the little finger carpometacarpal joint (CMCJ) are common injuries. They may involve a fracture of the metacarpal(s). This injury pattern is typically sustained from an axial force along the little metacarpal, often associated with proximal and dorsal subluxation of the metacarpal base. This displacement is further compounded or persists due to the pull of the extensor carpi ulnaris tendon which inserts onto the base of the little finger metacarpal (Niechajev, 1985). The little finger metacarpal may be affected in isolation, or with other CMCJs, in particular, the ring finger metacarpal.

A range of treatment options exist for the treatment of these injuries. Options include non-operative management, closed reduction with K-wire fixation, and open reduction and internal fixation (ORIF).

The objective of this study was to systematically review comparative studies of closed little finger CMCJ fracture subluxations.

Methods

A review protocol was developed prospectively in conjunction with the Preferred Reporting Items for Systematic Review and Meta-analysis Protocols (PRISMA-P) guidelines (Moher et al., 2015).

A search strategy was designed that used the multipurpose field to combine both index and free terms searching, and comprised the following terms:

'Metacarpus' OR 'Metacarpal'

AND 'Fracture' OR 'Subluxation' OR 'Dislocation'

AND 'Little' OR 'Fifth'

Initially, the search strategy was applied in parallel to the following databases on 25th November 2015, and then re-run on 15th January 2017: Allied and Complementary Medicine (AMED) from 1985 to November 2015, EMBASE (1980 to 2015 Week 47), Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) (1946 to Present). No language restrictions were imposed. If required, non-English language abstracts and articles were translated electronically. The UKCRC Registered Clinical Trials Unit Network was also searched. Search results were de-duplicated electronically then this was checked manually. The retained article abstracts were screened against pre-specified stepwise inclusion criteria. Within these, human studies of management of little finger metacarpal injuries, where the either the entire cohort comprised patients with fracture/subluxation/dislocation injuries, or specific sub-group data were provided for them, were included.

If abstracts were unclear or lacked requisite detail, the full text articles were screened. The details of whether retrieved studies met inclusion/exclusion criteria were recorded independently by two researchers with disagreements resolved by a third researcher. The references of the final included articles were also screened for additional articles. If further data were required, the authors of primary studies were contacted.

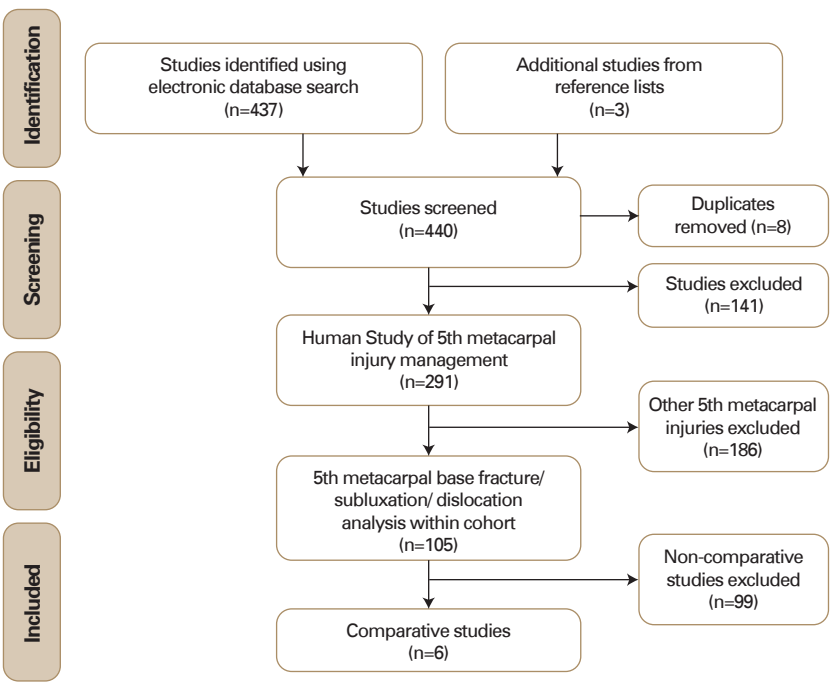
From the final included articles, data were extracted independently by two researchers who were plastic surgery registrars with an interest in hand surgery. Risk of bias was assessed at study level using the Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) tool by one researcher (Sterne et al., 2016). ROBINS-I involves assessing the risk of bias in each of seven domains. The risk of bias varies from low, moderate and serious to critical. In some circumstances, no information was available in the study to make a judgement. This was performed for each outcome in each study.

If appropriate, conventional head-to-head meta-analysis or frequentist network meta-analysis was performed. If not suitable for meta-analysis (e.g. critical risk(s) of bias in included studies), a narrative synthesis was performed.

Results

The electronic database search retrieved 437 articles after electronic deduplication (Figure 6.1). There were no further active trials of little finger metacarpal base injuries identified on the UKCRC Registered Clinical Trials Unit Network. Three further studies were identified after a search of the reference lists of the final included articles; two of these were included (Gehrmann et al., 2015; Lawlis and Gunther, 1991). Eight further duplicates were removed manually during the screening process. 141 studies were excluded as they were not studies of human little metacarpal injuries, and a further 186 studies were excluded as they pertained to other little finger metacarpal injuries rather than CMC joint subluxations/dislocations. Ninety-nine studies were excluded as they lacked any comparative methodology. Six studies made arm–to–arm comparison between different treatment strategies, and were included (Frick et al., 2011; Gehrmann et al., 2015; Petrie and Lamb, 1974; Kjaer-Petersen et al., 1992; Schortinghuis and Klasen, 1997; Lawlis and Gunther, 1991).

Figure 6.1 Article screening process



Included study characteristics

The characteristics of the included studies are summarised in Table 6.1. All six studies were non-randomised cohort studies. Four were clearly retrospective in design; the study design was not clear in the other two.

Specific study questions and hypotheses were not always clearly stated. Reviewing the methods, results and article presentations, two studies primarily evaluated whether fracture-dislocation configurations were of relevance (Kjaer-Petersen et al., 1992; Gehrmann et al., 2015). One study primarily evaluated whether operative management was necessary (Petrie and Lamb, 1974). The remaining three studies investigated whether open reduction and internal fixation was an effective management strategy (Frick et al., 2011; Lawlis and Gunther, 1991; Schortinghuis and Klasen, 1997).

Study designs varied and were not always well-described; some focussed on early outcome within the first 18 months (Frick et al., 2011; Gehrmann et al., 2015), whereas others reported long term outcomes after several years of follow up. In two studies, different interventions were used for different injury patterns (Frick et al., 2011; Kjaer-Petersen et al., 1992). In a further two, all participants had failed closed reduction without splinting, but no further descriptions intervention were provided (Gehrmann et al., 2015; Lawlis and Gunther, 1991). In the final two, no description of the choice of intervention was provided (Petrie and Lamb, 1974; Schortinghuis and Klasen, 1997).

All studies had a preponderance of young men. In some studies, only injuries to the little finger were eligible for participation (Petrie and Lamb, 1974). In other studies little and ring finger injuries were eligible for participation (Gehrmann et al., 2015; Kjaer-Petersen et al., 1992; Schortinghuis and Klasen, 1997). In the other two studies, injuries to any finger CMC joint were eligible for participation (Frick et al., 2011; Lawlis and Gunther, 1991).

The outcomes studied varied between all studies; only one used an independently-developed patient-reported outcome measure (PROM), the Disabilities of the Arm, Shoulder and Hand (DASH) (Gehrmann et al., 2015).

Table 6.1 Characteristics of included studies

STUDY	ASPECT	DETAILS
Frick (2011)	METHODS	Retrospective case note review. Non-randomised. Mean follow-up: 5 months
	PARTICIPANTS	100 participants, 98 men: 2 women, mean age 28 (range: 18-74) Little finger CMCJ injuries with or without other CMCJ injuries
	INTERVENTIONS	Closed: Reduction & K-wiring (60/100) Open: Reduction & K-wiring (17/100) or ORIF with a screw (13/100)
	OUTCOMES	Pain during grip: Open: 7/35, Closed: 10/56 Loss of full flexion: Open: 1/35, Closed: 1/56 Subjective strength loss: Open: 8/35, Closed: 12/56 Imperfect reduction: Open: 8/40, Closed: 24/60
	NOTES	Pure dislocations were mainly treated closed (11/12 dislocations) Conflicts of interest declared (none)
Gehrmann (2015)	METHODS	Study design unclear. Non-randomised. Mean follow-up: 17.6 months
	PARTICIPANTS	39 consecutive participants, all men, mean age: 31 (range 18-93) Little finger or ring and little finger CMCJ injuries
	INTERVENTIONS	Closed reduction and plaster: 5/39 Closed reduction and K-wiring (10/39) Open reduction and K-wiring (18/39) Open reduction and K-wiring & screw/plate (4/39) Open reduction and plating (2/39)
	OUTCOMES	Disabilities of the Arm, Shoulder and Hand (DASH) function patient-reported outcome measure (PROM): Non-operative: mean 10.4 (range 3.3 to 17.5) months, closed reduction and K-wire: mean 9.3 (range 0.8 to 13.3) months Grip strength: group data not presented. Radiographic changes: group data not presented.
	NOTES	All operative cases failed initial attempt at non-operative treatment. Incomplete reporting of outcomes by treatment groups. Conflicts of interest declared (none)

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STUDY	ASPECT	DETAILS
Kjaer-Petersen (1992)	METHODS	Study design not clear. Probably retrospective and non-randomised. Mean follow-up: 52 months
	PARTICIPANTS	64 participants, 49 men: 15 women, median age: 38 (range: 9-88) Little finger CMCJ injuries only
	INTERVENTIONS	No reduction, & plaster (POP, 11/64) Closed reduction & plaster (CRPOP, 25/64) Closed reduction & K-wiring (CRIF, 9/64) Open reduction & K-wiring (ORIF, 19/64)
	OUTCOMES	Pain: POP: 1/9, CRPOP: 9/20, CRIF: 2/8, ORIF: 7/15 X-ray changes: not presented by group
	NOTES	Undisplaced fracture preference: no reduction, & plaster Displaced fracture preference: closed/open reduction, & K-wiring Method of fixation varied with fracture pattern: if multi-fragmentary, inter-metacarpal fixation used. No declaration of conflicts of interest. Incomplete reporting of outcomes by treatment groups.
Lawlis (1991)	METHODS	Retrospective case note review. Non-randomised. Follow-up: 69.6 – 90 months
	PARTICIPANTS	20 participants, 17 men: 3 women, mean age: 32 (range: 13-67) CMCJ injury of any finger, including multiple CMCJ injuries
	INTERVENTIONS	No treatment (1/20) Closed reduction and plaster (3/20) Open reduction and K-wiring (15/20) Arthrodesis (1/20)
	OUTCOMES	Bespoke classification into: Excellent outcome: none: 0/1, closed: 1/3, ORIF: 12/15, arthrodesis: 1/1 Good outcome: none: 0/1, closed: 0/3, ORIF: 0/15, arthrodesis: 0/1 Satisfactory outcome: none: 0/1, closed: 0/3, ORIF: 1/15, arthrodesis: 0/1 Unsatisfactory outcome: none: 1/1, closed: 2/3, ORIF: 1/15, arthrodesis: 0/1 Percentage of extension and flexion: reported inconsistently Grip strength: reported inconsistently Time to return to work: included unemployed, not recorded Need for further reconstruction: none: 0/1, closed: 2/3, ORIF: 1/15, arthrodesis: 0/1
	NOTES	All patients initially failed closed reduction alone. Conflicts of interest declared (none)

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STUDY	ASPECT	DETAILS
Petrie (1974)	METHODS	Retrospective follow-up study. Non-randomised. Mean follow-p: 54 months
	PARTICIPANTS	23 participants, 15 males: 8 females, mean age: 43 (range: 16-69) Little ray CMCJ injuries only
	INTERVENTIONS	Unrestricted mobilisation (14/19) Closed reduction and transverse K-wire fixation (4/19)
	OUTCOMES	Severe pain duration: non-operative: 4 weeks, K-wire: 0 weeks Moderate pain duration: non-operative: 4 weeks, K-wire: 5 weeks Time off work: non-operative: 3 weeks, K-wire: 7 weeks Loss of grip strength: non-operative: 4.5cm, K-wire: 14cmHg[a] Shortening on radiographs: non-operative: 3.3mm, K-wire: 1.3mm
	NOTES	No details of treatment choice rationale. No declaration of conflicts of interest.
Schortinghuis (1997)	METHODS	Retrospective follow-up study. Non-randomised. Mean follow-up: 79 months
	PARTICIPANTS	15 participants, all men, mean age: 25 (range 19-39) Little or ring finger CMCJ injuries
	INTERVENTIONS	Open reduction and internal fixation (11/15) Closed reduction and plaster (4/15)
	OUTCOMES	Full subjective "functional recovery": Open: 9/11, Closed: 4/4 Degenerative arthritis on radiographs: Open: 0/11, Closed: 1/4 Range of motion: incompletely reported
	NOTES	No details of treatment choice rationale. Incomplete reporting of outcomes. No declaration of conflicts of interest.

([a]To describe grip strength, the maximum pressure generated in a mercury manometer by a narrow cylinder was gripped was studied and reported in cm. Further details of the unit were not specified)

Risks of biases of included studies

All included studies were at critical risk of appreciable bias in one domain or at serious risk of bias in two or more domains. The injury pattern was the confounder that accounted for all critical risks of bias. In the studies concerned (Frick et al., 2011; Gehrmann et al., 2015; Kjaer-Petersen et al., 1992; Schortinghuis and Klasen, 1997) treatment allocation varied with injury pattern, yet injury

pattern is likely to affect the clinical outcome itself (Kjaer-Petersen et al., 1992). The potential consequence is to favour non-operative treatments in these studies.

No studies described blinded measurement of outcome. Given that the treatment options being compared would be identifiable by the assessor (e.g. due to scars from open surgery) this puts them all at serious risk of bias in this domain.

No studies had prospectively published or registered protocols, so all were at least at moderate risk of bias relating to the selection of reported outcomes. In some studies, the disparity between the methods and results sections of the articles increased this to a serious risk for certain outcomes.

A summary of the risks of bias is included in Table 6.2. Rather than detailing these by individual outcome, a summary of each article's highest risk is provided.

Table 6.2 Consolidated summary of risks of bias in included studies, based on ROBINS-I tool domains

STUDY	BIAS DOMAIN	RISK OF BIAS	JUSTIFICATION OF RISK
Frick (2011)	Confounding	Critical	Different interventions were used for different injury patterns, with pure dislocations generally treated closed.
	Selection	No information	Unclear basis for recruitment of patients into study
	Intervention classification	Low	Intervention status is well-defined and based on information from the time of intervention
	Deviation from intervention	Low	No clear deviations from intervention
	Missing data	No information	No information describing whether further participants might have been available
	Measurement of outcome	Serious	Subjective outcomes with unblinded assessors
	Selection of reported result	Moderate	No clear evidence of *a priori* plan of analysis

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STUDY	BIAS DOMAIN	RISK OF BIAS	JUSTIFICATION OF RISK
Gehrmann (2015)	Confounding	Critical	Different interventions were used for different injury patterns, with pure dislocations generally treated closed.
	Selection	Low	Consecutive patients
	Intervention classification	Low	Intervention status is well-defined and based on information from the time of intervention
	Deviation from intervention	Low	No clear deviations from intervention
	Missing data	Low	No clear missing data from consecutive participants
	Measurement of outcome	Serious	Subjective outcomes with unblinded assessors for some outcomes.
	Selection of reported result	Serious	Grip strength and radiological outcomes were not presented by treatment groups
Kjaer-Petersen (1992)	Confounding	Critical	Different interventions were used for different injury patterns.
	Selection	Low	Methods imply that all eligible patients were identified and included
	Intervention classification	Low	Intervention status is well-defined and based on information from the time of intervention
	Deviation from intervention	Low	No clear deviations from intervention
	Missing data	Moderate	Slight differences in missing data between intervention groups
	Measurement of outcome	Serious	Subjective outcomes with unblinded assessors.
	Selection of reported result	Serious	Radiological outcomes not presented by treatment group
Lawlis (1991)	Confounding	Serious	All patients had failed initial closed reduction in isolation. However, the rationale for treatment choice is not described
	Selection	Low	Methods imply that all eligible patients were identified
	Intervention classification	Low	Intervention status is well-defined and based on information from the time of intervention
	Deviation from intervention	Low	No clear deviations from intervention
	Missing data	No information	20/34 patients included, but detail of missing participants not provided
	Measurement of outcome	Serious	Subjective outcomes with unblinded assessors
	Selection of reported result	Moderate	No clear evidence of *a priori* plan of analysis

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STUDY	BIAS DOMAIN	RISK OF BIAS	JUSTIFICATION OF RISK
Petrie (1974)	Confounding	Serious	Confounding expected, but no rationale for treatment choice described
	Selection	No information	Unclear basis for recruitment of patients into study
	Intervention classification	Low	Intervention status is well-defined and based on information from the time of intervention
	Deviation from intervention	Low	No clear deviations from intervention
	Missing data	No information	19/23 patients included, but detail of missing participants not provided
	Measurement of outcome	Serious	Subjective outcomes with unblinded assessors
	Selection of reported result	Moderate	No clear evidence of *a priori* plan of analysis
Schortinghuis (1997)	Confounding	Critical	Different interventions were preferred for different clinical circumstances. Injury pattern likely to affect outcome. Likely to favour closed reduction and plaster
	Selection	Low	Methods imply that all eligible patients were identified
	Intervention classification	Low	Intervention status is well-defined and based on information from the time of intervention
	Deviation from intervention	Low	No clear deviations from intervention
	Missing data	Low	No clear missing data
	Measurement of outcome	Serious	Subjective outcomes with unblinded assessors
	Selection of reported result	Serious	Ranges of motion not presented fully by treatment group.

Study findings

Due to the heterogeneity in study designs, study inclusion criteria, treatments compared, and high risks of bias, neither head-to-head nor network meta-analyses were conducted, instead a narrative synthesis is provided.

The two studies that were not at critical risk of bias may be expected to provide more reliable data (Sterne et al., 2016).

One study concluded that open reduction and internal fixation

(ORIF) is a suitable option (Lawlis and Gunther, 1991). 12/15 of the ORIF group achieved an "excellent" outcome, compared to 1/3 of the closed group. However, this study included injuries to all fingers, not just the little finger. Additionally, no statistical analysis was provided to support this statement and it involved the comparison of 15 patients treated with open reduction and internal fixation to only three treated closed. Running Fisher's Exact test for these data generates a p value of 0.172, i.e. the difference between the treatments remain statistically insignificant.

The other less biased study concluded that it surgical management of little finger injuries may not be necessary (Petrie and Lamb, 1974). In this study, non-operative treatment did not involve closed reduction and plaster immobilisation. Instead, it involved free unprotected mobilisation. But no statistical analysis was performed and the group sizes were small (14 *versus* 4). Additionally, the rationale for choosing operative management in some cases was not clear. The mobilisation group returned to work at a mean of 3 weeks, whereas the closed reduction and K-wiring group returned to work at a mean of 7 weeks. Despite greater radiological displacement, the mobilisation group experienced a mean 4.5cmHg loss of grip strength using bespoke system akin to a sphygmomanometer, whereas the K-wire group experienced and average of 14cm loss of grip.

The remaining four studies are at critical risk of bias, so their findings must be interpreted with great caution or disregarded (Sterne et al., 2016). Again, these typically had small group sizes. Only one study included any statistical analysis (Gehrmann et al., 2015) and the statistical analysis was only applied to the comparison between isolated little finger injuries and combined ring and little finger injuries. No analysis of treatment comparisons was provided. The conclusions drawn by the authors of these articles is that are that ring and little finger combined injuries behave similarly to isolated little finger injuries (Gehrmann et al., 2015) and that fixation, in particular with open reduction, is effective and potentially valuable in the management of carpometacarpal fracture dislocations in general (Frick et al., 2011; Kjaer-Petersen et al., 1992; Schortinghuis and Klasen, 1997).

Discussion

This review has demonstrated a marked paucity of clinical evidence to inform treatment decision-making for fracture-dislocations of the little finger carpometacarpal joint. The comparative evidence that does exist is of poor quality, with marked risks of bias.

Another review article concluded that non-operative treatment was rarely appropriate (Büren et al., 2016). However, this other review was not conducted in a systematic fashion, omitted articles included in the present systematic review, and it only briefly discussed management as part of a broader scope that included diagnosis and other aspects of the care pathway. However, the belief that operative management is required for the management of these injuries persists, as more severe injuries were typically treated operatively in most of the studies included here (Frick et al., 2011; Gehrmann et al., 2015; Kjaer-Petersen et al., 1992; Schortinghuis and Klasen, 1997).

The limited evidence available for interpretation in the literature suggests that this may not be true. Better outcomes for some functions might be achieved by mobilising the patient, albeit with poorer anatomical restoration. The importance of anatomical restoration is not well proven, though the data available suggest that operative treatment may deliver acceptable outcomes, despite being reserved for more challenging injuries.

It should be noted that the data supporting good outcomes from non-operative treatment involved full, free mobilisation (Petrie and Lamb, 1974). Assuming that the non-operative treatments studied in the other articles are reflective of clinical practice, closed reduction and plaster immobilisation is probably the most common non-operative treatment. However, the relative benefit of this compared either operative management (open or closed) or free mobilisation is not clear.

Conclusion

At present, there is insufficient data available to make an evidence-based recommendation for the management of these injuries. The relative advantages and disadvantages of *all* treatment options (free mobilisation, closed reduction and plaster immobilisation, closed reduction and K-wiring and open reduction and internal fixation) should be considered in shared decision-making on a case-by-case basis.

There is a need for higher quality comparative data, randomised or non-randomised, to inform management decisions for patients with these injuries.

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METACARPAL NECK FRACTURES

Wing YUM MAN, Ryan TRICKETT

Introduction

Metacarpal neck fractures are common and are usually associated with alcohol and violence (Gudmundsen and Borgen, 2009; Trybus et al., 2006). The mechanism of striking an object with a clenched fist typically causes longitudinal compression through the knuckles resulting in a subcapital fracture with apex dorsal angulation (Soong et al., 2010). Fractures of the little finger (fifth) metacarpal neck, commonly termed the "Boxer's fracture", account for 25% of all metacarpal fractures (Gudmundsen and Borgen, 2009).

The majority of these fractures are simple closed injuries that respond well to conservative management. There are, however, numerous forms of splintage, casts or even braces available at the clinician's disposal (Harding et al., 2001; Hofmeister et al., 2008; Konradsen et al., 1990). A Cochrane review on the conservative management of fifth metacarpal neck fractures concluded that no treatment strategy was statistically superior to the other (Poolman et al., 2005), but studies were of poor quality.

The limit of acceptable palmar angulation also appears to be controversial. Recommendations in the literature vary from 20° to 70° and acceptable limits vary between the metacarpals (Braakman et al., 1998; Ford et al., 1989; Hansen and Hansen, 1998; Konradsen et al., 1990; Kuokkanen et al., 1999; McMahon et al., 1994; Statius Muller et al., 2003). Furthermore, the issue of the optimum surgical technique also arises. The last few decades have seen an increase in the array of materials and instrumentation available to the surgeon and so options for the reduction and maintenance of reduction have increased with improved understanding of biomechanical principles of internal fixation (Westbrook et al., 2008).

Methods

The objective of this process was to identify and review all prospective randomised controlled trials concerning the treatment of

metacarpal neck fractures. The search strategy is described in Table 7.1.

Articles reporting results in a heterogenous sample of metacarpal fractures (e.g. inclusive of base, neck and shaft fractures) were excluded when the results were reported collectively.

Table 7.1 Search strategy metacarpal neck fractures (Completed 9th November 2016)

#	Search Term (.mp)	Number of Returned Articles
1	Metacarpal	15620
2	Neck	502002
3	Metaphysis	10940
4	Fracture	481078
5	Injury	1931819
6	#2 OR #3	512303
7	#1 AND #6	762
8	#4 OR #5	2276412
9	#7 AND #8	422
10	De-duplicate #9	286

Selection Criteria and Assessment of Methodological Quality

Types of studies

All randomised controlled trials (RCTs) and pseudo-randomised controlled trials (PRCTs), comparing either conservative or operative management of metacarpal neck fractures, were included. Observational, non-randomised trials and case reports were excluded.

Assessment of methodological quality of included studies

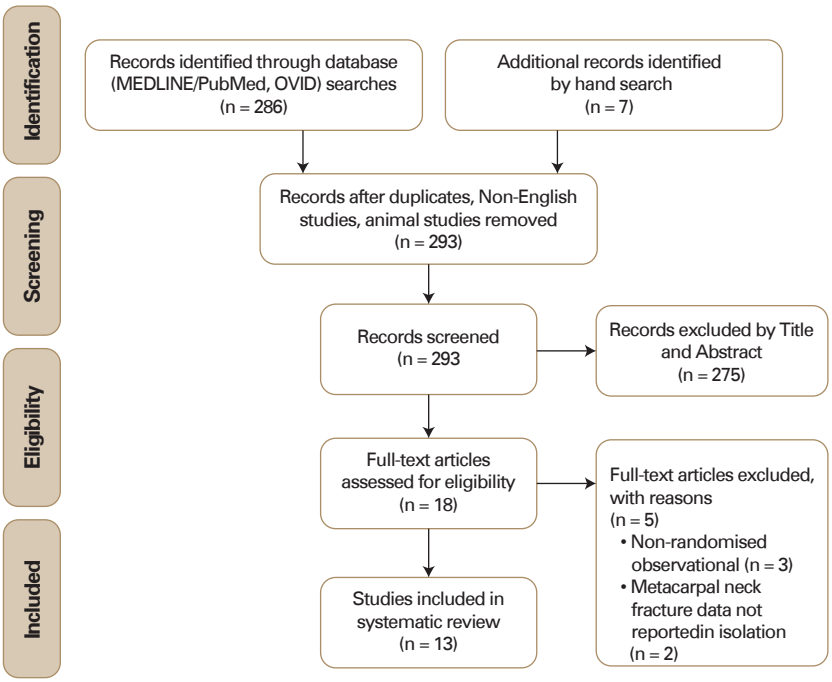
The quality of the selected studies was independently assessed using the Coleman methodological score (Coleman et al., 2000).

Results

A total of 286 articles were identified and a further seven articles added, following a hand search of included reference lists. Of this total of 293 articles subject to title and abstract review, 275 were excluded; 18 full-text articles were reviewed. Five were rejected as they were non-randomised observational studies or did not report

metacarpal neck fracture data in isolation (Figure 7.1). In total 13 randomised controlled trials (RCTs) were included, reporting results in 745 patients.

Figure 7.1 PRISMA Flowchart depicting the selection process



Methodological Quality

The mean Coleman score was 70.4 (57 – 84). All included studies (Fujitani et al., 2012; Hansen and Hansen, 1998; Harding et al., 2001; Hofmeister et al., 2008; Kim and Kim, 2015; Konradsen et al., 1990; Kuokkanen et al., 1999; Sletten et al., 2015; Statius Muller et al., 2003; Strub et al., 2010; van Aaken et al., 2016; Winter et al., 2007; Wong et al., 2006) were randomised controlled trials, and gave good descriptions of any surgical techniques. Outcome measures were also clearly defined and follow-up timings were clearly stated in the text.

Studies differed in their study size, the use of radiological assessment in their follow-up, the number of interventions per group,

the use of an independent assessor in radiological assessment at follow-up and their use of an accepted validated outcome measure. The detailed Coleman methodological analysis of the included studies are summarised in Table 7.1.

Outcome Measures

The 13 papers used a variety of outcome measures, mainly focussing on ranges of movement (ROM), grip strength measured with a Jamar dynamometer and radiological assessments. The most consistently reported measures were grip strength (Fujitani et al., 2012; Kim and Kim, 2015; Kuokkanen et al., 1999; Sletten et al., 2015; Strub et al., 2010; van Aaken et al., 2016; Winter et al., 2007; Wong et al., 2006) and ROM (Hansen and Hansen, 1998; Harding et al., 2001; Kim and Kim, 2015; Kuokkanen et al., 1999; Sletten et al., 2015; Statius Muller et al., 2003; Strub et al., 2010; van Aaken et al., 2016; Winter et al., 2007; Wong et al., 2006). However, these results were not measured or reported consistently with some authors referring to the outcome measurement as a proportion of the uninjured contralateral side. Furthermore, in the majority of cases a mean value was reported with a range rather than a standard deviation. As such, further meta-analyses were not possible.

For a summary of the included studies see Table 7.2.

Of the 13 included studies, seven trials investigated the use of conservative treatments only (Hansen and Hansen, 1998; Harding et al., 2001; Hofmeister et al., 2008; Konradsen et al., 1990; Kuokkanen et al., 1999; Statius Muller et al., 2003; van Aaken et al., 2016), four compared the use of different operative techniques (Fujitani et al., 2012; Kim and Kim, 2015; Winter et al., 2007; Wong et al., 2006) and two compared operative to conservative techniques (Sletten et al., 2015; Strub et al., 2010).

Two of the studies investigating operative techniques compared bouquet (intramedullary) pinning with transverse pinning (Winter et al., 2007; Wong et al., 2006). Winter et al., demonstrated improved ROM with intramedullary pinning but equivocal patient satisfaction, and Wong et al., reported no statistical differences

in ROM, grip strength and pain at 6 weeks and 3 months after surgery. Of the two studies Wong et al., had a higher Coleman methodological analysis score (71 vs 62).

The studies comparing operative treatment (bouquet technique) to conservative treatment (Sletten et al., 2015; Strub et al., 2010) demonstrated no statistical difference in grip strength or ROM at one year.

Discussion

It appears that most research efforts have been focused on identifying the optimal method of conservative management for these fractures. Given the heterogeneity of the data sets it would be difficult to make definitive recommendations based on the studies reviewed. However, the five studies comparing functional treatment to casting (Hansen and Hansen, 1998; Konradsen et al., 1990; Kuokkanen et al., 1999; Statius Muller et al., 2003; van Aaken et al., 2016) all favoured functional treatment, with beneficial effects demonstrated for both ROM and grip strength.

Among the surgical treatments the limited high quality research available suggests that intramedullary and dorsal plating techniques both are effective in maintaining fracture reduction. The evidence for transverse pinning is mixed, with a higher quality study reporting its efficacy comparable to antegrade pinning (Wong et al., 2006).

As limited research on the surgical options is available it is difficult to make definitive recommendations on optimum treatment. However, it appears that functional treatment such as neighbour strapping and early movement, provides satisfactory outcomes with the added benefits of quick application and tolerability. Surgical intervention may be indicated if there is clinical malrotation (which appears very rare) or palmar angulation exceeds 30^{o} more than the contralateral side as measured on the lateral oblique view. However, the thresholds for surgical intervention have not been firmly established. Transverse pinning has been shown to have

equivocal outcomes to antegrade pinning (Wong et al., 2006) as well as being less technically demanding.

Only a single RCT investigated the use of dorsal plating and showed similar results to intramedullary wiring in 30 patients (Fujitani et al., 2012).

Conclusion

The current evidence suggests conservative functional techniques are the optimum treatment. However, it is difficult to make definite recommendations due to the heterogeneity of the data. There is scope for further comparative studies, particularly utilising modern operative techniques. However, these studies should only be performed if the potential benefits of operative treatment can outweigh the surgical risks. With demonstrably excellent results following functional treatment, it seems unlikely that surgical fixation of the majority of these will offer additional benefits. Perhaps future research should explore which injuries do less well with conservative treatment and so might benefit from surgical treatment whilst the majority can be safely managed conservatively.

Table 7.1 Modified Coleman Methodological Analysis scores for included studies

	B. Strub et al	Hofmeister et al	Harding et al	Sletten et al	Kim et al	van Aaken, C. et al	Kuokkanen et al	Konradsen et al	Winter et al	Hansen et al	Fujitani et al	Statius Muller al	Wong et al
1. Study size - Number of patients (N)	4	7	4	7	4	4	0	4	0	7	0	4	4
2. Mean follow-up	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Percent of patients with follow-up (radiographic and clinical)	5	5	0	0	5	5	5	5	5	0	5	3	5
4. Number of interventions per group	5	5	10	5	5	5	5	5	5	10	10	10	10
5. Type of study	15	15	15	15	15	15	15	15	15	15	15	15	15
6. Diagnostic certainty	5	5	5	5	5	5	5	5	5	5	5	5	5
7. Description of surgical technique	5	5	5	5	5	5	5	5	5	5	5	5	5
8. Description of postoperative rehabilitation	3	0	5	5	5	5	0	0	0	0	0	0	5
Part B - 1. Outcome criteria													
Outcome measures clearly defined? (2)	2	2	2	2	2	2	2	2	2	2	2	2	2
Timing of outcome assessment clear? (2)	2	2	2	2	2	2	2	2	2	2	2	2	2
Use of outcome criteria with reported good reliability? (3)	0	3	0	3	3	3	0	0	0	0	0	0	0
Use of outcome with good sensitivity? (3)	0	3	0	3	3	3	0	0	0	0	0	0	0
2. Procedure for assessing outcomes													
Subjects recruited? (5)	5	5	5	5	5	5	5	5	5	5	5	5	5
Independent investigator (2 for radiographic, 2 for clinical)	0	4	0	0	4	0	0	0	0	0	0	0	0
Written assessment? (3)	0	3	0	3	3	3	0	0	0	0	0	0	0
Patient centred data collected? (3)	3	3	3	3	3	3	3	3	3	3	3	3	3
3. Description of subject selection process													
Selection criteria reported and unbiased (5)	5	5	5	5	5	5	5	5	5	5	5	5	5
Recruitment rate reported and > 80% (5)	5	5	5	5	5	5	5	5	5	5	5	5	5
Eligible subjects not included in the study satisfactily accounted for (5)	5	5	5	5	5	5	0	0	5	5	0	5	0
Total	**69**	**82**	**71**	**78**	**84**	**80**	**57**	**61**	**62**	**69**	**62**	**69**	**71**

Table 7. 2 Characteristics of the 13 included studies

Author	Year	Country	*n*	Mean age	Study Type	Group 1	Group 2	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Fujitani et al	2012	Japan	30	30.5	RCT	Bouquet pinning	Dorsal plating	12 months	ROM, grip strength (Smedley dynamometer), radiological assessment	Bone union was achieved successfully in all patients. Hardware was removed in all patients with intramedullary nails at an average of 19.5 weeks. Seven of the patients with plate fixation required plate removal. At 3 months post-operatively there was better grip strength in the plating group ($p<0.05$). At 6 and 12 months there was no significant difference between the groups regarding grip strength. At 6 and 12 months patients in the intramedullary pinning group showed a significant increase in MCPJ ROM.	Both procedures are highly effective in maintaining fracture reduction. Plate fixation provides earlier recovery of powerful hand function, and intramedullary nailing allows a wide range of finger motion.	62
Harding et al	2001	UK	73	26.5	RCT	Metacarpal brace	Neighbour strapping	3 weeks	Pain verbal rating, Tenderness at fracture site, ROM, satisfaction.	Patients treated with a brace complained of less pain ($p = 0.01$) and hand better ROM ($p = 0.03$), also more returned to work by 3 weeks ($p = 0.007$)	The metacarpal brace had significantly less pain than those treated with neighbour strapping, and this facilitated an early return to work.	71
Hofmeister et al	2008	United States	81	25	RCT	Short- arm cast with volar outriggers	Short-arm cast to PIPJ	3 months	DASH, ROM, grip strength (Jamar), radiological assessment	DASH scores at follow-up between 2 groups were similar, although less disability occurring with short arm cast, but not statistically significant. Final MCPJ ROM was slightly better with short arm cast; loss of only 1° of extension compared to loss of 7° ($p = 0.118$)	No significant differences between 2 groups on maintenance of reduction or final lateral radiographs. Advantages to short arm cast include quicker application, better tolerability, ROM and final grip strength	82

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Author	Year	Country	*n*	Mean age	Study Type	Group 1	Group 2	Follow-up	Outcomes	Key results	Conclusion	Coleman score
J. K. Kim and D. J. Kim	2014	South Korea	46	29	RCT	Antegrade pinning	Retrograde pinning	6 months	ROM, VAS pain, grip strength (Jamar), DASH, radiological assessment	Patients in the antegrade group achieved better outcomes for all clinical parameters at 3 months post-operatively.	At 6 months there were no differences in clinical or radiological outcomes.	84
Konradsen et al	1990	Denmark	58	Median age 22	RCT	Plaster cast	Functional cast	3 months	ROM, grip strength (Mygripper), radiological assessment	At cast removal no patients had rotation or frontal plane deformities. 28 patients in the plaster cast group had ROM restriction of 25° in the wrist and 24 patients with 20° restriction in the MCPJ. Compared to 4 patients in the functional group with 10° restriction of wrist movement ($p < 0.01$) and 14 with an MCPJ restriction of 20° ($p < 0.05$).	Functionally treated patients returned to work faster than patients treated with cast. Functional casting also reduced volar angulation by one third compared to plaster cast immobilisation.	61
Kuokkanen et al	1999	Finland	29	Median age 29	RCT	Elastic bandage	Reduction/ splintage	3 months	ROM, grip strength (Jamar), radiological assessment	All fractures united. The ROM of MCP ($p = 0.02$) and PIP ($p = 0.01$) joints were higher in the elastic bandage group at 4 weeks, but there was no difference at 3 months. The grip force was considerably better in the elastic bandage group at 4 weeks ($p = 0.002$) and still slightly better at 3 months ($p = 0.07$)	Fifth metacarpal subcapital fractures can be successfully treated without closed reduction and splinting.	57
P. B. Hansen and T. B. Hansen	1998	Denmark	105	not reported	RCT	Plaster cast	Functional brace/ Elastic bandage	3 months	VAS pain, ROM, fracture tenderness, satisfaction	At 4 weeks patients treated with a plaster-of-Paris had significantly more restricted movement in the MCPJ compared with the two other groups, but there was no difference between those treated wit a functional brace and those treated with elastic bandage ($p = 0.32$). At 3-months follow-up group treated with an elastic bandage had significantly more restricted movement in the MCPJ compared to the other two groups. No difference in patient satisfaction between the three groups.	Recommend the functional brace for treatment of fractures of the neck of the ring and little finger metacarpals.	69

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Author	Year	Country	*n*	Mean age	Study Type	Group 1	Group 2	Follow-up	Outcomes	Key results	Conclusion	Coleman score
Sletten et al	2015	Norway	85	27	Multi-centred RCT	Bouquet pinning	Neighbour strapping	12 months	QuickDASH, VAS pain, VAS satisfaction, EQ-5D-3L, Questionnaire, ROM, grip strength (Jamar).	At 1 year, no statistical differences between groups in QuickDASH score, pain, satisfaction, finger ROM, grip strength or quality of life.	Recommend conservative treatment with early mobilisation for fractures up to 45-50 palmar angulation in the lateral view.	78
Statius Muller et al	2003	Netherlands	35	29	RCT	Ulnar gutter cast	Pressure bandage	3 months	ROM, satisfaction, pain perception, return to work/ hobby and need for physiotherapy, radiological assessment	At 12 weeks no statistical differences between both treatment groups regarding ROM, pain, satisfaction, return to work/ hobby or need for physiotherapy.	A pressure bandage for 1 week, followed by immediate mobilisation is a sufficient alternative treatment for a fifth metacarpal neck fracture if not angulated more than 70º and not rotated.	69
Strub et al	2010	Switzerland	40	34	prospective pseudo-randomised study	Bouquet pinning	Splintage	12 months	ROM, radiological assessment, VAS pain, grip strength (Jamar), time off work, satisfaction.	No significant differences in ROM or grip strength at 12 months. Satisfaction and appearance superior in surgical group.	Intramedullary splinting for displaced fractures of the little finger metacarpal neck offers an aesthetic, but not functional advantage.	69

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Author	Year	Country	*n*	Mean age	Study Type	Group 1	Group 2	Follow-up	Outcomes	Key results	Conclusion	Coleman score
van Aaken et al	2016	Switzerland	68	28.4	Multi-centred RCT	Soft wrap and neighbour strapping	Metacarpophalangeal extension cast	4 months	QuickDASH, VAS pain, satisfaction, ROM, grip strength, radiological assessment	At 4 months no significant difference between two groups in QuickDASH or secondary outcomes.	Favour soft-wrap and buddy taping due to shorter time lost from work and reduced indirect costs.	80
Winter et al	2007	France	36	31.4	RCT	Transverse pinning	Bouquet pinning	3 months	VAS pain, ROM, grip strength (Jamar), satisfaction, radiological assessment	At final follow-up total active motion showed a significant difference between the two groups, with a better result in the intramedullary pinning group ($p = 0.02$). The active range of motion of the MCPJ was also significantly different, with a better result in the intramedullary pinning group ($p = 0.0037$)	Study showed that intramedullary pinning gave better functional outcomes than transverse pinning, although the former was more technically demanding.	62
Wong et al	2006	China	59	22.5	prospective pseudo-randomised study	Antegrade pinning	Transverse pinning	24 months	ROM, grip strength, VAS pain, radiological assessment	No statistical differences in the total active motion, grip strength and VAS pain score at 6 weeks and 3 months after surgery. All patients achieved union of their fracture. No statistically significant differences in time to union, which occurred approximately 10 weeks after surgery in both groups.	Both methods are comparable, good and safe methods of treating closed, displaced fractures of the metacarpal neck of the little finger, without significant complications.	71

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METACARPAL SHAFT FRACTURES

Daniel WINSON

Methods

A literature search was carried out to find articles describing treatment of metacarpal shaft fractures. The exclusion criteria for the searched articles were articles not in English, duplicates, discussion of principles, studies not describing metacarpal shaft fractures and studies not conducted in vivo.

Articles reporting results in a heterogenous sample of metacarpal fractures (e.g. inclusive of base, neck and shaft fractures) were excluded when the results were collectively reported.

	[All .mp searches]	
1	Metacarpal	15620
2	Shaft	37384
3	Diaphysis	11804
4	Fracture	481078
5	Injury	1931819
6	#2 OR #3	48090
7	#1 AND #6	702
8	#4 OR #5	2276412
9	#7 AND #8	386
10	Deduplicate	255

Results

A total of 253 articles were identified and subjected to title and abstract review. A further eight papers where identified giving a total of 261 papers. After manual removal of duplicates (six articles) this left 255 papers. All 255 abstracts were screened; 172 articles were rejected on the basis of the exclusion criteria.

Therefore, 82 full text articles were obtained and reviewed. Of these, 73 were rejected so that only randomised control trials, systematic reviews and comparative studies were included. The final report is therefore based on the nine publications. These nine stud-

ies included two Systematic Reviews, two Randomised Control Trials (RCT) and five Cohort Studies.

Each paper provided a good description of the techniques used to fix the fractures, including post-operative management and were a good guide to treatment. Where a paper described fixation of both phalangeal and metacarpal fractures only the metacarpal fractures were included. Likewise if both metacarpal neck and shaft fractures were described only the shaft fractures were included.

Two methods of treatment described in the literature at large (cerclage wire and interosseous wire fixation) are not reported in any of the nine studies as there are no RCTs or comparative studies involving these methods. The included studies describe treatment methods for a variety of fracture patterns including transverse, spiral and oblique. Comminuted fracture patterns were not included.

The treatment types and number of fractures treated are shown in Table 8.1 below.

A summary of each study is shown below in Tables 8.2, 8.3 and 8.4.

Table 8.1 Treatment Types

Treatment Type	Number of fractures treated
Metacarpal Cast	20
Functional Cast	22
Ulnar Gutter Splint	8
Thermoplastic Brace	6
Compression glove	21
Plaster splint	21
Conservative Treatment (unspecified)	113
Transverse K-Wire fixation	74
Intramedullary Fixation	81
Interfragmentary screw fixation	22
Plate Fixation	60
Total	448 (211 non-op, 203 operative)

Table 8.2 Studies describing conservative treatment

Ref Nº	Author	Title	Summary
1	Konradsen L et al	Functional treatment of metacarpal fractures: 100 randomized cases with or without fixation	Randomised control trail comparing closed reduction and immobilisation with either a plaster cast (n 20) or a function cast (n22) for 3 weeks post-injury. Maximum angulation in each group was 30^0 (plaster) and 24^0 (functional). Plaster cast was in the form of either an ulnar gutter or dorsal cast with immobilisation of MCPJ and PIPJ of the involved and adjacent digit. Functional cast allowed free movement of both the wrist and digit joints. Functional casting achieved significantly better results in terms of fracture angulation, PIPJ/MCPJ/Wrist stiffness, grip strength and return to work times.
2	Jones A. R	Reduction of angulated metacarpal fractures with a custom fracture-brace.	Retrospective cohort study comparing manipulation followed by ulnar gutter splinting (n=8) and thermoplastic fracture brace with no manipulation (n=6). Follow-up was for 12 weeks (8-22 weeks). No significant difference between post-treatment fracture angulation in the two groups (P <.05). All fractures healed clinically and radiologically. The mean time to clinical union was 3.5 ± 8 weeks in fracture brace and 3.9 ± 0.6 weeks in the manipulation group. Upon removal of splints the gutter splint patients had significantly higher joint stiffness; 30^0 reduction in range of movement in MCPJ in the gutter group vs 7^0 in the fracture brace (P<.01).
3	McMahon P. J et al	Initial treatment of closed metacarpal fractures: a controlled comparison of compression glove and splintage.	Prospective RCT comparing treatment in a palmar plaster slab from proximal forearm to fingertip (n=21) and Lycra Compression Glove (n=21). Clinical review was at 2, 3 and 4 weeks' post injury. There was significantly less loss of flexion of the MCP and IPJs in the glove group for weeks 2 and 3 but no significant difference at week 4. For both joint circumference and hand size there was a significant difference in favour of the glove at week 2 but not at weeks 3 and 4.

Table 8.3 Studies describing conservative Vs surgical treatment

Ref Nº	Author	Title	Summary
4	Westbrook A	The clinical significance of malunion of fractures of the neck and shaft of the little finger metacarpal.	Retrospective Cohort study comparing conservative (n=113) and operative treatment (n=26, 4 IM k-wire, 22 plated) for shaft fractures. Outcome measures used were hand grip and little finger strength, DASH and SportDash scores at 2 years post-fracture. No significant difference between conservative and operative. Comparison of non-operative (n=26) and operative (n=13) treated fractures with more than 30^0 of palmar angulation showed that outcomes were not significantly different, using hand grip (p=0.57), little finger (p=0.65), DASH (p=0.61), SportDash (p=0.63) or aesthetic (p=0.61) scores.

Table 8.4 Studies describing surgical treatments

Ref Nº	Author	Title	Summary
5	Biz C	Comparison of percutaneous intramedullary Kirschner wire and interfragmentary screw fixation of displaced extra-articular metacarpal fractures.	Prospective Cohort study of closed metatarsal shaft fractures treated with either intramedullary K-wire fixation (n=31) or interfragmentary screw fixation (n=22). Treatment choice was based on surgeon's preference. No statistically significant difference in MAYO Wrist Score or Dash Score. 8 cases of non-union in k-wire group and 1 in screw group. No difference in stiffness or range of movement.
6	Sletten I. N	Isolated, extra-articular neck and shaft fractures of the ring and little finger metacarpals: a comparison of transverse and bouquet (intra-medullary) pinning in 67 patients.	Retrospective Cohort study comparing transverse K wire fixation (n=31) and bouquet K wire fixation (n=12). The follow-up was longer in transverse wire group at 28 (13-39) months compared to 17 (13-28) months in the bouquet group. There was no significant difference in QuickDASH, VAS, grip strength or TAM at follow-up. 12% of patients in transverse had superficial infection treated with antibiotics compared to none in the bouquet group.

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Ref Nº	Author	Title	Summary
7	Greeven A. P. A.,	Open reduction and internal fixation versus percutaneous transverse Kirschner wire fixation for single, closed index to little finger metacarpal shaft fractures: a systematic review.	Systematic review of literature to compare K wire fixation with ORIF. 5 papers identified (2 ORIF/ 3 K-wire). There is no record of the technique used for each study. Total of 36 fractures treated with ORIF and 65 with K wiring. Functional outcome using TAM and DASH was similar for both groups. There was a 22% complication rate in the ORIF group (2 infections, 6 stiffness or pain requiring re-operation). 35% of K wire patients had a superficial infection, all of which were treated with oral antibiotics. The study reported a higher complication rate with K wire fixation but acknowledges that the complications in the ORIF group are more significant.
8	Özer K.,	Comparison of intramedullary nailing versus plate and screw fixation of extra-articular metacarpal fractures.	Prospective Cohort study comparing intramedullary fixation using the Hand Innovations, Inc. 1.6mm Implant (n=38) and Syntes LC-DCP with 2.0mm and 2.4mm screws (n=14). A two surgeon series where all metacarpal shaft fractures were fixed with a plate and screws (PS) for 6 months before switching to intramedullary nail (IMN) for a further 6months. Operative times were significantly less in IMN group (15min vs 34min) There was no statistical significant difference in radiographic findings, TAM or DASH scores. Loss of reduction and nail penetration occurred in 5 patients in the IMN group. 15 IMN patients had extensor tendon irritation requiring hardware removal without extensor tenolysis compared to 2 in PS group who also required tenolysis.
9	Takigami H	Internal fixation with the low profile plate system compared with Kirschner wire fixation: clinical results of treatment for metacarpal and phalangeal fractures.	Retrospective Cohort study comparing low profile plate and screws (n=24) and K wire fixation (n=10). They excluded some comminuted fractures. There was no significant difference between the two groups in terms of function. The time to bone union was significantly better in the K wire group (1.6months vs 2.6months, $p<0.05$). Complications included; 1 superfical wire infection, 3 loose screws, 4 pain at wiring site.

Outcome Measures

The nine papers used outcome measures which mainly focused on range of movement. Total active movement (TAM) and the Disabilities of the Arm, Shoulder and Hand (DASH) were used widely; this became one of the criteria for selecting the papers, as less structured outcome measures gave no clear information. However, these scoring systems were not used consistently. Some studies report outcomes as being good, fair or poor and others also report radiological outcomes in terms of angulation, shortening and union. Some of the papers reported complications such as infection, wound healing, shift of implants, CRPS, mal-union etc. but a consistent list was not evident.

Discussion

A relatively large number of studies on metacarpal fractures were identified; however, many were either cadaveric studies or small cases series. There was a lack of randomised control trials and non-randomised comparative studies. As previously stated not every treatment option for metacarpal fractures was included in this subchapter as the supporting literature failed to make the inclusion criteria. It was however gratifying to see robust evidence for conservative treatment options in the form of two randomised control trials.

The literature tells us that for conservative treatment of transverse metacarpal fractures application of a functional cast significantly improves outcome and therefore the authors would sanction use of these over standard casting techniques or compression gloves.

Deciding which treatment option to use for those metacarpal fractures requiring fixation is less straightforward. The reviewed literature suggests that there is no significant difference in outcome between different fixation techniques. Some studies report higher complication rates with K wiring, although these complications are predominantly superficial wound infections requiring oral antibiotics only. These studies are limited as they contain small sample sizes (a mean size of 24 fractures per treatment arm) and patients

who have not been randomised to a treatment arm. Often the decision on which technique to use was based on surgeon preference leading to selection bias. The largest sample size in the reviewed literature was the ***systematic review*** by Greevan ***et al*** (2016). Although a systematic review the paper reviewed predominantly case series with little mention of surgical technique or fracture configuration, thereby making true comparison difficult. Westbrook et al (2008) compared non-operative and surgical treatments of little finger metacarpal fractures finding no significant difference in functional outcomes, suggesting that little finger metacarpal shaft fractures could all be treated non-operatively if the patient is willing to accept an aesthetic abnormality.

Further randomised control trials with larger sample sizes are required to indicate which treatment option is best for metacarpal shaft fractures as well as more robust evidence in the use of other fixation techniques such as cerclage wiring.

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FRACTURE SUBLUXATIONS/DISLOCATIONS OF THE BASE OF THE MIDDLE PHALANX

Andrew LOGAN, Anca BREAHNA

Methods

The objective of this process was to identify and review studies concerning the treatment of dorsal fracture dislocations of the proximal interphalangeal joints. Included injuries were those that involved a fracture to the base of the middle phalanx with dorsal subluxation or dislocation of the proximal interphalangeal joint. The search strategy is described in Table 9.1. Articles reporting results of fractures without dorsal dislocation, or those describing fractures around the proximal interphalangeal joint not exclusively affecting the middle phalangeal base fractures were excluded.

Table 9.1 Search strategy (completed 27th December 2016)

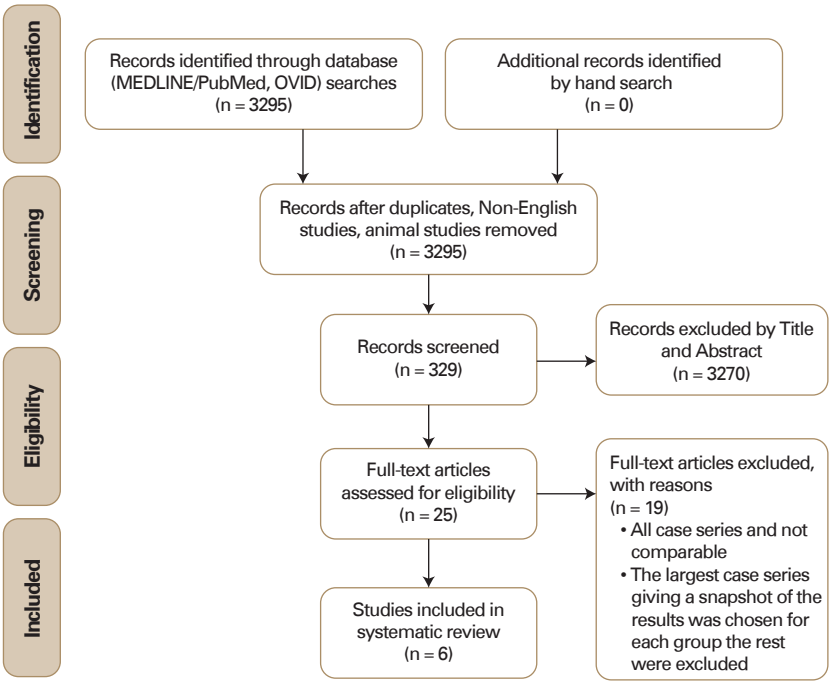
	[All .mp searches]	
1	PIP	65797
2	Interphalangeal	13820
3	Phalanx	13714
4	Phalangeal	6372
5	Middle	5365977
6	Fracture	481078
7	Injury	1931819
8	Dislocation	112005
9	Subluxation	20999
10	#1 OR #2	77658
11	#3 OR #4	18292
12	#5 AND #11	4735
13	#10 OR #12	81317
14	#6 OR #7 OR #8 OR #9	2348756
15	#13 AND #14	6423
16	Limit [English & Human]	4424
17	Deduplicate	3295

Selection Criteria and Assessment of Methodological Quality

Types of studies

Simple case reports, case series and personal opinions on techniques dominated the published literature. No prospective randomised controlled trials identified. The majority of the case series published results in cohorts of fewer than ten patients. Given the heterogeneity of the injuries described, the method of outcomes assessment and the retrospective nature of publication, a simple snapshot of the current literature was obtained by selecting the largest case series for each of the treatment strategies identified.

Figure 9.1 PRISMA flowchart depicting the selection process.From Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6:e1000097. For more information, visit www.prisma-statement.org.



Results

A total of 3295 articles were identified and subjected to title and abstract review. 3149 articles were rejected, as they were either case series of fewer than ten patients or opinions on the treatment of these injuries rather than describing the outcome of treatment.

A further 121 articles were rejected as they were related to fractures around the proximal interphalangeal joint without dislocation or the injuries were more than 6 weeks old.

Twenty-five articles were obtained and reviewed. These articles were grouped into the following relating to the type of treatment:

- Comparative articles comparing one treatment with another – 4 articles
- Dynamic traction – 10 articles
- Extension block splinting – 1 article
- Extension block pinning – 3 articles
- Hemi Hamate arthroplasty – 2 articles
- Open reduction and internal fixation – 3 articles
- Volar plate arthroplasty – 2 articles

All the included articles were case series. Articles attempting to compare different treatment types were non-randomised case series. There was significant variation in the described percentage of the middle phalanx articular surface that was fractured and the size of the fragments, with mixed reporting of this variable.

None of the articles were directly comparable. No articles directly compared treatment methods and there was variability in fracture configuration and measured outcomes in those articles describing the similar treatments. Therefore a single representative article was chosen to illustrate the outcome for each treatment type. This was selected as the article with the greatest number of included patients and sufficient details of the outcomes measured.

Treatment Types and Outcomes

The descriptions below are summarised in Table 9.2

Although the chosen articles were in our opinion the best ones available, not all articles had a complete outcome data set.

Dynamic traction: Ruland et al (2008)

There were 34 patients with 26 fracture dislocations (direction not specified) and eight pilon fractures. The mean articular surface in-

volvement was 48%. The mean follow up was 16 (6-48) months. The mean total range of motion of the PIP Js was 88° (60-115°). The mean loss of extension was 5° (minus 10-25°). The mean flexion was 93° (85-115°). There were eight pin track infections. There was concentric reduction of the PIPJ on the final radiographs in all 26 fracture dislocations. All patients returned to their prior level of activity. There was no assessment of pain.

Extension block splinting: Hamer and Quinton (1992)

They reported on 27 consecutive patients treated with closed reduction and extension block splintage. The percentage surface involved in the fracture was a mean of 42% (10-66%). The mean time for splintage was 5 weeks. Where there was a centrally depressed fragment and the depressed fragment sat on the proximal phalanx head giving rise to the 'V' sign on the lateral radiographs this was associated with a less favourable outcome. In three patients the splint could not control the subluxation. Two of these were treated with K wiring and one with a volar plate arthroplasty. The mean time to follow up was 20.6 months (2-42). The mean range of movement at final follow up was 87° (20-110°) compared to the uninjured side of 99° (75-110°). Six patients had some pain. Five had a poor result; all had a comminuted fracture and a large central depressed fragment.

Extension block pinning: Waris et al (2010)

They treated 55 dorsal fracture dislocations with closed reduction and extension block wiring. The mean articular surface involvement was 49% (30-69%). Twenty cases needed additional percutaneous fracture reduction (16 closed and 4 open). All the open cases required additional K wires. Five patients had superficial pin site infections treated successfully with antibiotics. 41 joints were included in the final follow up at a mean of 5.2 (1-10.6) years. Two had had joint salvage procedures for osteoarthritis. The mean range of movement at final follow up was from 6° of fixed flexion (range 0-50°) to 86°of flexion (range 50 -110°). The mean tip to palm distance was 11mm (0-50mm). 38% reported some pain. Nineteen patients had minor symptoms; six had major symptoms. They reported no ra-

diological degenerative changes in 37%, mild OA in 49% severe in 10%. Recurrent subluxation was present radiologically in 29% of patients and in 67% of those who reported pain.

Hemi Hamate arthroplasty: Calfee et al (2009)
They reported 20 patients with final objective outcome data. Twelve were operated on within 6 weeks of injury; eight were classed as chronic injuries. The mean percentage joint involvement was 62% (50 -90%). The mean follow up of 4.8 (1-7) years. The mean fixed flexion deformity was 19° (0-80°) and the mean flexion was 89° (45-105°) giving a mean arc of movement of 70° (0-100°). At final follow up 14 patients had radiographs that showed all grafts had healed and all joints remained located. Six had joint space narrowing. The mean visual analogue score for pain was 0.7 for the acute group and 2.5 for the chronic group. No patient was unable to return to their previous occupation or sporting activities. One patient reported mild aching over the hamate donor site. No patients required secondary procedures.

Open reduction and internal fixation (ORIF): Cheah et al (2012)
They reported on 13 patients. The fixation was a volar plate and screws. The mean articular surface involvement was 44% (30 -70%). The mean follow up was 25 (12-60) months. The mean active joint ROM was 75° (10-100°). Four had the plate removed. All returned to their original occupation. Twelve of the 13 patients reported either no or mild pain. Two patients were not satisfied with the outcome. All fractures united in good alignment. Three showed radiological evidence of degenerative change.

Volar plate arthroplasty: Eaton et al (1980)
They reported on 24 patients, seven of whom were operated on within 6 weeks. All had > 40% articular involvement. The mean follow up was 38 (6-121) months. For the acute cases there was an mean ROM of 95°. Four of the seven cases needed dynamic extension splinting. The flexion contracture at final follow up was a mean of 6°. None of the acute cases reported pain at final follow up.

Table 9.2 Summary of the outcomes for each treatment type

	Dynamic traction	Extension block splinting	Extension block pinning	Hemi Hamate arthroplasty	ORIF	Volar plate arthroplasty
Number of patients	26	27	55	20	13	7
Mean time of review post injury	16 months (6-84)	20.6months (2-42)	5.2 years (1-10.6)	4.8 years (1-7)	25months (12-60)	38months (6-121)
% Articular surface fractured	46%	42% (10 -66)	49% (30 -69)	62% (50-90)	44% (30-70)	>40%
Mean PIPJ range of movement	88° (60-115)	87° (20-110)	Not stated	70° (0-100)	75° (10-100)	95°
mean PIPJ extension	5° (-10 -25)	Not stated	6° (0-50)	19° (0-80)	Not stated	6°
Mean PIPJ Flexion	93° (85-115	Not stated	86° (50-110)	89° (45-105)	Not stated	Not stated
Complications	8 pin track infections	5 poor results	5 pin site infections	1 mild ache over donor site	Not stated	Not stated
Pain at final follow up	Not stated	6 had some pain	38%	Mean VAS 0.7	92% none or mild pain	No late pain
Final radiograph	All concentrically reduced	Arthritic change in 22% 19% of joints slightly incongruent	Arthritic change in 59%. Recurrent subluxation 29%	All grafts healed. 30% joint space narrowing	All united with good alignment. Arthritic change in 23%	Not stated

Discussion

The authors of this section were not surprised that there were no comparative studies comparing the treatment methods for these injuries. There are too many variables involved with regard to the fracture pattern and severity, as well as small numbers of cases presenting to individual hand units.

The articles available were therefore case series. The outcome data were also incomplete in most of the full articles reviewed (Table 9.2).

Overall, in a significant number of cases, the available choice of treatment depends on the fracture pattern. Closed dynamic trac-

tion would only be suitable for the early acute cases where the fracture fragments are still mobile. Volar plate arthroplasty and hemi-hamate arthroplasty can be performed sub-acutely or for injuries where the fracture is considered unreconstructable. Open reduction and plate fixation could be considered for large single volar fracture fragments but is unlikely to be considered where there is a higher degree of comminution. Dorsal blocking wires may only be considered if the percentage of the volar articular surface that is uninvolved is sufficient to allow joint stability and adequate articulation once the dorsal blocking wire is removed. A similar consideration should be made for simple dorsal block splinting, although it is likely that this method is less able to control grossly unstable joints. Thus, although some fracture patterns may allow the option of more than one treatment type there are some fracture patterns that are more treatment specific.

Conclusion

The current literature does not inform us as to the comparative merits of the various treatments available for these complex injuries. However, it is clear form the literature that if the fracture is diagnosed and treatment commenced earlier, there is likely to be a greater the number of treatment options available to the clinician. Future comparative trials must employ criteria whereby the treatment methods being used can be applied to all of the included fracture patterns in the study. The variety in type and severity of these fractures with small numbers in each category, as well as the behavioural differences of each of these makes it difficult for any future trial to answer adequately the question as to which treatment method is best for each fracture type. There is a need for long term multicentre comparative studies for well defined patterns of injury.

Overview

Overall there were some findings that came as no surprise and some that were rather surprising.

Of no surprise was the lack of randomised controlled trials found

for any type of fracture reviewed and a general paucity of comparative studies of any nature. Many of the studies were retrospective case series, often containing several types of fractures. There was also a paucity of studies found which highlight the outcomes after non-operative treatment. This may reflect the tendency of authors to write about and journals to publish on more novel and arguably more interesting methods.mSurprisingly, some relatively common fractures and in particular diaphyseal and condylar fractures of the phalanges, have very little written about them at all.

There are certain treatments for fracture management that are commonly used in the assumption that these are superior to other methods. An example is the tendency to treat Bennett's fractures operatively rather than non-operatively. There is, however, remarkably little good quality objective evidence to support this. In general, the evidence to support what we current assume to be "best practice" is distinctly lacking.

There is certainly a need for higher quality comparative data, randomised (ideally) or non-randomised to inform our decision making. Future research and publications could be greatly improved by using a consistent set of outcome measures and this will also need to focus on patient reported outcomes and functional measurements. Comparison of case series could be improved by restricting fracture types to categories with similarity and not including other fracture types in the same publication.

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3.2 Scaphoid Fractures- the Evidence

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Emerging Treatments
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Summary and Introduction

In this chapter, we have collated the best quality evidence on several areas of scaphoid fracture management.

- Imaging
- Managing the Acute scaphoid fracture
- Scaphoid non-union
- Optimising scaphoid fixation
- Emerging Treatments

IMAGING

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Introduction

The aim of this section is to synthesise the evidence related to scaphoid imaging, covering all aspects from the diagnosis of the acute fracture, the diagnosis of union or non-union of the acute fracture, the assessment of mal-union and non-union and the assessment of union after non-union surgery.

Diagnosis of Acute Fracture

Radiographs on Day 1

What are Scaphoid views?

At first presentation of a suspected scaphoid injury, scaphoid view radiographs are normally performed as the initial investigation. Scaphoid views vary between institutions but usually comprise 3 to 5 views. The set of five views typically includes postero-anterior, lateral, semi 45° prone oblique, semi 45° supine oblique and the "Ziter" view (wrist in slight ulnar deviation with beam angled at 20° towards the elbow, so as to be perpendicular to the axis of the scaphoid and to avoid overlap of the other carpal bones over the scaphoid) (Bhat et al., 2004). Some authors have suggested even more views (Compson et al., 1997).

How many fractures are picked up on initial radiographs?

We know that up to 30% of all scaphoid fractures might not be detected on initial radiographs (Barton, 1992). The study by Jorgsholm et al., comparing initial radiographs with MRI as the gold standard, showed initial plain radiographs to have a 70% sensitivity and 98% specificity for scaphoid fractures (Jorgsholm et al., 2013).

What views are best for showing scaphoid fracture?

Compson et al., (1997) performed a study on cadaver bones and

concluded that scaphoid waist fractures are best seen on an ulnar deviated PA view and true lateral. Dorsal sulcal fractures are best seen on a 45° semi- pronated view. Proximal pole fractures are best seen on a 45°semi- supinated oblique view (Compson et al., 1997; Singh, 2011).

Clinical Scaphoid Fractures with Normal Initial Radiographs

Delayed Radiographs (Table 1)

The standard practice in many institutions for the clinically suspected scaphoid fracture is to immobilise the injured wrist and perform repeat radiographs at 10 to 14 days. It is assumed that during this period the fracture will become visible due to resorption around the fracture (Bohler et al., 1954; Russe, 1960). Several studies (Low and Raby, 2005; Tiel-van Buul, 1992) have found that follow-up radiographs do not produce reliable or reproducible results. However, Gabler et al., (2001) found that follow-up radiographs combined with clinical examination by a senior hand surgeon managed to detect all scaphoid fractures demonstrated by MRI.

Table 1 Evidence for Different Imaging Modalities for Clinical Scaphoid- Delayed Radiographs 10-14 days

Authors	Study	Gold Standard*	Conclusions
Gabler et al (2001)	Prospective, 121 patients with initial and follow-up radiographs and clinical examination.	MRI	All 28 scaphoid fractures identified by clinical examination (senior hand surgeon) and follow up radiographs
Dias et al (1990)	Retrospective review of 20 patients with initial and follow-up radiographs by 20 observers	6 week and 12 week radiographs (and followed up for a year)	The follow-up radiographs did not provide reliable or reproducible evidence of fracture
Tiel-van Buul et al (1992)	Retrospective review of 60 patients with initial radiographs and follow up radiographs at 10-14 days and at 6 weeks. 3 observers	Bone Scan	Radiographs are not reliable even with 2 and 6 week follow-ups. Low inter-observer agreement.

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Authors	Study	Gold Standard*	Conclusions
Munk et al (1995)	Prospective multicentre, 1052 patients with initial and follow-up radiographs	Nil	150 scaphoid fractures identified on initial radiographs and a further 10 scaphoid fractures at 10-14 days
Low and Raby (2005)	Retrospective, 50 patients with initial and follow-up radiographs.	MRI	Follow-up radiography has poor sensitivity, poor negative predictive value and poor reliability

* By definition the gold standard is assumed to have 100% sensitivity and 100% specificity for detecting scaphoid fractures, but it is impossible to prove that any imaging technique has such accuracy. Thus the results of each study are just a comparison with the modality chosen as the "gold standard", and should be considered in that manner. For example were the fractures missed by CT scan but shown on the "gold standard" MRI actually fractures, or just bone bruises?

A number of papers (McLaughlin and Parkes, 1969; Leslie and Dickson, 1981; Duncan and Thurston, 1985) suggest fractures only diagnosed on a second scaphoid series of X-rays (10-14 days after injury) are incomplete fractures and will heal uneventfully without immobilising the wrist in plaster. However CT and MRI were not available at the time of these studies and one cannot be certain that all these "fractures" were actually fractures, rather than soft-tissue injuries. This is because there is often uncertainty whether scaphoid series radiographs do, or do not, show a fracture (Dias et al., 1990).

CT (Table 2)

CT scanning of suspected scaphoid fractures is becoming more popular and is more accessible in many hospitals than MRI scanning. Generally, published reports confirm CT to have a good specificity (93-100%), but poorer sensitivity (67-94%) in comparison to the "gold standard" of MRI (q.v.). One important question which is not often considered, is whether fractures not detected by CT scan are so undisplaced that they would heal without any treatment.

Table 2 Evidence for Different Imaging Modalities for Clinical Scaphoid-Computed Tomography

Authors	Study	Gold Standard*	Conclusions
Temple et al (2005)	Sagittal CT and radiographs compared in 11 cadavers with no fracture, iatrogenic, undisplaced scaphoid fractures and displaced fractures. 8 observers	Iatrogenic fractures in cadaver.	Sagittal CT sensitivity for detecting undisplaced fracture 100%, specificity 93%.
Ilica et al (2011)	Prospective study. CT performed in 54 patients with clinical scaphoid and normal radiographs.	MRI	Sensitivity 86%, specificity 100%, PPV 100%, NPV 91%.
Nguyen et al (2008)	Retrospective review. CT performed on 102 patients with clinical scaphoid fractures and normal radiographs.	Nil	23 (22%) had a scaphoid fracture on CT with negative radiographs.
Cruickshank et al (2007)	Prospective study. 47 patients with clinical scaphoid fractures had early CT.	Repeat radiographs, clinical examination at 10-14 days (+ MRI for equivocal cases)	CT was 94.4% sensitive and 100% specific.
Mallee et al (2015)	Prospective study of 40 patients who had CT and MRI of clinical scaphoids.	Radiographs at 6 weeks	CT sensitivity 67%, specificity 96%, accuracy 91%.

* By definition the gold standard is assumed to have 100% sensitivity and 100% specificity for detecting scaphoid fractures, but it is impossible to prove that any imaging technique has such accuracy. Thus the results of each study are just comparison with the modality chosen as the "gold standard", and should be considered in that manner. For example were the fractures missed by CT scan but shown on the "gold standard" MRI actually fractures, or just bone bruises?

MRI (Table 3)

MRI has recently been described in the UK's NICE guidelines (2016) for imaging of the scaphoid, as the recommended "gold standard" for confirming or refuting the presence of a scaphoid fracture. It is acknowledged in the NICE recommendations that MRI probably does not have 100% specificity for identifying fractures, such that reliance on MRI may result in over-treatment of some patients; but it was felt sensitivity was the most critical outcome for decision-making. One of the reasons for the reduced specificity is thought to be the presence of bone bruising without a fracture. Bone bruising is defined as an area of signal loss

on T1 images and high signal intensity on T2 images, thought to be secondary to microfractures of trabecular bone, oedema and bleeding in the fatty marrow (Khalid et al., 2010). This can be indistinguishable from an undisplaced fracture, although some have claimed it is possible to distinguish between the two, by using a combination of T1, SE and STIR sequences (Khalid et al., 2010; Brydie and Rabie, 2003). The other stated advantage of MRI that is frequently highlighted, is the ability to diagnose other fractures or problems in the wrist. However, it could also be argued that this may overcomplicate a diagnosis that would not have required any change in management, resulting in increased anxiety for the patient, and perhaps the clinician.

Table 3 Evidence for Different Imaging Modalities for Clinical Scaphoid- Magnetic Resonance Imaging

Authors	Study	Gold Standard*	Conclusions
Patel et al (2013)	RCT. 84 patients randomised into either MRI or control groups (exam + radiographs)	None- cost effectiveness study	3 scaphoid fractures in MRI group. 4 Scaphoid fractures in control. 29 other diagnoses in MRI group.
Brooks et al (2005)	RCT. 28 patients randomised to either MRI or control group.	None- cost effectiveness study	3 fractures in MRI group and 4 in control group. MRI reduced days spent in cast.
Jenkins et al (2008)	Retrospective study with 200 patients with clinical scaphoid. 16% incidence of proven fracture.	None- cost effectiveness study	Extrapolation of other literature applied to this cohort suggested that MRI has the best diagnostic performance
Gooding et al (2004)	Prospective study with two groups: MRI (44 patients) and control group (38)	None- cost effectiveness study	MRI group had 10 scaphoid fractures, control group had 2 scaphoid fractures. MRI reduces unnecessary time in cast and picks up other injuries.
Mallee et al (2015)	Prospective study of 40 patients who had CT and MRI of clinical scaphoids.	Radiographs at 6 weeks	MRI sensitivity 67%, specificity 89%, accuracy 85%.
Beeres et al (2008)	Prospective study of 100 patients who had MRI and Bone Scan.	Evidence of fracture on MRI + Bone Scan or radiographs.	MRI sensitivity 80%, specificity 100%.

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Authors	Study	Gold Standard*	Conclusions
Khalid et al (2010)	Prospective review of 611 patients with clinical scaphoid and normal initial radiographs. All underwent MRI.	None	342 abnormal scans, of which 272 bony injuries, of which 56 scaphoid fracture, 61 scaphoid bruise.
Brydie and Raby (2003)	Prospective review of 195 patients with clinical scaphoid and normal initial radiographs had MRI.	None	Scaphoid fracture in 37 patients (19%). 20 bone bruising. 37 other fractures. Normal in 99 (50%). They advocate that MRI should be Gold standard for 'clinical scaphoid.'
Bretlau et al (1999)	Prospective study of 47 patients with clinical scaphoid and normal initial radiographs. All had extremity MRI at 4 and 11 days.	Radiographs at 11 weeks	7 scaphoid fractures at initial MRI and 2 fracture or bone bruise. Second MRI confirmed 9 scaphoid fracture. 2 lost to follow up. The other 7 confirmed as scaphoid fracture. 100% sensitivity.
Kumar et al (2005)	Prospective study. 22 patients with clinical scaphoid and normal initial radiographs. All had MRI. 13 patients had normal initial MRI and went for 2nd review and MRI at 10 days.	Clinical review at 10 days +/- second MRI scan.	6 scaphoid fractures picked up on initial MRI. The 13 normal initial MRI's were found to have no pathology on second review. Sensitivity 100%. Specificity 100%.
Hunter et al (1997)	Prospective review of 36 patients with clinical scaphoid and normal initial radiographs. All had MRI. Followed up with radiographs at 2 weeks.	Follow-up radiographs 2-3 weeks indicating evidence of fracture or healing.	13 scaphoid fractures detected on initial MRI. 2 lost to follow up. 11 remaining had 2 weeks XR- 10/11 showed bone healing. 100 % sensitivity. Specificity 91%.
Tiel-van Buul et al (1996)	Prospective study. 16 patients with clinical scaphoid and normal initial radiographs. Bone Scan and MRI performed in all.	Bone Scan	Bone Scan 7 fractures, MRI 5 fractures. 2 from bone scan proven on XR. MRI sensitivity:78%, specificity 100%.

* By definition the gold standard is assumed to have 100% sensitivity and 100% specificity for detecting scaphoid fractures, but it is impossible to prove that any imaging technique has such accuracy. Thus the results of each study are just comparison with the modality chosen as the "gold standard", and should be considered in that manner. For example were the fractures missed by CT scan but shown on the "gold standard" MRI actually fractures, or just bone bruises?

Bone Scan (Table 4)

Bone Scans are nowadays hardly ever used in the UK due to increased availability of CT and MRI. Studies on their use nearly all concur with their very high sensitivity, but poor specificity, which can result in over treatment of patients.

Table 4 Evidence for Different Imaging Modalities for Clinical Scaphoid- Bone Scan

Authors	Study	Gold Standard*	Conclusions
Beeres et al (2008)	Prospective study of 100 patients who had MRI and Bone Scan.	Evidence of fracture on MRI + Bone Scan +/ or radiographs.	Bone Scan sensitivity 100%, specificity 90%.
Bayer et al (2000)	Retrospective review of 40 patients with clinical scaphoid and normal radiographs with bone scan 2/52 after injury.	Clinical follow-up 6 months to 2 years	23 abnormal bone scans with 8 scaphoid fractures.
Jorgensen et al (1979)	Prospective review of 50 patients with clinical scaphoid and normal initial radiographs. Bone scan and radiographs performed in all at day 10. Repeat radiographs again at day 20.	Radiographs at day 20.	22 scaphoid fractures. Bone scan sensitivity 100%. Specificity 37%.
Young et al (1988)	Prospective review of 23 patients with clinical scaphoid and normal initial radiographs. Bone scan at 10-14 days.	Examination and radiographs performed at 3 weeks.	3 confirmed scaphoid fractures. Bone scan picked up 8. Sensitivity 100%. Specificity 75%.
Akdemir et al (2004)	Prospective study. 32 patients with clinical scaphoid + normal initial and 2 weeks radiographs. Bone Scan performed at 2 weeks.	Clinical examination + radiographs at 2 months.	12 with normal bone scan. 8 scaphoid fractures. 12 had other fractures. Sensitivity 100%. Specificity 85%.
Waizenegger et al (1994)	Prospective study. 84 patients with clinical scaphoid and normal initial radiographs. Bone Scan performed.	Repeat radiographs or CT.	19 showed increase uptake around scaphoid. 7 confirmed as fracture. Sensitivity 100%. Specificity 84%.
Stordahl et al (1984)	Prospective study. 28 patients with clinical scaphoid and normal initial radiographs. Bone scan at 2 weeks.	Repeat radiographs at 6 weeks.	Sensitivity 100%. Specificity 58%.

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Tiel-van Buul et al (1993)	Prospective study. 119 patients with clinical scaphoid and normal initial radiographs had bone scan performed.	Clinical review and radiographs at 1 year	21 confirmed fractures radiologically. Bone scan showed 35. Sensitivity 100%, specificity 85%.
Querellou et al (2009)	Prospective study. 86 patients with clinical scaphoid and normal initial radiographs.	Clinical examination at 3 months +/- CT or MRI.	40 normal scans. 46 abnormal. 15 scaphoid fractures. Sensitivity 97%. Negative Predictive Value 98%.

* By definition the gold standard is assumed to have 100% sensitivity and 100% specificity for detecting scaphoid fractures, but it is impossible to prove that any imaging technique has such accuracy. Thus the results of each study are just comparison with the modality chosen as the "gold standard", and should be considered in that manner. For example were the fractures missed by CT scan but shown on the "gold standard" MRI actually fractures, or just bone bruises?

Diagnosis of displacement of acute fractures

The only confirmed risk factor for non-union of a scaphoid waist fracture is displacement (Bhat et al., 2004; Swart and Strauch, 2013; Amirfeyz et al., 2011). However, there is no standardised definition of displacement and so this varies between studies (Swart and Strauch, 2013).

Radiographs

It is generally believed that radiographs are inadequate for assessing displacement and this has been confirmed by two studies (Bhat et al., 2004). Desai et al., (1999) studied 151 patients prospectively and demonstrated that two experienced hand surgeons had poor inter- and intra-observer reliability in assessing displacement and predicting the likelihood of union. Interestingly, this paper also reported no effect of X-ray assessments of displacement on outcome, but subsequent studies using CT and MRI suggest that it is not possible to accurately predict displacement on plain radiographs (Bhat et al., 2004; Lozano-Calderon et al., 2006).

CT

CT has been found to improve both intra- and inter- observer reliability of assessment of scaphoid fracture displacement (Lozano-Calderon et al., 2006). Another study of 31 patients found that fractures displaced less than 2mm on CT were likely to unite with

non-operative treatment (Amirfeyz et al., 2011). A study by Grewal et al., (2013), looked at 219 CT scans of scaphoid fractures retrospectively and found that displacement, humpback deformity and comminution lead to higher risk of non-union.

MRI

Bhat et al., (2004) looked at displacement on MRI of 50 patients with scaphoid fractures. They found satisfactory inter- and intra-observer reliability for diagnosis of displacement. They also reported that displacement as assessed on MRI, is a significant determinant and predictor of union of a scaphoid fracture. All of the 40 undisplaced fractures in that series went on to unite, whereas only six of the nine displaced fractures united.

Significance of proximal fragment sclerosis

Proximal fragment sclerosis develops only after several weeks and probably indicates revasclarisation and deposition of new bone after an ischaemic episode rather than ongoing avascular necrosis (Buchler and Nagy, 1995). Green (1985) observed that radiologically dense proximal fragments often bleed at operation and others have shown that rotation of the proximal fragment can mimic sclerosis on radiographs. Dawson et al., (2001) performed dynamic MRI with Gadolinium enhancement on 32 fractures of the scaphoid to assess vascularity. They found that non-union occurred in four fractures (12%), all of which demonstrated enhancement of the proximal fracture fragment. In contrast all six of the fractures whose proximal fracture fragments did not enhance at all, and thus probably had no blood supply, united.

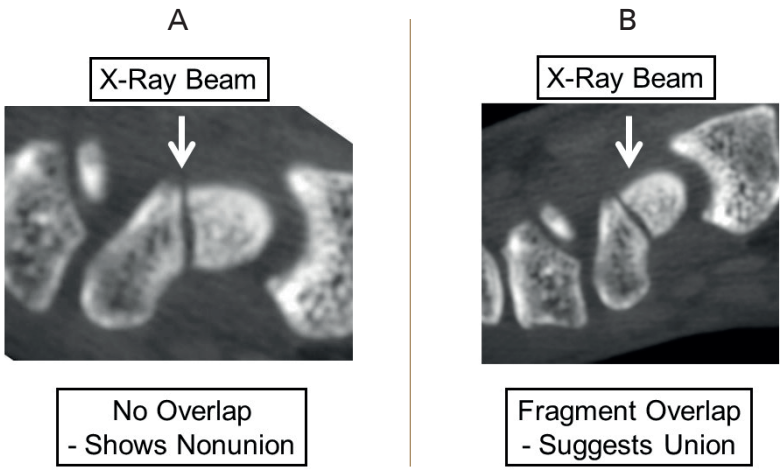
Diagnosis of Union/Non-union of Acute Fracture (Table 5)

Radiographs and trabecular crossing

Radiographs are classically the most common modality used to assess fracture union, however a number of studies have shown difficulty in relying on radiographs alone (Desai et al., 1999; Dias et al., 1998). Figure 1 shows the importance of the direction of the X-ray beam in relation to the fracture. If it is perpendicular, the non-union will be seen easily, whereas if the X-ray beam is

not perpendicular, it may give the false impression of trabecular crossing.

Figure 1 A) the X-ray beam is precisely perpendicular to the scaphoid fracture and will clearly show the fracture non-union. B) the x-ray beam is not perpendicular to the fracture non-union and will pass through both fracture fragments as well as the non-union. This will give the appearance of bridging trabeculae and fracture union.



As trabecular crossing and sclerosis of the fracture line are difficult to assess, surgeons mainly rely on the absence of a gap at the fracture site to diagnose union. A recent study of 47 patients found good inter- and intra-observer reliability for diagnosing non-union on 6-week scaphoid series radiographs (Hannemann et al., 2015), but not such reliability for diagnosing either complete or partial union. Thus there was good specificity for diagnosing non-union, but poor sensitivity. Several articles support the increased accuracy of CT scans for diagnosing union or non-union (Amirfeyz et al., 2011; Buijze et al., 2012), but none was found published on the use of MRI to assess union of an acute fracture.

Scaphoid series radiographs and the relevance of the clinical findings

Dias et al., (1989) are the only authors who have commented in detail about the clinical and radiological findings looking at scaphoid union. They looked at 82 patients with fracture of the

scaphoid waist. They found the incidence of non-union to be 12.3%, and partial union at about 25%. They categorised patients into three groups:

Painless and looks united on radiographs: In this study, 63% had union on radiographs. Of these patients, only 9% had symptoms of mild pain. They had excellent ranges of movement and good grip strength which was essentially equal to the opposite side.

Painful but looks united on radiographs: 33 patients in this group had some pain in the region of the ASB, but of these only nine had an un-united fracture (although that was 9 of the 10 with a non-union). Pain was not specific for non-union.

Painless but fracture still visible though no clear gap on any radiographs: Partial unions are fractures that have evidence of some bridging trabeculae in some areas of the cross section of the fracture. Singh et al., (2005) reported that partial unions demonstrated on CT almost always go on to unite, even if only 25-49% of the fracture cross-section has "united" on the 12 week CT scan. "Complete" union was confirmed clinically and on further CT scans.

Table 5 Evidence for diagnosis of Union/Non-union of Acute Scaphoid Fracture

Authors	Study	Gold standard for defining union/nonunion	Conclusions
X-ray			
Hannemann et al (2015)	Prospective study. 47 patients with acute, undisplaced scaphoid waist fractures. Diagnosis made on initial radiographs. All fractures treated in cast. 6 week radiographs assessed for union by 4 observers. Classes as union, partial union or no union.	None	Average sensitivity for diagnosing union of scaphoid waist fracture was 65%. Average specificity was 67%. PPV was 93%. Good inter- and intra-observer reliability for diagnosing non-union. Moderate for full union and fair for partial union.
Dias et al (1988)	Retrospective study. 20 radiographs of scaphoid fractures taken at 12 weeks post fracture were assessed by 8 observers on 2 occasions.	None	Poor agreement on union of the fracture. Radiographs at 12 weeks do not provide reliable and reproducible evidence of healing.

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Dias et al (1989)	Retrospective review. 82 patients with fracture waist of scaphoid treated in a cast. Patients followed up clinically and plain radiographs at ~ 1 yr.	Undefined wrist radiographs at 1 year	Definite union in 63%, only 9% had mild symptoms. 12.3% non-union (clear blue sky)- most had pain and stiffness. 25% had partial union. 75% of this group had pain, but ROM was good.
CT			
Buijze et al (2012)	Retrospective review of 30 scaphoid waist fractures. Sagittal CT scans 6 weeks after injury were reviewed by 89 observers.	Radiographs at 6 months.	Average sensitivity of diagnosing fracture union 78% and specificity was 96%. Average accuracy was 84%.
Amirfeyz et al (2011)	31 patients with displaced scaphoid waist fractures. CT scan performed in long axis of scaphoid. 2 observers.	None (paper focused more on prediction of union/non-union than the diagnosis)	High inter-observer reliability for fracture gap.

Assessment of Malunion

Although some patients have been described as having symptoms requiring surgical correction (Nakamura et al., 1991), malunion of the scaphoid may not cause any symptoms or loss of function, as evidenced in the paper by Forward et al., (2009).

Value of radiographs

In the paper by Nakamura et al., (1991), radiographs were used to assess patients pre-operatively. Measurements were made of the radiolunate and scapholunate angles and carpal height ratio. There do not appear to be any comparisons to other imaging modalities in the literature.

Value of CT

CT is the most commonly used imaging modality to assess malunion, but it is important to be aware that measurements can be affected by both the position of the wrist in the CT scanner and the assessor's selection of the most central sagittal image (Forward et al., 2009; Ring et al., 2005). All measurements of malunion require CT images in the long axis of the scaphoid, and assume that all uninjured scaphoid bones have similar proportions.

CT scans probably provide better qualitative assessments of malunion than radiographs, and allow better appreciation of any angular deformity and scaphoid collapse. Amadio et al., (1989) described the lateral intra-scaphoid angle but Forward et al., (2009) reported difficulty in identifying the landmarks from which to determine both the lateral and antero-posterior (AP) intra-scaphoid angles. Bain et al., (1998) advocated the measurement of scaphoid height to length ratio as a more reliable technique. More recently, Berg et al., have suggested a 3 dimensional analysis looking at height to length ratios in both sagittal and coronal planes.

Value of MRI

MRI is seldom used to assess deformity in malunion and no evidence was found regarding this.

Assessment of non–union

While the diagnosis of a scaphoid non-union can often be made on radiographs, further imaging may be required to differentiate a partial union from non-union and help plan the surgical approach and technique.

CT scanning to assess the deformity – does it have any value?

A CT scan most precisely defines the architecture and orientation of the non-union. It also:

i. clarifies the location (proximal pole, waist or distal pole) of the fracture;
ii. the size of the proximal and distal fragments which may sometimes be too small to accommodate a cannulated headless screw;
iii. demonstrates the extent of any deformity at the non-union;
iv. demonstrates the degree of bone resorption at the fracture site.

Nakamura et al., (1991) found displacement at the fracture non-union was more readily detected on CT rather than with plain radiography. They identified volar and dorsal types of deformity; similar patterns were found by Moritomo et al., (2000) who noted that all non-unions with volar deformity were associated with a dorsal intercalated segment instability (DISI) deformity. Careful

correction of deformity at the non-union during surgical reconstruction of the scaphoid may improve wrist function and reduce the risk of late–onset degenerative change (Amadio et al., 1989; Fernandez at al., 1998; Fisk, 1980; Forthman and Jupiter, 2003; Lynch and Linscheid, 1997; Jiranek et al., 1992). This is as non-unions which heal with malunion may have a greater impairment in function and more severe radiographic arthrosis (Forthman and Jupiter, 2003). Most modern practice therefore, is to perform a CT scan to assess the severity of the deformity and select appropriate surgery.

Value of MRI to assess deformity in non-union

Whilst the MRI scan is highly sensitive for detecting suspected acute fractures and the assessment of vascularity in non-union, there has been no evaluation of its value for assessing deformity

Value of MRI to assess vascularity

The vascularity of proximal pole fracture non-union fragments cannot be assessed pre-operatively with radiographs or CT scans (Green, 1985; Coblenz et al., 2006; Perlik and Guilford, 1991). It can be assessed with MRI before non-union surgery (Coblenz et al., 2006; Schmitt et al., 1997) and may determine whether a vascularised or non-vascularised bone graft is used for the reconstruction. In addition, pre-operative determination of proximal fracture fragment vascularity may predict the outcome of bone-graft surgery, especially as this can be predicted by per-operative visual inspection of vascularity (Green, 1985).

Table 6 characterises the findings of studies that review the accuracy with which pre- operative MRI scans predict the vascularity of the proximal fracture fragment when intra-operative visual inspection or biopsy histopathology is used as the "gold standard". Some of these studies report improved accuracy with contrast-enhanced imaging.

While there is good evidence surrounding the reliability of MRI scans in predicting proximal scaphoid vascularity, there is continued controversy as to their value in managing post- operative scaphoid union. The table below summarises the evidence (Table 7).

Table 6 The reported value of MRI in predicting the vascularity of the proximal fragment of a fracture non-union.

Authors	Study Characteristics	Gold Standard/ Outcome	Results/Conclusion
Günal et al (1999)	32 scaphoid non-unions prospectively evaluated with MRI for vascularity	Correlated with intraoperative findings for punctate bleeding of fracture fragments	No correlation in 13 of 32 patients: 7 had preoperative normal MRI but no punctate bleeding 6 had preoperative MRI of avascularity but punctate bleeding during surgery
Perlik et al (1991)	Diagnostic accuracy test for avascularity on 10 scaphoid non unions for radiographs, CT and MRI	Histopathological interpretation of surgical specimens	MRI accurately predicted scaphoid viability in all 10 cases (compared with diagnostic errors in 6 of 10 radiographs and 1 of 7 CTs)
Trumble (1990)	12 scaphoid fractures prospectively studied with MRI before open reduction internal fixation and bone grafting	Intraoperative surgical biopsy specimens	MRI showed all 6 patients with biopsy specimens showing avascular necrosis demonstrated decreased signal intensity in the proximal pole fragment
Cerezal et al (2000)	30 scaphoid non unions prospectively examined with unenhanced and gadolinium enhanced MRI	Correlated with intraoperative findings for punctate bleeding of fracture fragments	Global sensitivity, specificity and accuracy of gadolinium enhanced MR imaging were 66%, 88% and 83% respectively (36%, 78% and 68% respectively for unenhanced MRI)
Ng et al (2013)	35 scaphoid delayed or non unions had unenhanced, contrast enhanced and dynamic contrast enhanced MRI imaging retrospectively reviewed and graded for vascularity	Proximal fragment vascularity graded at the time of surgery	Dynamic contrast enhanced MRI had a higher diagnostic accuracy over non enhanced or contrast enhanced MRI Sensitivity, specificity, positive and negative predictive values and accuracy were 67%, 86%, 67%, 86% and 80% respectively.

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Bervian et al (2015)	19 scaphoid non unions evaluated pre operatively for necrosis of the proximal scaphoid fragment by radiographs, CT and MRI	Correlated with intraoperative findings for punctate bleeding as well as biopsy pathological examination	MRI with marked low signal intensities on T1 images are strong indicators of osteonecrosis of the proximal fragment. All patients with low signal were from patients diagnosed with necrosis of the proximal fragment. CT showed no correlation
Schmitt et al (2011)	Pre operative MRI to diagnose osteonecrosis of proximal fragment in 88 scaphoid non unions	Correlated with intra operative bleeding points on the osteotomy site	Sensitivity, specificity, PPV, NPV and accuracy for nonenhanced MRI: 96.3%, 100%, 100%, 82.6% and 82.9% respectively Sensitivity, specificity, PPV, NPV and accuracy for contrast enhanced MRI: 76.5%, 98.6%, 92.9%, 94.6% and 94.3% respectively Sensitivity for detecting avascular proximal fragments better in contrast enhanced MRI ($p<0.001$)
Donati et al (2011)	28 scaphoid non unions had unenhanced and enhanced MR imaging reviewed to rate viability of proximal pole	Surgical findings in all patients Histological and surgical findings in 11 patients	Diagnostic performance of dynamic gadolinium enhanced imaging inferior to that of standard MR

Table 7 The reported value of MRI assessments of the vascularity of the proximal fragment of a fracture non-union for predicting union after bone graft surgery.

Authors	Study Characteristics	Gold Standard/ Outcome	Results/Conclusion
Cerezal et al (2000)	Prospective examination of 30 scaphoid non unions with unenhanced and Gadolinium enhanced MR imaging	Union after surgery determined by absence of pain and plain radiographs	The correlation of unenhanced MR imaging and results after surgery was not statistically significant ($p < 0.2$) The correlation of enhanced MR images and post operative results were highly significant ($p < 0.0001$) An absence of gadolinium enhancement was associated with unsuccessful results

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Singh et al (2004)	Prospective examination of 16 scaphoid non unions with gadolinium enhanced MR imaging pre surgery	Union after surgery (serial plain XRs or CT if radiographs inconclusive)	No relationship was found between MR enhancement and the outcome of surgery. Union was achieved in both fractures that had less than 25% enhancement of the proximal pole
Megerle et al (2011)	Prospective examination of 60 scaphoid non unions using a gadolinium enhanced MRI scan	Union after surgery (radiographs or CT if union in doubt)	No significant correlation between pre operative MRI assessment of vascularity and subsequent union of scaphoid
Fox et al (2015)	Retrospective review of unenhanced and enhanced MRI scans from 18 scaphoid non unions	Union after surgery (postoperative CTs and radiographs)	In proximal poles with decreased T1-W signal or lack of enhancement, a higher rate of osseous union was found when vascularised grafts were used compared to non vascularised grafts
Ciprian et al (2004)	Prospective examination of 21 scaphoid non unions with MRI (unenhanced and gadolinium enhanced) prior to bone grafting (14 conventional bone graft, 7 vascularised bone graft)	Postoperative rate of union	The absence of enhancement of the proximal scaphoid fragment leads to poor surgical results except for vascularised bone graft

Identifying union following non-union surgery for the scaphoid

Whilst there is an evidence base studying scaphoid union following fracture, there seems a paucity of such literature in imaging to identify union following non-union surgery. The pitfalls of using radiographs to assess union for acute fractures have long been known (Dias et al., 1988; Dias, 2001); these difficulties are exacerbated following surgery.

Radiographic features of trabeculae crossing the fracture or sclerosis at the fracture site are compromised by overlapping projections and can give a false "objective" impression of radiographic union (Dias, 2001). As such, it becomes difficult to positively identify

bone union on radiographs. Most clinicians rely on the absence of adverse features that would suggest failure of union to monitor post-operative progress. Dias (2001) characterised some of these adverse features (Table 8) and suggested the 'diagnosis of the state of union is based on the persistent absence of these adverse features over time…at least 6 months and probably 1 year'. Should there be concerning features, CT or MRI scans are recommended.

Most outcome studies have reported union based on serial radiographs, though some also incorporate CT imaging. Metal artefact limits the value of cross sectional imaging (CT and MRI) to assess union in the post-operative scaphoid. Whilst modern software can reduce the effect of metal artefact on CT, there is no literature providing evidence of the reliability of CT scans diagnosing union or non-union in the presence of metalwork.

Metal implants cause profound degradation of image in a largely non clinical study of MRI scans (Ganapathi et al., 2002). Smaller screws, titanium screws and MR scans performed in longitudinal alignment with the z-axis of the magnetic field produced fewer artefacts. A further study suggested that titanium screws scanned in longitudinal alignment with the z axis with an extremity surface coil did not preclude clinically important assessment of the bone marrow signal (Ciprian et al., 2004).

Table 8 Plain radiograph adverse features which suggest failure of union after non-union surgery (Dias 2001)

Fracture Gap	Persistent gap or gap that becomes more defined with time. It is essential to obtain comparable projections using the shape of scaphoid and implant as clues.
Implant (screw)	Movement of implant or progressive lucency around implant suggests mobility at fracture site or graft interface
Displacement	Graft or fracture displacement on corresponding interval radiographs suggests failure of union.

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ACUTE SCAPHOID FRACTURES

Joseph J. DIAS

Epidemiology

Scaphoid fractures are common and account for around 2% of all fractures(Rhemrev et al., 2009). Young men, particularly between ages of 15 and 24 have the highest incidence of scaphoid fractures (Garala et al., 2016). Only 12% of scaphoid fractures occur in female patients, and the highest incidence is in girls between 10 and 14 years of age. A scaphoid fracture is uncommon after the age of 40 years (Garala et al., 2016). Social deprivation is associated with scaphoid fractures with the incidence in the most deprived being greater. 77% of fractures involve the waist of the scaphoid, 18% the tuberosity and around 5% involve the proximal pole.

Examination

If the anatomical snuffbox is tender this has a sensitivity of 90%, but low specificity of 40% for a scaphoid fracture. Tenderness at the scaphoid tuberosity supports a diagnosis of scaphoid fracture with sensitivity of 87% and specificity of 57%. A combination of signs is better than a single sign (Parvizi et al., 1998). Ulnar deviation of the wrist increases pain and when this test causes pain on the radial side of the wrist should indicate the possibility of a fracture (Duckworth et al., 2012).

Suspected scaphoid fractures

Much emphasis has been put on the litigation risk of missing a scaphoid fracture. A very small proportion of patients who (a) present having fallen on the outstretched hand, (b) have tenderness in the anatomical snuff box and (c) whose scaphoid radiographs do not demonstrate an obvious fracture will have a fracture of the scaphoid. For every 100 patients presenting to the emergency department with these three criteria only 3 will have a scaphoid fracture (DaCruz et al., 1988).

Classification

The scaphoid fracture can be classified in various ways but no classification is clearly predictive of union or helps determine treatment and so their value Is more descriptive than clinically relevant

(Russe 1960; Cooney et al. 1980; Herbert and Fisher 1984; Compson et al. 1998)

Treatment of bicortical fractures

Advice to patients

There is very little difference in union rates or time to return to work between operative and non-operative treatments; the surgical benefits are transient (Yin et al., 2007). Minor complications are higher in those who had surgery. In a pairwise meta-analysis no cumulative evidence was found to support routine surgical treatment and "aggressive non-surgical management" in a plaster cast was recommended as the current mainstay for scaphoid waist fractures (Ibrahim et al., 2011). A more recent meta-analysis (Alnaeem et al 2016) reviewed 10 studies and found the mean return to work was 46 days and 77 days for percutaneous fixation and cast respectively; the mean time to union was 44 days and 79 days and a complication rate of 14% and 7% respectively.

Cast treatment

The thumb does not need inclusion (Clay et al 1991) in the plaster cast. 90% will unite. The 1/10 with a clear gap confirmed as not united on a CT scan can be fixed surgically (Dias et al., 2005). The success rate of this method of management- "the aggressive non-operative method", is very high and almost as good as after immediate fixation of all scaphoid fractures. If the fracture does not unite according to set criteria (Dias, 2001) then surgery is considered. Partial union can be assessed on a CT scan (Singh et al., 2005) and if it is over 50% the wrist probably does not need protection for daily activity and in almost all cases the union will progress. However, at present we have very little data on partial union of the scaphoid.

For undisplaced fractures of the scaphoid the period of immobilisation in a cast may be shorter as many will heal after four weeks in a cast. This reduces the duration of disability imposed by immobilisation of the wrist (Geoghegan et al., 2009).

Immediate fixation of scaphoid fractures

Surgeons choose between these palmar or dorsal approaches. Individuals with stiff wrists or with a hypoplastic distal pole of their scaphoid may be best approached from the dorsum of the wrist (Slade and Jaskwhich, 2001).

Complications

Surgery exposes patient complications. These are uncommon and include infection (<0.1%), nerve injury (2%), stiffness, CRPS and implant related problems (Dias et al., 2005). The complications of the fracture include malunion and avascularity.

Malunion

The scaphoid fracture can malunite (Amadio et al., 1989) whether it is fixed or treated in a cast. The malunion is typically in flexion creating a "humpback" deformity that can restrict extension of the wrist and could possibly impair function and lead to post-traumatic osteoarthritis. The impact of malunion after an acute fracture is uncertain (Forward et al., 2009), as stiffness may mask the effects of malunion on joint function. The evidence of effectiveness for a corrective osteotomy of the scaphoid and the threshold of malunion when such correction should be considered remains undefined.

Avascularity

Increased radio-density of the proximal fragment may represent avascular necrosis of the scaphoid (Figure 5). Increased density in the proximal fragments is observed in 30% of acute scaphoid fractures and this may be transient (Russe, 1960). The appearance of increased density may be due to surrounding osteoporosis. This appearance is a poor predictor of vascularity of scaphoid seen at operation.

Displaced scaphoid fractures

Displaced fractures do worse than undisplaced fractures (Dias and Singh, 2011). Displacement is defined by the step, gap or the angle between the proximal and distal part of the scaphoid. It is traditional to use either 2 mms or 1 mm as a threshold to define scaphoid displacement and there are different methods to assess angulation between the distal and proximal parts of the scaphoid, the most robust of which is the Height to Length ratio. Fracture displacement is better assessed on MRI and CT than on scaphoid series radiographs (Davis, 2013).

Union rate is poorer if the fracture is displaced and that displacement can be seen on a CT scan (Singh et al., 2012). However, the rate of union if a displaced fracture is treated in a cast is reduced to 85% and displacement does not prevent union in most cases. Displaced fractures with 3mm or more gap have a significant non-union rate if treated non-operatively. Surgical fixation may be an alternative in these cases. On the other hand, Singh et al., (Singh et al., 2012) performed a meta-analysis using a criterion of 1mm gap or step to define the fracture displacement. The study revealed displaced scaphoid fractures treated surgically have 2% non-union rate compared to 18% when treated in a plaster cast.

The consequence of the fracture healing in a displaced position is malunion, but we have no evidence of what symptoms our patients may experience if the scaphoid heals in a slightly malunited position.

Proximal pole scaphoid fractures

Proximal pole fractures are different although uncommon and accounting for around 5% (Eastley et al., 2013). The relative risk of non-union in proximal pole scaphoid fractures compared to fractures of the waist of the scaphoid is 7.5, although 2/3 of these fractures will still unite in a cast. There is no evidence to support early fixation of proximal pole fractures at present.

Distal pole fractures

These fractures have a good prognosis and generally unite owing to good vascularity of the distal pole. Most of these fractures are treated non-operatively in a cast for 4-6 weeks with good short-term results. Long-term outcome studies for this specific type of fracture are not available.

Smoking

Smoking has a significant impact on the rate of union, and has been defined for patients having surgery for non-union of scaphoid fractures (Little et al., 2006) with a relative risk of failure of union of 3.7. Smoking delays union after a fracture or non-union so if the fracture in a smoker is also proximal the odds of failure of union are particularly high.

Union

Assessment of scaphoid fracture union is challenging. The exact definition of union is debated and different clinical and radiological imaging modalities have been suggested to aid in diagnosis, all of which are prone to errors of interpretation. The clinical assessment of union is unreliable.

Park et al., (Park et al., 2013) used serial radiographs to assess union, which was demonstrated by bridging bone on at least two views. Dias et al., (Dias et al., 1988) found poor intra- or inter-observer agreement on radiographs taken at 12 weeks to measure union.

CT scan is increasingly being used and percentage of trabecular continuity across the whole width of scaphoid (Figure 3) is one way to determine degree of union (Dias, 2001). Grewal et al., (Grewal et al., 2013), using a CT scan, quantified union based on two methods, the mean percentage union and the weighted mean percentage union. Both methods had a high inter-rater reliability.

Outcome

In one series, 20% of patients had some pain and tenderness 1.7-2.6 years after a healed scaphoid fracture but grip strength and

wrist movement were nearly normal. The persistent symptoms may be attributed to damaged articular cartilage at the time of the injury (Dias et al., 1989).

Another study (Lindström and Nyström, 1990) assessed 229 acute scaphoid fractures which had united with non-operative treatment at seven years and found that 11% experienced persistent symptoms, including pain at rest (3%), restricted ranges of motion (6%), pain with wrist motion (10%) and weakness of grip (11%). This study noticed osteoarthritis in 5% of wrists after a fracture of the scaphoid. Another study (Duppe et al., 1994) found marked painful radiocarpal osteoarthritis in only 1/47 patients who had a healed fracture over 31 years before; although the rate of osteoarthritis seen on radiographs was 7%, the remaining patients were asymptomatic.

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SCAPHOID NON-UNION

Mark BREWSTER, Richard PINDER, Lindsay MUIR

Defining non-union

The exact definition of scaphoid non-union varies throughout the literature, confounding comparisons between papers. In a review in 2016 Ferguson et al., assessed 144 studies of non-unions, the majority using a combination of radiographs, CT and MRI to aid diagnosis. Thirty-two articles failed to note which modality of imaging was used. Radiological features, e.g. absence of crossing trabeculae, required to make a diagnosis of non-union were not described in any study. Seventeen studies used the duration from injury to diagnosis to define a non-union ranging from 12 weeks to 1 year. Only seven studies reported their definition of delayed union which ranged from 8 weeks to above 24 weeks. Even in these few studies there is a grey area of overlap between descriptions of delayed union and non-union.

Frequency of non-union

Reported non-union rates for scaphoid fractures treated simply with plaster cast immobilisation are around 14% for waist fractures (Clay 1991) and 34% for proximal pole (PP) fractures (Eastley 2013). Even after primary surgical treatment of acute scaphoid fractures, non-union is still seen with rates of 1.5% (Majeed 2014) for waist fractures and 30-90% for PP fractures (Brogan 2015).

Methodology for this section

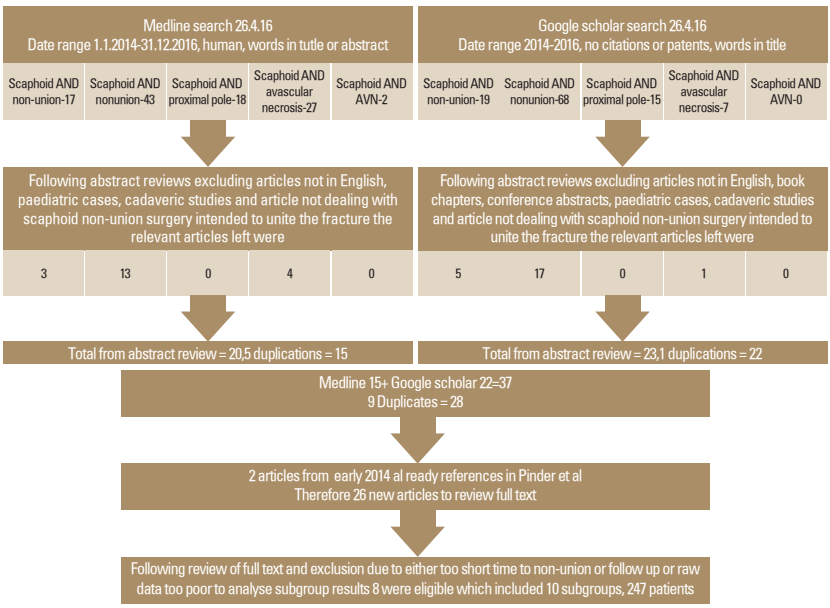
This section will explore the best available evidence to help surgeons make an informed choice on their patient's future management and prognosis with reference to:

- Bone grafts
- Fixation methods
- Prognosis of a fracture of the proximal pole or with avascular necrosis (AVN)
- Impact of delays in diagnosis and smoking on fracture union

To provide evidence for the first three points the raw data from a

review article by Pinder et al (2015) were obtained and combined with new data from a literature search completed in April 2016. New searches were completed in Medline and Google Scholar to include 2014-2016, thus overlapping with Pinder et al (2015) and using identical inclusion and exclusion criteria. This new search revealed eight new eligible articles with ten subgroups and a total of 247 patients. These were added to the 48 articles containing 63 subgroups and 1602 patients from the original 2009-2014 review. Together this made 56 articles, 73 subgroups and 1849 patients.

Figure 1 PRISMA flow chart of new literature search results 26.4.16.



These new data sets, which will be referred to as 'Brewster et al', were then reviewed by a statistician to allow best comparison of evidence (Peter Nightingale – Statistician, University Hospital, Bimingham)

Bone grafts

Types of bone graft

Bone grafts for scaphoid surgery are classically divided into non-vascularised bone graft (NVBG) and vascularised bone graft (VBG), then further sub-divided by donor site location and content

i.e. cancellous or cortico-cancellous bone. NVBG are commonly harvested from the distal radius (DR) or iliac crest (IC) with numerous other less common sites including the olecranon (Poggetti 2015) and ribs (Veitch 2007). VBG are most commonly harvested from the volar DR, pedicled on the volar carpal artery initially described by Kuhlmann in 1987, or dorsal DR, pedicled on the 1,2, inter-compartmental supra-retinacular artery (1,2 ICSR) described by Zaidemberg in 1991. The IC free vascularised graft was described by Pechlaner et al in 1987 and more recently the free medial femoral condyle (MFC) VBG, first described for scaphoid non-union surgery by Larson et al 2007, is increasing in popularity especially for more complex larger scaphoid defects. Other less common sites include bone from the 1st (Bertelli 2007) and 2nd metacarpals (Sawaizuma 2004).

'Brewster et al' reviewed the last 17 years of published evidence (in adults and in English). Table 1 shows the graft types in the review and union rates.

Table 1 Graft type distribution in Brewster et al (which comprises raw data from Pinder et al (2015) and a new search 2014-2016) and the union rates with CI.

Graft location	Papers (Subgroups)	Sub-groups analysed (patients)	Union Incidence Estimate (95% CI)
Iliac Crest	20 (26)	NVBG 24 (649) VBG 1 (60) Other 1(11)	87 (80-93)
Distal Radius Volar	8 (9)	VBG 9 (181)	97 (93-100)
Distal Radius Dorsal	13 (14)	VBG 14 (335)	90 (79-97)
Distal radius	11 (13)	NVBG 13 (378)	86 (79-92)
MFC	1 (1)	VBG 1 (10)	100 (69-100)
1ST MC	2 (2)	VBG 1 (10) Other 1 (24)	89 (75-98)
2nd MC	1 (1)	VBG 1 (10)	100 (69-100)
Rib	1 (1)	NVBG 1 (14)	100 (77-100)
Olecranon	1 (1)	NVBG 1 (80)	90 (81-96)
Bone substitute	1 (1)	1 (15)	93 (68-100)
None	4 (4)	NVBG 4 (72)	98 (87-100)

There are clearly numerous variables which influence these figures, some of which will be addressed in more detail in this section. However, none of the graft types shown in Table 1 were shown to be statistically significantly better than any other for scaphoid union.

One aspect to consider when discussing the results of certain graft types is whether they lend themselves to different pathologies. This would confound the generalisation of data. The dorsal DR graft appears to be more commonly used in more proximal fractures and VBGs are more likely in PP or AVN cases. These would be less likely to heal because of the challenging biological environment. Thus in the review by Ferguson et al (2016) the overall union rates for all fractures were 84% for VBG and 80% for NVBG, although in the VBG group 42% were PP fractures whereas that figure was only 15% in the NVBG group.

Complications

In 2013, Garg and colleagues published a prospective randomised controlled trial comparing NVBGs from the DR and IC. There was no difference in union rates (87%), range of movement and functional scores between the two groups. They noted a considerably higher complication rate within the IC group. This increased complication rate was supported by the review by Pinder (2015) which revealed a complication rate of 9% for IC compared to 1% for DR donor site.

MFC donor site morbidity has been shown to be moderate in a recent review by Windhofer et a*l* (2016). Patients can expect knee discomfort for several weeks, and a return to a preoperative state at 3 months. 9% experienced ongoing continuous knee pain, and 22% reported intermittent knee pain.

Fixation Methods

Types of fixation

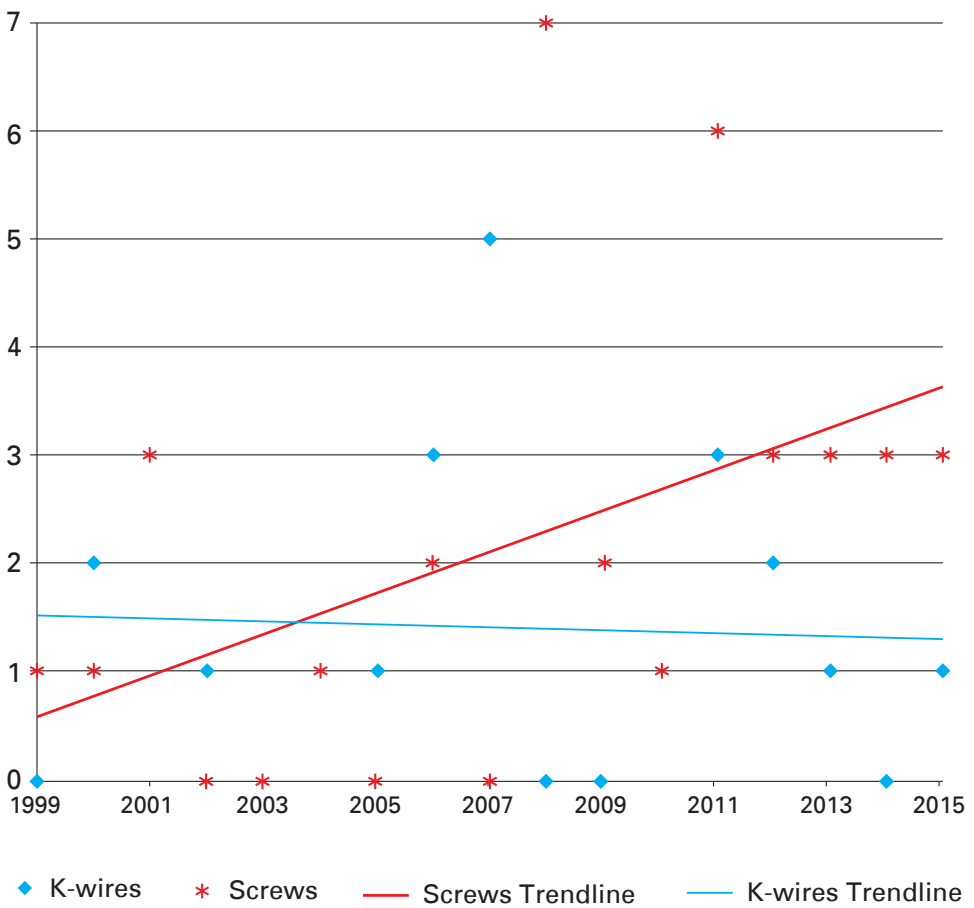
The most common fixation methods for scaphoid non-unions are K-wires, screws or no fixation using a graft to wedge open the scaphoid. In this sub-chapter we reviewed 34 papers (40 sub-

groups) of screw fixation, 24 papers (28 subgroups) of K-wire fixation, four papers (4 subgroups) with no implant fixation and one subgroup with K-wire and external fixator stabilisation.

Trends in fixation

The trends of these fixation methods in Brewster et al over the last 17 years have been plotted to reveal the gradual trend towards screw fixation, but with K-wire fixation still very common in non-union surgery. (Figure 2)

Figure 2 Plot of frequency of subgroups using screws and K-wires for non-union fixation 1999-2015 using data from Brewster et al (which comprises of raw data from Pinder et al (2015) and a new search 2014-2016).



Rates of union with different fixation

Table 2 Further analyses these fixation methods in relation to type of graft used from Brewster et al (which comprises of raw data from Pinder et al (2015) and a new search 2014-2016).

Fixation Method / Graft Vascularity	Papers	Sub-groups analysed (patients)	Union Incidence Estimate % (95% CI)
Screw	33	40 (1066)	90 (86-94)
K-wire	24	28 (655)	92 (86-96)
NVBG	27	38 (1121)	89 (84-93)
VBG	25	27 (606)	94 (88-98)
Screw + NVBG	18	24 (721)	90 (85-94)
Screw + VBG	10	10 (247)	91 (79-99)
K-wire + NVBG	10	11 (295)	88 (77-96)
K-wire + VBG	14	16 (336)	94 (88-99)

From the figures in Table 2 both screw and K-wire fixation, NVBG and VBG and combinations of fixation and graft type are analysed; no fixation methods, graft type or combination were seen to be significantly superior to another in the treatment of scaphoid non-unions. This may contradict many surgeons' beliefs and challenge their choice of fixation and grafting methods in these cases.

There are certainly confounding factors in this data set when grouped and compared in this way. In subgroups using K-wire fixation, 79% included PP fractures and 55% included cases of AVN. This compares with 55% and 43% respectively in the screw fixation group. The K-wire group includes a higher proportion of fractures with poor prognostic factors which may skew the results producing a falsely low union rate for K-wire fixation. The choice may be explained by a reluctance on behalf of the surgeon to place a screw in a small sclerotic PP due to the potential of fragmentation or further disturbing the poor vascularity or bony architecture.

Proximal pole fractures

Defining proximal pole fractures

Roughly a third of PP fractures treated in a plaster cast progress to non-union (Eastley 2013). As with non-union, the definition of a PP

fracture also varies in the literature. A meta-analysis by Eastley et al (2013) revealed that nine of the eligible 11 articles defined the PP poorly. In the two in which it was defined more objectively; it was defined as the 'proximal third' and 'the proximal 25%'. This suggests that the data on 'proximal pole' fractures are heterogeneous making comparison difficult. The authors of this meta-analyses suggest the definition of the proximal fifth (20%) of the scaphoid on radiographs should be used to define the proximal pole.

Treating proximal pole fractures

In this new review, (Brewster et al), seven studies reported results purely for PP non-unions. The fractures were treated with a combination of fixation methods and graft types with an overall union rate after surgery of 89% (95% CI 69-100%). The only significant difference in outcomes was when any group was compared with the Thompson (2008) study which has a very low union of 27% (95% CI 6-61%). If this study were excluded as a separate graft type (periosteal patch), then there were no significant differences found between NVBG or VBG, or between screws and K-wire fixation when treating PP fractures (Table 3).

Table 3 Further analyses of PP fracture union rates from Brewster et al (which comprises of raw data from Pinder et al (2015) and a new search 2014-2016). *(Thompson (2008) not included)

Fixation Method / Graft Vascularity	Papers (Subgroups)	Sub-groups analysed (patients)	Union Incidence Estimate % (95% CI)
All	7 (7)	7 (115)	89 (69-100)
NVBG *	3 (3)	3 (51)	93 (62-100)
VBG	3 (3)	3 (53)	97 (85-100)
Screws	4 (4)	4 (60)	81 (42-100)
K-wires	3 (3)	3 (55)	97 (85-100)
DR Dorsal	4 (4)	4 (79)	91 (71-100)
Rib	1 (1)	1 (14)	100 (77-100)
Iliac crest NVBG	1 (1)	1 (11)	100 (72-100)
Iliac crest & periosteal patch (Thompson)	1 (1)	1 (11)	27 (6-61)

AVN

Defining AVN

In the review by Ferguson et al (2016) a total of 547 (43%) of the 1265 PP non-unions were reported to have AVN of the proximal fragment. As with non-union and PP fractures, the definition of AVN is not consistent in the literature. Ferguson et al (2016) identified that the method for diagnosing AVN varied with authors using either radiographs, MRI or macroscopic appearance at surgery. No definition was provided in four of the 44 studies reviewed.

In the current review (Brewster et al) six subgroups were solely cases with AVN in which two noted MRI and intraoperative findings to assess AVN, one noted the use of radiographs, CT, MRI and intraoperative findings, two noted only intraoperative findings and one only noted MRI to identify AVN. Of the five who described intraoperative findings, three diagnosed AVN with the tourniquet still inflated and two with it deflated.

Many surgeons would see the gold standard as intra-operative assessment and should be aware of the limitations of diagnosing AVN with modern imaging. One consideration for the surgeon, which currently has no clear evidence, is whether intra-operative assessment is best performed with the tourniquet inflated or deflated.

Fox et al (2010) found that T1 weighted unenhanced MRI had a sensitivity, specificity, and accuracy of 55%, 94%, and 79%, respectively, for diagnosing AVN. STIR sequences were not seen to improve these results. The evidence assessing 1.5Tesla versus 3Tesla scanners, dynamic MRI and combinations of sequences is not currently available.

Table 4 Further analyses outcomes of AVN in scaphoid non-union surgery from Brewster et al (which comprises raw data from Pinder et al (2015) and a new search 2014-2016).

Fixation Method / Graft Vascularity	Papers (Subgroups)	Sub-groups analysed (patients)	Union Incidence Estimate % (95% CI)
All	6 (6)	6 (99)	91 (71-100)
NVBG	1 (1)	1 (11)	27 (6-61)
VBG	5 (5)	5 (88)	91 (71-100)
Screws	3 (3)	3 (53)	81 (34-100)
Screws without Thompson	2 (2)	2 (42)	96 (89-100)
K-wires	3 (3)	3 (46)	97 (84-100)
DR Dorsal	4 (4)	4 (78)	96 (88-100)
MFC	1 (1)	1 (10)	100 (69-100)
IC & DR periosteal patch	1 (1)	1 (11)	27 (6-61)

Treatment of AVN

In the six subgroups of AVN, the fractures were treated with a combination of fixation methods and graft types with an overall union rate of 91% (95% CI 71-100%) (Table 4). As with PP fractures the periosteal patch (Thompson 2008) gave significantly poorer results, however there were no other series of true NVBG. Therefore the outcome of treating VBG versus NVBG for scaphoid fractures with AVN could not be assessed. There was no significant difference found between fixation with screws or K-wires in scaphoid fractures with AVN.

In the review by Ferguson et al (2016) the 292 scaphoid fractures with AVN undergoing VBG had a union rate of 74% (95% CI 0–100%) this was compared with 62% (95% CI 0–100%) for the 236 scaphoid fractures with AVN treated with NVBG.

Delay in treatment and smoking

For this section, the literature search was conducted using Medline with exclusion criteria articles not in English and patients aged under 16 (Table 5). The date range was up to May 2016 with no start date. The reference lists of all included articles were studied for any additional relevant papers.

Table 5 Breakdown of literature search for smoking and delayed union.

Search term	Total records identified and screened	Records excluded	Full articles assessed	Studies included
Scaphoid and fracture	388	347	41	11
Scaphoid and smoking	11	1	10	9
Scaphoid and delay	52	41	11	10
Scaphoid and non-union	275	243	32	12
Scaphoid and salvage	68	63	5	2
Total	794	695	99	44

Delayed treatment of an acute fracture

Delays in treatment occur both due to patient neglect and missed diagnosis by medical professionals. Table 6 summarises three papers which considered the initial causes for delay in scaphoid fracture treatment.

Table 6 Summary of papers reporting delay in diagnosis of scaphoid fractures

Author	Non-unions	No. presenting acutely to doctor	No. diagnosed at 1st consultation (all had radiographs)	Notes
Reigstad (2012)	270	146 (55%)	117 (80%)	Patients not presenting immediately after injury had a median time to diagnosis of 1 year (range 0.3-15)
Langhoff (1988)	285		253 (89%)	10% diagnosed at 2nd and 1% at at 3rd radiographic review
Bannerman (1946)	66			All armed forces - 42% not diagnosed immediately

The importance of delay in initiating treatment was recognised in 1944 by Robertson and Wilkins in their study of 100 scaphoid fractures treated at a Royal Naval hospital. Table 7 shows a summary of the publications assessing the effect on a delay in treatment of acute scaphoid fractures.

Table 7 Summary of literature exploring treatment delay and union rates in acute scaphoid fractures.

Author	Scaphoid fractures	Time in cast (weeks)	Delay to treatment (weeks)	Union (%)	Additional Information
Robertson (1944)	52	11	<1	100	
	48	26	>1 - a few yrs	27	
Grewal (2015)	19 waist	11.0 +/- 6.5	10.5 +/- 4.3 (6-23)	84	Overall union increased to 96% if patients with diabetes, comminution or hump back deformities were excluded
	5 PP	14.2 +/- 8.7	10.5 +/- 4.3 (6-23)	83	
Langhoff (1988) (P<0.01)	154	9.3	<4	96	A higher proportion of PP fracture were seen in the >4/52 group which may be a confounding factor
	22	17	>4	55	
Bannerman (1946)	54	16.0-22.1	<25.7	100	
	12	<23.8	>25.7	17	
Eddeland (1975)	92	10.5	<4	96	
	15		4-52	27	
	27		>52	4	

A study by Brogan et al., (2015) focused on the effect of delay to fixation in acute PP fractures. Delays of up to 28 days did not affect outcome, however rates of union were much greater (70% versus 23%) in radiologically "undisplaced" fractures. They therefore recommended early fixation to avoid fracture displacement.

The literature shows that a large proportion of cases have a delay in treatment because the patient has not sought medical advice immediately. There remains a large number of patients who seek medical attention and either remain undiagnosed and untreated or are diagnosed at subsequent consultations.

It appears from the data (Table 7) that, in acute fractures, the delay in initiating treatment does lead to increased non-union rates; beyond 4 weeks after injury appears to be the time when the prognosis worsens.

Delay before surgery for scaphoid non-unions.

A number of studies have included the effects of delayed treatment of established non-unions in their data. Table 8 summaries the data.

Table 8 Summary of literature reviewing non-union and delays in surgery of scaphoid non-unions

Author	Scaphoid fractures	Treatment	Union (%)	Delay to treatment	Statistically significant difference
Werdin (2014)	54 (all PP fractures)	VBG (45 volar DR, 9 dorsal DR)	68.5	1.7yrs for unions 3.4yrs for non-unions	NO
Trezies (2000)	113	Mixed BG	75	<5yr	NO
	9	Mixed BG	78	<5yr	
	4	Mixed BG	67	Unknown	
Euler (2014)	16		100	6-12mnths	NO (all non-unions were smokers, a possible confounding factor)
	10		60	>12 months	
Nakamura (1993)	38	Herbert and wedge graft	100	<5 yr	NO
	12	Herbert and wedge graft	75	>5yr	
Pinder (2015)	1602 (48 articles)	Numerous combinations of bone graft, k-wires and screws	91	<12months	NO
			88	12-36 months	
			93	>36 months	
			81	Unknown	
Inoue (1997)	130	Herbert	92	<5 yrs	YES p<0.05
	30	Herbert	80	>5yrs	
Schuind (1999)	96	BG + IF	79	<3 yrs	YES p0.014
	26	BG + IF	63	>5yrs	
Ramamurthy (2007)	159			continuum	YES p=0.018

Ramamurthy et al (2007) examined the records of 159 patients treated for non-union and demonstrated graphically as a contin-

uum that the more proximal the fracture, or the greater delay to non-union treatment, the greater the risk of non-union (p=0.018).

The results in Table 8 show a mixed picture in the evidence for the effect of delayed treatment of established non-unions. Three papers show a statistically significant increase in non-union if the delay was >5 years (Inoue, 1997; Schuind, 1999; Ramamurthy, 2007). One article's findings were similar with a 5 year cut off but no statistical analysis provided (Nakamura, 1993). One found an increase after 12 months but not statistically significant; the data were confounded by smoking (Euler, 2014). Two papers found no effect (Werdin, 2014; Trezies, 2000); one review article found no effect, with the longest delay group being >3yrs. However they found a trend towards an increase in the rate of non-union if the delay time was unsure (Pinder, 2015).

This would suggest there may be a poorer prognosis when treating an established non-union >5 years from the date of injury.

Union rates and smoking

Smoking has a deleterious effect on fracture healing (Gaston, 2007). This probably translates to increased non-union rates in scaphoid fractures. Table 9 summarises the current literature.

Table 9 Summary of literature reviewing the association between smoking and scaphoid non-union.

Author	Scaphoid fractures (type)	Total number Non-smokers No. (% union)	Total number smokers No. (% union)	P value (other ratios noted)
Werdin (2014)	75 (all PP)	-	-	>0.1
Özalp (2015)	58	23 (95.7%)	35 (80%)	0.09
Ramamurthy (2007)	94	-	-	0.13
Ditsios (2016) (meta-analysis)	256	-	-	(10 fold increase in non-union in smokers)

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Author	Scaphoid fractures (type)	Total number Non-smokers No. (% union)	Total number smokers No. (% union)	P value (other ratios noted)
Hirche (2014)	39	15 (93%)	13 (54%)	0.029 (NB High - 28% -loss to follow up)
Dinah (2006)	37	17 (82.4%)	20 (40%)	<0.01
Chang (2006)	50	-	-	0.02 (Odd ratio 5.44)
Little (2006)	64	34 (88%)	30 (57%)	0.005

Overall smoking appears to increase the rates of non-union following scaphoid surgery. Three series found a trend towards a worse prognosis (Werdin, 2005; Özalp, 2015; Ramamurthy, 2007) and five found a statistically significant difference between the groups (Ditsios, 2016; Hirche, 2014; Dinah, 2006; Chang, 2006; Little et al., 2006).

Discussion

Summary

- Cessation of smoking is strongly advised
- Early diagnosis and earlier treatment of acute fractures improves the outcomes
- A delay in presentation of >4 weeks appears to increase the risk of non-union when treating scaphoid fractures non-operatively
- Earlier treatment of established non-unions is recommended to improve union rate.
- A poorer prognosis ensues if scaphoid non-union surgery is performed >5yrs from initial injury
- There is no evidence that a single graft type is better than another, irrespective of the fracture site or vascularity.
- Increased complications of more distant sites and technical difficulties of VBG and free VBG must however be noted
- There is no evidence of superiority for screws over K-wires, however, as with certain graft types, K-wires appear to be utilised more frequently for cases with poorer prognosis i.e. AVN and PP fractures.
- No comparison of VBG and NVBG could be achieved for AVN cases although no difference in union rates was seen between these two groups for PP fractures.

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OPTIMISING SCAPHOID FIXATION

Shai LURIA

Introduction

The single headless screw fixation technique for scaphoid fractures has become the most prevalent treatment strategy since its introduction by Herbert and Fisher in 1984. Their design included a guiding jig, which may prevent distraction of the fracture when placing the implant, and facilitates the insertion of a screw of adequate length. The differential pitch of the threads of this intramedullary implant generate compression of the fracture, creating rigid fixation leading to shorter periods of wrist immobilization. A distal-volar approach to the scapho-trapezial joint was recommended (Herbert and Fisher 1984). Although revolutionary, there are several limitations to this technique and the results are not always optimal (Pinder et al 2015). Placement of a single cannulated screw in the centre of the proximal fragment was recommended by Adams et al., (1988) and later found to be superior to eccentric positioning of the screw in a cadaver model (McAllister et al 2003). This simple approach that disregards the fracture and addresses the scaphoid central axis has become common practice. Different surgical approaches, the use of different or multiple implants, and attempts at addressing the morphology of the fracture when placing the implant are still being explored today.

The range of surgical approaches

Dorsal proximal and volar distal approaches are usual in both open and percutaneous techniques (McQueen et al., 2008; Slade et al., 2006; Coso et al., 1986). The preferred approach depends on the safe and optimal screw placement - in particular avoiding screw protrusion and defining safe zones for this purpose (Jung et al., 2011; Leventhal et al., 2009; Levitz and Ring, 2005; Guo and Tian, 2011). A distal volar entry point may be achieved using traction and ulnar deviation. A more ulnar distal approach results in better central positioning in the proximal pole of a longer screw but necessitates excision of part of the trapezium (Levitz

and Ring, 2005). This was confirmed using a 3D computer model, where a safe zone was defined around the inner cortical surface of the scaphoid. The longest screw length that did not violate the safe zone was found to pass close to the tuberosity (Leventhal et al., 2009). According to a finite element analysis of cadaver bone density and cortical thickness, more rigid fixation can be achieved between the midcarpal side of the tuberosity and the radial side of the proximal pole (Lee et al., 2012). Damage to the scaphotrapezial joint in the distal approach is a theoretical concern but has not been been proven (Filan and Herbert, 1996) even with a formal trans-trapezial approach (Meermans and Verstreken, 2008). The trans-trapezial approach results in a centrally placed screw in both the proximal and distal parts of the scaphoid, unlike the standard volar approach, which can result in central positioning only in the proximal part. In this study of 14 cadaver wrist pairs, the trans-trapezial approach had a measureable biomechanical advantage (Meermans et al., 2014).

The dorsal proximal approach to distal and waist fractures resulted in a more centrally placed screw in 6 paired cadaver wrists, compared to a volar approach, but no differences in more proximal fractures (Chan and McAdams 2004). Dorsally placed screws were found to be more closely in line with the longitudinal axis of the scaphoid as well as more perpendicular to the fracture in a radiographic comparison of the volar (N=19) vs. the dorsal approach (N=22) (Jeon et al., 2009). No differences in functional outcome or bone union were found but the study may not have been adequately powered to detect a difference.

Different or multiple implants

Although single cannulated headless screw fixation has become widespread, failed fixation is not uncommon. Artificial models of fractured scaphoids suggest that rotational stability with plate fixation outperforms one or two screws (Jurkowitsch et al., 2016). Due to the risk of articular prominence, the use of this technique may be appropriate in recalcitrant or unusual cases (Dodds and Halim, 2016, Moon et al., 2013).

Using finite element analysis, the configuration of Kwire fix-

ation was shown to be optimal with 2 K-wires separated as far as possible from each other and when crossing each other in the two planes (Ezquerro at al., 2007). Although the cannulated screw has been demonstrated to be superior to two parallel wires biomechanically (Carter at al., 1991; Panchal at al., 2007) as well as clinically in cases of fracture non-union (Christodoulou at al., 2001, Merrell at al., 2002), a different wire configuration might prove comparable.

There is conflicting evidence supporting any one screw type since most have adequate compression properties (Fowler and İlyas, 2010; Hart at al., 2013). Multiple studies comparing different first and second-generation screws show differences in compression forces in cadaver and foam models. Second generation screws have better biomechanical characteristics than first generation screws but the Mini-Acutrak 2 (Acumed) generates the highest compression force (Assari at al., 2012). In a different study, The Kompressor screw (Integra Life Sciences) with its dual threaded components that can be moved independently exhibited the highest compression forces (Crawford et al., 2012). Differential forces in a cadaver model along the fully threaded Acutrak 2 suggested it was inferior to screws without a thread around the central part of the screw (Koh at al., 2015). These forces have been found to be scientifically significant in some studies but it is doubtful whether there are clinical implications for these minor and variable differences (Fowler and İlyas, 2010, Hart at al., 2013, Gruszka at al., 2016). A significant decrease in force with time (Gruszka at al., 2016, Gruszka, 2012) and with screw reinsertion has been reported (Hart et al., 2013). A longer screw was found to be biomechanically superior in ten cadaver wrists, but no advantage was found with the addition of a K-wire (Dodds at al., 2006).

Clinical studies to date are retrospective and report no difference between Acutrak and Herbert screws in cases of fracture non-union (Gereli at al., 2011; Gregory 2008). A single retrospective study (Oduwole at al., 2012) indicated that the Acutrak was superior to the Herbert screw in fixation of fracture non-unions, although the difference may have been due to better placement of

the cannulated Acutrak screw over a guide wire as compared to the Herbert screw using a guiding Huene jig (Oduwole at al.,., 2012).

Addressing the morphology of the fracture

The recommendation to place a single cannulated screw along the long axis of the scaphoid may disregard the morphology of the fracture. A finite element examination of unstable Herbert B type fractures (Herbert and Filan, 1984) showed clear biomechanical advantages when placing the screw perpendicular to the fracture in comparison to the long axis of the scaphoid (Luria at al.,., 2010). Another finite element study indicated that a perpendicular screw in a horizontal oblique fracture took up a smaller area of the fracture surface needed for apposition and healing (Hart at al.,., 2013). Several unsuccessful attempts have been made to replicate this difference in cadaver studies. A long axis screw proved to be of similar strength as the perpendicular screw in vertical oblique (Luria, at al., 2012), and horizontal oblique (Faucher at al., 2014) fractures. In horizontal oblique fractures, a shorter perpendicular screw had the same strength as the longer long axis screw (Faucher at al., 2014).

Until recently, transverse waist fractures were thought to be the most common type of scaphoid fracture (Brondum at al., 1992, Russe at al., 1960). 3-D analysis of the morphology of wrist fractures revealed that most scaphoid fractures are horizontal oblique (Luria 2015). This further challenges the common practice of placing a longitudinal screw at a wide angle to the horizontal oblique fracture. Biomechanical and clinical studies have yet to demonstrate the advantage of placing a screw perpendicular to the fracture. To place a screw perpendicular to a horizontal oblique fracture, standard approaches may be insufficient.

Conclusion

When fixing scaphoid fractures, due consideration must be given to the surgical access, the orientation of the fracture, its longitudinal location, the optimum position of the implant within the bone and the relative compression and stability afforded by various implants.

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EMERGING TREATMENTS

Lizzie PINDER

Introduction

Established treatments for scaphoid fractures have been discussed in previous sections of this chapter. In this final section, we focus on novel techniques which have more limited evidence.

Rib Autograft

The treatment of choice for a fracture of the proximal pole of the scaphoid is fixation. Occasionally this is technically impossible, because of proximal pole comminution, small fragment size, incompetence of the subchondral bone plate due to necrosis or fragmentation, or previous unsuccessful fixation and grafting (Sandow, 2001). Salvage surgery is indicated in the presence of symptomatic arthritis, but may be considered too extreme in the earlier stages. A chondro-osseous autograft is an attractive alternative in the absence of arthritis; conventionally it is obtained from the medial femoral condyle.

The rib autograft is an established treatment for temporomandibular joint defects, but is a novel proximal scaphoid donor site (Sandow 2001; Macintosh and Henny, 1977). The surgical technique has been well described, but the evidence base is limited to level 4 studies (Sandow 2001; Sandow 1998; Veith et al., 2007; Yeo et al., 2013). The largest cohort included 47 patients, with outcomes presented at a median follow-up of 15 months (Sandow 2001). Median wrist function scores appeared to improve following surgery but were not statistically compared to pre-operative scores. Earlier work by the same author reported significant improvements in wrist score, grip strength and range of movement compared to baseline at median 2 years follow up (Sandow, 1998). Four patients required further surgery (styloidectomy) and one developed a haemothorax. Similar results were reported by Veitch et al (2007). Wrist function scores (modified Green and O'Brien), grip strength and pain significantly improved at a mean follow

up of 64 months compared with pre-operative measurements. The ranges of movement were unchanged. A final case series describes the post-operative outcomes of only three patients (Yao et al., 2013).

Whilst the published results are promising, there is a lack of robust evidence supporting this procedure; no long term outcomes are available. Nevertheless, the technique has been applied successfully to other joints suggesting further study is warranted.

Vascularized Osteochondral Rib Graft

Published evidence is limited to one case report (Lanzetta 2009). The vascularized rib graft was based on the intercostal vessels, the internal mammary artery and vein. The graft incorporated radiologically, but radiocarpal arthrolysis and radial styloidectomy were required 1 year following surgery. There is insufficient evidence to recommend this technique.

Coracoid Bone Graft

Details of this technique were presented at the British Society for Surgery of the Hand Autumn Meeting 2015 but published results are awaited.

Pyrocarbon Adaptive Proximal Scaphoid Implant (APSI)

Scaphoid prosthetic replacement was described as early as 1974 (Barber, 1974). The implant was manufactured from acrylic, but later, other materials were used including silastic, titanium and vitallium (Swanson et al., 1997; Leslie et al., 1991; Zemel et al., 1984). Results were suboptimal and none achieved sustained widespread use. More recently, an interposition arthroplasty made of pyrocarbon has become available. This material is of particular interest as it is inert, biocompatible, and has a modulus of elasticity close to bone. The implant does not adhere to the surrounding tissue, but rather follows the path of least resistance during wrist movement, “protecting” the implant from dislocation(Capo and Tan 2007). Another distinguishing feature is the two radii of curvature producing an ovoid shape, which is designed to conform

to the scaphoid fossa. When implanted, the width in the sagittal plane is larger than the coronal plane which in theory promotes synchronous movement with the proximal row. Fixation or soft tissue augmentation is not required because of the theoretical adaptive mobility (Gras et al., 2012)"container-title":"Journal of Wrist Surgery","page":"159-164","volume":"1","issue":"2","-source":"PubMed","abstract":"Fractures of the proximal pole of the scaphoid with associated avascular necrosis and nonunion are well known to be problematic. Many techniques for fixation and reconstruction of the proximal pole of the scaphoid have been reported, often with poor results. One of the newer modalities of treatment for these difficult cases is excision of the proximal pole and replacement with a pyrocarbon implant. The ovoid shape of the implant acts as a spacer and repositions itself throughout the range of motion of the wrist. The procedure can be performed arthroscopically, thus reducing the morbidity and allowing the procedure to be a day case. Satisfactory results have been reported in elderly patients, but there is a paucity of literature regarding the outcomes in younger patients. This multicenter retrospective study evaluates the clinical, radiologic, and functional outcomes in patients under the age of 65 years with a minimum follow up of 5 years. There were 14 patients with scaphoid nonunion advanced collapse (SNAC; the procedure may be performed open or arthroscopically.

Despite being available for several years, clinical evidence is limited to a small number of case series (Capo and Tan, 2007, Gras et al., 2012; Pequinot et al., 2000; Daruwalla et al., 2013; Berzero and Grandis, 2005)advances are directed at developing procedures that are less invasive, with smaller incisions and shorter rehabilitation times. Minimally Invasive Hand and Wrist Surgery is the only book devoted exclusively to these exciting new percutaneous and minimal access techniques for the treatment of chronic and traumatic conditions of the hand and wrist. Nearly forty procedures are described, with step-by-step details and abundant illustrations, all contributed by the leading international experts who are pioneering these new approaches.","ISBN":"978-1-4200-1973-5","lan-

guage":"en","author":[{"family":"Capo","given":"John T."},{"-family":"Tan","given":"Virak"}],"issued":{"date-parts":[["200 7",9,27]]}},{"id":628,"uris":["http://zotero.org/users/2103448/ items/BR5FMGCP"],"uri":["http://zotero.org/users/2103448/ items/BR5FMGCP"],"itemData":{"id":628,"type":"article-journal","title":"Treatment of Avascular Necrosis of the Proximal Pole of the Scaphoid by Arthroscopic Resection and Prosthetic Semireplacement Arthroplasty Using the Pyrocarbon Adaptive Proximal Scaphoid Implant (APSI. Pequignot et al., (2013) reported preliminary results of 25 patients with a mean follow up of 6 years, however their series also included other pathologies (ten cases of scapholunate advanced collapse and one case of failed silicone partial replacement). For the cohort as a whole, 60% were pain free and 88% were satisfied. A case series originating from Italy, again including cases with a mixed aetiology, reported resolution of symptoms in 63% of patients (Berzero and Grandis 2005).

Of 14 patients treated with an arthroscopically sited APSI in 2007 (Gras et al., 2012)., 3 experienced implant subluxation. The remaining patients were reported as being free of significant pain although no data were presented. The same unit later reported outcomes for 14 patients all of whom were younger than 65 years. Visual analogue scores had improved at a follow up of mean 8.7 years, as did ranges of wrist movement and grip strength, but no comparative statistics were performed to detect significant differences compared to baseline. Revision rates appeared high, as six of the 14 patients required surgery either to revise the implant, perform salvage surgery, or perform a radial styloidectomy. As a result, their recommendation is to perform simultaneous radial styloidectomy at index surgery if there is any suggestion of arthritic wear in that area.

Comparative statistics were included in only one study which originates from the United Kingdom (Daruwalla et al 2013). Twelve patients were included and mean follow up was 18 months. Significant improvements in visual analogue and DASH scores were seen compared to baseline and all but one was "very satisfied". There are some limitations to this study. One patient was excluded

from analysis as they suffered an implant dislocation following a fall and inpatient procedures were excluded potentially introducing case-mix bias. Reporting bias may also have been introduced as the patient satisfaction scores were obtained verbally by the operating surgeon.

Scaphoid fractures occurring more distal than the proximal pole are an absolute contraindication to APSI. Gras and colleagues (2012) included two patients in their study with scaphoid waist fractures, both of whom experienced implant subluxation requiring revision to scaphoidectomy and four corner fusion. The APSI implant is designed only to replace the proximal pole, greater amount of bone resection renders the implant less stable and more vulnerable to dislocation. Furthermore, fewer secondary restraining ligaments are maintained with greater bone resection, again increasing the risk of instability.

To date there is no robust evidence supporting the widespread insertion of proximal pole pyrocarbon interposition prostheses.

Bone Morphogenic Protein (BMP)-2

BMP-2 is a group of cytokines with osteoinductive properties which may potentially benefit patients in whom achieving scaphoid union is particularly challenging. There is evidence to support its use in spinal surgery although more recently concerns have been raised regarding its complications including uncontrolled bone formation (Hustedt and Blizzard, 2014). The evidence for using BMP-2 in scaphoid surgery is sparse. Ablove and Abrams (2015) reported union and no complications in all four cases treated surgically with BMP2 and screw exchange. Conversely surgeons from Charlotte NC in the USA identified that two of their six patients did not unite requiring partial wrist fusion, and the four that did heal developed heterotopic ossification (Brannan et el., 2016)products such as recombinant human bone morphogenetic protein (rhBMP-2. One patient required excision of heterotopic ossification and capsulectomy. Whilst the principle of BMP-2 is compelling, it remains off-label when used in scaphoid surgery, it has no definite established benefit and carries the risk of failure and stiffness.

Other possibilities for the future

Guided Screw placement

Some implant companies now offer navigated distal locking screw placement for intramedullary nailing systems. Hoffmann et al., adapted this technology to create an electromagnetic guided method of percutaneous scaphoid screw placement (Hoffman et al., 2015)"container-title":"The international journal of medical robotics + computer assisted surgery: MRCAS","page":"52-57","volume":"11","issue":"1","source":"PubMed","abstract":"BACKGROUND: Central screw positioning in the scaphoid provides biomechanical advantages.\nMETHODS: A prospective randomized study of six fluoroscopically guided and six electromagnetically navigated screw (ENS. Their randomised study of 12 cadavers identified a significant operating time and x-ray exposure advantage with their new technique compared to the traditional fluoroscopic method. Despite the small study size, statistical significance was reached, although the clinical benefit and cost effectiveness is perhaps less certain as the reduction in operating time was merely 7 minutes. Furthermore, even if the basic equipment is already available, there are additional set up costs as a custom probe hook and computer software are required. Further clinical evidence and cost analysis is required.

Dorsal Plating

Dorsal plating is a novel fixation technique for scaphoid fractures, however evidence is limited to an article describing the surgical technique which also briefly summarizes the outcome of ten patients (Bain et al., 2015). Nine achieved clinical and radiological union, but time to union and the criteria were not defined. Dorsal plating may be advantageous as it acts as tension band in the absence of volar comminution, but whether there is an advantage over conventional treatment is unclear.

LIPUS and PEMF

Scaphoid fractures are vulnerable to non-union, particularly proximally. Two modalities which may influence fracture heal-

ing are low-intensity pulsed ultrasound (LIPUS) and pulsed electromagnetic fields (PEMF) (Farkash et al 2015, Ebrahim et al 2014)"container-title":"Journal of Orthopaedic Surgery and Research","volume":"10","source":"PubMed Central","abstract":"Background\nThe standard treatment to enhance fracture healing of scaphoid nonunions is surgery. Low-intensity pulsed ultrasound (LIPUS. There are few studies assessing their impact on scaphoid fractures (Farkash et al 2015, Ricardo 2006, Carlson et al 2015)"container-title":"Journal of Orthopaedic Surgery and Research","volume":"10","source":"PubMed Central","abstract":"Background\nThe standard treatment to enhance fracture healing of scaphoid nonunions is surgery. Low-intensity pulsed ultrasound (LIPUS. For fractures in general, a meta-analysis did not identify an advantage of either technique compared with control (Ebrahim et al 2014)"container-title":"Canadian Journal of Surgery","page":"E105-E118","volume":"57","issue":"3","source":"PubMed Central","abstract":"Background\nTo best inform evidence-based patient care, it is often desirable to compare competing therapies. We performed a network meta-analysis to indirectly compare low intensity pulsed ultrasonography (LIPUS. With respect to scaphoid fractures, significantly quicker healing times are implied by a double-blind control study of LIPUS following muscle-pedicled bone grafting for scaphoid non-union (Ricardo, 2006) 21 fractures of the scaphoid with established nonunion treated with vascularised pedicle bone graft were selected for inclusion in a double-blind trial. All patients were males, with an average age of 26.7 years (range 17–42 years. Assessments were made at monthly intervals but the mean time to healing was compared between groups rather than the proportion achieving union at each time interval which is a potential limitation of the study. Level 1 evidence also shows that PEMF is not effective for acute scaphoid fractures (Hannermann et al., 2012). Clinical healing times were similar to controls (no pain with longitudinal compression) at 4, 9, 12, 24 and 52 weeks but favoured the controls at 6 weeks (no union in 38% of PEMP group compared with 7% controls). Radiological union was similar for both groups with a median of 9 weeks to union. A separate analysis found that the

treatment was not cost effective (Hannermann et al 2015). We do not recommend PEMF as an adjunct to scaphoid fracture treatment however the effect of LIPUS requires further study.

Conclusion

Evidence for these novel techniques is currently sparse and warrants further study. We caution that procedures should be performed within a research environment in order to collect robust data, to facilitate regular patient review and to identify complications early.

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FINAL CONCLUSIONS AND FUTURE RESEARCH

Summary

Imaging of scaphoid fractures: The acute scaphoid fracture can usually be diagnosed on at least one of five specific scaphoid views, but about 30% may not on early images. Repeat radiographs performed 10 to 14 days later will detect the majority of undisclosed fractures; CT scan has a 67 to 94% sensitivity and MRI scanning close to 100% sensitivity. Displacement predicts non-union and is best detected by CT rather than plain radiographs. The clinical relevance of a "sclerotic" proximal pole is not clear; it is not related to poor vascularity or poor healing. Whilst an MRI can assess vascularity, the prediction of healing has not been established. Plain xrays are not reliable in assessing union but CT scan has a much higher reliability. Partial unions almost always proceed eventually to union. Malunion can be diagnosed best on CT but images in the sagittal axis of the scaphoid are required. CT scans are most reliable in defining the architecture of non-union and thus planning surgery. The most reliable assessment of non-union despite surgery is not established.

Acute scaphoid fractures: a combination of physical signs must be elicited; only 3% of patients with a fall on the outstretched hand with snuffbox tenderness and normal scaphoid radiographs will actually have a scaphoid fracture. No classification is predictive of union or determines treatment. There are transient benefits to early surgical fixation with an earlier return to work and earlier union although higher complication rate. A plaster cast does not need thumb inclusion. Displaced fractures, diagnosed on CT, should be treated surgically. 66% of proximal pole fractures unite in a cast. Smoking delays union. 11- 20% of patients are still symptomatic years after a scaphoid fracture.

Scaphoid non-union: this is seen in about 14% of waist fractures and 34% of proximal pole fractures. It is not clear whether vascularised bone graft may enhance union because the cases in which they

are used have a more challenging biological environment. Iliac crest graft has a similar union rate to distal radius graft but a much higher complication rate (9% vs 1%). The evidence comparing wires with screws is confounded by a higher use of wires in the proximal pole. There may be a benefit for vascularised graft in avascular necrosis. Fractures should be treated within 4 weeks to optimise the chance of healing. There may be a poorer prognosis in securing union of a fracture sustained more than 5 years previously.

Optimising scaphoid fixation: The entry point and position of the screw within the axis may not influence outcome; the screw can be perpendicular to the scaphoid axis or to the fracture. If k-wires are used, 2 should be employed as far apart as possible and crossed. Different screws have different compression properties but there is no evidence that this makes a difference.

Emerging Treatments: rib osteochondral graft, vascularised rib graft, coracoid graft, pyrocarbon proximal pole implant (APSI), dorsal plating all might be of use but the evidence is not definitive. Bone morphogenic protein has no definite established benefit and carries the risk of failure and stiffness. Pulsed electromagnetic fields do not aid union in acute fractures: the value of low intensity pulsed ultrasound is unproven

Future research

There are, and always will be, many unanswered questions. Areas of particular relevance include:

- Standardisation of outcome reporting for various techniques to allow better comparison, given the challenges of running sufficiently powered randomised trials.
- Novel modalities to enhance bone healing – growth factors such as BMP or indirect modalities such as ultrasound or electromagnetic fields
- Optimised screw placement; optimised fragment stability
- More reliable techniques to secure bone union in proximal pole fractures
- Salvage procedures to include reliable scaphoid replacement or excision and reconstruction

3.3 Tendon Reconstruction of the Unstable Scapholunate Dissociation. A Systematic Review

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Introduction

Except for a paper on the stabilizing mechanisms of the wrist published by Gilford et al., in 1943, wrist instability did not reach mainstream attention until 1972 when Ron Linscheid and Jim Dobyns published what was later considered the seminal study on the subject (Linscheid et al., 1972). Six years later, the same authors reported a detailed retrospective review of 55 patients whose wrist dysfunction had been treated with a variety of tendon ligamentoplasties (Palmer et al., 1978). What follows is a systematic review of these and subsequent techniques. The goal is to ascertain which reconstruction is best and what would be the ideal indications. The so-called "dynamic scaphoid stabilization" techniques, involving transplantation of one wrist extensor tendon onto the neck of the scaphoid to minimise its flexion (Seradge et al., 2004), will not be discussed in this article.

Indications of ligamentoplasties for the unstable scapholunate (SL) joint

The treatment of SL dissociations is stage dependent (Kitay and Wolfe, 2012; Wolf and Wolfe, 2016). In the early stages of SL ligament insufficiency, the secondary stabilizers are often able to preserve the overall carpal alignment, and only occasionally, under special loading conditions, the proximal pole of the scaphoid may displace beyond normal limits. Treatment in these early stages is mostly symptomatic, emphasizing restoration of the mechanisms of neuromuscular control of SL joint stability (Esplugas et al., 2016; Karagiannopoulos and Michlovitz, 2016; Wolff and Wolfe, 2016).

If the destabilizing forces keep acting on the wrist, the secondary stabilizers may deteriorate allowing progressive radio-carpal capsular elongation. In such circumstances, the occasional scaphoid subluxation may become permanent, forcing the rest of the carpal bones to adjust their positions to its new collapsed configuration. As long as carpal misalignment can be easily reduced, a tendon reconstruction may help controlling the underlying instability (Garcia-Elias and Lluch, 2016; Luchetti et al., 2013).

Once the wrist has collapsed, three concurrent phenomena can be observed. 1) the empty spaces so created are progressively filled with fibrosis; 2) the adjacent capsular tissues retract; and 3) the misaligned carpus becomes progressively stiff, and no longer reducible. In such advanced cases, the wrist is no longer unstable. Tendon reconstructions in such advanced cases make no sense (Garcia-Elias and Lluch, 2016; Kitay and Wolfe, 2012; Moran et al., 2006).

In short, there is good agreement in the literature as to when a tendon reconstruction is indicated. these techniques are only recommended for unstable, undisplaced or displaced but easily reducible SL dissociation with normal cartilage (Garcia-Elias and Lluch, 2016; Kitay and Wolfe, 2012; Moran et al., 2006). If carpal misalignment is not easily reducible or if the chronicity of the case has led to localized degenerative osteoarthritis, these techniques are seldom indicated.

Modalities of carpal ligamentoplasties using tendons

To restabilize the unstable carpus, three major types of ligamentoplasties have been recommended. 1: "SL loop" techniques; 2) reconstruction of the dorsal SL ligament; and 3) stabilization of the radio-scapho-trapezoid column.

1. Tendon ligamentoplasties of both palmar and dorsal SL ligaments; the" SL loops"

The technique described by Dobyns and Linscheid, known as the "SL loop", consisted of threading a strip of extensor carpi radialis longus (ECRL) tendon through two parallel dorsopalmar drill holes; one across the lunate, another across the proximal pole of the scaphoid. The aim was to create a loop around the joint; tightening it closes the SL diastasis (Palmer et al., 1978; Linscheid and Dobyns, 1992). The tendon strip was "distally based", i.e. it was not detached from its distal insertion onto the base of the second metacarpal. With this, the natural tendency of the lunate to rotate into extension ("Dorsal Intercalated Segment Instability" or DISI) would, in theory, be prevented. At follow-up, the results were considered "… sufficiently successful to warrant continued trial" (Palmer et al., 1978; Linscheid and Dobyns, 1992).

It took more than a decade for that "continued trial" to materialize. In 1991 Almquist et al., proposed a modified "SL loop" technique using a distally based strip of extensor carpi badialis brevis (ECRB) tendon. Aside from weaving that strip around the SL joint, the tendon was also used to reinforce the volar radio-scapho-lunate ligament of Testut in order to prevent the DISI pattern of malalignment (Almquist et al., 1991). Known as the "four-bone tendon weave", the technique involved large palmar and dorsal wrist incisions. At a mean follow-up of 56 months, 86% of patients had returned to their previous occupations with a mean arc of wrist flexion-extension of 89° and 73% of their contralateral grip strength. Recent publications by Corella et al., (2013) and Ho et al., (2015) have shown that most "SL loop" alternatives can be done arthroscopically with less morbidity and better results.

When drilling a tunnel across the proximal scaphoid, it is important to be aware of the risk of interfering with the poor blood supply of that part of bone. Should that happen, necrosis, fragmentation and early degenerative osteoarthritis are likely. As demonstrated by Palmer et al., (1978), Taleisnik (1985) and De Smet et al., (2011) this complication is not rare and gives marked morbidity encouraging alternative techniques.

2. Tendon stabilization of the radio-scapho-trapezoid column

Giorgio Brunelli reported on a different strategy to treat the unstable scaphoid (Brunelli and Brunelli, 1995). In this case a distally based strip of flexor carpi radialis (FCR) tendon was used to stabilize the radio-scapho-trapezoid column. The proximal end of the tendon strip was threaded through a transverse antero-posterior tunnel across the distal scaphoid and tightly reattached onto the dorsal rim of the radius, distal to Lister's tubercle. With this, two tenodeses were created - one volar scapho-trapezoid, another dorsal radio-scaphoid. The association of the two tenodeses was most effective in maintaining the scaphoid in its normal 45 degrees alignment relative to the main axis of the forearm. Although useful in preventing scaphoid collapse, and safe in terms of not violating the internal vascularization of the scaphoid, this innovative technique was found to have two major drawbacks: 1) it did not correct the lunate misalignment; and 2) it restrained wrist flexion too much (Moran et al., 2006). Yet, the early results reported by its conceivers were good (Brunelli & Brunelli, 1995). No long term follow up has been published of patients having had the original Brunelli technique.

To overcome the drawbacks of the original technique, several modifications were recommended (Corella et al., 2013; Garcia-Elias et al., 2006; Hyrkas et al., 2008; Sousa et al., 2014; Van den Abbeele et al., 1998). Most of them kept the first (volar) part of the procedure as originally recommended by Giorgio Brunelli. The dorsal part was modified in a variety of ways. Instead of reattaching the end of the tendon graft to the dorsal rim of the radius, Moran et al., (2006) recommended inserting it onto the dorsum of the lunate; Corella et al., (2013) suggested threading it through a

postero-anterior tunnel across the lunate; Ross et al., (2013) recommended rerouting the end of the tendon strip across the lunotriquetral joint and back again onto the scaphoid; and finally Van den Abbeele et al., (1998) and subsequently Garcia-Elias et al., (2006) proposed using the distal insertion of the dorsal radiotriquetral ligament to anchor the tendon strip. Although it was a modification of the Brunelli technique, the alternative described by Garcia-Elias and associates is known as the "three-ligament tenodesis" (3LT) (Garcia-Elias et al., 2006; Talwalkar et al., 2006).

3. Tendon ligamentoplasty of only the dorsal SL ligament

Isolated dorsal SL tendon ligamentoplasty was first reported by Pechlaner (2000), and later modified by Cizmar et al., (2010), and Fok and Fernández (2015). Two oblique tunnels were drilled across the dorsal corners of the scaphoid and lunate and a tendon graft was threaded through them to reconstruct only the dorsal component of the SL ligamentous complex. As with most other wrist ligamentoplasties, the short and mid-term results were encouraging (Cizmar et al., 2010); the long-term outcomes remain unknown.

Many treatments have been suggested for SL instability. Which one has the best chances of restoring acceptable levels of function for an adult with a symptomatic SL instability? To answer this we performed a systematic review of published outcomes, following PRISMA guidelines.

Materials and Methods

The databases Pubmed/MEDLINE and Cochrane Clinical Trial Register were searched from January 2000 to September 2016 to identify case series of non-arthritic wrists that had a tendon reconstruction of the SL ligaments as the only treatment for either an undisplaced SL dissociation or for a displaced but reducible SL instability. For a case series to be eligible, it had to have at least eight patients followed for at least 6 months. In order not to miss any significant study, different combinations of the following Medical Subject Headings (MeSH) were used: "scapholunate dissociation", "scapholunate instability", "ligament reconstruction",

"tendon reconstruction", "tenodeses" and "tendon transfer". From the title and abstract of the papers identified during the initial search, we pulled out all relevant articles for further analysis of their full text, using the above criteria.

Results

Table 1 shows the flowchart summarizing the selection of relevant articles for this review. The initial search identified 1983 publications about surgical management of chronic, non-arthritic SL dissociation. After evaluation of the abstracts, 1933 articles were excluded for not having quantitative information about the target question or for their being insufficient numbers of observations or duration of follow-up. From that first search, a total of 50 potentially eligible case series remained. Following further analysis of their full text we excluded 38 articles for a variety of reasons including unacceptable heterogeneity of the sample, the use of a combination of treatments, poor description of the surgical technique or inadequate outcome quantification. This left 13 case series, involving 299 patients (Table 2). Of those, 153 patients had the modified Brunelli technique described by Van de Abbeele et al., (1998); 78 had the 3LT technique described by Garcia-Elias et al., (2006); 29 had the modified Pechlaner technique described by Cizmar et al., 2010. 23 had the "four-bone tendon weave" descried by Almquist et al., 1990); and 17 had the arthroscopically guided "SL tendon loop" described by Ho et al., (2015).

Unfortunately, the evidence provided by the case series was of suboptimal quality. All analyses were retrospective; the number of patients per technique was too small; and the dispersion of outcomes too large to allow a meta-analysis. This, however, did not prevent us from having a close look at the available data. What follows are comments made after that analysis.

Complete pain relief and durable restoration of normal carpal alignment was seldom achieved regardless of the technique utilized. Most frequently, after a tendon reconstruction for carpal instability, the wrist is able to move actively up to 68% of its normal-flexion-extension, 85% of its radioulnar inclination and recovers 78% of its normal grip strength (Table 3).

Table 1 Flowchart summarizing the selection of relevant articles for this review

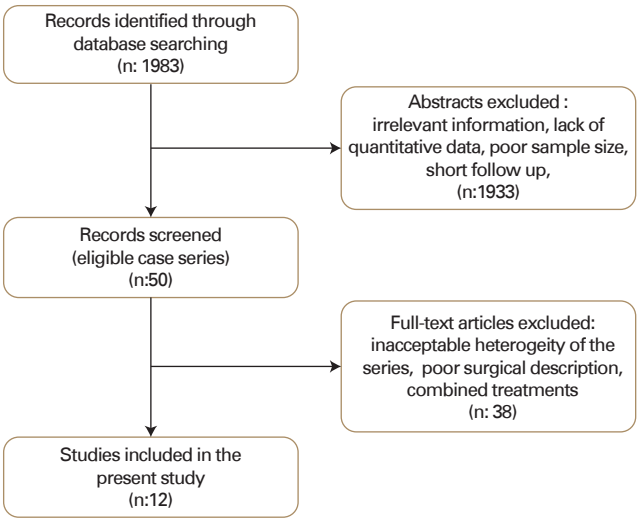

Table 2 Case series of patients who had SL ligamentoplasty using a tendon graft for the treatment of a chronic SL dissociation treated by tendon ligamentoplasty

Authors	N:	SLD Staging[1]	Technique	Tendon used	Avg. Follow-up (mo)
Elgammal and Lukas, 2016	20	4 *	3LT	FCR	24
Ho et al.,2015	17	3–4 *	Arthroscopic SL tendon loop	PL	48
Sousa et al., 2014	22	3-4 **	Modified Brunelli	FCR	61
Ellanti et al., , 2014	13	---	Modified Brunelli	FCR	12
Nienstedt, 2013	8	---	Modified Brunelli	FCR	165
Pauchard et al., 2013	20	2 -3 ***	3LT	FCR	25
Cizmar et al., 2010	29	2-3 *	Modified Pechlaner	PL +, FCR	37
Chabas et al., 2008	19	---	Modified Brunelli	FCR	37
Links et al., 2008	21	---	Modified Brunelli	FCR	29
Links et al., 2008	23	---	4-bone weave	ECRB	29
Moran et al., 2006	15	2-3 **	Modified Brunelli	FCR	36
Garcia-Elias et al., 2006	38	3-4**	3LT	FCR	46
Talwalkar et al., 2006	55	---	Modified Brunelli	FCR	48
TOTA.	**299**	**---**	**---**	**---**	**47**

SLD: Scapholunate dissociation. 3LT: Three-ligament tenodesis; FCR: Flexor Carpi Radialis; PL: Palmaris longus; ECRL: Extensor Carpi Radialis Longus;
Staging systems used. *SL. Stagin. according to Geisslet et al . (1996); **SLD Staging according to Garcia-Elias et al., (2006); SLD Staging according to Dréant and Dautel, (2003)

Table 3 Outcome of the patients who had SL ligamentoplasty using a tendon graft for the treatment of a chronic SL dissociation treated by tendon ligamentoplasty

Authors	Range of motion at follow-up (degrees)				Grip strength (% contralat)	Return to previous occupation (%)
	Flexion	Extension	Radial incl.	Ulnar incl.		
Elgammal and Lukas, 2016	60	68	20	42	84	76
Ho et al.,2015	54	41	19	31	81	75
Sousa et al., 2014	---	---	---	---	67	59
Ellanti et al., , 2014	38	56	20	20	75	100
Nienstedt, 2013	64	37	21	32	85	87
Pauchard et al., 2013	39	43	14	24	76	75
Cizmar et al., 2010	62	60	24	30	77	---
Chabas et al., 2008	41	50	24	29	78	63
Links et al., 200. (*)	45	55	13	21	84	---
Liinks et al., 200. (**)	27	36	14	21	84	---
Moran et al., 2006	40	43	16	26	87	73
Garcia-Elias et al., 2006	51	52	15	28	65	76
Talwalkar et al., 2006	45	55	17	29	80	34
TOTAL (Avg)	**47**	**49**	**18**	**28**	**78**	**71**

(*) Modified Brunelli; (**) Four-bone tendon weave

Insufficient evidence was found to declare one technique superior to another (Tables 4 and 5); yet there are trends. Wrists treated arthroscopically tended to have better ranges of motion and grip strength than those which had open reconstructions. By contrast, the differences between the modified Brunelli and the 3LT method were insignificant. In other words, attaching the end of the tendon graft onto the surface of the lunate or to the dorsal radiotriquetral ligament appears to be irrelevant: the outcomes obtained through both techniques are almost identical. (Tables 4 and 5)

Only one study compared two tendon reconstructions: the modified Brunelli technique (21 patients) and the "four-bone tendon weave" (23) (Links et al., 2008). The mean follow-up for the first group was 29 (range, 24-36) months and for the second 29 (range, 23-39) months. The patients that had the modified Brunelli technique had better pain relief, DASH scores, ranges of motion and grip strength than the patients who had a "four-bone tendon

weave"; the differences were all statistically significant (p<.001). The need for two long incisions, instead of one, may explain the larger reduction of motion after a "four-bone tendon weave" as compared to the modified Brunelli procedure.

Table 4 Average mobility of the wrist measured at follow-up per ligamentoplasty

Surgical technique			Avg. Range of motion at follow-up			
	Patients (n:)	Number of studies	Flexion	Extension	Radial incl.	Ulnar incl.
Modified Brunelli	110	5	46^0	48^0	20^0	27^0
3LT	78	3	48^0	45^0	16^0	27^0
Four-tendo. weave	23	1	27^0	36^0	14^0	21^0
Modified Pechlaner	29	1	62^0	60^0	24^0	30^0
Arthroscopic SL loop	17	1	60^0	68^0	20^0	42^0

Table 5 Average grip strength (% of contralateral) at follow-up per ligamentoplasty

Surgica technique	Patients (n:)	Number of studies	% Grip strength
Modified Brunelli	132	6	78%
3LT	78	3	74%
Four-tendon weave	23	1	84%
Modified Pechlaner	29	1	78%
Arthroscpic SL loop	17	1	84%

The only study comparing the outcome of a tendon reconstruction (modified Brunelli) with that of an alternative (capsulodesis) was published by Moran et al., (2006). Fourteen out of 29 patients with chronic SL dissociation had had a dorsal capsulodesis and 15 a modification of the Brunelli technique. The differences between the two groups were not statistically significant. At a mean follow-up of 36 (range 24–84) months the capsulodesis group showed a mean arc of flexion of 44° (range 10-55°), a mean arc of extension of 49° (range 15-70°) and a mean SL gap of 4.5 mm measured on unloaded postero-anterior wrist radiographs. The tenodesis group had a mean arc of wrist flexion of 40° (range 10-60°), a mean arc of extension o. 43° (20-65°) and a mean SL gap of 4.3 mm.

Discussion

A joint is said to be kinetically stable when it is capable of bearing physiologic loads without losing its normal anatomical relationships throughout the entire range of motion (IFSSH Anatomy and Biomechanics Committee, 1999). For this to occur there is a need for a precise coordination of both static (capsule and ligaments) and dynamic (muscles) stabilizers (Esplugas et al., 2016; Hagert et al., 2016; Riemann and Lephart, 2002a, Salva-Coll et al., 2013). Such coordination is mediated by the sensorimotor control system, a complex network of neural structures that control joint stability based on the proprioceptive information provided by multiple receptors located in the skin and within the fibres of tendons and capsular ligaments (Hagert et al., 2016; Riemann and Lephart, 2002b; Karagiannopoulos and Michlovitz, 2016).

It is a long time since the concept of ligaments being the only carpal stabilizers was proved to be wrong. Now there is clinical evidence suggesting that, for a joint to be stable, there is no need for all ligaments to be intact. It is not unusual to see individuals with apparently normal, stable, asymptomatic wrists who have substantial ligament tears during a routine radiographic examination. The existence of compensatory mechanisms ensuring stability despite the presence of considerable ligament defects is not speculation but a proven fact (Esplugas et al., 2016; Riemann and Lephart, 2002b). Indeed, stability is a multifactorial phenomenon in which ligaments play a significant role, but not as prominent as previously assumed. No matter how well a ligament has been reconstructed, if it has been done with a denervated portion of tendon, the graft is not likely to grow mechanoreceptors within its remodeled fibres and much less to be recognized by the sensorimotor system as an integral part of that system (Kim et al., 2012). When we reconstruct a "new ligament" using a denervated portion of tendon, the most we can hope for is to create a provisional tether that avoids unwanted subluxations while the sensorimotor control system adjusts its components to tackle the new unstable situation. In other words, reconstructing a ligament is no different to placing an internal splint that avoids a particular type of displacement; a helpful, but provisional solution.

Poor results are not always the consequence of a suboptimal ligament reconstruction; sometimes, it results from a wrong interpretation of what is unstable and what is not (IFSSH Anatomy and Biomechanics Committee, 1999). In many publications the carpus is said to be unstable when some or all of its elements are misaligned (Garcia-Elias and Lluch, 2016). Should that be correct, all well aligned wrists would be stable and all malaligned wrists should be unstable. Obviously, this is not always the case. There are normally aligned, yet unstable SL joints, and badly misaligned but stiff, thus stable, wrists. The first would be good candidates for tendon reconstruction, but not the second. If a stiff, malaligned wrist is treated as if it were unstable, the end result will always be disappointing. Techniques of ligament reconstruction cannot be blamed for failure when used for the wrong indication.

Recommendations For Future Research

Since the turn of the 21st century, wrist surgery has progressed considerably in incorporating and adapting state-of-the-art technology to the surgeon's needs, and designing specific treatment strategies for the different stages of carpal instability. Unfortunately, it has not progressed much in the clarification of questions such as: may an unstable wrist be normally aligned?; and is wrist malalignment always unstable? In theory, everybody involved in wrist surgery should know the answer to these questions. In practice, it is not unusual to see a modified Brunelli technique being used in malaligned, stiff wrists. No wonder those results are disappointing! Indeed, teaching the basics and clarifying misconceptions, particularly those influencing the treatment decision process, are the first and most important tasks that need being tackled. And, of course, when it comes to deciding what ligament reconstruction is best, one needs to be aware that ligaments are not cables that can be substituted by tendons without paying a functional penalty. Disseminating correct understanding of the mechanisms of stabilization is as important, if not more so, than planning prospective, randomized trials using a validated control group for comparison. Certainly, no real progress is possible if not based on a solid foundation. Nothing less is acceptable.

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3.4 Thumb TMC Joint Osteo-Arthritis

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Chapter structure

A. Introduction

B. Section 1. Systematic-review and meta-analysis: Trapeziectomy and hematoma arthroplasty, ligament reconstruction and tendon interposition arthroplasty (LRTI), trapezio-metacarpal (TMC) arthrodesis
   i. Material and methods (1)
   ii. Results (1)
   iii. Discussion (1)

C. Section 2. Systematic review: Thumb TMC total arthroplasty
   i. Material and methods (2)
   ii. Results (2)
   iii. Discussion (2)

D. Discussion

E. Conclusions

Introduction

Symptomatic thumb trapezio-metacarpal (TMC) joint osteo-arthritis (OA) may require surgery to excise, suspend, interpose or fuse the joint, after conservative treatment has failed. The most common procedures proposed to patients are: simple trapeziectomy and hematoma arthroplasty, arthroplasty with ligament reconstruction and tendon interposition (LRTI), spacer implant arthroplasty, partial or total joint replacement, joint fusion.

In recent years, there is increasing interest in establishing a consensus on which procedures are best for treating TMC OA. To date a final agreement has not been reached; even how to assess the outcomes better is still under debate. (Martou et al., 2004; Li et al., 2011; Wajon et al., 2015; Vermeulen et al., 2011).

No procedure has been shown to be better in terms of pain relief, physical function and global patient evaluation, moreover there are no consistent methods of evaluation to compare the different techniques. (Zafonte et al., 2014).

Current comparative studies are focused on a number of established surgical techniques. New options have also been proposed, e.g. arthroscopic or mini-open procedures, implant arthroplasties, biological fillers and osteochondral transplants.

Systematic reviews have been performed recently aiming to clarify what is still disputed. Simple trapeziectomy is the treatment of choice for thumb CMC J OA, based upon short term follow up. There is no evidence that LRTI is superior to simple total trapeziectomy. (Martou et al., 2004; Li et al., 2011; Wajon et al., 2015; Vermeulen et al., 2011; Zafonte and Szabo, 2014). Yet trapeziectomy and LRTI seems to be the treatment of choice for many surgeons. Wolff and colleagues recently reported of a survey on 1156 members of the American Society for Surgery of the Hand: the majority of the correspondents (62%) perform trapeziectomy with LRTI for Eaton stage III TMC OA, 16% would use trapeziectomy with TI, 6% trapeziectomy with pinning, 2% trapeziectomy without pinning, 2% implant arthroplasty, 12% other techniques. (Wolff and Delaronde, 2012)

Arthrodesis is rarely used if compared to biological arthroplasties; some authors advocate its use for younger active patients in early Eaton stages. (Kvarnes and Reikerås, 1985; Hartigan et al.,

2001; Mureau et al., 2001; Rossi et al., 2005; Hart et al., 2006).

TMC total arthroplasty is reported to give a more rapid recovery (Ulrich-Vinther et al., 2008); conversely there is an increased cost of the procedure and quite a number of specific complications such as implant loosening and subsidence, subluxation or dislocation and periprosthetic fracture (Giddins, 2012).

The purpose of this chapter is to analyse the current literature on the most common surgical procedures for primary TMC OA according to the PRISMA statement.

This chapter consists of two parts. The first one concerns biologic arthroplasties (simple trapeziectomy, trapeziectomy with ligament reconstruction or tendon interposition) and arthrodesis; a second section consists of a systematic review of TMC joint total replacement.

B. SECTION 1. SYSTEMATIC-REVIEW AND META-ANALYSIS:

i. Simple trapeziectomy and hematoma arthroplasty,

ii. Ligament reconstruction and tendon interposition arthroplasty,

iii. TMC joint arthrodesis

Materials and Methods (section1)

This systematic review was performed in accordance to the PRISMA statement and analysis.

Inclusion criteria

According to Jovell and Navarro-Rubio classification (Jovell et al., 1995), [table 1], we considered studies within levels I to V for the treatment of primary osteoarthritis (OA). We included meta-analysis of randomized controlled trials (RCTs), large-sample RCTs, small-sample RCTs, non-randomized controlled prospective trials, non-randomized controlled retrospective trials. All papers provided at least a comparison of two surgical techniques. Meta-analyses and systematic reviews were considered separately. The procedures were: simple trapeziectomy with or without hematoma distraction (the use of K wires or other distraction devices was recorded), trapeziectomy with ligament reconstruction, tendon interposition or both (LRTI), (temporary pinning with a K wire was recorded), tightrope suspension and arthrodesis with or without an associated bone graft. All articles were written in English.

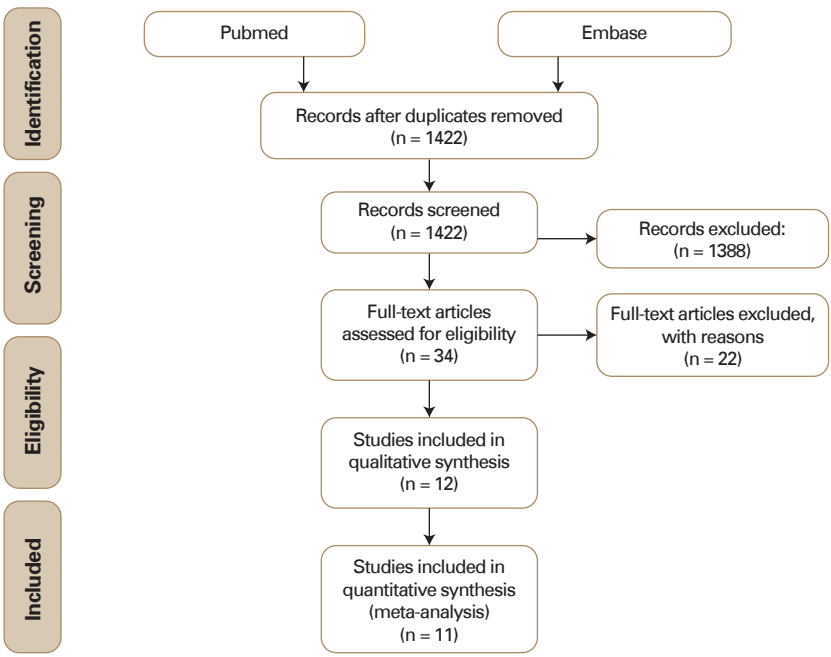
Exclusion criteria

We excluded studies comprising rheumatoid (RA) and post-traumatic arthritis as well as papers on revision procedures. Moreover, given the high incidence of TMC OA in females, we also excluded studies performed on a population mostly of men. We finally omitted studies where partial trapeziectomies were included.

Literature Search

The literature search was performed by two reviewers (GM, CC) in PubMed and EMBASE platforms, including articles up to 31st August 2016. A combination of the following terms was used for the research matching the anatomical site, the pathology and the kind of treatment: thumb or trapezio-metacarpal, TMC, CMC and arthrosis or arthritis, rizoarthrosis and trapeziectomy, arthrodesis, joint fusion, arthroplasty and ligament reconstruction and tendon interposition, suspension, LR, TI, LRTI. Two reviewers (GM and CC) independently included the articles on the basis of title and abstract and following the inclusion criteria. If in doubt or disagreement, a third reviewer (MC) was involved.

Figure 1



Assessment of methodological quality

Two reviewers independently assessed the methodological quality using the Coleman's scoring system (Coleman et al., 2000) [table 2 and 3]. In Part A it was not possible to establish the last parameter of the cited score, "compliance of patients to the rehabilitation" as in some of the studies it was not reported. Therefore the senior author elected to convert the item to "description of postoperative rehabilitation" with the following scores: good (10), fair (5), absent (0).

Part B, originally designed for the lower limb in patients performing sport, is unclear: the third item in section two and three was decoded by us as "recruitment rate reported: >80%" (5) [section 2] and "eligible subjects recruited in 100%" [section 3] (5).

Data extraction

Information about the kind of treatment, the stage of disease, the number of cases/patients, the ratio of men to women, the dominant/not dominant hand and the follow-up expressed in years or months were extracted.

Eight items were considered: pain, DASH score grip strength, key and tip pinch strength, ranges of motion (ROM) (palmar and radial abduction) and complications.

Pain was recorded when reported either in a visual analogue scale (VAS) score or in the pain section of the patient rated wrist and hand evaluation (PRWHE) pain scale. The VAS scores were converted to a mm scale (0-100). Infrequently used pain scores e.g. the Buck-Gramko assessment, were excluded.

Subjective functional evaluation was most commonly expressed as a DASH score; other score systems, such as PRWHE, were used occasionally.

Strength was recorded as grip, tip and key pinch; it was expressed in kilograms (correctly kilograms force) or Newton (N).

ROM was most commonly reported in terms of radial and palmar abduction, so these items were collected.

Complications were registered and divided into six groups: scar tenderness; nerve dysfunction (reported as "sensory disturbance" by some authors); pain related problems (persistent severe pain, CRPS); tendon related problems (tendonitis, including De Quervain's syndrome, "tendon pulling sensation", tendon lesion); infection (superficial or deep); and surgical revision for any reason (tendonitis, infection, neuroma, persistent pain, hardware complication, non-union).

For each study arm, the mean and standard deviations (SD) were recorded; when the SD was not reported, it was extrapolated from the corresponding standard error when available. In all studies with missing standard deviations or for any other doubts, the correspondent author was contacted by email to ask for the missing data.

Table 1 Jovell and Navarro-Rubio classification

Level	Strength of evidence	Type of study design
I	Good	Meta-analysis of randomized controlled trials
II		Large-sample randomized controlled trials (n≥ 25 for each group)
III	Good to fair	Small-sample sample randomized controlled trials (n≤ 25 for each group)
IV		Non-randomized controlled prospective trials
V		Non-randomized controlled retrospective trials
VI	Fair	Cohort studies
VII		Case–control studies
VIII	Poor	Non-controlled clinical series; descriptive studies
IV		Anecdotes or case reports

Table 2 Coleman methodology score system Part A

Section	Number or factor
Part A-only one score to be given for each of the seven section	
1. Study size (10)	>60 (10) 41-60 (7) 20-40 (4) <20, not stated (0)
2. Mean duration of follow-up (5)	>24 (5) 12–24 (2) <12, not stated or unclear (0)

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Section	Number or factor
3. Number of different surgical procedures included in each reported outcome (10)	One surgical procedure only (10) More than one surgical procedure, but >90% undergoing one procedure (7) Not stated, unclear, or <90% undergoing one procedure (0)
4. Type of study (15)	Randomized control study (15) Prospective cohort study (10) Retrospective study (0) Diagnostic certainty (5)
5. Diagnostic certainty (5)	In all (5) In >80% (3) In <80% (0)
6. Description of surgical procedure (5)	Adequate (5) Fair (3) Inadequate (0)
7. Description of postoperative rehabilitation (10)	Well described, >80% complying (10) Well described with 60%–80% complying (5) Protocol not reported or <60%–80% complying (0)

Table 3 Coleman methodology score system Part B

Section	Number or factor
Part B-scores may be given for each option in each of the three section if applicable	
1. Outcome criteria	Outcomes measures clearly defined (2) Timing of outcome assessment clearly stated (e.g. at best outcome after surgery or at follow-up) (2) Use of outcome criteria that has reported good reliability (3) Use of outcome with good sensitivity (3)
2. Procedure of assessing outcomes	Subjects recruited (results not taken from surgeons' files) (5) Investigator independent of surgeon (4) Written assessment (3) Completion of assessment by subjects themselves with minimal investigator assistance (3)
3. Description of subject selection process	Selection criteria reported and unbiased (5) Recruitment rate reported: >80% or <80% (5) Eligible subjects not included in the study satisfactorily accounted for or 100% recruitment (5)

Statistical Analysis

Meta-analyses were conducted using *metan* command with Stata 14.2 software (StataCopr, College Station, TX). Missing SD

were imputed as the mean value of SDs in other studies in the meta-analysis. Random-effects were used in all cases since high heterogeneity was expected. Data were not pooled if heterogeneity was very high (I-square>75%) unless point estimates were in the same direction of benefit or harm. A "leave-one-out" sensitivity analysis was conducted to examine the effect of each study on the pooled estimate.

Results (section 1)

At a first screening PubMed and EMBASE showed 1422 potential articles for systematic review. On the basis of title and abstract, and papers written in a language other than English, 1388 papers were excluded. The main reason of exclusion for clinical trials was the absence of a control group. The remaining 34 articles were evaluated for inclusion/exclusion criteria in the full text. In this group, further exclusion criteria were studies including patients affected by conditions different from OA (RA, post-traumatic osteoarthritis) (De Smet et al., 2004; Schröder et al., 2002), studies including revision procedures, series including patients with a follow-up shorter than 12 months (Davis and Pace 2009; Park 2008), studies which were not clear on how the data had been referred to the examined groups (Hollevoet et al., 1996 ; Taylor et al., 2005) and series with a preponderance of men (Sandvall et al., 2010). Groups including partial trapeziectomy were also excluded. (Burton and Pellegrini 1986, Schröder et al., 2002; García-Mas and Solè 2009).

Finally, 12 studies met all selection criteria; four systematic reviews were taken into account for discussion [Fig. 1].

The data derived from the selected studies were grouped according to the type of treatment: group 1 simple trapeziectomy; group 2 trapezectomy and TI or LRTI; and group 3 TMC arthrodesis. Group 1 included simple trapeziectomy and hematoma distraction arthroplasty, group 2 included trapezectomy with TI/LRTI with FCR, APL or PL tendons ND group 3 included arthrodesis performed by mini condylar blade, mini plate and screws or Kwires, with or without bone graft.

No studies reporting simple ligament reconstruction after trapeziectomy fulfilled the criteria.

The overall number of cases in this systematic review was 979; there were 267 cases in group 1, 479 in group 2, and 233 in group 3. The weighted average follow-up was a mean of 63 (64 for group 1, 61 for group 2, and 64 for group 3) months. The weighted mean patient age was 58 (60 for group 1, 59 for group 2 and 53 for group 3) months.

Methodological quality evaluation

If the methodology score was lower than 50 points, the study was discussed for inclusion by all the authors. All included studies were then considered in the quantitative analysis.

Table 4

	Kvarnes 1985	Hartigan 2001	Mureau 2001	Rossi 2005	Hart 2006	Raven 2007	Field 2007	Salem 2012	Gangopadhyay 2012	Vermeulen 2014	Elvebakk 2015	Corain 2016
1.Study size (10)	10	10	7	10	4	10	10	10	10	4	10	10
2. Mean duration of follow-up (5)	5	5	5	5	5	5	2	5	5	2	5	5
3. Number of different surgical procedures included in each reported outcome (10)	10	10	10	10	10	10	10	7	7	10	10	10
4. Type of study (15)	15	0	0	0	15	0	15	15	15	15	15	15
5. Diagnostic certainty (5)	5	5	3	5	3	5	5	0	5	5	5	5
6. Description of surgical procedure (5)	3	5	3	5	5	5	5	5	5	5	3	3
7. Description of postoperative rehabilitation (10)	5	5	5	5	5	5	5	5	5	5	5	5
Outcomes measures clearly defined (2)	2	2	2	2	2	2	0	2	2	2	0	0
Timing of outcome assessment clearly stated (e.g. at best outcome after surgery or at follow-up) (2)	2	2	2	2	2	2	2	2	2	2	2	2
Use of outcome criteria that has reported good reliability (3)	3	3	3	0	0	3	3	3	0	3	3	3
Use of outcome with good sensitivity (3)	3	3	3	3	3	3	3	3	3	3	3	3
Subjects recruited (results not taken from surgeons' files) (5)	0	0	0	0	0	0	0	0	0	0	0	0
Investigator independent of surgeon (4)	0	4	0	0	0	4	4	0	4	4	0	0

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	Kvarnes 1985	Hartigan 2001	Mureau 2001	Rossi 2005	Hart 2006	Raven 2007	Field 2007	Salem 2012	Gangopadhyay 2012	Vermeulen 2014	Elvebakk 2015	Corain 2016
Written assessment (3)	0	3	3	0	3	3	3	3	3	3	3	3
Completion of assessment by subjects themselves with minimal investigator assistance (3)	0	3	3	0	3	3	0	3	3	3	3	3
Selection criteria reported and unbiased (5)	0	0	0	0	0	0	5	5	5	5	5	5
Recruitment rate reported: >80% or <80% (5)	5	5	0	0	5	5	5	5	5	5	0	5
Eligible subjects not included in the study satisfactorily accounted for or 100% recruitment (5)	5	0	0	0	5	0	5	0	0	5	0	5
Total	73	65	49	47	70	65	82	73	79	81	72	82

Characteristics of studies included

Kvarnes et al. in 1985 published the outcomes of the treatment of TMC OA by trapezium excision (five cases), arthrodesis with staples (18 cases), and Swanson replacement (seven cases) compared to an external control group of 22 patients. The study population was of 69 subjects (M:F=17:52) with a mean age at surgery of 56 years, with disease stages I to V (Kellgren & Lawrence) and a final follow-up of 72 (range: 24-132) months. Complications were not reported and unfortunately the measurement of grip strength, tip pinch, and key pinch were obtained with a dynamometer in Kp (Central Institute of Industrial Research, Oslo) with a scale not comparable with other dynamometers (as a consequence, this study is the only one of the twelve that could not be used for any quantitative analysis). The Authors concluded that the procedure of choice was the arthrodesis (Kvarnes and Reikerås, 1985)

Hartigan et al. (2001) compared arthrodesis and trapeziectomy with LRTI (FCR). The first group had 44 thumbs (37 women and five men) with a follow-up of 73 months; the second was composed by 49 thumbs (36 women and 3 three men) with a mean follow-up of 63 months. The disease stages were Eaton II to IV.

The evaluated parameters (grip strength measured by Jamar, key pinch, and tip pinch, VAS for pain, radial and palmar abduction and complications) are reported in table 2; however, standard deviations were missing. The authors found comparable outcomes for the two procedures, except for a slight increase in TMC ROM following LRTI. The subjective outcomes were similar, with high levels of satisfaction. The rate of complications was higher after arthrodesis, but mostly these were minimally symptomatic. (Hartigan et al., 2001)

Mureau et al. (2001) retrospectively compared 24 thumbs (13 women and four men) treated by tendon interposition arthroplasties (with FCR, PL or APL) and 32 by arthrodesis (23 women and three men) fixed by K-wires with or without the use of an autologous bone graft. The mean follow-ups were 6 and 7.4 years respectively. Stages I to IV (Eaton & Littler classification) were included. Grip strength and thumb tip and key pinch strengths were measured with a Greenleaf Medical pinchmeter and a Jamar dynamometer. VAS scores and complications were reported. In the arthrodesis series, the authors found non-unions in three cases out of 14 using an iliac crest bone grafting compared with four out of 11 patients treated without bone grafting. No statistically significant difference was found in tip pinch, key pinch and grip strength between the tendon interposition arthroplasty and arthrodesis groups even if LRTI arthroplasty was considered preferable to arthrodesis in advanced stages of arthritis. Arthrodesis in isolated TMC OA was judged as good as LRTI when associated with good interphalangeal (IP) and metacarpophalangeal (MCP) joint mobility. (Mureau et al., 2001)

Rossi et al. (2005) reported a retrospective study in which 78 thumbs treated with arthrodesis by K-wires were compared to 41 thumbs treated with trapeziectomy and tendon interposition with the APL tendon. The follow-up was a mean of 36 months for both groups; the disease stages were II to IV following the Eaton classification. Grip strength was measured by a Jamar dynamometer. Tip pinch (Baseline Mechanical Pinch Gauge) and key pinch,

radial and palmar abduction and complications were reported. Standard deviations were not available. The authors concluded that disease stage and patients' level of activity and employment should guide the choice of surgical strategy. Stages II and III in Eaton's classification may be treated with joint fusion, while stage IV characterized by STT involvement should be treated by LRTI. The authors noted that arthrodesis is a reliable surgical strategy in Eaton's stage III or less, regardless of the patient's age, providing greater pinch strength (Rossi et al., 2005).

Hart et al. (2006) performed a randomized prospective controlled trial to compare arthrodesis to trapeziectomy and LRTI with a radial split of FCR. The two groups consisted of 20 thumbs each, with a mean follow-up of 6.8 years treating stage IV disease (Eaton & Littler classification). Twenty-four were women and 13 men. All patients were evaluated with the Buck-Gramcko score. Six months post-operatively the functional recovery was slower and the post-operative pain lasted longer in patients undergoing arthroplasty; however outcomes were similar over a longer follow-up. It is to be noted that only older patients reported a subjective better performance after arthroplasty than fusion. The authors concluded that arthrodesis was better for younger and active subjects, while arthroplasty was adequate for older patients. (Hart et al., 2006)

Raven et al. (2007) published a non-randomized controlled study comparing 18 simple trapeziectomies (11 women and seven men) to 17 LRTI with FCR (14 women and three men), and 28 arthrodesis by mini-plate (24 women and four men). The mean ages were 58, 65 and 61 years respectively; the mean follow-ups were 13, 8 and 9 years respectively. Grip strength (measured by a Jamar dynamometer: Therapeutic instrument™, Clifton, N.J. 07012,U.S.A.), tip pinch and key pinch strength, VAS, radial abduction and DASH survey were recorded and reported in table 2, as well as complications. The standard deviations for all cohorts were kindly provided by the Author following our request. According to the results, simple trapeziectomy showed similar good

long-term outcomes compared to trapeziectomy combined with tendon interposition and TMC arthrodesis. Resection arthroplasty had fewer complications and re-interventions compared to arthrodesis and does not require a tendon harvest (Raven et al., 2007).

Field and Buchanan (2007) published a randomized controlled single blind trial of simple trapeziectomy (32 cases, with 28 women and four men) versus LRTI with a split FCR tendon (33 cases with 28 women and five men). The mean age was 55 years; the follow-up was at least 12 months. Grip strength, tip pinch and key pinch were measured with a Jamar dynamometer and a pinchmeter (Jamar Technologies Inc. Clifton, NJ, USA); VAS, radial and palmar abduction and complications were reported. In this study, data had to be extracted from diagrams; standard deviations were obtained from the Cochrane collaboration (Wajon et al., 2015). It is to be noted that the key pinch values in the paper were discordant from those obtained by the Cochrane collaboration: for this reason, these datawere ignored in this study. No significant differences between the two groups were found for grip strength, key pinch and tip pinch. The complication rate was higher in the LRTI group but this was not significant. In conclusion, there was no benefit for LRTI with FCR split over trapeziectomy (Field and Buchanan 2007).

Salem and Davis published a randomized controlled study comparing simple trapeziectomy (59 cases; 51 women and eight men) and trapeziectomy with LRTI with FCR (55 cases; 46 women and nine men). The mean follow-up was 6 (range 4.2-8.1) years. The Cochrane collaboration contacted Davis to confirm that this study was based on the same cohort of patients reported in 2009 in another of his studies. Seventeen patients underwent bilateral surgery (simple trapeziectomy in one thumb and trapeziectomy with LRTI on the other); data showed slightly better results in key and tip pinch with LRTI (without statistical significance, p:0,75 and 0,62). The kind of dynamometer used was not reported. Other clinical data are summarised in table 2 (as standard deviations

obtained by Cochrane collaboration are discordant for key pinch values these results were not considered). Additional procedures were: thumb metacarpophalangeal joint (MCP) K-wiring; MCP joint capsulodesis; carpal tunnel release; De Quervain's release; and trigger thumb release.

Gangopadhyay et al. (2012) reviewed 153 cases of the same cohort of patients studied by Davis et al. in 2004 (Wajon et al., 2015), including 53 cases of simple trapeziectomy, 46 trapeziectomies with PL interposition, and 54 trapeziectomies with LRTI with FCR interposition. The mean follow-up was 6 (range: 5-18) years. All patients were women with a mean age of 57 years. The stages of disease were II to IV (Eaton & Littler classification). The study took into consideration grip strength and tip and key pinch strength (calibrated grip and pinch meter Jamar, Jackson, MO); VAS scores were not available. Complications were reported. Additional procedures were: MCP K wiring; MCP joint capsulodesis or fusion; carpal tunnel release,; De Quervain's release; and trigger thumb release. The authors did not find any benefit from LRTI over simple trapezectomy at 5 years follow-up: they concluded that the simple excision of the trapezium was the most important "effective component" of surgery as the additional soft tissue procedures did not give any further benefit (Salem and Davis 2012).

Vermeulen et al. (2014) published a randomized controlled trial of arthrodesis versus trapeziectomy and LRTI with an FCR split. The patients were all women over 40 years of age, with Eaton disease stage II to III. The first group had 17 and the second 21 patients. All of the patients were followed-up at 12 months. Pain, extracted from PRWHE survey and DASH scores, grip strength, measured with a hydraulic hand dynamometer (E-link H500 hand Kit, Biometrics, Gwent, UK), tip and key pinch strengths and complications were reported. The authors found more moderate to severe complications and more revision procedures following TMC arthrodesis compared to trapeziectomy with LRTI. Furthermore, patients showed a preference for trapeziectomy and LRTI, even if their scores at PRWHE and DASH survey were similar. They did

not recommend arthrodesis in the treatment of stage II or III TMC OA in women over 40 years of age. (Vermeulen et al., 2014)

Elvebakk et al. (Elvebakk et al., 2015; Saehle et al., 2002) published a review of 49 cases of simple trapeziectomy compared to 55 cases of trapeziectomy and LRTI with APL in the same hospital. The mean follow-ups were 2.2 and 3.5 years respectively. The stages of the disease as well as the ratios of men to women are not available. VAS scores, grip strength (measured by Jamar dynamometers -JA Preston Corp, Clifton, NJ, USA), key pinch, radial abduction and DASH were reported. The results were similar in the two groups; the outcomes were mostly better after simple trapeziectomy. The authors conclude that the outcome with simple trapeziectomy is at least as good as trapezectomy with APL LRTI and therefore this should be preferred. (Elvebakk et al., 2015)

Corain et al. compared hematoma distraction trapeziectomy (56 cases; 41 women and 15 men) to APL LRTI (64 cases; 53 women and 11 men). Stages of disease were Eaton III to IV. The follow-up was 6.6 and 7 years respectively. Grip strength, tip pinch, and key pinch were evaluated (no reference to the method of evaluation is reported in the article; the Author confirmed by email that a Jamar dynamometer had been used and Newton was the unit of measure). No complications were reported for simple trapeziectomy, while LRTI had 15% of FCR tendonitis. The Authors recommend simple trapeziectomy instead of LRTI for the better results in terms of pain relief and a lower rate of complication, whereas no significant differences in grip and pinch strength were found. (Corain et al., 2016)

Four systematic reviews were found on the PubMed and Embase databases: surgery for thumb (trapeziometacarpal joint) osteoarthritis (Review), published in 2015 by Cochrane collaboration (Wajon et al., 2015); surgical treatment of osteoarthritis of the carpometacarpal joint of the thumb: a systematic review, edited by Martou in 2004 (Martou et al., 2004); Surgical management of primary thumb carpometacarpal osteoarthritis: a systematic review, by Vermeulen et al. in 2011 (Vermeulen et al.,

2011); and comparison of trapeziectomy and trapeziectomy with ligament reconstruction and tendon interposition: a systematic literature review, edited in 2011 by Li et al. (Li et al., 2011.) Another systematic review published in 2006 in the Chinese Journal of Evidence-Based Medicine, written in Chinese, was not considered. (Kan et al., 2006)

Martou et al. (2004) examined 26 articles with 18 comparative studies and eight systematic reviews including stage II Eaton or greater, in order to identify the surgical technique offering the best outcome. The techniques taken into consideration were trapeziectomy with and without interposition, arthrodesis, osteotomy, and joint replacement. The authors found a great variability in outcomes measurement and no specific technique was identified to give better results. Data showed that ligament LRTI gave no additional benefit when compared with TMC fusion and trapeziectomy alone or with TI. (Martou et al., 2004)

Vermeulen et al. (2011) compared eight surgical techniques: volar ligament reconstruction; metacarpal osteotomy; TMC arthrodesis; implant joint replacement; trapeziectomy; trapeziectomy with TI; trapeziectomy with LR; and trapeziectomy with LRTI. Their results, in agreement with other reviews, showed that no surgical procedure is proven to be superior to another and that trapeziectomy with LRTI was associated with a higher complication rate versus simple trapeziectomy. (Vermeulen et al., 2011)

Yu Kit Li et al. (2011) reported a systematic review on randomized controlled trials comparing simple trapeziectomy and LRTI on the following criteria: key and tip pinch; postoperative adverse events; pain scores; DASH scores; and grip strength. Two systematic reviews and four randomized controlled trials were identified and included; no statistically significant differences were found. The authors recommended a new systematic review on randomized controlled trials with a longer follow-up and homogeneity in terms of Eaton staging and the surgical interventions. (Li et al., 2011)

Wajon et al. (2015) updated the 2005 and 2009 Cochrane reviews, selecting randomized, or quasi-randomised, controlled trials (RCTs); the review consists of 11 studies and 670 participants. The treatments included were: trapeziectomy; trapeziectomy with LR; trapeziectomy with interpositional arthroplasty (IA); LRTI; Artelon joint resurfacing; Swanson joint replacement; and TMC arthrodesis. No procedure demonstrated any superiority over another in terms of pain, physical function, quality of life, patient global assessment, adverse events or treatment failure (re-operation). Low quality evidence suggests that trapeziectomy with LRTI does not provide additional benefits and results in more adverse events, over trapeziectomy alone. (Wajon et al., 2015)

Table 5

Authors	Treatment	Stage Disease	Evidence	Cases	Mean age at surgery	Follow-up
Kvarnes et al. 1985	Total Trapeziectomy	Kellgren & Lawrence III-V	Level V	12 M:F 17:52	56 R 45-70	72 m. R 24-132
Raven et al. 2007	Total Trapeziectomy	Eaton II-III	Level V	18 F:M 11:7 D:ND 13	58 R 38-76	13y R 3-23
Field and Buchanan 2007	Total Trapeziectomy	Eaton III- IV	Level II	32 F:M 28:4 D:ND 20:12	55 R 49-75	12 m.
Salem and Davis 2012	Total Trapeziectomy	N.A.	Level II	59 F:M 51:8, 17 bilateral	N.A.	6.2 y R 4.2-8.1
Gangopadhyay et al 2012	Total trapeziectomy with hematoma and distraction (K-wire)	Eaton and Littler II-IV	Level II	53 F:M 53:0 D:ND 30:23	57 R 44-74	6y median R 5-18
Elvebakk et al 2015	Total Trapeziectomy	N.A.	Level V	49 F:M 42:7	65 R 48-77	26 m. R 15-26
Corain et al 2016	Total trapeziectomy with hematoma and distraction (K-wire)	Eaton III-IV	Level II	56 F:M 41:15	63.5 R 45-77	6.6 y R 3-10

Table 6

Authors	Pain (SD, p value)	Grip strength (SD, p value)	Key pinch (SD, p value)	Tip pinch (SD, p value)	Palmar, Radial Abduction (SD, p value)	DASH (SD, p value)	Complications
Kvarnes et al. 1985	VAS N.A.	n 5 Post 11.4 Kp SD 5.8	2.8 Kp SD 1.3	n 5 Post 2.7 Kp SD 1.8	N.A.	N.A.	N.A.
Raven et al. 2007	Post 4 (0-100) SD 18, 2 vs 3 p > 0.05 1 VS 2 p > 0.05 1 VS 3 p 0.02	Post 22 Kg SD 12, 2 vs 3 p > 0.05 1 VS 2 p > 0.05 1 VS 3 p > 0.05	N.A.	Post 2.7 Kg SD 0.6, 2 VS 3 p > 0.05 1 VS 2 0.029 1 VS 3 0.017	Rad Post 45° p=0.0001 1 VS 2, p=0.0046 2 VS 3	Post 26 SD 25, 2 vs 3. p > 0.05 1 VS 2 p > 0.05 1 VS 3 p > 0.05	2 Superficial radial nerve dysfunction 1 re-resection
Field and Buchanan. 2007	Pre 7.6 SD 1.3 Post 1.6 (0-10) § SD 2.3 ⓘ	Pre15 post 19 Kg §	Pre 3.5 Post 4.6 Kg § ⃠	Pre 2.7 Post 4.1 Kg §	Rad Pre 52° Post 70° SD 3.1 Palm Pre 49° Post 54° SD 2.5	N.A.	2 superficial wounds infections 1 Superficial radial nerve dysfunction 1 CRPS
Salem and Davis 2012	VAS N.A.	Pre 17.1 Post 21.8 Kg p>0.1 SD 8.17ⓘ	Pre 4 Post 3.7 Kg ⃠ p>0.1	Pre 2.7 Post 2.8 Kg p>0.1 SD 1.47 ⓘ	N.A.	Pre 53 Post 31 SD 19.18 ⓘ	3 Palmar cutaneous branch of Median Nerve dysfunction 1 De Quervain's disease 1 CRPS
Gangopadhyay et al 2012	VAS N.A.	Pre 14 Post 20 Kg median p 0.908	Pre 3.6 Post 4.1 Kg median p 0.471	Pre 2.3 Post 2.7 Kg median p 0.681	N.A.	N.A.	2 Sup. radial n. dysfunction, 2 Palmar cutaneous median n. dysfunction
Elvebakk et al 2015	4 R 0-83 (0-100) median	Post 28 Kg SD 17	Post 4 Kg SD 2	N.A.	Rad Post 49° SD 9	Post 25 median	1 Avulsion of EPB, 1 partial rupture of FCR
Corain et al 2016	Pre 9.5 Post 0.9 (0-10) SD 0.3 p<0.05	Pre 109.8Post 176.5 Newton, 17.99 Kg SD 6.8 (0.69)	Pre 16.7 Post 48 Newton, 4.89 Kg SD 4.9 (0.49)	Pre 15.3 Post 41.2 Newton, 4.2 Kg SD 8.8 (0.89)	N.A.	Post 17 SD 1.9	No complication

Table 7

Authors	Treatment	Disease Stage	Evidence	Cases	Mean age at surgery	Follow-up
Hartigan et al. 2001	Total Trapeziectomy With LRTI (FCR)	Eaton II-IV	Level V	49/68 F:M 36:3	52 R 43-59	63 m. R 26 -108
Mureau et al. 2001	Trapeziectomy With TI (FCR,PL,APL)	Eaton & Littler I-IV-Unknow	Level V	24 F:M 13:4	57.6	6 y
Rossi et al. 2005	Total Trapeziectomy with TI (APL)	Eaton III-IV	Level V	41	58	36 m.
Hart et al. 2006	Trapeziectomy With LRTI (FCR)	Eaton & Littler IV	Level III	20 F:M 24:13	59 R 49-75	6.8 y R 2-10
Raven et al. 2007	Total Trapeziectomy With LRTI (FCR)	Eaton 0-IV	Level V	17 F:M 14:3 D:ND 6:11	65 R 47-80	8 y R 5-12
Field and Buchanan 2007	Total Trapeziectomy With LRTI (FCR)	Eaton III-IV	Level II	33 F:M 28:5 D18:15	55 R 49-75	12m.
Salem and Davis 2012	Total Trapeziectomy With LRTI (FCR)	N.A.	Level II	55 F:M 46:9, 17 bilateral	N.A.	6.2 y R 4.2-8.1
Gangopadhyay et al. 2012	Total trapeziectomy with TI (PL) + K-wire	Eaton and Littler II-IV	Level II	F:M 46:0 D:ND 22:24	57 R 40-75	6y median R 5-18
	Total trapeziectomy with LRTI (FCR) + K-wire	Eaton and Littler II-IV		F:M 54:0 D:ND 22:32	57 R 44-55	
Vermeulen et al. 2014	Total trapeziectomy with LRTI (FCR)	Eaton II-III	Level II	21 F:M 21:0	59	12 m.
Elvebakk et al. 2015	Total Trapeziectomy With LRTI (APL)	N.A.	Level V	55	58 R 44-73	3.5 y R 1-5
Corain et al. 2016	Total Trapeziectomy with TI (APL)	Eaton III-IV	Level II	64 F:M 53:11	61.5 R 45-77	7 y R 3-10

Table 8

Authors	Pain (SD, p value)	Grip strength (SD, p value)	Key pinch (SD, p value)	Tip pinch (SD, p value)	Palmar, Radial Abduction (SD, p value)	DASH (SD, p value)	Complications
Hartigan et al. 2001	Post 2.1 (0-10) p > 0.05	Post 25 Kg p > 0.05	Post 5 Kg p<0.001	Post 4 Kg p > 0.05	Rad Post 48° Palm Post 47°	N.A.	4 Persistent pain (> 3 m) 1 sup. wound infection 1 CRPS
Mureau et al. 2001	Post 23.5 (0- 100) SD 26.9 p 0.030	Post 22.4 Kg SD 10.3 p 0.760	Post 5.4 Kg SD 2 p 0.971	Post 3.4 Kg SD 1.7 p 0.753	N.A.	N.A.	1 infection 1 CRPS 1 persistent pain
Rossi et al. 2005	VAS N.A.	23 Kg	4.6 Kg	3.8 Kg	Rad Post 45° Palm Post 43°	N.A.	6 first metacarpal base collapse
Hart et al. 2006	VAS N.A. Buck Gramco Score	N.A.	N.A.	N.A.	N.A.	N.A.	2 CRPS (resolved after physioterapy) 3 persistent pain
Raven et al. 2007	Post 10 (0- 100) SD 15, 2 vs 1 p > 0.05 1 VS 2 p > 0.05 1 VS 3 p 0.02	20Kg SD 8, 2 vs 3 p > 0.05 1 VS 2 p > 0.05 T VS A p > 0.05	N.A.	3 Kg SD 0.3 2 VS 3 p > 0.05 T VS 2 0.029 T VS 3 0.017	Rad Post 64° p=0.0001 1 VS 2, p=0.0046 2 VS 3	27 SD 26, 2 vs 3 p > 0.05 1 VS 2 p > 0.05 1 VS 3 p > 0.05	4 Sup. radial nerve dysfunction 1 CRPS type 1
Field and Buchanan 2007	Pre 7.6 SD 1.9 Post 1.5 (0-10) § SD 1.8 ⓘ	Pre 16 Post 23 Kg	Pre 3.9 Post 4.9 Kg § ⃠	Pre 2.5 Post 3.8 Kg §	Rad Pre 54 Post 58° SD 2.4 Palm Pre 50° Post 62° SD 2.2	N.A.	1 superficial wound infection 1 Superficial radial nerve dysfunction 6 wound adherence 4 CRPS
Salem and Davis 2012	VAS N.A.	Pre 16.6 post 24.1 N.A. p>0.1 SD 9.98 ⓘ	Pre 4 post 4.1 Kg p>0.1⃠	Pre 2.9 Post 3 Kg p>0.1 SD 1.06 ⓘ	N.A.	Pre 49 Post 30 SD 29.59	4 Sup. radial nerve dysfunction 1 FCR pulling 1 De Quervain's disease 1 Scar tenderness

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Gangopadhyay et al. 2012	VAS N.A. p 0.383	Pre 13 Post 18 Kg median p 0.908	Pre 3.5 Post 3.4 Kg median p 0.471	Pre 2.3 Post 2.5 Kg median p 0.681	N.A.	N.A.	2 Sup. radial n. dysfunction, 2 Palmar cutaneous median n. dysfunction, 1 FCR/pollicis longus pulling sensation
	VAS N.A.	Pre 13 Post 20 Kg median p 0.908	Pre 3.2 Post 3.6 Kg median p 0.471	Pre 2.3 Post 2.7 Kg median p 0.681	N.A.	N.A.	1 Sup. radial n. dysfunction, 3 Palmar cutaneous median n. dysfunction, 2 FCR/pollicis longus pulling sensation, 2 Scar tenderness
Vermeulen et al. 2014	VAS N.A. PRWHE PAIN RANGE 0-50 Pre 33.9 Post 16 SE 2.7	Pre 21.2 Post 23.2 Kg SE 1.1	Pre 4.8 Post 4.4 Kg SE 0.3	Pre 2.8 Post 3.1 Kg SE 0.3	N.A.	Pre 44.3 Post 20.6 SE 3	3 Sensory disturbance 2 Tendinitis succesfully treated with corticosteroid 1 Mild CRPS type I
Elvebakk et al. 2015	11 R 0-85 median	21 Kg SD 10	3.8 Kg SD 1.4	N.A.	Rad Post 51° SD 16	median 28 R 0-84	4 Sup. radial nerve dysfunction
Corain et al. 2016	Pre 8.5 Post 2 (0-10) SD 0.4 p<0.05	Pre 123.6 Post 181.3 Newton SD 1.7 (18.48 Kg SD 0.17)	Pre 17.6 Post 54.9 Newton SD 4.9 (5.59 Kg SD 0.499)	Pre 20.6 Post 42.1 Newton SD 2.9 (4.29 Kg SD 0.295)	N.A.	18.2 SD 1.2	9 cases of FCR tendinitis

Table 9

Authors	Treatment	Disease Stage	Evidence	Cases	Mean age at surgery	Follow-up
Kvarnes et al.1985	TMC arthrodesis (Staples)	Kellgren & Lawrence I-II	Level V	53 (no bone graft)	56 R 45-70	72 m. R 24-132
Hartigan et al. 2001	TMC arthrodesis (K-wires 40, tension band 2, minicondylar blade plate 16)	Eaton II-III	Level V	58 F:M 37:5, 44 (+ bone graft), 14 (no bone graft)	51 R 41-59	73 m. R 27 -252
Mureau et al. 2001	TMC arthrodesis (K-wires)	Eaton & Littler I-IV-Unknow	Level V	32 F:M 23:3, 15 (+ bone graft) 17 (no bone graft)	54.2	7.4 y
Rossi et al. 2005	TMC arthrodesis (K-wires)	Eaton II-III	Level V	78 (no bone graft)	48.5	36 m.
Hart et al. 2006	TMC arthrodesis (K-wires)	Eaton & Littler IV	Level III	20 F:M 24:13, 20 (no bone graft)	55 R 49-75	6.8 R 2-10 y
Raven et al. 2007	TMC arthrodesis (Mini plate)	Eaton 0-IV	Level V	28 F:M 24:4 D12, 7 (+ bone graft) 21 (no bone graft)	61 R 46-78	9 y R 4-27
Vermeulen et al. 2014	CMC arthrodesis (Plate and Screws)	Eaton II-III	Level II	17 F:M 17:0, 17 cases (no bone graft)	59	12 m.

Table 10

Authors	Pain (SD, p value)	Grip strength (SD, p value)	Key pinch (SD, p value)	Tip pinch (SD, p value)	Palmar, Radial Abduction (SD, p value)	DASH (SD, p value)	Complications
Kvarnes et al.1985	VAS N.A.	n 18 Post 16.1 Kp SD 8.8	n 18 Post 5.1 Kp SD 1.7	n 18 Post 4.8 Kp SD 2.4	N.A.	N.A.	N.A.
Hartigan et al. 2001	n 44 Post 3.1 (0-10) p > 0.05	n 44 Post 25 Kg p > 0.05	n 44 Post 6 Kg p<0.001	n 44 Post 5 Kg p > 0.05	Rad Post 45° Palm Post 42°	N.A.	16% 9/58 non-union (1 plate) 3 revisioned with graft and plate 1 deep infection (revision surgery) 2 sup. infection 1 Sup, radial n. dysfunction 2 (surgery) hardware remove. (6 Reoperations)

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Authors	Pain (SD, p value)	Grip strength (SD, p value)	Key pinch (SD, p value)	Tip pinch (SD, p value)	Palmar, Radial Abduction (SD, p value)	DASH (SD, p value)	Complications
Mureau et al. 2001	Post 39 (0-100) SD 30 p 0.030	Post 21.6 Kg SD 10.1 p 0.760	Post 5.1 Kg SD 2.2 p 0.971	Post 3.1 Kg SD 1.5 p 0.753	N.A.	N.A.	1 infection 2 CRPS 2 persistent pain (2 revision surgery) 2 sup. radial n. dysfunction (2 neurolysis) 2 k-wire fracture, 2 non-union (1 K. wire removal, 1 re-arthrodesis), 3 K wire removal. 3 of 14 patients with iliac crest bone grafting and 4 of 11 patients without bone graft developed non-union (10 Reoperations)
Rossi et al 2005	VAS N.A.	27 Kg	5.8 Kg	4.5 Kg	Rad Post 42° Palm Post 39°	N.A.	9 non-unions
Hart et al. 2006	VAS N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	2 CRPS (resolved after physiotherapy) 2 persistent pain
Raven et al. 2007	Post 23 (0-100) SD 27, 2 VS 3. p > 0.05 1 VS 2 p > 0.05 1 VS 3 p 0.02	17 Kg SD 12, 2 VS 3 p > 0.05 1 VS 2 p > 0.05 1 VS 3 p > 0.05	N.A.	2.8 Kg SD 0.5, 2 VS 3 p > 0.05 1 VS 2 0.029 1 VS 3 0.017	Rad Post 50° p=0.0001 2 VS 1, p=0.0046 2 VS 3	25 SD 22, 2 VS 3 p > 0.05 1 VS 2 p > 0.05 1 VS 3 p > 0.05	5 sup. radial n. dysfunction 3 CRPS 6 non-union (in cases without bone graft) 3 re-operation with graft. 15 hardware removal. (22 reoperations)
Vermeulen et al. 2014	VAS N.A. PRWHE PAIN RANGE 0-50 Pre 39.5 Post 19.9 SE 3.9	Pre 15.8 Post 18.7 Kg SE 3.9	Pre 3.7 Post 4.3 Kg SE 0.5	Pre 2.2 Post 3.3 Kg SE 0.6	N.A.	Pre 33.9 Post 33.9 SE 2.3	3 Scar tenderness 3 Sensory disturbances 2 Neuroma treated successfully with cortico steroids 3 Delayed union 1 Mild CRPS type I 2 Non-union (requiring additional surgery) 1 CRPS type I. (2 reoperations)

Legend:

§ Value obtained from diagram

ⓘ obtained from Cochrane

⦸ Discordant value with Cochrane

p value: when reported surgical techniques where indicated as follows: (1) Trapeziectomy, (2) LRTI, (3) Arthrodesis

F:M female/male,

D:ND dominant: not dominant

Complications (overall)

Simple trapeziectomy (267 patients): 3% (10) sensory nerve dysfunction or sensory disturbance, 0.7% (2) infection, 0.7% (2) pain related problems, 1.1% (3) tendon related problems and 0.3% (1) reoperation.

LRTI (479 patients): 5% (24) sensory nerve dysfunction or sensory disturbance, 0.6% (3) infection, 3.7% (18) pain related problems, 1.8% (9) scar tenderness and 3.3% (16) tendon related problems.

Arthrodesis (233 patients): 4.7% (11) sensory nerve dysfunction or sensory disturbance, 1.7% (4) infection, 6.4% (15) pain related problems, 1.2% (3) scar tenderness and 17% (40) reoperation. Non-union was not considered a complication if asymptomatic and not requiring revision surgery.

Table 11

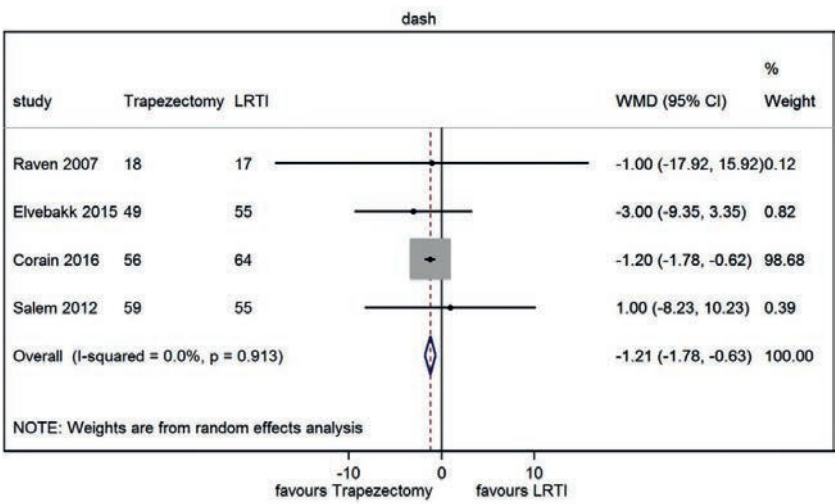
Trapeziectomy (n 267)	LRTI (n 479)	Arthrodesis (n 233)
(10) 5 Superficial radial nerve dysfunction 5 Palmar cutaneous branch of Median Nerve dysfunction	(24) 16 Superficial radial nerve dysfunction 5 Palmar cutaneous branch of median nerve dysfunction 3 Sensory disturbance	(11) 8 Superficial radial nerve dysfunction 3 Sensory disturbances
(2) 2 superficial wounds infections	(3) 3 superficial wound infection/ infection	(4) 3 superficial wound infection/infection 1 deep infection (revision surgery)
(2) 2 CRPS	(18) 10 CRPS 8 persistent pain	(15) 9 CRPS 4 persistent pain
(3) 1 De Quervain's disease 1 Avulsion of EPB, 1 partial rupture of FCR	(9) 9 Scar tenderness	2 Neuroma treated successfully with cortico steroids
(1) 1 re-resection	(16) 1 De Quervain's disease 4 FCR/pollicis longus pulling sensation 2 Tendinitis succesfully treated with corticosteroid 9 FCR tendinitis	(3) 3 Scar tenderness
	(others) 6 first metacarpal base collapse	(40) 40 Reoperation for revision or hardware removal

Statistical Analysis

Group 1 vs 2 (Trapeziectomy vs LRTI)

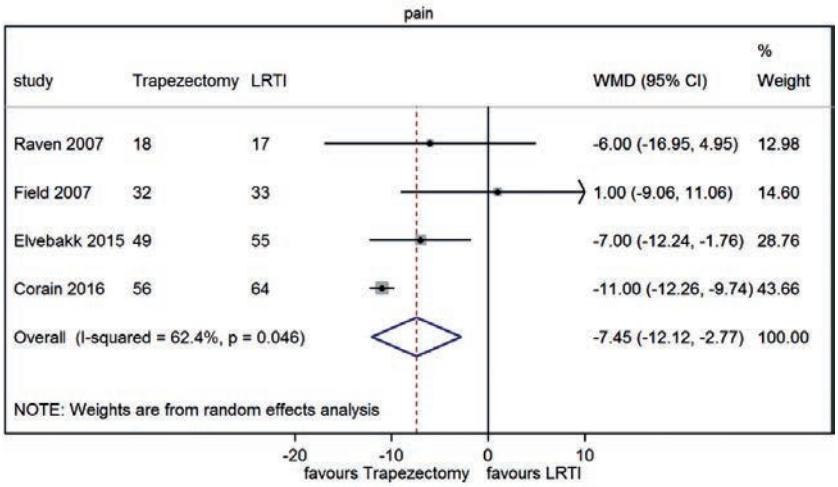
Considering a difference in DASH scores of 10 units as clinically significant, our analysis (four studies, 373 cases) suggested that a statistically significant, but clinically unimportant difference (1.21, 95%CI: -1,78, -0.63) exists between trapeziectomy and trapeziectomy with LRTI. This precision is due to the narrow SD in Corain et al. 2016, which is much smaller than that of other studies.

In a leave-one-out analysis (table 12), when the paper of Corain et al. (2016) is excluded, the point estimate remains about the same (difference: 1.7, 95%CI: -6.7, 3.3) but it is no longer significant (p=0.780). Nonetheless, a difference larger than about 5 units is ruled out, which is compatible with no major difference in efficacy between trapeziectomy and trapeziectomy with LRTI.

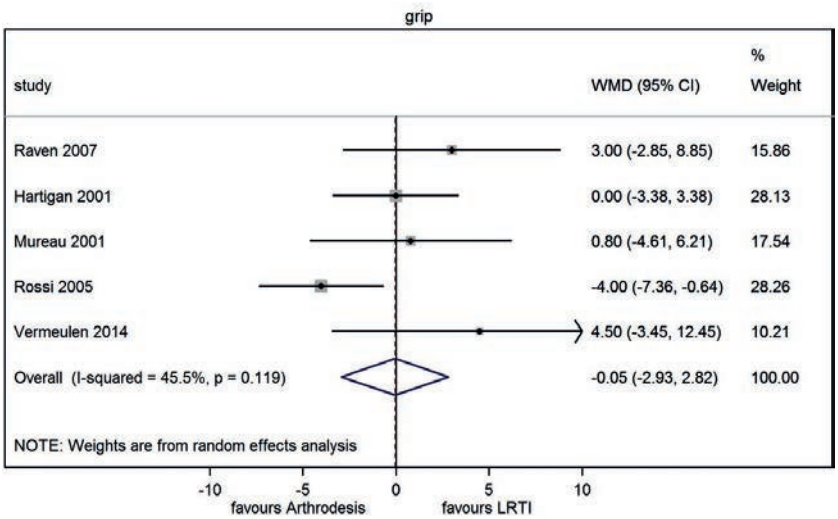


The large influence of the study of Corain et al. (2016) was also apparent in the meta-analysis of pain scores (four studies, 324 cases), which showed moderate-high heterogeneity (I-square: 62%, p=0.002). The results suggest that trapeziectomy is more effective in reducing pain than trapeziectomy with LRTI, with a statistically significant, but not clinically relevant difference (-7.45; 95%CI: -12.12, -2.77). In this analysis, three studies out of four compared LRTI with FCR to simple trapeziectomy (Field and Buchanan

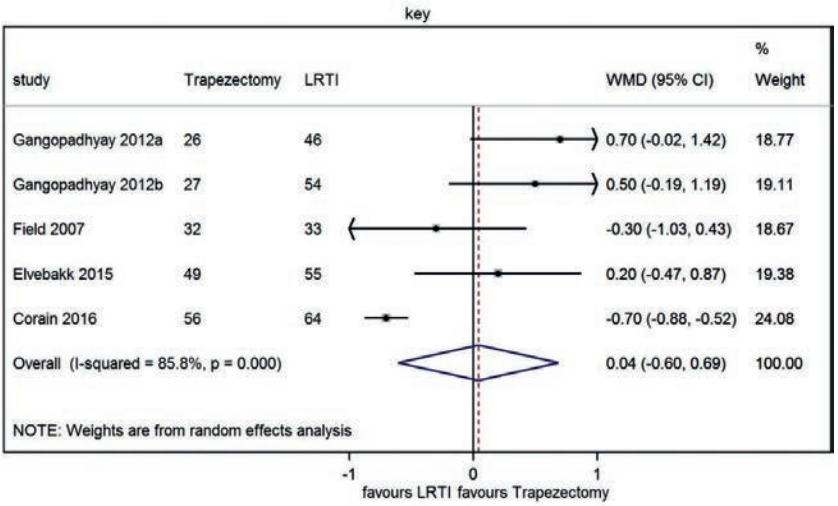
2007; Raven et al. 2007; Elvebakk et al. 2015) and one hematoma arthroplasty with K wire distraction (Corain et al. 2016). The results did not change in a leave-one-out meta-analysis, except when the study by Elvebakk et al. (2015) was removed, which made the difference not statistically significant.



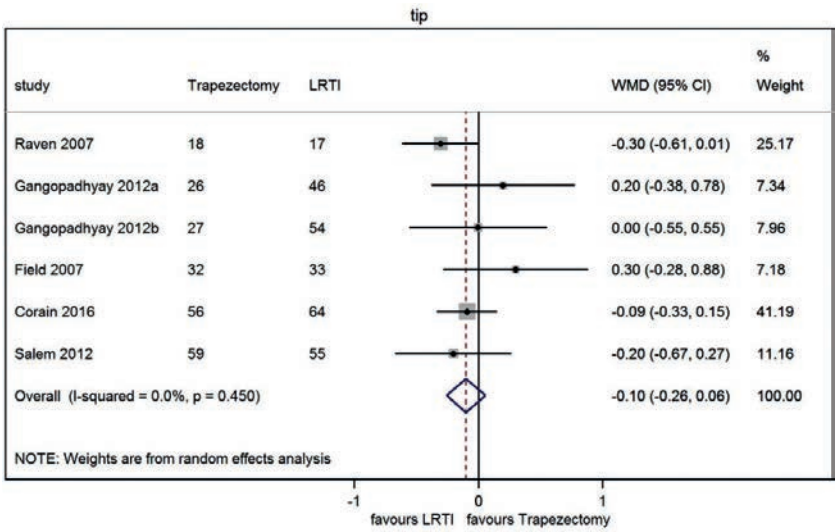
Considering a significant difference as 5 kgf, a meta-analysis of grip strength (six studies, 591 cases) did not show a significant difference between the two techniques. A difference of 0.02 kgf (95%CI: -1.9, 1.86) in favour of LRTI (I-square: 53.1%, p=0.982) was reported. The results were robust as they did not change in leave-one-out sensitivity analyses (table 12).



For key pinch we considered a difference of 1 kgf as clinically significant. The meta-analysis of the available data from four studies (442 cases) found very high heterogeneity (I-square: 86%); Corain et al. (2016) was an outlier. The meta-analysis found a small difference of 0.04 kg f (95%CI:-0.6, 0.69) in favour of trapeziectomy, which was not significant (p=0.901); this will also be within experimental error so not clinically relevant. Again the results were insensitive to leave-one-out techniques (Table 12).



For tip pinch, considering a significant difference of 1 kgf (five studies, 487 cases), this suggests a clinically unimportant and statistical non-significant difference between trapeziectomy and LRTI of 0.1 kgf (95%CI: -0.26, 0.06) in favour of trapeziectomy with LRTI (I-square: 0.0%, p=0.216), with no change in leave-one-out sensitivity analyses (Table 12). Again 0.1kgf will be within experimental error so not clinically relevant.



For radial abduction we found high heterogeneity among three studies (204 patients), which showed discordant effects; thus a meta-analysis was not appropriate.

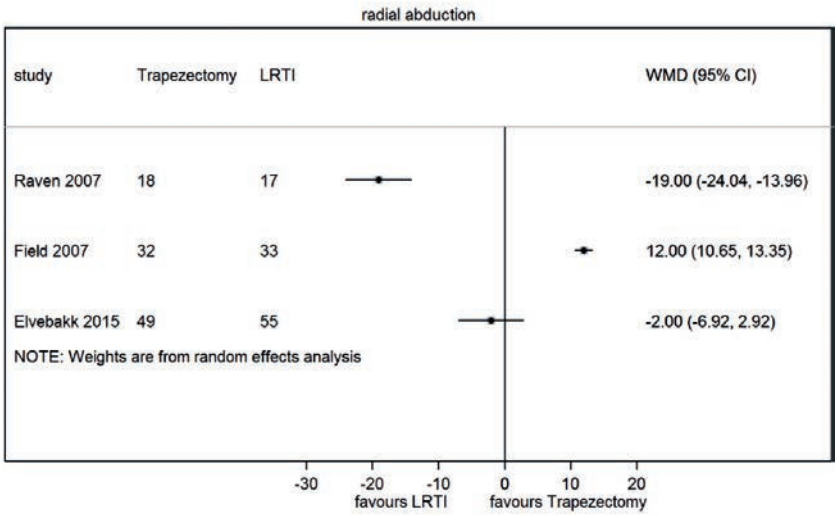
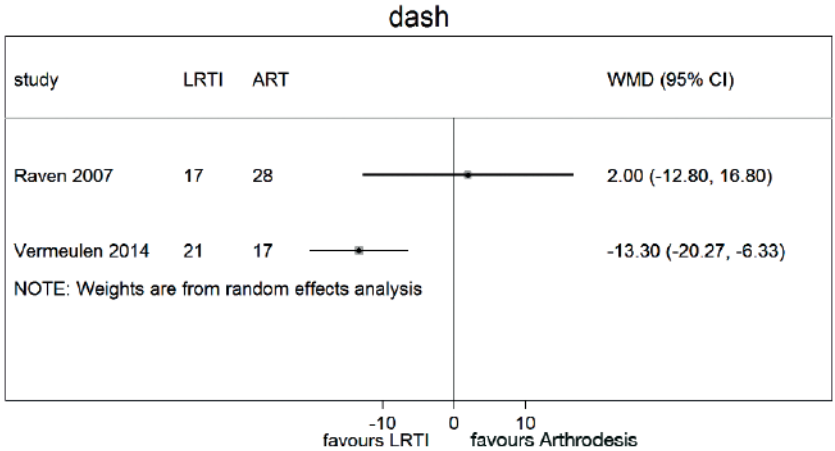


Table 12

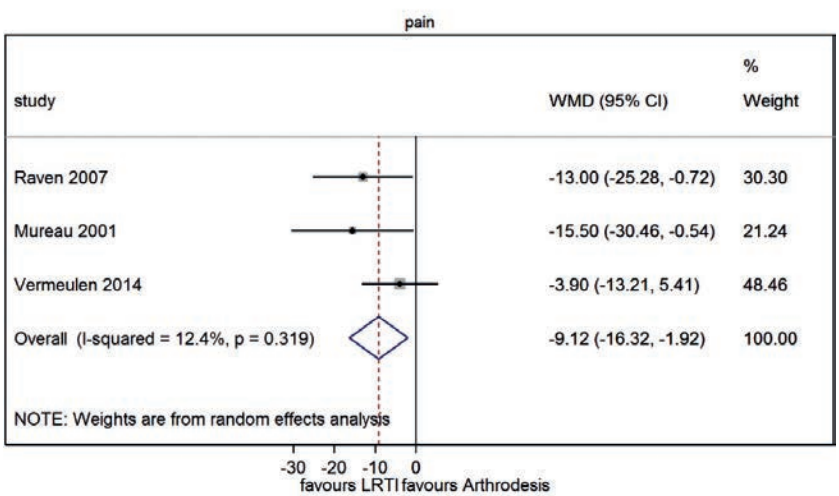
Outcome	Study	MD (95%C)	p-value	I squared
DASH	**All (n.4)**	**-1.2 (-1.8, -0.6)**	**<0.001**	**0%**
Excluded	Raven et al. 2007	-1.2 (-1.8, -0.6)	<0.001	0%
	Elvebakk et al. 2015	-1.2 (-1.8, -0.6)	<0.001	0%
	Corain et al. 2016	-1.7 (-6.7, 3.3)	0.780	0%
	Salem and Davis 2012	-1.2 (-1.8, -0.6)	<0.001	0%
Pain	**All (n.4)**	**-6 (-17, -5.0)**	**0.002**	**62%**
Excluded	Raven et al. 2007	-7.4 (-12.9, -2.0)	0.008	73%
	Field and Buchanan 2007	-9.8 (-12.7, -6.9)	0.000	29%
	Corain et al. 2016	-5.4 (-9.7, -1.1)	0.013	0%
	Elvebakk et al. 2015	-6.6 (-14.2, 0.98)	0.088	67%
Grip	**All (n.7)**	**-0.02 (-1.9, 1.8)**	**0.982**	**53%**
Excluded	Raven et al. 2007	-0.12 (-2.1, 1.9)	0.898	59%
	Gangopadhyay et al. a	-0.27 (-2.4, 1.8)	0.800	56%
	Gangopadhyay et al. b	0.06 (-2.2, 2.3)	0.956	61%
	Field and Buchanan 2007	0.49 (-1.5, 2.5)	0.624	51%
	Elvebakk et al. 2015	-0.58 (-1.4, 0.3)	0.197	9%
	Corain et al. 2016	0.41 (-2.5,3.3)	0.785	60%
	Salem and Davis 2012	0.50 (-1.7, 2.7)	0.662	57%
Key	**All (n.5)**	**0.04 (-0.6, 0.7)**	**0.901**	**86%**
Excluded	Gangopadhyay et al. a	-0.12 (-0.7, 0.5)	0.703	82%
	Gangopadhyay et al. b	-0.07 (-0.7, 0.6)	0.839	85%
	Field and Buchanan 2007	0.13 (-0.7, 0.9)	0.748	89%
	Elvebakk et al. 2015	0.01 (-0.7, 0.7)	0.982	87%
	Corain et al. 2016	0.28 (-0.1, 0.7)	0.188	28%
Tip	**All (n.6)**	**-0.1 (-0.26, 0.06)**	**0.216**	**0%**
Excluded	Raven et al. 2007	-0.03 (-0.2, 0.1)	0.737	0%
	Gangopadhyay et al. a	-0.12 (-0.3, 0.04)	0.140	0%
	Gangopadhyay et al. b	-0.1 (-0.28, 0.08)	0.279	13%
	Field and Buchanan 2007	-0.1 (-0.3, 0.03)	0.118	0%
	Corain et al. 2016	-0.08 (-0.31, 0.14)	0.470	15%
	Salem and Davis 2012	-0.08 (-0-26, 0.10)	0.416	12%

Group 2 vs 3 (LRTI vs Arthrodesis)

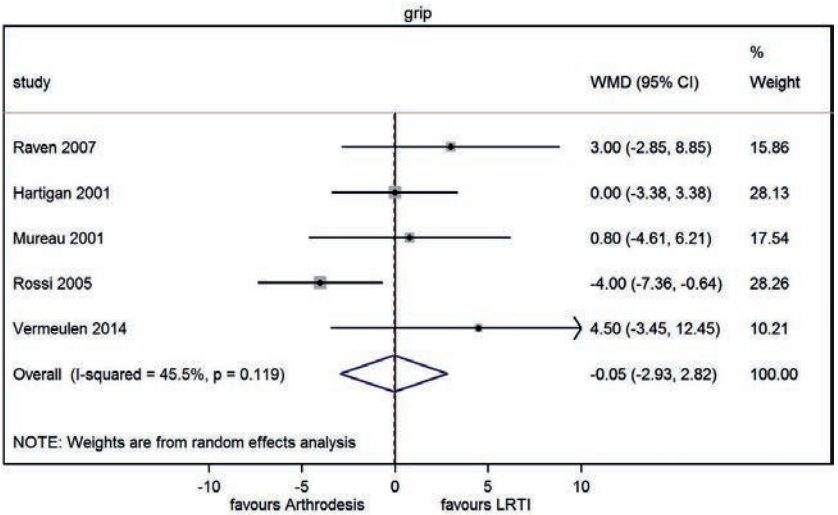
For DASH scores we found high heterogeneity between the two included studies (83 patients, I-square: 70.2%) so a meta-analysis is not appropriate. Vermeulen et al. (2014) found a significant benefit for trapeziectomy with LRTI with FCR, while Raven et al. 2007 showed no difference vs. arthrodesis. We could not find clinical or methodological explanations for such a difference.



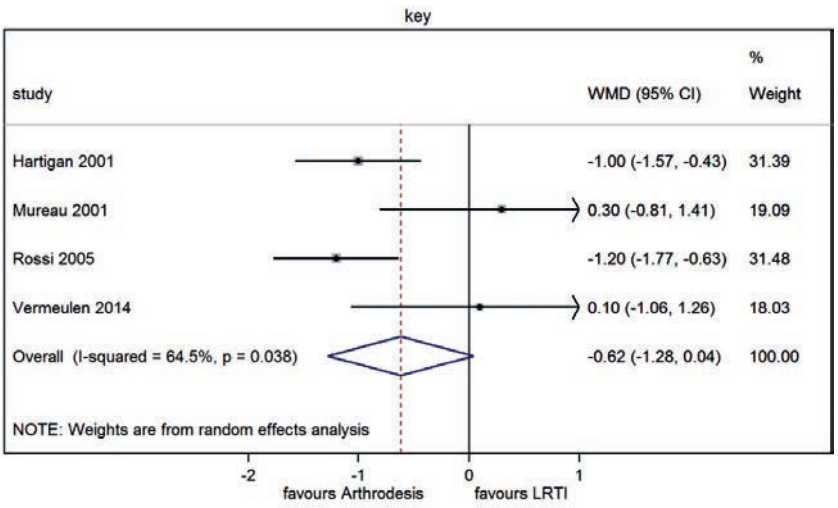
Three studies (139 cases) showed a clinically significant difference for pain scores between trapeziectomy with LRTI and arthrodesis in favour of trapeziectomy with LRTI with a difference of 9.12 (95%CI: -16.32, -1.92); that was statistically significant (I-square: 12.4%, p=0.013). Raven et al (2007) reported on trapeziectomy with LRTI with FCR vs arthrodesis with a miniplate, Mureau et al. (2001) on trapeziectomy with LRTI with FCR, PL or APL vs arthrodesis with K wires and Vermeulen et al. (2014) on trapeziectomy with LRTI with FCR vs arthrodesis with a plate and screws. As they are only three studies, a leave-one-out analysis is not appropriate (Table 13).



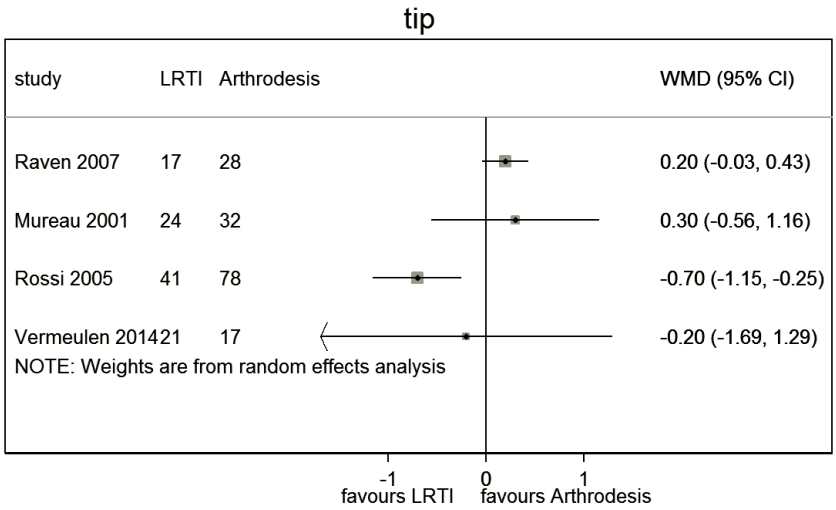
For grip strength no difference was found between trapeziectomy with LRTI and arthrodesis (five studies, 365 cases) (difference: 0.05, 95%CI: -2.93, 2.82) with a moderate statistical heterogeneity (I-square: 46%, p=0.970). These results were robust in leave-one-out sensitivity analyses (Table 13).



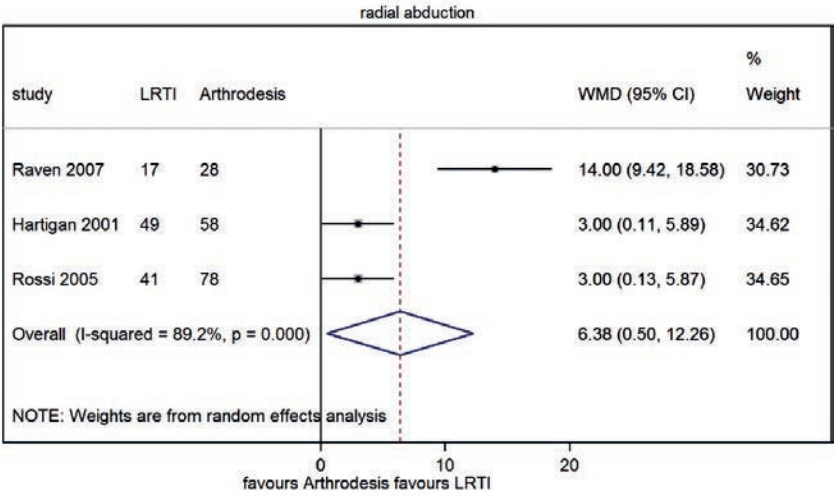
High heterogeneity was detected for key pinch (I-square: 64.5%; 4 studies, 320 cases). Rossi et al. (2005) and Hartigan et al. (2001) favoured arthrodesis whilst Vermeulen et al. (2014) and Mureau et al. (2001) favoured trapezectomy and LRTI. The estimated mean difference was -0.62 (95%CI: -1.28, 0.04); it approached, but it did not reach, statistical significance (p=0.067).



High heterogeneity was found for tip pinch (four studies, 258 cases; -0.05 95%CI: -2.93, 2.82; I-square: 75.9%, p=0.725) since two studies favoured trapeziectomy with LRTI and two other favoured arthrodesis. Thus, a meta-analysis was not conducted. Overall, these results do not suggest a difference between the two techniques.



Three studies (271 cases) showed a difference for radial abduction between trapeziectomy with LRTI and arthrodesis in favour of trapeziectomy with LRTI with a difference of 6° (95% CI: 0.50, 12.26) which was statistically significant (I-square: 89.2%, p=0.033). However, this is around measurement error and the estimate was imprecise and sensitive to the removal of two studies in leave-one-out analyses. Of note Hartigan et al. (2001)and Rossi et al. (2005) had standard deviations imported from other studies.



For palmar abduction (two studies, 226 cases), the results favour trapeziectomy with LRTI over arthrodesis for ROM (5° 95%CI: 3.52, 5.48) although this is probably within measurement error. Although there was moderate heterogeneity (I-square: 56.9%, p<0.001) the difference was highly significant in both studies.

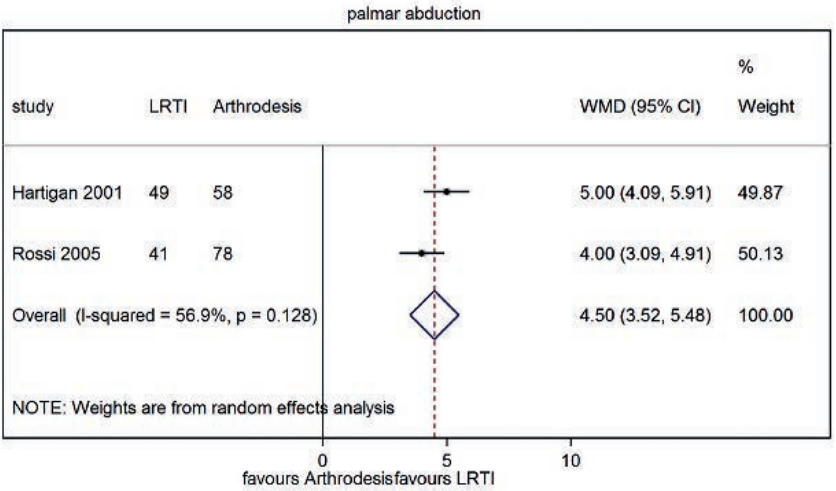


Table 13

Outcome	Study	MD (95%C)	p-value	I squared
Pain	**All (n.3)**	**-9.1 (-16.3, -1.9)**	**0.013**	**12%**
Excluded	Raven et al. 2007	-8.1 (-19.1,2.8)	0.144	40%
	Mureau et al. 2001	-7.5 (-16.3, 1.2)	0.091	25%
	Vermeulen et al. 2014	-14 (-23,5, -4.5)	0.004	0%
Grip	**All (n.5)**	**-0.06 (-2.9, 2.8)**	**0.970**	**46%**
Excluded	Raven et al. 2007	-0.64 (-3.8, 2.5)	0.687	47%
	Hartigan et al. 2001	0.29 (-3.8, 4.4)	0.891	58%
	Mureau et al. 2001	-0.06 (-3.6, 3.5)	0.974	57%
	Rossi et al. 2005	1.1 (-1.3, 3.6)	0.371	0%
	Vermeulen et al. 2014	-0.6 (-3.5, 2.3)	0.687	47%
Key	**All (n.4)**	**-0.6 (-1.3, 0.04)**	**0.067**	**64%**
Excluded	Hartigan et al. 2001	-0.36 (-1.4,0.7)	0.510	75%
	Mureau et al. 2001	-0.9 (-1.4,-0.3)	0.002	49%
	Rossi et al. 2005	-0.3 (-1.2,0.6)	0.506	66%
	Vermeulen et al. 2014	-0.8 (-1.5,-0.1)	0.024	65%
Radial abduction	**All (n.3)**	**6.4 (0.5, 12.3)**	**0.033**	**89%**
Excluded	Raven et al. 2007	3.0 (0.97,5.0)	0.004	0%
	Hartigan et al. 2001	8.3 (-2.4, 19.1)	0.129	94%
	Rossi et al. 2005	8.4 (-2.4, 19.1)	0.129	94%

Group 1 vs 3 (trapeziectomy vs arthrodesis)

Only one study compared trapeziectomy to arthrodesis (Raven et al., 2007; 46 cases). The majority of the outcome measures showed non-significant differences. For the DASH score, the mean difference was of 1 point (10 for relevance). Grip strength was a mean of 5 kgf stronger with a arthrodesis. For tip pinch the difference was minimal (0.10 kgf) in favour of trapeziectomy. Of note the VAS scale showed a relevant mean difference of 19 points less for trapeziectomy vs arthrodesis (p-value 0.02).

Discussion (section 1)

We systematically reviewed the literature on primary thumb TMC joint OA surgery with the aim of including all published randomized and non-randomized controlled studies. We included only studies with a minimum follow up of 12 months. A shorter FU is

almost certainly not adequate to assess the final outcomes when comparing different procedures which are very variable and procedure-dependent (see implants vs. biologic arthroplasties). (Low and Hales, 2014)

Difficulties in assessing the data were caused by a lack of information, e.g. standard deviations or use of different outcome evaluation systems that are non comparable in quantitative analyses. Some low quality data meant we applied a leave-one-out technique to statistical analysis.

Comparing trapeziectomy with LRTI to simple trapeziectomy, the analysis was not able to ascertain any difference in terms of strength, patient's global assessment,or ROM; trapeziectomy gave a clinically irrelevant, even if statistically significant, improvement in pain scores.

Complications were reported in a descriptive way; a meta-analysis was not suitable given these data were sparse and heterogeneous. Overall trapeziectomy alone had a lower complication rate than trapezectomy and LRTI or TI; tendon related problems were 1.1% vs 3.3% and pain related problems were present in 0.7% vs 3.7%.

LRTI may achieve a better outcome in terms of pain, and radial and palmar abduction when compared to arthrodesis. In addition in a qualitative analysis there were more complications with arthrodesis and consequently revisions are more frequent than for trapeziectomy with LRTI, (6.4% to 3.7% pain related problems, and 17% of re-intervention in arthrodesis and 0% in LRTI). No differences were observed as to grip strength, key pinch, tip pinch or DASH scores. Overall, as arthrodesis did not show any advantage vs biological arthroplasties, even in terms of strength, the main issue to be considered when preferring a fusion seems to be the higher risk of complications.

C. SECTION 2: SYSTEMATIC-REVIEW: TOTAL JOINT PROSTHESIS

Nadine HOLLEVOET
Grey GIDDINS

Material and Methods (section 2)

A systematic literature review was performed in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement for developing study protocols and reporting systematic reviews (Moher et al., 2009).

The inclusion criteria for the systematic review were: full reports written in English, French or German of total joint replacement in patients with primary osteoarthritis of the trapeziometacarpal joint, studies reporting pain, strength, radiological changes or failure rate as outcomes with a mean follow-up of 12 months and studies with a design classification of levels I to VI , as classified by Jovell and Navarro-Rubio (Jovell and Navarro-Rubio, 1995).

The exclusion criteria were studies with a mean follow-up of less than 12 months, reports of patients with trapeziometacarpal joint osteoarthritis that could not be separated out from cases of rheumatoid or post-traumatic arthritis, case reports, revision procedures, cadaver studies, biomechanical studies, non implant arthroplasty such as tendon interposition arthroplasty, hemiarthroplasty, spacer implant and reviews. Studies in which more than one type of implant was used and results were not reported separately were also excluded.

PubMed/Medline and EMBASE databases were searched up to 31 October 2016 by three reviewers (KH, NH and GG). A combination of the following key terms were used for searching strategy: trapeziometacarpal osteoarthritis, trapeziometacarpal arthroplasty, trapeziometacarpal joint, TMCJ, trapeziometacarpal replacement, thumb carpometacarpal arthroplasty, thumb CMC joint replacement and thumb CMC joint prosthesis. The bibliographies of all the retrieved papers were hand-searched. All potentially relevant papers were reviewed.

The outcome measurements were pain measured by pain assessment scoring systems, radiological changes, thumb grip or pinch strength and failure defined by the revision or removal of the implant.

The survival rates of implants and the method to determine these were recorded. Only articles with removal or revision of the prosthesis as end point were selected. It was noted if a cumulative survivorship analysis was performed and with which method. Usually the product-limit method (Kaplan and Meier, 1958) or the method of Armitage (1971) was used. Implants were considered to have a good result if the failure rate is lower than 1% per year. If the failure rate was lower than 1 % per year, follow-up should be at least 10 years before any final conclusion can be made. In case of higher failure rates, results can be reported with shorter follow-up (Murray et al., 1993).

Assessment of the level of evidence was done according to Jovell and Navarro-Rubio (Jovell and Navarro-Rubio, 1995) (table 1) and assessment of the methodological quality with the Coleman Methodology scoring system (Tallon et al., 2001) (table 2).

Results (section 2)

Results were found for 20 different total joint prostheses: Arpe prosthesis (Isselin, 2001); Braun and Braun-Cutter prosthesis (Braun, 1982, 1985, Badia and Sambandam, 2006); Beznoska (Jurča et al, 2016); cemented resurfacement arthroplasty (Uchiyama et al., 1999; Pérez-Ubeda et al., 2003; van Rijn and Gosens, 2010); de la Caffinière prosthesis (de la Caffinière and Aucouturier, 1979); Electra prosthesis (Regnard et al., 2006); Guepar I prosthesis (Alnot and Saint Laurent 1985; Alnot et al., 1993, Alnot and Muller, 1998); Guepar II prosthesis (Masmejean et al., 2003); Isis (Seng and Chantelot, 2013); Ivory (Goubau et al., 2013); Ledoux prosthesis (Ledoux, 1997); Maia (Jager et al., 2013; Bricout and Rezzouk, 2016); Mayo Clinic prosthesis (Cooney et al., 1987); Moje Acamo (Hansen and Vainorius, 2008); Motec (Krukhaug et al., 2014); Nahigian prosthesis (Hannula and Nahigian, 1999); Roseland prosthesis (Moutet et al., 2001); Rubis II (Dunaud et al., 2001) and Steffee prosthesis (Ferrari and Steffee, 1986). Papers concerning seven of these did not fit the eligibility criteria because

they included patients with conditions other than primary osteoarthritis (Braun, Guepar I, Ledoux, Maia, Mayo clinic and Steffee prostheses) or results were published in Czech (Beznoska).

We included 37 articles with studies of 13 different prostheses with design classifications of I to VI (Figure 1). In the article of Krukhaug et al., 2014, results of two different total joint arthroplasties were reported. Counting these as separate studies, 36 studies were level VI, one study was level IV, and one level III. The mean age of the patients at operation ranged from 54 to 71 years old. The mean follow-up ranged from 12 to 228 months, with a follow-up of 5 years or more in eleven studies. The characteristics of the de la Caffinière prosthesis, the Electra prosthesis, and the other implants are shown in Tables 4, 6, and 8, respectively.

Outcomes

Table 5, 7 and 9 show the outcomes. A total of 19 studies measured grip strength; 20 studies measured key pinch strength; nine studies measured tip pinch; and 16 studies measured both grip and key pinch strength. A total of 33 studies measured the levels of pain. Various assessment systems were used, most commonly the visual analogue scale (VAS) (14 studies). The criteria for radiographic evaluation were not consistent in all studies, so we only listed the commonly reported problems: lucency around the implant or clear loosening; and subluxation or dislocation. The two main long term complications were implant loosening and dislocation, which are also the main reasons for revision. Loosening was the main radiographic problem for the de la Caffinière and Electra prosthesis; rates ranged from 10% to 44% for the de la Caffinière and from 3% to 53% for the Electra prosthesis. Dislocation was reported mainly for prostheses with an unconstrained design as the Arpe prosthesis. Across all studies failure rates ranged from 0% to 42%. For the Arpe it ranged from 5% to 22%, for de la Caffinière prosthesis from 0% to 26% and for the Electra prosthesis from 3% to 35%.

Literature quality and risk of bias

The majority of the reports were not high quality. There were only two prospective controlled studies, six prospective cohort stud-

ies and 30 retrospective studies. Often the studies (Guardia et al., 2010; Hannula and Nahigian, 1999; Lemoine et al.; 2009; Masmejean et al., 2003; Regnard 2006; Maes et al., 2010; Moutet et al., 2001; Semere et al., 205; Seng and Chantelot 2013) were reports of implants by the original developer of the implant increasing the risk of bias.

Total joint arthroplasty implants

De la Caffinière prosthesis

The de la Caffinière prosthesis consists of a polyethylene cup recessed into the trapezium and a cobalt-chrome alloy metacarpal component. It was first introduced in 1971. Early findings were reported in 1979, which revealed the best results in patients who had the procedure for pain and instability, with less good outcomes for those who complained of stiffness preoperatively (de la Caffinière and Aucouturier 1979). There are longer follow-up studies for this implant than any other (Johnston et al. 2012) allowing for a reasonably reliable assessment of its value.

Survivorship was good in the studies of Chakrabarti et al., (1997) and Johnston et al. (2012) with 89% at 16 years and 74% at 26 years and moderate in the study of Van Capelle et al. (1999) (72% at 16 years). Poor survivorship was reported by Wachtl et al., (1998) with 66% survival at 5 years. Good pain relief was reported in 44% to 93% of patients. The main problem with the de la Caffinière prosthesis is loosening (rates ranging from 10 to 44%). Therefore it has been advised to use this prosthesis only in elderly low demand patients (van Cappelle et al., 1999; De Smet et al., 2004).

Electra prosthesis

The Electra prosthesis is modeled on the de la Caffinière prosthesis with a metal stem and a cup. Regnard (the developer) published good outcomes in a series of 100 patients followed up for a mean of 54 months (Regnard et al. 2006). Independent authors have reported very high failure rates (Klahn et al., 2012; Hernandez-Cortez et al., 2012 and Hansen et al., 2013) suggesting this implant should be used with great caution (Giddins 2012).

Other

We included reports of 11 other total joint arthroplasties. These include the Arpe, Braun-Cutter (a modification of the Braun prosthesis), cemented resurfacement arthroplasty, Guepar II, Isis (a modification of Guepar II), Ivory, Moje Acamo, Motec, Nahigian, Roseland and Rubis II. Most of these have very few reports. Some have been withdrawn or changed without reports of the reasons why. For the majority the data are not of high quality (Table 8).

Implants when reported by the originator versus reported by others

There were several reports of implants by the original developer (marked with the reference in bold in the tables) which may increase the risk of bias. We attempted to analyse the difference of the results between the originator and other authors. Unfortunately the majority of the reports were not high quality and the measurement standards were different among them, which made the pooling of data impossible. Although we could not compare these data directly, the failure rates reported by the developers tended to be lower than reported by others (Table 9).

Survivorship

Suvivorhip was reported for nine different prostheses in 15 studies: de la Caffinière (4), Arpe(2), Electra (1), cemented surface replacement (2), Moje Acamo (1), Ivory(1), Motec (2), Roseland (1) and Rubis II (1) (Table 3). A cumulative survivorship analysis was performed in ten studies.

Discussion (section 2)

The gold standard for surgical treatment of thumb CMC joint arthritis remains a trapezectomy (Vermeulen et al. 2011). Because of the increased cost of the implant, a total joint replacement needs to be significantly better than trapezectomy or its modifications to justify its use. The cost of prostheses increases if a secondary operation is required because of loosening or complications such as dislocation. As the mean age of patients at the time of surgery ranged between 54 and 71 years, studies with a long follow-up of perhaps 20 to 30 years are needed.

Several studies have shown earlier recovery of function than following a trapezectomy (Jager et al., 2013; Jurča et al., 2016, Ulrich-Vinther et al., 2008), but follow-up in these studies is short.

Survival rates with removal or revision of the prosthesis as end point were found for nine implants in 15 papers (Table 3). However, because of differences in methodology in determining survival rates and short follow-up, the implant with the best survival rate could not be identified.

This does not mean that implant arthroplasty should be abandoned for thumb CMC joint OA. Rather this is to highlight the paucity of the surgical literature and identify that the only appropriate way forwards is with properly powered randomized controlled trials (RCT) comparing trapezectomy (or possibly one of its variants) with thumb CMC joint replacement over a long period. Nonetheless there are sufficient data to conclude that as yet total joint replacement of symptomatic thumb CMC joint OA does not reliably give better results than trapezectomy and has some very high rates of failure. No single implant can be recommended as previously noted (Giddins 2012, Huang et al, 2015) and many implants should only be used with great caution if at all.

Figure 1 Flowchart illustrating the selection of trials included in the systematic review.

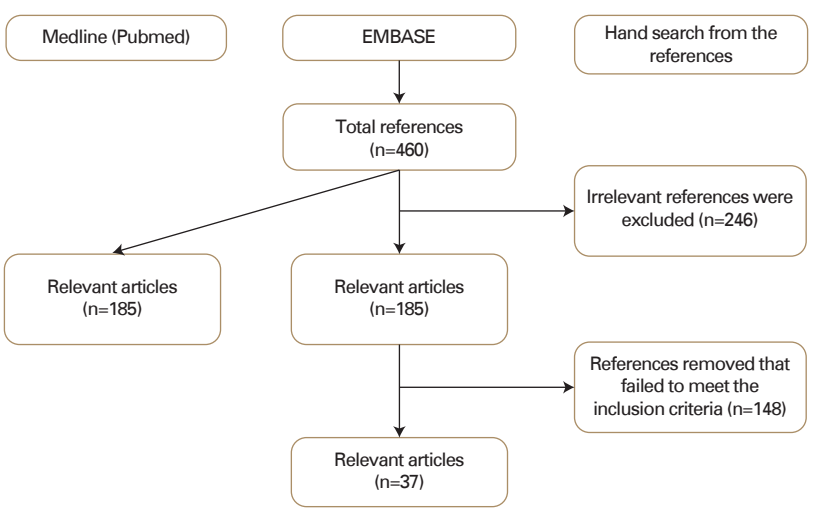


Table 1 Classification in levels of evidence based on the type of study design (as described by Jovell and Navarro-Rubio)

Level	Strength of Evidence	Type of Study Design
I	Good	Meta-analysis of randomized controlled trials
II	-	Large-sample randomized controlled trials (n ≧ 25)
III	Good to fair	Small-sample randomized controlled trials (n < 25)
IV	-	Nonrandomized controlled prospective trials
V	-	Nonrandomized controlled retrospective trials
VI	Fair	Cohort studies
VII	-	Case control studies
VIII	Poor	Noncontrolled clinical series; descriptive studies
IX	-	Anecdotes or case reports

Table 2 Coleman methodology score

		Coleman score
Study size	> 60	10
	41-60	7
	20-40	4
	< 20 or not stated	0
Mean duration of follow-up	> 24 months	5
	12-24 months	2
	< 12 months, not stated or unclear	0
Number of different surgical procedures included in each reported outcome	Only one surgical procedure	10
	More than one surgical procedure, but >90% undergoing one procedure	7
	Not stated, unclear, or <90% undergoing one procedure	0
Type of Study	Randomized control study	15
	Prospective cohort study	10
	Retrospective study	10
Diagnostic certainty	In all	5
	In >80%	3
	In < 80%	0

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		Coleman score
Description of surgical procedure	Adequate	5
	Fair	3
	inadequate	0
Description of postoperative rehabilitation	Well described, >80% complying	10
	Well described, 60-80% complying	5
	Protocol not reported or < 60-80% complying	0

Table 3 Survivorship of total joint arthroplasties for the trapeziometacarpal joint

Implant	Authors	N	% men	% lost	Survival	Cummulative survival Analysis
Arpe	Apard and Saint-Cast (2007)	43	6	26	85% at 5 year 79% at 11 years	Armitage
	Vander Eecken et al. (2012)	49	18	12	97%at 5 years	None
Cemented surface replacement	Pendse et al., (2009)	62	34	0	91% at 3 years	Kaplan Meier
	Ten Brinke et al., 2016	10	10	0	80% at 5 years	none
de la Caffinière	Wachtl et al., (1998)	43	n/a	19	66% at 5 years	Armitage
	Van Capelle et al. (1999)	77	14	0	72% at 16 years	Armitage
	Chakrabarti et al., (1997)	93	12	22	89% at 16 years	Armitage
	Johnston et al., (2012)	93	12	47	74% at 26 years	Kaplan Meier
Electra	Krukhaug et al., (2014)	29	28	n/a	90% at 5 years	Kaplan Meier
Ivory	Goubau et al., (2013)	24	5	8	95 % at 5 years	None
Moje Acamo	Hansen and Vainorius (2008)	9	33	0	66 % at 1 year	None
Motec	Krukhaug et al., (2014)	53	40	-	91% at 5 years	Kaplan Meier
	Thilleman et al., (2016)	42	19	0	58% at 2 years	Kaplan Meier
Roseland	Semere et al., (2015)	64	6	24	91% at 10 years	None
Rubis II	Maes et al., (2010)	118	6	14	93% at 5 years 90% at 12 years	Kaplan Meier

Table 4 Study characteristics of the de la Caffinière prosthesis

Authors	Patients/ implants	Mean age at surgery	Follow-up months (mean)	Evidence	Coleman score	
					Separate	Total
Nicholas and Calderwood. 1992	17/20	57	8-120 (64.2)	VI	4,5,10,0,5,0,0	24
Nonnenmacher and Graftiaux, 1994	16/20	55	12-132 (60)	VI	4,5,10,0,3,3,5	30
Chakrabarti et al., 1997	71/93	57	72-192 (132)	VI	10,5,10,0, 0,5,0	30
Wachtl et al., 1998	- /43	-	45-81 (64)	VI	7,5,10,0,3,5,5	35
van Cappelle et al., 1999	63/77	62	24-192 (102)	VI	10,5,10,0,5,0,0	30
De Smet et al., 2004	40/43	54	15-69 (26)	VI	7,5,10,0,5,5,0	32
Johnston et al., 2012	26/39	57	192-312 (228)	VI	4,5,10,0,0,0,0	19

Table 5 Details of outcome measurements using de la Caffinière prosthesis

Authors	Pain	Mean grip strength (Kgforce)	Mean key pinch strength (Kgforce)	Mean tip pinch strength (Kgforce)	Radiographic findings	Failure rate	Predominant Complication
Nicholas and Calderwood. 1992	80% painfree	-	-	-	1/20 dislocation;1/20 trapezial collaps, 1/20 radiolucent lines	0%	pain
Nonnenmacher and_Graftiaux, 1994	70% good pain relief 11/16 patients pain free	17 Kpa	4 Kpa	-	4/20 trapezial fractures with dislocation; 3/20 cup loosening; 1/20 stem loosening	25% (5/20)	trapezial fracture and dislocation
Chakrabarti et al., 1997	93% good pain relief (VAS)	22/21 (operated/ non-operated)	-	-	10/93 loosening (7 cups, 3 stems)	12% (11/93)	loosening

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Authors	Pain	Mean grip strength (Kgforce)	Mean key pinch strength (Kgforce)	Mean tip pinch strength (Kgforce)	Radiographic findings	Failure rate	Predominant Complication
Wachl et al., 1998	44% no pain 48% pain with effort 4% pain at rest	28/27.6 (operated/ non-operated	7.5/8 (operated/ non-operated)	3.9/3.8 (operated/ non-operated)	1/43 dislocation; 9/43 loosening	23% (10/43)	loosening
van Cappelle et al., 1999	75.4% good pain relief (VAS)	-	-	-	13/77 loosening; 15/77 severe loosening with need for revision	21% (16/77)	loosening
De Smet et al., 2004	70% good pain relief (VAS)	17.6/23.8 (pre-op / post-op) p<0.05	5.32/5.97 (pre-op / post-op) p<0.01	-	19/43 loosening; 4/43 cup fracture; 1/43 cortex perforation	2 % (1/43)	loosening
Johnston et al., 2012	27 (VAS)	15.7/17.8 (operated/ non-operated)	-	2.9/3.7 (operated/ non-operated)	14/39 loosening (11 cups, 3 stems)	26%	loosening

Table 6 Study characteristics the Electra prosthesis

Authors	Patients / implants	Mean age at surgery in years	Follow-up month (mean)	Evidence	Coleman score	
					Separate	Total
Regnard, 2006	100/100	59	36-78 (54)	VI	10,5,10,10,5,5,0	45
Hansen and Snerum, 2008	16/17	54	22-52(35)	VI	0,5,10,0,5,5,10	35
Ulrich-Vinther et al., 2008	36/36	58	12	IV	10,2,0,15,5,5,0	37
Hernández-Cortés et al., 2012	19/19	57	24-36 (29)	VI	0,2,10,10,5,5,0	32
Hansen and Stilling, 2013	11/11	60	24	III	0,2,10,15,5,5,10	47
Krukhaug et al., 2014	- /29	62	- (24)	VI	4,2,10,0,5,0,0	21
Chug et al., 2014	14/16	70	12-38 (26)	VI	0,5,10,0,5,3,10	23

Table 7 Details of outcome measurements the Electra prosthesis

Authors	Pain	Mean grip strength (Kg)	Mean Key Pinch strength (Kg)	Mean Tip Pinch strength (Kg)	Radiolographic findings	Failure rate	Predominant Complication
Regnard, 2006	81% pain free	28	6	-	15/100 loosening; 7/100 dislocation	17% (17/100)	Loosening
Hansen and Snerum, 2008	-	-	-	-	5/17 cup loosening; 1/17 dislocation	35% (6/17)	Loosening
Ulrich-Vinther et al., 2008	3.8/0.5 (VAS) (pre-op / post-op) p<0.001	10.5/25.6 (pre-op / post-op) p<0.05	5.0/5.6 (pre-op/ post-op) p<0.05	4.0/5.3 (pre-op/ post-op) p<0.05	2/19 osteolysis around cup	3% (1/36)	tendon problems
Hernández-Cortés et al., 2012	8.4/4.6 (VAS) (pre-op / post-op) (p<0.001)	-	3.1/2.2 (pre-op/ post-op)	-	10/19 osteolysis; 1/19 periprosthetic fracture	16% (3/19)	cup loosening
Hansen and Stilling, 2013	No significant differences to de la Caffinière cup (VAS)	No significant difference to de la Caffinière cup	-	-	0.8 mm mean implant migration	9% (1/11)	cup loosening
Krukhaug et al, 2014	-	-	-	-	1/29 loosening; 1/29 dislocation; 1/29 instability	10% (5 year failure rate)	dislocation and pain
Chug et al., 2014	34.2/5.4 (pre-op/post-op) PRWE (p<0.01)	27/28 (operated/ non-operated)	3.6/3.9 (operated/ non-operated)	4/4.3 (operated/ non-operated)	1/16 cup loosening	6% (1/16)	intraoperative trapezium fracture

Table 8 Study characteristics of total arthroplasty using other prostheses

Implant	Authors	Patients/ implants	Mean age at surgery	Follow-up month (mean)	Evidence	Coleman score	
						Separate	Total
Arpe	Brutus and Kinnen, 2004	52/63	55	5-40 (14.8)	VI	10,2,10,0,3,5,5	35
	Jacoulet, 2005	29/37	67	- (36)	VI	4,5,10, 0,3,5,10	37
	Apard and Saint-Cast, 2007	25/32	59	60-138 (86)	VI	7,5,10,0,0,5,5	32
	Vander Eecken et al., 2012	41/49	55	36-132 (72)	VI	7,5,10,0,3,5,5	35
	Martin-Ferrero, 2013	60 /65	58	120-150 (127.2)	VI	10,5,10,10,3,5,0	43
Braun-Cutter	Badia and Sambandam, 2006	25/26	71	26-68 (59)	VI	4,5,10,10,5,5,0	39
Cemented resurfacement arthroplasty	Pendse et al., 2009	50/62	64.5	24-84 (36)	VI	10,5,10,0,3,5,10	43
	ten Brinke et al., 2016	10/10	n/a	60	VI	0,5,10,10,5,0,0	30
Guepar II	Masmejean et al., 2003	60/64	58	12-84 (29)	VI	10,5,10,0,3,5,5	38
	Lemoine et al., 2009	68/84	61	12-115 (50)	VI	10,5,10,0,3,0,0	28
Isis	Seng et al., 2013	26/30	n/a	18-47 (30)	VI	4,5,7,0,3,10,5	34
Ivory	Goubau et al., 2013	22/22	66	60-77 (67)	VI	4,5,10,10,5,5,10	49
	Spaans et al., 2016	20/20	60	26-52 (37)	VI	4,5,10,0,3,5,10	37
Moje Acamo	Hansen and Vainorius, 2008	9/9	58	12 (12)	VI	0,2,10,0,5,5,0	22
	Kaszap et al., 2012	12/12	64	- (50)	VI	0,5,10,0,5,5,0	25
Motec	Krukhaug et al., 2014	- /53	63	- (22.8)	VI	4,2,10,0,5,0,0	21
	Thillemann et al., 2016	40 /42	59	14-46 (27)	VI	7,5,10,0,5,5,10	42
Nahigian prosthesis	Hannula and Nahigian, 1999	30/34	58	15-86 (47)	VI	4,5,10,0,3,3,0	25
Roseland	Schuhl, 2001	43/45	59	1-50 (14)	VI	7,2,0,0,3,3,5	20
	Moutet et al., 2001	24/27	62	24-61 (38)	VI	4,2,10,0,3,5,10	34
	Zollinger et al., 2008	27/32	n/a	7-66 (39)	VI	4,5,10,0,5,0,10	34
	Guardia et al., 2010	68/79	61	- (44)	VI	10,5,10,0,3,5,5	38
	Semere et al., 2015	51/64	58	≥120 (150)	VI	10,5,10,0,0,5,10	40
Rubis II	Maes et al., 2010	106/118	62	- (88)	VI	10,5,10,0,0,3,5	33

Table 9 Details of outcome measurements of other prostheses

Implant	Authors	Pain	Mean grip strength (Kg)	Mean key pinch strength (Kg)	Mean tip pinch strength (Kg)	Radiographic findings	Failure rate	Predominant Complication
Arpe	Brutus and Kinnen, 2004	0.1 on a scale 0-4.	-	6.6 (98.5% of opposite side)	-	3/63 cup loosening; 1/63 stem loosening	5% (3/63)	dislocation (6/63)
	Jacoulet, 2005	all pain free	23	4	-	1/37 cup loosening	8% (3/37)	dislocation (2/37)
	Apard and Saint-Cast, 2007	5/32 pain with prolonged use; 3/32 pain in cold	20	5.7	-	2/32 dislocation, 5/32 loosening	22% (7/32)	loosening
	Vander Eecken et al., 2012	1 (VAS) post-op	-	-	-	1/43 cup loosening; 1/43 cup perforation, 1/43 polyethylene wear	9% (4/43)	dislocation (2/43)
	Martin-Ferrero, 2013	7.4/1.1 (VAS) (pre-op/post-op) P<0.001	-	4.3/5.6 (pre-op/ post-op) P=0.005	-	14% minor loosening; 8% failed	5% (3/65)	loosening
Braun-Cutter	Badia and Sambandam, 2006	24/26 complete pain relief	-	3.5/5.5 (pre-op / post-op)	-	No loosening or subsidence	4% (1/26)	posttraumatic dislocation 1/26
Cemented resurfacement arthroplasty	Pendse et al., 2009	1.29 (VAS)	19.6	-	4	11/62 trapezial loosening 1/62 metacarpal loosening	11% (7/62)	loosening
	ten Brinke et al., 2016	-	-	-	-	-	20% 2/10	-
Guepar II	Masmejean al., 2003	78% (50/64) pain free (Alnot and Muller's classification)	19 79% of opposite side	6 94% of opposite side	-	6/64 radiolucent lines 1/64 metacarpal sinking	2% (1/64)	loosening
	Lemoine et al., 2009	3.5/0.7 (Alnot and Muller's classification) p < 0.0001	20.8/20.4 (operated/non-operated)	4/4.2 (operated/non-operated)	-	33% lucent lines; 3% cup loosening; 3% stem loosening	1% (1/84)	pain

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Implant	Authors	Pain	Mean grip strength (Kg)	Mean key pinch strength (Kg)	Mean tip pinch strength (Kg)	Radiographic findings	Failure rate	Predominant Complication
Isis	**Seng et al., 2013**	8.1/3.4 (VAS) (pre-op/post-op)	17 75% of opposite side	5 75% of opposite side	3 73% of opposite side	20% radiolucent lines; 10% loosening	3% (1/30)	loosening
Ivory	Goubau et al., 2013	8.1/1.2 (VAS) (pre-op/post-op) p<0.0001	17.2/22.5 (pre-op/post-op) p<0.001	4.5/5.1 (pre-op/post-op) p=0.18	-	1/22 cup instability; 1/22 osteolysis	5% (1/22)	sensory branch radial nerve dysaesthesia
	Spaans et al., 2016	1.9 (VAS)	23.7/26.1 (operated/non-operated)	4.5/4.5 (operated/non-operated	2.4/2.6 (operated/non-operated-	2/20 minor osteolysis cup; 1/20 trapezium collaps	10% (2/20)	dislocation 2/20
Moje Acamo	Hansen and Vainorius, 2008	-	-	-	-	8/9 osteolysis	33% (3/9)	osteolysis around the implant
	Kaszap et al., 2012	92% pain	-	-	-	10/12 implant migration; 11/12 implant tilting; 9/12 radiolucent lines	42% (5/12)	implant migration or loosening
Motec	Krukhaug et al., 2014	-	-	-	-	3/53 loosening	9% (5 year failure rate)	dislocation and pain
	Thilleman et al., 2016	1/4 with activity / at rest (NRS)	-	-	-	9/42 cup loosening 3/42 dislocation	42% (2 years	loosening
Nahigian prosthesis	Hannula and Nahigian, 1999	23% excellent results, 51% good results	36.2/43.4 (pre-op / post-op)	3.6/6.2 (pre-op / post-op) p<0.001	n/a	13/23 radiolucent lines	13% (5/39)	loosening

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Implant	Authors	Pain	Mean grip strength (Kg)	Mean key pinch strength (Kg)	Mean tip pinch strength (Kg)	Radiographic findings	Failure rate	Predominant Complication
Roseland	Schuhl, 2001	35% painfree; 39% infrequent pain	-	-	-	8/45 cup loosening; 2/45 stem loosening; 1/45 dislocation	18% (8/45)	loosening
	Moutet et al., 2001	67% painfree	89% of the other side	95% of the other side	-	1/27 stem loosening; 1/27 trapezial fracture	0%	trapezial fracture and loosening
	Zollinger et al., 2008	7.4/1.2 (VAS) (pre-op/post-op) p=0.000	-	-	-	2/32 dislocation	9% (3/32)	dislocation
	Guardia et al., 2010	70% satisfactory results	-	-	-	2/79 dislocation; 1/79 trapezium fracture	4% (3/79)	dislocation
	Semere et al., 2015	41% pain free; 50% occasional pain	22	6	4.5	33/47 cup subsidence; 31/47 stem subsidence	9% (6/64)	loosening
Rubis II	Maes et al., 2010	77% pain free; 33% moderate pain.	-	-	100% of opposite side	5% osteolysis base stem, 9% osteolysis around stem and cup	8% (9/118)	dislocation (8%)

D. Discussion

The scientific evidence in the management of thumb CMC joint OA has not achieve a consensus about the best options. EBM still lacks for influence in this field. (Wolf and Delaronde 2012; Aliu et al., 2013) Hand surgeons should be aware of the merits and limitations of these studies as they could have a high impact on the different aspects of the professional environment. Quoting a recent article by Zafonte and Szabo: "the study findings may not always be in alignment with one's clinical gestalt. Practicing quality, EBM should be a combination of one's own clinical expertise and high-level evidence studies". (Zafonte and Szabo 2014)

Our systematic review on trapeziectomy alone and LRTI, based on controlled randomized and non-randomized trials with a minimum follow-up of 12 months, showed equivalent results on post operative VAS between the two groups; moreover, it was unable to detect a difference in terms of DASH, grip strength, key pinch, tip pinch or ROM. In a qualitative analysis some complications were more frequent for LRTI in respect to trapeziectomy (tendon related problems: 3.3% vs. 1.1%, and pain related problems (persistent severe pain, CRPS): 3.7% vs. 0.7%).

Stronger evidence suggests that LRTI may have better results over arthrodesis in terms of ROM (radial and palmar abduction) and pain (VAS 0-100: 9.12, I-square: 12.4%, p=0.013). A qualitative analysis shows a higher incidence of pain related problems and re-interventions with TM arthrodesis. No differences were observed as for grip strength, key pinch, tip pinch or DASH.

The high heterogeneity of data observed in the studies weakens the efficacy of our analysis on the outcomes. Moreover, it has to be noted that outcomes are not yet measured using standardised endorsed procedures. "Researchers should focus on developing more sensitive outcome measures that are indicative of the specific changes in hand function after CMC OA" surgery. (Vermeulen et al., 2011) Altogether, patients' assessment, expressed by an objective rating system, could be a synthetic tool of evaluation. Standard surveys, like DASH or PWRHE, could as well contribute to

establish the outcomes quality, in the absence of upper extremity comorbidities (Calfee et al., 2015).

The terms "simple Trapeziectomy" and "hematoma arthroplasty" are quite often used as synonyms. Conversely, they should be more clearly differentiated. Sonographic studies of the interposed tissue following trapeziectomy and 1st metacarpal suspension show a mesenchymal tissue, derived from blood, interposed between scaphoid and the metacarpal base (Putterie et al., 2014). On the other hand, simple trapeziectomy, as described by Salem and Davis in 2014, can often lead to the base of 1st metacarpal articulating directly over the distal scaphoid with no significant clinical difference at a 6 years follow-up. (Salem and Davis 2014)

Hematoma arthroplasty may deserve further investigations on the quality of the soft tissue constituting the new thumb basal joint. Eventually an RCT on simple trapeziectomy and hematoma arthroplasty might be performed.

Regarding TMC total joint replacement, the short-term outcomes are better than trapeziectomy and LRTI. Data demonstrate that patients with TMC joint prostheses reached the end point of pain reduction as early as after 3 months (Ulrich-Vinther et al., 2008; Jager et al., 2013; Jurča et al., 2016). Conversely the long term complication rate is higher. There are reports of many implants. The reported outcomes are very variable: for some there are good long-term outcomes to beyond 10 years, for others there are unacceptably high early rates of failure. The implant with the best survival rate could not be identified because of the differences in methodology to determine the survival rates and of an overall short-term follow-up. Because of the cost of the implant, a total joint replacement should give significantly better results than trapeziectomy, or its modifications, to justify its use; moreover, costs increase when a secondary procedure due to loosening, dislocation or other complications is required. Even if research on new implant arthroplasties should not be abandoned, to date no single implant can be recommended for TMC joint OA, as previously noted (Giddins, 2012; Huang et al., 2015), and many implants should only be used with caution if at all.

E. Conclusions

Those who try to make a point on rizoarthrosis face the evidence that discussing such a topic requires an approach somehow atypical and that theoretical studies and research should rather go against the flow, if compared to the current investigations on joint reconstructive surgery. It seems clear that a morphological replacement strategy cannot help as much as the understanding of the peculiar biomechanics of this articulation following a "mesenchymal arthroplasty" after trapezium excision.

Statistical studies may substantially contribute to ascertain the evidences on the assumptions and trends given for accepted in any medical treatment plan. However, these studies are very dependent on how the data are collected and on the criteria on which the analysis is based. Finding objectivity in this process is a key point to get a valid result.

The outcomes of this study, in line with the most recent ones, confirm that the simpler procedure seems to be the better when assessed in terms of global patients' satisfaction, lesser costs, lower incidence of complications. Waiting for the "perfect arthroplasty" to be described, all of the currently available surgical options should be compared taking into account the foregoing considerations. Future research should help to assess the short and long term outcomes and the healthcare and personal costs, so that surgeons and patients can make fully informed choices. (Marks et al., 2013)

Hematoma arthroplasty should likely be better defined, and could more appropriately be named as "mesenchymal arthroplasty". In fact, it is appropriate to differentiate it from a simple trapeziectomy, as its efficacy is based on favouring the formation of an interposed tissue, derived from the blood clot, absent or deficient when the 1st metacarpal base is left free to proximalize and articulate directly with the scaphoid. How, and for how long in some instances, the post-trapeziectomy space should be kept distracted, in order to permit the maturation of the mesenchymal spacer induced by the hematoma, should be object of focused analyses. LRTIs should, as well, be included in the "mesenchymal arthroplasty" group, as the ligament reconstruction and tendon interposition keep the post-trapezectomy space open, inducing the formation of a composite mesenchymal spacer that is generated by the post-operative hematoma together with the interposed tendon tissue.

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3.5 Systematic Review of the Management of Distal Radial Fractures

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Distal radial fractures (DRFs) are common injuries at any age but particularly in the older person. The management of patients with distal radial fractures remains controversial. There are many studies that have analysed specific sections of the management of DRFs but there are very few randomised controlled trials. The management of children's fractures involving the distal radius will not be discussed.

This work is based upon a very large piece of work performed by surgeons and therapists under the auspices of the British Society for Surgery of the Hand (BSSH) and the British Orthopaedic Association (BOA). This has been provided very kindly with the permission of the authors at short notice. It does not represent the full data set which is to be published separately in the near future. It is based upon a series of very detailed systematic reviews providing a comprehensive in depth analysis of the management of adult distal radius fractures. The data provided below is a summary of the work sufficient to inform readers but without affecting the publishing priorities of the BSSH and BOA.

Epidemiology

DRFs are the commonest adult orthopaedic injury; an understanding of its epidemiology is therefore of huge importance (O'Neill et al., 2001). Around 70,000 individuals sustain a DRF per year in the UK. Estimates for the direct medical cost alone for treatment of fractures of the forearm and wrist in the UK have been predicted to total over £35 million by 2020 and DRF accounts for the majority of these (Burge et al., 2001). In the USA, Medicare paid $170 million in DRF related payments in 2007. 2.5% of all emergency department visits in Denmark are related to DRFs (Shauver et al., 2011). A bimodal distribution is well reported (Donaldson et al., 1990; Court-Brown and Caesar, 2006). Injury may result from high-energy trauma in a young patient, but most commonly follows a fall onto the outstretched hand in older patients with underlying osteoporosis. DRF is seen more frequently in men in younger patients and women in older patients. In patients aged over 65 years of age DRF accounts for up to 18% of all fractures (Baron et al., 1996).

Numerous epidemiological studies of DRF have been conducted in many different countries with wide ranging incidence rates reported, reflecting differences in the populations studied and the methods of patient identification (Court-Brown and Caesar, 2006; Diamantopoulos et al., 2012; Bentohami et al., 2014; Flinkkil et al., 2011; Brogren et al., 2007; Thompson et al., 2004). In a recent UK trial incidence rates of 9/10,000 and 36.8/10,000 person-years were reported for men and women respectively (O'Neill et al., 2001).

Some studies have suggested incidence rate is rising. However, others have shown no significant change in incidence of DRF with time; Lofthus et al., 2008, reported no increase in fracture incidence in Oslo over a 20 year period while Jaglal et al., 2005, reported a decline in the incidence of osteoporotic hip and DRF over a 13 year period in Ontario. They thought this was related to a simultaneous increase in BMD testing and treatment with bone-sparing medications. Fracture liaison services have also developed significantly over recent years following publication of specific guidelines and the benefits of these services has been clearly demonstrated in the UK (McLellan et al., 2011).

Emergency departments treat the most fractures overall during summer due to paediatric injuries when children are not at school and involved in more outdoor activities (Bhattacharyya and Millham, 2001; Gill and Goldacre, 2009.) Adult DRFs occur more frequently in winter (Falch, 1983; Wareham et al., 2003). Falls due to slippery outdoor surfaces are likely to explain this but evidence is scarce. A study from Finland has demonstrated an association between wintry weather and an increased risk of DRF (Flinkkilä et al., 2011).

Jacobsen et al., (1999) reported on the effect of weather and seasonality on hip and wrist fractures in Rochester, Minnesota over a 38 year period. They noted wintery conditions were associated with the greatest increase in incidence of wrist fracture for women aged 35-65. An increased risk of DRF persisted in older women but was less pronounced. There was minimal influence of weather on the risk of hip fracture in women aged over 75. They felt the differences were explained by the nature and location of

the falls. DRF more commonly occurs due to a trip or slip outdoors in patients with good neuromuscular control who attempt to stop their fall by placing their hand out (Campbell et al., 1988).

Prevention of distal radius fractures and subsequent fragility fractures

DRF is an injury of particular interest as it is known to have positive predictive value for subsequent fracture at other body sites including vertebrae and neck of femur which have high associated morbidity, mortality and management costs (Johnson et al., 2017; Owen et al., 1982; Robinson et al., 2002). Improved understanding of the groups most at risk of DRF may therefore benefit understanding of fracture epidemiology as a whole and also allow identification of groups at risk of further fracture in whom secondary preventative treatment strategies may be of benefit.

There is mounting evidence that individuals with a previous history of fragility fracture are at an increased risk of subsequent fracture (Porthouse et al., 2004; Gehlbach et al., 2010). Several studies, including meta-analyses, have demonstrated that distal radius fracture pre-disposes to future hip fracture (Crandall et al., 2015; Cuddihy et al., 1999; Johnson et al., 2017). Haentjens et al., (2003) observed that short and long term risks of hip fracture were increased after DRF. Their findings suggest that DRFs are an early and sensitive marker of skeletal fragility, particularly in men. The greatest risk for hip fracture after distal radius fracture has been shown to be within the first year after the wrist injury (Chen et al., 2013; Lauritzen et al., 1993). The incidence of osteoporotic fracture, including hip fracture, can be significantly reduced with appropriate treatment of high-risk groups (Cranney et al., 2001; Ettinger et al., 1999; Larsen et al., 2004). Evaluation of patients with a DRF and initiation of secondary preventative strategies, represents an economically viable opportunity to reduce the incidence of subsequent, potentially more serious fragility fractures.

Primary prevention would be the ideal intervention but with limited resources identifying and treating such a large population is unlikely to be economically viable. Bone mineral density (BMD)

is a strong predictor of fracture risk in both men and women. However, it is neither financially nor logistically feasible to perform osteoporosis screening in the form of BMD testing on the whole population. Five to six times as many patients would need to be identified, assessed and treated to achieve a similar fracture incidence reduction as that achieved with secondary prevention (Marsh et al., 2011; Mitchell, 2011).

Secondary prevention is effective and efficient (Cooper et al., 2011). Fracture liasion services are successful and cost effective. Further fragility fractures can be reduced by 50% (Felsenberg et al., 2005; Meunier et al., 2005). Identifying and treating these patients would prevent an estimated 25% of hip fractures per year. Reduction of hip fracture rate with alendronate treatment has been shown to be significant with secondary prevention but not for primary prevention. Alendronate use following an initial non-vertebral fracture produces a significant relative risk reduction of further fracture. Along with reducing fracture risk pharmacological therapy has been shown to improve quality of life and reduce mortality (Eastell et al., 2001; Lyles et al., 2007; Silverman et al., 2007).

In a Canadian study Majumdar et al., (2008) randomly allocated wrist fracture patients to an intervention involving patient education and the provision of evidence based guidelines to their family doctor. Compared to the control group osteoporosis treatment rate was three times higher at 6 months following wrist fracture. In a further study by Majumdar et al., (2011) a cost effectiveness analysis conducted one year after initial fracture showed that for every 100 patients in the intervention group three fractures, including one hip fracture, were prevented. $26,800 was saved over a patient's lifetime and 1.1 quality-adjusted life year gained.

Classification

There are at least 15 different classification systems described for DRFs, each with their own strengths and problems (Shehovych et al., 2016). Classification systems should facilitate communication, and ideally predict prognosis and inform treatment (Andersen et

al., 1996). They should be easy to use and demonstrate reliability, relevance and reproducibility.

Fernandez

The Fernandez classification system uses a simple numerical system based on the mechanism of injury. It describes the type of fracture along with the soft tissue injury and also incorporates distal radio-ulnar joint (DRUJ) injuries. Each classification has a prognosis and treatment recommendation. Drawbacks are that it is complicated to use with poor inter and intra-observer reliability (Andersen et al., 1996).

Frykman

The Frykman classification system is a descriptive tool for fractures of the distal radius. Historically it has been widely used (Belloti et al., 2008). There are eight categories for four main injury types with the possible addition of an ulna styloid fracture to each type. It does not take into account displacement, comminution or shortening with no correlation found with functional outcome one year after fixation. Reliability and reproducibility is fair to moderate between observers with particular difficulty seen in agreement on involvement of the DRUJ (Keerthi et al., 2013; Kural et al., 2010).

Universal

The Universal classification system was designed to improve on the Frykman classification. It is simple; it categorizes fractures as displaced and non-displaced, and extra and intra-articular. Treatment recommendations are also provided. It is easy to use but only has fair to moderate reliability and fair to substantial reproducibility (Belloti et al., 2008).

Melone

The Melone classification describes intra-articular fracture patterns based on four components of an intra-articular injury; the radial shaft, the radial styloid, dorso-medial and palmar-medial fragments of the lunate facet of the distal radius. Reliability has been shown to be poor with observers finding it difficult to identify the named fragments (Andersen et al., 1996).

Arbeitsgemeinschaft für Osteosynthesefragen (AO)

The AO classification system is more descriptive of the fracture itself; it uses an incrementing alphanumeric system which represents the complexity of the fracture. The system shows substantial intra-observer reliability when identifying the main groups (A – extra-articular, B – partial articular and C - complete articular) but decreases to moderate with the addition of sub-group identification (Plant et al., 2015). It is comprehensive and popular for research but complex and time consuming.

Radiographic parameters and functional outcome

Many different radiographic parameters can be measured during the assessment of distal radial fractures, including radial height, ulnar variance, dorsal/ palmar tilt, carpal alignment, and intra-articular gaps and steps. There is an extensive published literature investigating the relationship between radiological parameters and functional outcome but the results are conflicting. Most studies are case series and many are retrospective. Some societies have issued recommendations regarding how much displacement can be accepted before fixation is required but acknowledged that the evidence supporting this is weak.

Several authors have reported poor functional outcome after mal-union with radial shortening or increased ulnar variance and subsequently advocated the restoration of length as the most important factor. Brogren et al., (2011) prospectively reviewed 143 consecutive patients with DRF one year after injury. The DASH score was significantly higher in those with positive ulnar variance of 1mm or greater. In a randomised control trial comparing treatment methods for re-displaced DRF McQueen and Hajducka (1996) noted that positive ulnar variance of greater than 3 mm, compared with the unaffected side, was associated with reduced grip strength. Wilcke et al., (2007) found that in 78 patients retrospectively assessed after 22 months radial shortening ≥2 mm, dorsal angulation >15° and radial angulation >10° were each significantly associated with a poorer DASH score.

Finsen et al., (2013) reviewed 260 patients who underwent

non-operative treatment for DRF at a mean of 6.3 years previously. Bivariate analysis revealed a significant relationship between displacement and adverse outcome. However these variables only explained 23% of the variability of the clinical outcome with dorsal angulation, ulnar variance and radial inclination only accounting for 11%. The authors concluded that final alignment following DRF only has a minor influence on clinical outcome. In a prospective study of 66 patients treated with volar plating for DRF, Chung et al., (2007) found that only age and income were significantly associated with outcomes one year after surgery. Plant et al., (2017) recently compared a number of PROMs and physical measures of function with palmar tilt and ulnar variance in 50 patients who were treated surgically in a randomized control trial. The radiographic parameters were found to correlate poorly with measures of physical function and patient rated outcome scores at all time points assessed (3, 6 and 12 months). The authors commented that the results raised concerns about the use of radiological parameters to determine management and that restoration of 'normal' radiographic parameters may not be necessary to achieve a satisfactory functional outcome.

Age has also been shown to affect the relationship between malunion and outcome. Grewal and MacDermid (2007) found that malalignment of the distal radius is associated with higher reports of pain and disability in patients less than 65 years of age. In patients aged 65 years or over no radiographic parameter was found to influence PRWE or DASH scores. The relative risk of a poorer outcome with malalignment showed a decreasing trend with increasing age, with a significant reduction after 65 years. Other studies have reported similar findings in older groups of patients

It is established that persistent intra-articular step predisposes to the development of radiocarpal degenerative change. Knirk and Jupiter (1986) showed that a step of 2mm or more led to a 100% incidence of radiological arthritis in 40 young adults at mean follow up of 6.7 years. Subsequently the conclusions of this paper have been challenged. Catalano et al., (2006) found 76%

of patients with intra-articular displacement 7 years after internal fixation of a distal radius fracture had evidence of arthritis. This progressed when reassessed 15 years later. Cadaveric biomechanical studies have shown that an articular step of 1mm causes a significant increase in contact stresses.

The evidence that this radiologically proven arthritis correlates with symptoms and poor functional outcome is debatable. Studies by Trumble et al., (1994) and Chung et al., (2007) showed that residual articular displacement was associated with poor outcome. 93% of the patients in Knirk and Jupiter's study (1986) were symptomatic however 61% reported a good or excellent outcome and only one patient, with bilateral fractures, had to stop work due to their injury. The only functional limitation seen in the 15 year review of Catalano's original study was an insignificant reduction in wrist flexion. Forward et al., (2008) retrospectively reviewed 106 young adults with intra-articular distal radius fracture at a mean of 38 years and found DASH (Disabilities of Arm, Shoulder and Hand) scores were not different to population norms and functional impairment was less than 10% when assessed by the Patient Evaluation Measure (PEM). Kopylov et al., (1993) assessed patients who had sustained a wrist fracture 30 years previously. Radiographic osteoarthritis was associated with articular incongruity but 87% of patients described no difference between the injured and uninjured sides.

Reliability and reproducibility of radiographic parameters

There is little available evidence to demonstrate the validity and reproducibility of radiographic measurements of distal radius fractures. Most studies predate the modern digital software now commonly used to measure radiographic parameters. Kreder et al., (1996) developed a standardized method of measuring eight anatomic parameters of the distal radius to test inter-observer variation. Sixteen individuals were asked to measure these parameters on six radiographs of healed distal radius fractures. The results showed high rater agreement in measurements of palmar/dorsal

tilt, ulnar variance and radial shift, but poor inter-observer agreement of intra-articular step and gap. Johnson and Szabo (1993) reviewed inter-observer variability in assessment of radial angle and palmar tilt in a cadaver study. The mean standard deviation was 3.2 degrees for radial angle, 3.6 degrees for conventional lateral palmar tilt and 2.1 degrees for 15 degrees lateral palmar tilt.

Stirling et al., (2016) demonstrated strong correlation of both inter and intra-observer measurement of radial height, radial inclination and dorsal/palmar tilt using digital software frequently used in European hospitals. Assessment of articular step-off and gap was limited due to the small number of fractures with an intra-articular component; inter-observer correlation was poor for these parameters. This correlates with previous evidence suggesting variability in assessing gaps of less than 2mm, reflecting the challenge of interpreting the finer detail of these injuries. Computed Tomography (CT) scanning has been advocated in the pre-operative assessment of complex intra-articular fractures for this reason. Evidence exists that CT evaluation improves the sensitivity of articular surface gapping and may alter treatment plans compared with decision making based on radiographs alone. However, concordance of management decisions between observers based on CT is poor and it therefore may be an unnecessary and complicating investigation.

Presentation

The majority of adult DRF's occur in the older age group (fragility fractures) and less energy is required to produce the injury. In contrast, in the younger patient, DRFs may be associated with a high-energy mechanism leading to potential acute complications. Recognition of the personality of the fracture is a key aspect of the initial management at presentation. Open fractures and DRFs where there is marked median nerve involvement require emergency treatment.

Management

The management of DRFs remains controversial. There are many

papers with cohort studies but a paucity of randomized controlled trials. There is little evidence to direct clinicians in the Emergency Department as to which fractures require simple casting to those that require intervention.

The National Clinical Guideline Centre has produced clinical guidelines on the management of Fractures (non-complex): assessment and management. The recommendation is that dorsally displaced DRFs should be reduced at the earliest opportunity and ideally with real time image guidance and under intravenous regional anaesthesia by appropriately trained staff.

The British Orthopaedic Association (BOA) has produced guidelines (BOAST 7) that recommend 'following acute traumatic orthopaedic injury, patients should be seen in a new fracture clinic within 72 hours of presentation with the injury. This includes referrals from emergency departments, minor injury units and general practice'. The fracture clinics should be consultant led so that an appropriate treatment plan can be initiated.

Surgery

There are a variety of surgical options in the management of DRFs and controversy continues to exist over which is the best surgical option for which fracture pattern. A postal survey of orthopaedic surgeons treating distal radial fractures demonstrated no consensus at all with considerable variation (Nazar et al., 2009).

There is no evidence to support the best time for surgery to occur however the NICE guidelines on non-complex fractures recommends that for intra-articular fractures, surgery should occur within 72 hours of injury and for extra-articular fractures within 7 days of injury. From a patient perspective, an appropriate surgeon should perform surgery as soon as possible as delay confers no benefit to the patient.

External fixation

The popularity of external fixators in the management of distal radial fractures has declined with the advent of volar locking plates.

A meta-analysis concluded that 'For surgical treatment of distal radius fractures, internal fixation yields better functional outcomes, forearm supination, restoration of anatomic volar tilt and radial inclination, and fewer minor complications. The patients who received internal fixation using volar locking plates for the treatment of distal radius recovered more quickly than did patients who received external fixation'. There is still a place for external fixation primarily in the management of open fractures.

Intra-articular fractures

Historically there has been an ambition to restore articular congruency but the papers by Forward et al., (2008) and by Kopylov et al (1993) raise doubts that it has to be absolute. Some incongruency may be acceptable although there is no evidence to guide the clinician. There remains controversy over the type of fixation to be used to control intra-articular fractures. Options include volar locking plates, fragment specific fixation, various wiring techniques, dorsal plates and external fixators.

Whilst the type of fixation (O'Shaughnessy et al., 2015) may vary there is a general conclusion that the recognition and stabilization of volar rim fractures is critical to prevent carpal subluxation and subsequent degeneration (Harness et al., 2004; Kitay and Mudgal, 2014).

Extra-articular fractures

Despite many publications on the management of extra-articular fractures including three Cochrane reviews (Handoll et al., 2007a, b; Handoll and Madhok, 2009) there is no preferred solution whether nonoperative or surgical.

Extra-articular volar displaced DRFs have been traditionally treated by a volar buttress plate with minimal controversy however there remains huge controversy over the management of dorsally displaced DRFs. Over the past few years there has been an exponential trend to use internal fixation, primarily because of the increasing availability of volar locking plates. The DRAFFT study (Costa et al., 2014) attempted to address this problem but its

conclusions have been questioned (Fullilove and Gozzard, 2016). The randomized studies by Karantana et al., (2013), McFadyen et al., (2011) and Marcheix et al., (2010), all conclude that volar plating offers a better prospect of restoration of the anatomy with earlier return to functional activities. However, all of these studies had relatively short follow-up, so there are no conclusions of the long-term outcome though the trend is for the outcome at one year post-injury to be the same.

In Conclusion

The evidence for the management of distal radial fractures is scarce. The personality of the fracture, the patient's views and the experience of the clinician are all factors that should be considered in the decision to treat.

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CHAPTER 4

SOFT TISSUES

4.1 Systematic Review of Flexor Tendon Rehabilitation Protocols after Acute Flexor Tendon Repair in Zone 2

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Introduction

Immediate flexor tendon repair of the hand is common practice; however, routinely achieving successful outcomes from repair of flexor tendon injuries in zone 2 has remained an unsolved problem. Immediate repair has traditionally suffered rupture rates of c. 5% and adhesion rates requiring surgery of c 5% even in series from good units (Elliot and Giesen 2013).

In 1975, Duran and Houser reported their protocol with controlled passive motion; they stated that a minimal tendon excursion was sufficient to prevent restrictive adhesions following tendon repair (Duran and Houser, 1975). In 1977, Lister et al. reported encouraging results with immediate passive mobilization using an orthosis with rubber bands that allowed active digit extension and passive flexion. These two protocols and their modifications dominated until the 1990s, when the idea of an immediate controlled active mobilization was developed (Elliot et al., 1994; Bainbridge et al., 1994).

Two very exhaustive works have systematically reviewed the state of the art in flexor tendon rehabilitation up to 2011 (Chesney et al., 2011; Starr et al., 2013).

These two reviews both concluded that the controlled active motion protocols gave significantly higher rate of good and excellent results than other protocols. Chesney et al. concluded that there was no difference in rupture rates between active and passive protocols, while Starr et al. reported a higher rupture rate with active protocols.

In this chapter, we systematically review the literature from 2011 in order to refine and update the available information. We considered articles reporting protocols where flexion of the fingers were performed actively by the patient within one week from surgery, as belonging to group A (Active). We considered the articles with Kleinert or Duran protocols and their modifications, as belonging to group P (Passive).

We compared the results of the two groups in order to draw conclusions about: differences in the rate of ruptures; differences in the rates of good and excellent results.

Matherial and Methods

We search of PubMed and Cochrane databases to identify articles on flexor tendon injury, repair, and rehabilitation protocol. To prevent selection bias abstracts were blind reviewed. The search included keywords “flexor tendon repair”, “rehabilitation” and “hand” and limited to papers published from 2012 onward; this returned 93 results.

We included English language clinical studies that provided a description of the flexor tendon repair technique, rehabilitation protocol and an assessment of functional clinical outcomes, including complications, final digit motion (Libberecht et al., 2006) and evaluation with the original Strickland classification (Strickland and Glogovak, 1983).

Functional data reported with the modified Strickland classification or with a different classification, were re-analysed and converted to the original Strickland classifications which are “stricter” and thus potentially more robust. We only included papers with a minimum follow-up of 6 months.

The exclusion criteria were: reviews; case reports; papers with no reported results; biomechanical studies; papers with no report of the surgical technique; papers with no report of the rehabilitation protocol; papers not reporting on acute repairs; studies on flexor tendon injuries outside zones 1 and 2; and studies on animals or cadavers. Articles not reporting complications or rupture rate were excluded. We also excluded papers including children.

Eight articles meeting our criteria were identified through the search process.

The articles have a level of evidence 1 (1 paper), 3 (1) and 4 (6).

After assigning the papers to one of the two groups (A - active rehabilitation protocol; P - passive rehabilitation protocol) The total number of digits treated and the numbers with with good or excellent result was extrapolated were recorded. We repeated the process for tendon ruptures.

The percentages of the two groups were compared with the "N-1" Chi-squared test as recommended by Campbell (2007) and Richardson (2011).

Results

The results are summarized in Table 1.

Our analysis of the literature from 2012 reported the result of eight articles.

One article (Früh et al., 2015) provided two sets of patients for each of groups giving nine sets of patients.

Two sets of patient had the tendon repaired with a 2 strands core suture, two sets with a 4 strands core suture, three sets with a 6 six strands core suture and one set of patients with a 10 strands core suture.

There were five sets of patients in Group P with 380 treated digits. The rates of good or excellent results were a mean of 70% (range 53%-90%); the rupture rate was a mean of 3.2% (range 0%-7%),

There were four sets of patients in Group A with 198 treated digits. The rates of good or excellent results were significantly better at a mean of 85% (range 65%-89%))(p= 0.0007); the rupture rate was significantly higher at a mean of 4.5% (range 0%-5.7%) (p=0.42),

Table 1

Group P (Passive)	N. of digits	Suturing technique	Rehabilitation protocol	Ruptures (%)	Good and Excellent (%)
Früh et al., 2016	138	4 strand core suture Locking circumferential	Kleinert	7% (10)	53%
Rajappa et al., 2016	12	6 strand core suture Locking circumferential suture	Place and hold	0% (0)	83%
Quadlbauer et al., 2016	115	2 strand core suture Simple circumferential suture	Kleinert	0.9% (1)	90%
Farzad et al., 2014	64	2 strand core suture Simple circumferential suture	Kleinert and place and hold	0% (0)	59%
Savviddou and Tsai, 2015	51	6 strand core suture Simple circumferential suture	Early place and hold. From week 3, active motion	1.9% (1)	81%
	380			**3.2% (12)**	**70%**
Group A (Active)					
Das et al.,2014	52	2 strand core suture Locking circumferential suture	Early active mobilization	5.77% (3)	84%
Al-Quattan, 2012	28	10 strand core suture	Controlled active mobilization	0% (0)	89%
Moriya et al.,2012	97	6 strand core suture Simple circumferential suture	Modified Kleinert	5.4% (5)	83%
Früh et al., 2016	21	4 strand core suture Locking circumferential suture	Controlled active mobilization	5% (1)	65%
	198			**4.5% (9)**	**83%**

Discussion

Our analysis of the literature on Flexor Tendon repair from 2012, does show a significant difference between the rates of good or of excellent results between active and passive rehabilitation protocols for acute flexor tendon repairs in zone 2 of the hand. The ac-

tive protocols seem to provide a higher rate of good and excellent results, but also a slightly higher rate of rupture rates.

With regard to the rate of good and excellent outcomes, our results are in agreement with the analysis of the literature performed by Chesney et al. (2011) and Starr et al. (2013).

Our reported rupture rate is similar to that reported by Starr et al. (2013) but not the rate reported by with Chesney et al. (2011) who found no significantly higher rate of ruptures for the active protocols. Results of these two systematic reviews are summarized in Table 2.

Table 2

Chesney et al. 2011	Numbers of Digits	Ruptures rate	Excellent and good outcomes
Passive Protocols	590	4.9%	70.6%
Active Protocols	275	4.7%	94%
Starr et al. 2013			Excellent, good and fair outcomes
Passive Protocols	1518	3.5%	91%*
Active Protocols	1467	5.2%	94%*

The number underlined are calculated as significant

* In this review they only reported their poor result. We have assumed that the other results are excellent, good or fair.

Controlled Active Motion protocols are much simpler for the patient and the Hand Therapist (Bainbridge et al., 1994). In addition active mobilization protocols splints are simpler when compared to the rubber bands regimes, where a double splint, dorsal and volar, is sometimes required and there can be difficulty fitting and tensioning the rubber bands correctly.

Unfortunately, some of the examined studies presented confounding factors that might have altered our analysis of the results.

One article (Früh et al., 2015) with a very high number of treated tendons included some digits with concomitant fractures. Because the fractured digits included in the study underwent an unmodified rehabilitation protocol, we decided to include this study. The low rate of good or excellent results in both active and

passive protocols groups reported may be due to the concomitant fractures. Moreover, it is not clear from the article, how many fractured digits were included in each group.

One article (Moriya et al., 2015) included two digits with a lesion in zone 3 in a series of 112 digits. We considered this confounding variable not relevant, but we expect the functional results to be slightly bettered in the two digits with zone 3 injuries.

The result of this analysis are not definitive because of the paucity of published papers and treated digits. Most of the articles analysed were also level 4, with only one randomised prospect study. Nonetheless the results from the last 5 years confirm the results of two systematic reviews analysing the literature up to 2011. We recommend active rather than passive rehabilitation protocols for zone 2 flexor tendon repairs.

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4.2. Postoperative Care After Extensor Tendon Repair

Chapter Editor
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4.2.1 Rehabilitation of Extensor Tendons in the Finger Zones I to V

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Introduction

Rehabilitation regimens following extensor tendon repair can be broadly divided into immobilisation, early passive motion and early active motion (Tang, 2006). Traditionally, static splinting lasted for 3 to 4 weeks (Miller, 1942; Doyle, 1993), but this may result in tendon adhesion, loss of digital flexion, extensor lag, joint contracture and prolonged rehabilitation (Chester et al., 2002). An alternative approach, with early passive motion achieved using a dynamic splint, was introduced in the 1980s and subsequently validated in electrophysiological studies (Newport and Shukla, 1992). Beginning in the 1990s, early active motion was recommended to enhance the gliding of the healing tendon and to further reduce the potential for adhesions (Evans and Thompson, 1993).

The aim of this study was to systematically examine extensor tendon repair rehabilitation protocols by evaluating outcomes following surgical repair of finger zones I–V.

Methods

This systematic review was performed in accordance with the guidelines set out in the preferred reporting items for systematic review and meta-analysis (PRISMA) statement.

Eligibility /inclusion criteria

We included English language clinical studies that provided a description of the surgical repair of extensor tendon injuries in zones II–V and the rehabilitation protocol, as well as an assessment of function clinical outcomes including final digital motion and complications. Zone I injuries (Mallet finger) were excluded, as they are not usually treated postoperatively with an early motion protocol and it has already been the subject of a Cochrane review (Handoll and Vaghela, 2004). The exclusion criteria were: no or deficient results reported; an experimental study only; no reported rehabilitation protocol; treatment of conditions other than acute extensor tendon injuries; review articles; studies not involving finger zones II–V; and studies on paediatric patients (< 5 years of age). The thumb was not considered in this review due to its unique anatomy compared to the other digits.

Information sources and search strategy

Following discussions with a medical librarian, a literature search of studies on extensor tendon injury, repair and rehabilitation was carried out using the PubMed (accessed) and Cochrane databases, from their inception until August 2016, since other electronic databases such as EMBASE, CINAHL, and PEDro were not available in our institution. The initial search included the keywords “extensor tendon injuries”, “repair”, and “hand”. The term “hand” was chosen over “finger” because our study included extensor zone V in the Kleinert and Verdan classification (Kleinert and Verdan, 1983)].

Study selection

The titles and abstracts of all identified studies were examined by one reviewer (K.M.). In cases in which the suitability of a study for inclusion in this review was unclear, the entire article was obtained and assessed. Any issue pertaining to study eligibility was solved by discussion with the senior author (T.Y.).

Data collection process and data items

The following data were extracted from the included articles: author, year, sample size, number of injuries, age, gender, study design, zone of repair, as outlined by Kleinert and Verdan (1983), duration of follow-up, functional results and complications. Based on these data, the primary outcome was defined as the ranges of motion in the injured digit; the secondary outcome was the rate of complications, including tendon rupture, infection and extension deficit.

Assessment of the level of evidence and methodological quality

One independent reviewer (K.M.) determined each article's level of evidence, as outlined by the *Journal of Hand Surgery European Volume*, with a third reviewer available for dispute resolution. Two reviewers (K.M. and T.Y.) independently assessed the quality of the methodology used in each study according to the Coleman scale (Tallon et al., 2001), which assesses study quality based on a multipart questionnaire with sections on the following: 1) study size; 2) mean duration of follow-up; 3) number of different surgical procedures included in each reported outcome; 4) type of study; 5) diagnostic certainty; 6) description of the surgical procedure; and 7) description of the postoperative rehabilitation protocol. The possible scores range from 0 to 60 points, with higher scores indicating higher methodological quality. If the scores were not consistent, a consensus score was determined for each study.

Statistical analysis

Among the many methodologies for evaluating ranges of motion following extensor tendon repair, we chose two that are commonly used for comparative statistical analyses of the type performed in this review: 1) Miller's criteria (Miller, 1942), which assesses total extension deficit and flexion loss; and 2) Strickland and Glogovac's criteria (Strickland and Glogovac, 1980), which reports on the percent of normal active proximal interphalangeal (PIP) and distal interphalangeal (DIP) joint motion. Fisher's exact test was used to compare good and excellent rankings according to the Miller or Strickland and Glogovac criteria. All data from other methodologies used to evaluate ranges of motion were only summarised descriptively. In addition, the overall complication rates were compared using Fisher's exact test. A p-value < 0.05 was considered to indicate statistical significance.

Results

Study selection

From the searches 193 unique records were identified. Of these, 131 were excluded after screening the title or abstract, on the basis of a lack of relevance. The reference lists of the remaining 62 records were screened, which led to the identification of a further study, resulting in a final total of 68 eligible full-text articles. Of these, 53 were excluded, in most cases because extensor tendon repair was performed in zones other than II–V. Thus, 15 articles were included in the final review. Their characteristics are outlined in Table 1.

Demographic characteristics

Studies meeting all of the inclusion criteria described 480 injuries in patients ranging in age from 12 to 71 years who were treated postoperatively with static immobilisation (n = 190), dynamic extension splinting (n = 248) or early active mobilisation (n = 42). Nine studies did not clearly identify the ages of their cohorts. Five studies recorded gender; as expected men comprised 58–88% of the study participants. The follow-up times ranged from 1 to 240 months.

Preoperative characteristics

Twelve studies had exclusion criteria of concomitant injuries, such as fractures, joint damage, crush injuries, skin damage, tissue loss, neurovascular injuries and flexor tendon injuries. The concomitant injuries addressed by the exclusion criteria differed among the articles. In the remaining three studies, associated injuries were not among the exclusion criteria. Six studies recruited only patients with complete transection of the extensor tendon (Altobelli et al., 2013; Neuhaus et al., 2012; Newport et al., 1990; Purcell et al., 2000; Stuart and Zambia, 1965; Walsh et al., 1994); five studies included patients with partial lacerations (Crosby and Wehbé, 1999; Hung et al., 1990; Ip and Chow, 1997; O'Dwyer and Quinton, 1990; Saldana et al., 1991). The remaining four studies did not describe the extent of tendon division. Primary repair (end-

Table 1 Characteristics of included studies

Author (Year)	Study design (Cscore)	Sample characteristics	Exclusion criteria of concomitant injuries	Intervention (Start date)	Number of extensor tendon injuries (Zone of repair)	Mean duration of follow-up (Range)	Functional results Complications
Altobelli [1] (2013)	RS (32)	Mean age: 29.2(range: 19-49) %Male: 80%	Crush injuries Fractures	EAM+static splint for 3-5 wks (5 days)	6 (IV+V)	4 (2.5-6.5) mo	Miiler: E+G 6 No complication
Crosby [3] (1999)	RS (30)	Mean age: not reported %Male: not reported	Fractures	DES for 4 wks (1-5 days)	27 (III+IV+V)	7 (2-24) mo	Mean TAM 262 ° No complication
Evans [7] (1995)	RS (22)	Mean age: 41(range: 12-70) %Male: 84%	Flexor tendon injuries	Static splint for 3-6wks EAM+staticsplint for 4 wks (2-11 days)	38 (III) 26 (III)	2.5 (1.6-4) mo 1.7 (1-2.8) mo	Strickland: E+G 16 Extension deficit:6 Strickland: E+G17 No complication
Hung [10] (1990)	PS (27)	Mean age: not reported %Male: not reported	Fractures Jointdamage Flexor tendon injuries Neurovascular injuries	DES for 5 wks (4 days)	31 (II+III+IV+V)	6.7 (4-10) mo Button-hole deformity: 1	Mean TAM 217 °
Ip 11 (1997)	PS (38)	Mean age: not reported %Male: not reported		DES for 5 wks (2 days)	28 (IV+V)	Not reported (2-6 mo)	Dargan: E+G 24 No complication
Mehdinasab [13] (2012)	PS (43)	Mean age: not reported %Male: not reported	Fractures	Static splint for 4 wks (II+III+IV+V)	67 No complication	12 (4-17) mo	Miller: E+G 52
Neuhaus [15] (2012)	PS (32)	Mean age: 39.7(range: 15-66) %Male: 58%	Fractures Joint damage Crushinjuries Flexor tendon injuries	DES for 3 wks (3-7 days)	14 (IV+V)	3.6 (1.7-7.2) mo	Miller: E+G 13 No complication
Newport [16] (1990)	RS (30)	Mean age: not reported %Male: not reported		Static splint for 3-4 wks	33 (II+III+IV+V)	60 (6-240) mo	Miiler: E+G 12 Not reported

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Author (Year)	Study design (Cscore)	Sample characteristics	Exclusion criteria of concomitant injuries	Intervention (Start date)	Number of extensor tendon injuries (Zone of repair)	Mean duration of follow-up (Range)	Functional results Complications
O'Dwyer [19] (1990)	RS (30)	Mean age: not reported %Male: not reported		DES (Not reported)	88 (III+IV)	6 mo	Souter: E+G 78 Infection: 1 Extension deficit: 6
Purcell [20] (2000)	PS (27)	Mean age: not reported %Male: not reported	Crush injuries	Static splint	11 for 3 wks	4 mo (III+IV+V)	Strickland: E+G 11 Not reported
Saldana [21] (1991)	PS (32)	Mean age: not reported %Male: not reported	Fractures Tissue loss	DES for 6ws (2-3 days)	19 (III)	2.5 mo	Strickland: E+G 19 Extension deficit: 1
Slater [23] (1997)	RS (30)	Mean age: 33(range: 17-61) %Male: not reported	Fractures Crush injures Flexor tendon injuries Neurovascular injuries	EAM+static splint for 4-11 wks (3-7 days)	10 (V)	4.5 (1.5-12) mo	Miller: E+G 8 Mean TAM 252.5° No complication
Stuart [26] (1965)	RS (38)	Mean age: not reported %Male: not reported	Fractures Jointdamage Skin damage	Static splint for 3 wks	22 (V)	Not reported	Miller: E+G 16 No complication
Thomes [30] (1995)	RS (32)	Mean age: 31.6(range: 16-60) %Male: 81%	Fractures Skin damage	DES for 4ws (1-7 days)	29 (III)	1.7 (1-4) mo	Strickland: E+G 29 No complication
Walsh [31] (1994)	RS (19)	Mean age: 37.3(range: 20-71) %Male: 88%	Fractures Joint damage Tissue loss Flexor tendon injuries Neurovascular injuries	Static splint for 4wks DES for 4ws (2-7days)	19 (III+IV) 12 (III+IV)	2.6 mo 2.3 mo Mean TAM 240.4° No complication	Miller: E+G 17 Mean TAM 244.2° No complication Miller: E+G9

C score= Coleman score; RS= retrospective study; PS= prospective study EAM= early active motion; DES= dynamic extension splint

to-end repair performed within 24 h of injury) was performed in six studies (Crosby and Wehbé, 1999; Ip and Chow, 1997; Mehdinasab et al., 2012; Newport et al., 1990; O'Dwyer and Quinton, 1990; Purcell et al., 2000) and delayed primary or secondary repair (1–39 days after primary injury) was performed in five (Altobelli et al., 2013; Crosby and Wehbé, 1999; Mehdinasab et al., 2012; Neuhaus et al., 2012; Thomes and Thomes, 1995). The other studies did not document the timing of the repairs.

Intraoperative characteristics

Five studies did not describe the type of repair (Evans, 1995; Hung et al., 1990; Newport et al., 1990; O'Dwyer and Quinton, 1990; Walsh et al., 1994). In the other studies, the following repair techniques were used (frequencies are shown in parentheses): Kessler or modified Kessler (5 articles), horizontal mattress (5), figure of eight (3), Bunnell (one), Tsuge (one) and running interlocking horizontal mattress (one). The suture material for the core suture was nylon, braided polyester, polypropylene or polydioxanone. The size of the suture material was typically 4-0 or 5-0, except in three studies in which it was 3-0, one in which size 000 interrupted silk suture was used (Stuart and Zambia, 1965) and another that used an absorbable suture (braided polyglactin; Slater and Bynum, 1997). Epitendinous suture was performed with either 5-0 or 6-0 nylon or 6-0 polypropylene in three of the 15 studies (Mehdinasab et al., 2012; Neuhaus et al., 2012; Purcell et al., 2000).

Postoperative characteristics

In the static immobilisation regime, the PIP and DIP joints were usually immobilised with a static splint at 0° for 3–6 weeks after extensor tendon repair in zones III and IV. The DIP joint was not immobilised if the lateral band was intact. The metacarpophalangeal (MP) joint (at 0–70° of flexion), and the wrist (at 40° extension), were occasionally held using a static splint. Following repairs in zone V, a palmar splint was applied, with the wrist at 30–40° extension and the MP joints in 0–30° flexion, for 3–4 weeks. The PIP and DIP joints were usually left free to mobilise, but Purcell et al., (2000) immobilised the interphalangeal (IP) joints in extension.

After removal of the splint, active motion was instituted. Forceful flexion exercises were not deemed appropriate and the development of a lag was addressed with increased extension splinting and decreased flexion. In some of the studies, passive motion exercises were also prescribed between 2–6 weeks postoperatively at the same time as active motion was started.

In the dynamic splinting regime after extensor tendon repair in zones III or IV, the digit was usually placed in extension assisted with a dorsal hand- or forearm-based dynamic splint for 4–6 weeks (Fig. 1). However, Hung et al., (1990) immobilised the MP joint at 70–90° of flexion. The low-profile splint design incorporated a flexion block, which consisted of a stop bead placed on the outrigger line, or a leather yoke or palmar block attached to the splint, to restrict active PIP joint flexion to the desired amount during the rehabilitation. PIP flexion blocks at 0–45° were used in all but one study, in which the patient was instructed to perform active MP joint flexion to 30° and full flexion of the PIP joint (Ip and Chow, 1997). Only one study used a spring coil as a dynamic PIP extension splint, after suitable advice had been given to patients with central slip injuries (zones III and IV) (O'Dwyer and Quinton, 1990). After the repair of extensor tendon injuries in zone V, a dorsal forearm-based dynamic splint, positioning the wrist in 20–40° of extension, was used for 4–5 weeks (Fig. 2). Rubber band traction provided passive MP extension to neutral and allowed active "full" flexion. The use and degree of MP flexion blocking was determined during surgery. All flexion blocks consisted of a metal washer or rivet placed on the outrigger line or a palmar block attached to the splint. MP flexion blocks at 30–60° were used. Following dynamic splint placement, the patients were instructed to actively flex the involved digits to the flexion block, allowing dynamic extension to extend their digits. Following splint removal, active range of motion and tendon gliding exercises without any limitations were started.

In early active motion regimes after extensor tendon repair in zone III, the patients were instructed to use the exercise splint, which allowed the PIP joint to flex to 30° and the DIP joint to

20–25°, in addition to permitting active extension of the IP joints. Except during exercise, the IP joints of the involved digit were immobilised in a palmar static splint for 3–6 weeks. Following repairs in zones IV or V, early active motion exercises were performed with the wrist immobilised at 20–30° extension with a static splint, with or without a custom-moulded finger yoke, which may function to unload the repair and harness extension forces during active motion (Howell et al., 2005). Patients wore the splints for 3–11 weeks.

Primary outcome: ranges of motion

The Miller criteria were used in seven studies. Excellent or good results were reported for 69% of the digits treated with a static immobilisation protocol versus 85% of those treated with a dynamic splinting protocol and 88% of those treated with an early active mobilisation protocol. There was no significant difference in results between the groups (Fisher's exact test).

The original version of Strickland and Glogovac's criteria was used in four studies. A mean of 100% of the studies using dynamic splinting protocols reported excellent and good results, compared with 55% and 65% of the studies in which patients were treated with static immobilisation and early active mobilisation, respectively. Comparisons of the ranges of motion achieved with each rehabilitation regime showed that the differences were significant ($p<0.001$). The results are summarised in Table 2.

Two studies used total active motion (TAM) as the assessment scale. In the prospective study by Hung et al., (1990), 31 injured digits that underwent dynamic splinting had a mean TAM of 217° (range: 95–270°) after the repair of zones II–V, with a mean follow-up of 6.7 (range 4–10) months. In the study by Crosby and Wehbé (1999), in which 30 patients with 50 extensor tendon lacerations were treated with early passive motion and dynamic splinting, 27 of the lacerated tendons had a mean TAM of 262° for zones III–V. In a prospective study, Ip and Chow (1997) used a dynamic splinting protocol for 28 zone IV–V injuries, reporting "excellent and good" results in 86% of cases according to the

Dargan system of evaluation, which assesses extension and flexion lag, as well as pulp-to-palm distance (Dargan, 1969). O'Dwyer and Quinton (1990) analyzed 88 patients fitted with a dynamic extension splint, using the Souter scale, which assesses extension loss and distance from the tip of the flexed finger to distal palmar crease (Souter, 1967). "Excellent and good" results were reported for 89% of the patients with zone III–IV injuries.

Table 2 Functional assessment from studies using Miller criteria and the original version of the Strickland's criteria.

Protocol	Miller Criteria				The original version of Strickland Criteria*			
	Number of studies	Number of digits	Average: Excellent/ Good results (%)	Fair/ Poor results (%)	Number of studies	Number of digits	Average: Excellent/ Good results (%)	Fair/ Poor results (%)
Static immobilization	4	141	69	31	2	49	55	45
Dynamic extension splint	2	26	85	15	2	48	100	0
Early active motion	2	16	88	12	1	26	65	35

* Fisher's exact test showed that dynamic extension splinting protocols resulted in a significantly higher proportion of digits with excellent or good results, according to the original version of Strickland's criteria, than was achieved with static immobilisation or early active motion protocols.

Secondary outcome: complication rate

The most frequently reported complication was loss of extension. Three studies reporting decreased range of motion as a complication considering an extension lag ≥ 15°as noteworthy (Evans, 1995; O'Dwyer and Quinton, 1990; Saldana et al., 1991). In four studies, including those three studies, 14 cases of extension deficit or boutonierre deformity were reported (Evans, 1995; Hung et al., 1990; O'Dwyer and Quinton, 1990; Saldana et al., 1991): six in the static immobilisation group and eight in the dynamic splinting group. In the latter group, there was one infection (O'Dwyer and Quinton, 1990). In 13 studies, there was no case of tendon re-rupture regardless of the rehabilitation regime. In the other two studies, neither infection nor tendon re-rupture were reported as com-

plications (Newport et al., 1990; Purcell et al., 2000). The overall complication rate of patients with immobilisation was 4.1%; all of these complications were from loss of extension. In dynamic splinting, the overall complication rate was 3.6%: 3.2% due to reduced extension and 0.4% to infection. There were no complications associated with active motion rehabilitation. Fisher's exact test, used to compare the overall complication rate in each protocol, showed no significant difference between them. The results are summarised in Table 3.

Table 3 Average of complication rate per protocol.

	Number of studies	Number of digits	Complication Overall rate (%)*	Loss of extension or button hole deformity rate (%)	Re-rupture rate (%)	Infection rate (%)
Static immobilization	4	146	4.1	4.1	0	0
Dynamic extension splint	8	248	3.6	3.2	0	0.4
Early active motion	3	42	0	0	0	0

* Fisher's exact test showed no significant difference in the results achieved with the different protocols.

Literature quality and risk of bias

The majority of the studies were not of high quality, as indicated by the mean Coleman score of 30.8 (range: 19–43). There were no randomised controlled trials (level I or II evidence) among the 15 studies of patients with extensor tendon injuries involving zones II–V. The level of evidence in two retrospective comparative studies was level III (Evans, 1995; Walsh et al., 1994); in the remaining 13 studies, consisting of retrospective and prospective case series, it was level IV. In most studies, the selection bias was probably high because of the retrospective design and the absence of randomised controlled or prospective cohort designs. A number of studies had a high probability of observer bias, particularly two retrospective comparative studies that lacked descriptions about the method used to assess clinical outcome.

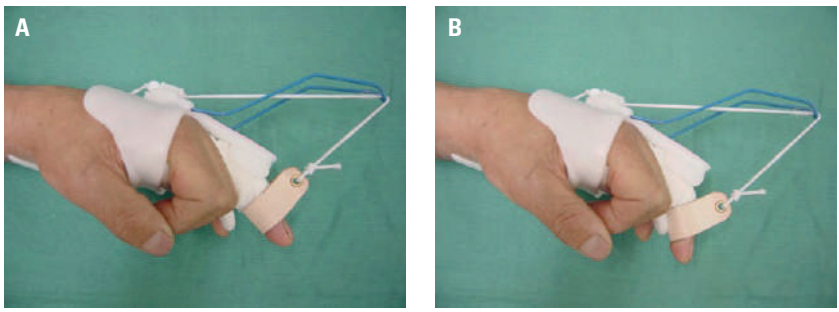
Discussion

To date, there have been three systematic reviews of the effectiveness of multidisciplinary rehabilitation for repairing extensor tendon injuries of the hand. Talsma et al., (2008) concluded that, following extensor tendon repair in zones IV–VIII, early controlled mobilisation, in which passive extension is permitted and early controlled active flexion is facilitated by dynamic splinting, leads to better functional results than immobilisation early in rehabilitation. However, at 3 months postoperatively, there were no obvious differences between the regimens. Sameen et al., (2011) also suggested better outcomes with dynamic rather than static splinting after extensor tendon repair in zones V–VII, but the data were not sufficient to allow a conclusive recommendation regarding the use of early active versus dynamic splinting. Ng et al., (2012) reviewed the highest level of evidence available on the relative merits of the different rehabilitation regimens following extensor tendon repairs of zones V–VI. Given the comparable outcomes between dynamic splinting and early active motion, the latter may be preferable, as it does not require the same level of technical expertise and may be less cumbersome for the patient. Nonetheless, a definitive approach remains unclear and there are as yet no systematic reviews, limited to extensor tendon injuries in zones I–V, in which rehabilitation protocols following surgical repair were compared

It is unfortunate that data relating to range of motion after extensor tendon repair in zone II to V are not reported uniformly throughout the articles. Variability leads to difficulty in comparing results. It should be noted that, in this review, few studies used criteria other than those of Strickland and Miller; thus, data which we used for the comparison were obtained from a relatively small sample. Statistical analysis showed a significant difference in the range of motion results among digits assessed using the original version of the Strickland and Glogovac's criteria. Although Fisher's exact test cannot identify a particular protocol yielding significantly better results, our data suggest that the best ranges of motion were achieved in digits treated with dynamic splinting. In addition, as there was no significant difference in the overall

complication rate among three regimens, it would follow that dynamic splinting protocols may represent the preferred choices when selecting a rehabilitation regimen following extensor tendon repair in zones II to V (Fig. 1,2). However, this represents weak evidence because no randomised controlled trials were identified in this review, and there were the relatively few studies offering a comparison between any postoperative protocols. It is clear that the studies needed to demonstrate the ideal rehabilitation protocol following zones II-V extensor tendon repairs have not yet been carried out.

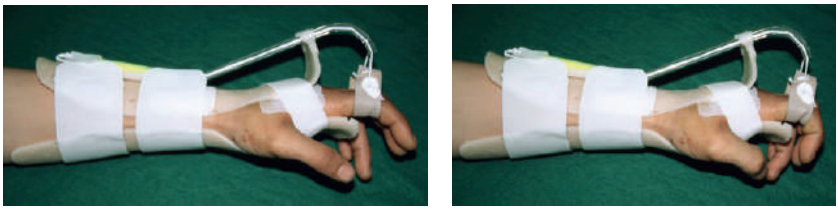
Figure 1 **(A)** The dorsal hand-based dynamic extension splint used for extensor tendon repairs in zones III and IV. Note the flexion block (arrow). **(B)** Active flexion is blocked with the palmar block attached to the splint (arrow).



The limitations of this systematic review include the relatively small sample sizes of included studies, ranging from six to 88, the paucity of randomised controlled trials and the relatively few studies on early active motion regimens (three, compared with six for static, and eight for dynamic, splinting regimens). Determination of the optimal rehabilitation protocol through a systematic analysis of the literature, in which the level of evidence is mostly level IV, is difficult due to the multitude of study variables (e.g. patient population, injury pattern, surgical technique and materials) and rehabilitation modifications. Other aspects of treatment such as surgeon's expertise, therapist's experience and patient compliance may also contribute. Multiple classification systems have been used to report functional results and other reported outcomes measures are variable throughout the literature, making comparison difficult. In addition, because many of the studies included

tendon injuries in several different zones, structural differences among the repaired sites (e.g., tendon diameter and excursion) complicated comparisons of the outcomes achieved with the three rehabilitation protocols. We also did not contact the authors of the studies to request original data, nor did we examine non-English-language publications, so relevant data may have been overlooked. High-quality randomised controlled trials in which standardised rehabilitation protocols for the different zones of the hand are compared separately should allow more reliable recommendations.

Figure 2 **(A)** The forearm-based dynamic extension splint used for extensor tendon repairs in zone V. Note the flexion block (asterisk). **(B)** Active fisting and flexion is blocked with the palmar block attached to the splint (asterisk).



In conclusion, the results of this systematic review provide weak evidence to support dynamic splinting protocols following extensor tendon repairs in zones II-V. They appear to give superior results with regard to the Strickland and Glogovac's criteria while maintaining an acceptably low rate of complications such as tendon rupture, infection and extension deficit.

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4.2.2 Rehabilitation of Extensor Tendons in the Hand and Forearm Zones VI to IX and of Extensor Pollicis Longus Tendon

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Introduction

Extensor tendon injuries in zones VI through IX usually require operative intervention. Although frequent, extensor tendon injuries have received little attention. They were traditionally rehabilitated with static splinting in an attempt to protect the site by limiting tension across the repair (Evans, 1989) With the introduction of new rehabilitation protocols the emphasis has moved towards early motion with dynamic extension splinting (DES) to provide passive movement and control the excursion of the tendons. Another popular rehabilitation approach is early active motion (EAM) which allows active mobilization of the repaired tendons by the patient but controls the range of motion by limiting the degree of flexion with a splint. It is thought to be simpler, less labour-intensive and less expensive.

Over the years very few prospective studies have been performed

comparing static, DES and EAM protocols; thus controversy has revolved around which rehabilitation protocols have yielded best outcomes. Several measures of outcome have been used such as extension lag, total active motion (TAM) and grip strength at completion of rehabilitation (Matzon and Bozentka 2010). The goal of this systematic review is to determine the effects of various rehabilitation protocols on the repair of extensor tendons in zones VI-IX.

Therapeutic measures aimed at thumb rehabilitation after extensor pollicis longus (EPL) injury are largely absent from the literature. The majority of the available literature either includes EPL rehabilitation in a general set of all extensor repair rehabilitation or targets a patient population whom have undergone tendon transfer for EPL repair (Browne Jr. and Ribik 1989) (Germann, et al., 2006). There does not seem to exist a study comparing static immobilization to early passive or early active motion, with publications drawing from personal preference for post-operative treatment regimens.

Systematic review

Methods

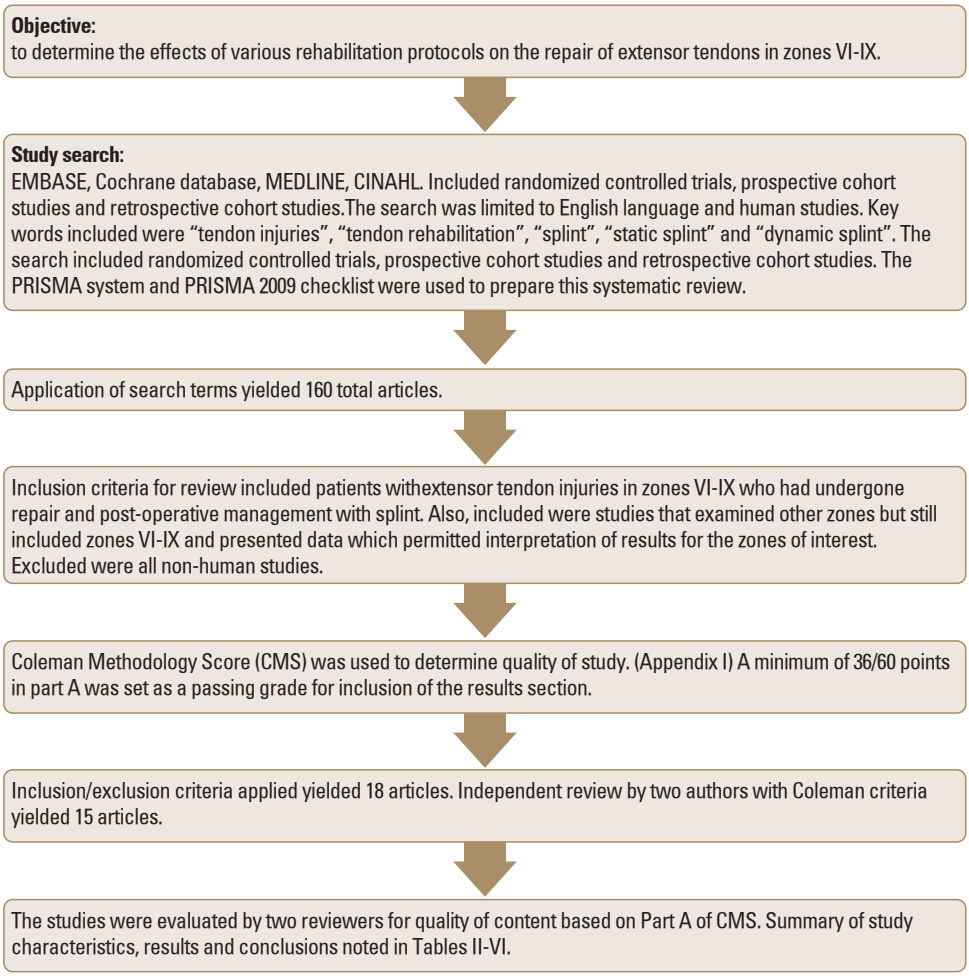
The PRISMA system and PRISMA 2009 checklist were used to prepare this systematic review. The study search is outlined in Figure 1. The search was preformed from 1947 – October, 2016 using the following databases: EMBASE, the Cochrane database, MEDLINE, and CINAHL. The search was limited to English language (as the authors only spoke English) and human studies. Key words included were “tendon injuries”, “tendon rehabilitation”, “splint”, “static splint” and “dynamic splint”.

The review on EPL literature was not included in the formal analysis given lack of adequate studies.

For extensor tendon injuries in zones VI-IX the search included randomized controlled trials, prospective cohort studies and retrospective cohort studies. The inclusion criteria were: papers studying patients with extensor tendon injuries in zones VI-IX who had undergone repair and post-operative management with splintage.;

and studies that examined other zones but still included zones VI-IX and presented data which permitted interpretation of results for the zones of interest; injuries in adults.

Figure 1 Screening process of this analysis.



The exclusion criteria were: non-human studies; biomechanical studies; studies on children and studies where we could not differentiate the data from injuries in other zones. The Coleman Methodology Score (CMS) was used to determine quality of each study. (Coleman et al., 2000) (Table 1).

Table 1 Coleman Methodology Score (CMS)

1. Study size – number of tendons (N) (if multiple follow up, multiply N by number of times subjects followed up)	• >60 • 41-60 • 20-40 • <20, not stated	10 7 4 0
2. Mean follow-up (months)	• >24 • 12-24 • <12, not stated	5 2 0
3. Number of different surgical procedures included in each reported outcome. More than one surgical technique may be assessed but separate outcomes should be reported	• One surgical procedure only • More than one surgical procedure, but >90% of subjects undergoing the one procedure • Not stated, unclear or <90% of subjects undergoin the one procedure	10 7 0
4. Type of study	• Randomised control trial • Prospective cohort study • Retrospective cohort study	15 10 0
5.Diagnostic certainty (use of preoperative ultrasound, MRI or postoperative histopathology to confirm diagnosis)	• In all • In >80% • In <80%, no, NS or unclear	5 3 0
6. Description of surgical procedure given	• Adequate (technique stated and necessary details of that type of procedure given) • Fair (technique only stated without elaboration) • Inadequate, not state or unclear	5 3 0
7. Description of postoperative rehabilitation	Well described with >80% of patients complying Well described with 60-80% of patients complying Protocol not reported or <60-80% of patients complying	10 5 0

Results

The reported data are often incomplete; some studies report scoring systems, some total angular movement (TAM) and some grip strength. We have only reported data which is reliable or complete enough.

Characteristics of included Studies for extensor tendon injuries in zones VI-IX

The literature search identified 160 potential articles. After applying inclusion and exclusion criteria the search yielded 18 articles

which were read in their entirety; 13 qualified for inclusion (Coleman et al., 2000). Table 1 lists Part A of the Coleman Methodology score. The screening process is shown in Figure 1. The definitions of the grading scales used to define outcomes are shown in Table 2. An attempt was made to extrapolate results for each zone of interest.

Static splinting

A retrospective analysis of 62 patients with 101 digits by Newport et al., (1990) used conventional static splinting for 3-4 weeks and evaluated the outcomes using the Miller classification scale (Newport, Blair and Steyers Jr, Long-term results of extnsor tendon repair 1990). Patients with complex injuries including fractures and heavy contamination were included in the study. Zone VI injuries had the highest percentage of excellent results compared to injuries in Zones VII and 8. For injuries in Zone VI loss of flexion was greater than loss of extension, primarily at the metacarpophalangeal (MP) joint (p=0.053); 45% of patients lost flexion and 14% lost extension.

A prospective study by Purcell et al., (2000) used a static splint for 0-3 weeks with night splinting in weeks 4-8. They evaluated the outcome with Strickland-Glogovac formula with final assessment at 4 months from injury (Purcell et al., 2000). They observed 100% excellent outcome for zone VI repairs. In comparison injuries in zones VII (2 digits) and 8 (3 digits) had only 28% and 60% excellent results, respectively.

In a prospective study Carl et al., (2007) studied 177 patients treated with static splinting for 6 weeks and an intense follow up rehabilitation regimen (which was not defined) following injuries in zones I-VI for two weeks until no improvement was observed. A score proposed by Gelmacher and Schwarzbach is used to estimate the outcome pre-operatively based on type of injury, positive predictive factors and negative predictive factors. All criteria are assigned a point value. The authors evaluated the outcomes using Geldmacher's evaluation tool and criteria Of those in zone VI (46 digits, 23% of all digits) nearly half had fair or poor results (Carl,

2007). The outcomes in this study were significantly worse ($p<0.05$) for injuries in in zone VI compared to injuries in the other the zones. Preoperative outcome estimation with Geldmacher criteria correlated strongly with outcome after treatment ($r=0.921$).

Dynamic splinting

Hung et al., treated patients with extensor tendon injures with dynamic splinting and used total active motion (TAM) as the endpoint (Hung et al., 1990). Injuries in zones VI and VII (7 digits combined for both zones) had a mean TAM of 254^0 (range 225-270°) at a mean follow up of 6.7 months (range 4-10 months) after injury. Zones of injury proximal to the MP joint had TAM greater than 200°.

Ip and Chow (1997) performed a large prospective trial of dynamic splinting of 101 extensor tendon injures in zones IV-VIII classified using the Dargan system (Ip and Chow 1997). Overall injuries in zones VI-VIII had excellent outcomes with Zones VI, VII and VIII with excellent outcomes in 94%, 100% and 81% of patients, respectively. Power grip was reported as good for 72 % for all zones and TAM for all zones and fingers was 245°. Individual power grip and TAM for Zones VI-VIII could not be extrapolated from the data.

A retrospective study was conducted by Crosby et al., (1999) which studied rehabilitation of 30 consecutive injuries in zones 3-7 and all thumb zones using early protected motion with dynamic splinting with passive motion for a mean of 4 weeks (Crosby and Wehbé 1999). Injuries in zones VI (6 digits) and 7 (9 digits) showed a mean TAM of 265° and 260°, respectively at a mean follow-up of 7 months (range, 8 weeks to 2 years). The mean grip strengths measured at final follow-up for injuries in zones VI and 7 were 92% and 100% of the expected result, respectively, based upon the contralateral hand. The time to return to activities was shorter for injuries in zones VI at a mean of 8 weeks compared to a mean of 16 weeks for injuries in zone VII.

Brüner et al., (2003) treated patients with dynamic splinting and early active motion for injuries in zones 5-7 (Brüner et al.,

2003). The protocol yielded a mean TAM of 236° and achieved a mean grip strength 91% of the uninjured hand for all zones at a mean follow-up of 21 months (range, 5-39 months). Extrapolating data for individual zones was not possible.

Early Active Motion

In a prospective cohort study Sylaidis et al., enrolled 27 patients with simple and complex extensor tendon injuries and treated them with early active mobilization without dynamic splinting, also known as 'The Norwich regime'. They reported their results using the Dargan criteria (Sylaidis et al., 1997). There were 91% excellent and good results for simple tendon injuries in zones 5-8 at 6 weeks. Similarly, for complex tendon injuries in zones 5-8 70% had excellent results at 6 weeks. The results were not reported by zone.

In a retrospective study of over 20 years with 140 patients with extensor tendon injuries in zones 4-7 Howell et al., presented a study using an immediate controlled active motion (ICAM) splint program (Howell, 2005). They reported results using Miller's criteria. (Table 2). Patients with injuries in zones VI and 7 accounted for 11% of the patients reviewed (the injuries could not be separated between these zones). Using Miller's criteria active extension lag was categorized as excellent in 114 tendons, good in 21, and fair in 5. Terminal flexion loss was noted to be excellent in 111 tendons, good in 20, and fair in 9.

Static versus Dynamic splinting

A prospective cohort study by Chow et al., was performed comparing dynamic splinting/early controlled mobilization (62 fingers of 54 consecutive patients) versus static splinting (35 fingers in 32 patients) in clean extensor tendon lacerations in zones IV-VII using the Dargan criteria (Chow et al., 1989). One hundred percent of the patients in the dynamic splinting/controlled mobilization group had an excellent outcome within 6 weeks of surgery compared to just 40% in the immobilization group.

A prospective, randomized, controlled study with dynamic ver-

sus static splinting for injuries in zones V and VI following extensor tendon repair was performed by (Mowlavi et al., 2004). This trial used TAM and grip strength as primary outcome measures. There was a statistically significant improvement in TAM in the dynamic group compared to the static group at weeks 4, 6 and 8 for injuries in all zones combined. However, at 6 months TAM was the same in the two groups (p=0.562). Similarly grip strength was better in the dynamic group when compared with the static group at 8 weeks (p=0.004) but not at 6 months (p=0.595).

Most recently Kitiş et al., performed a similarly designed prospective, randomized, controlled trial of dynamic versus static splinting in adult patients with injuries in zones V -VII (Kitiş et al., 2012). The outcomes were extensor lag, flexion deficit, TAM, grip strength and function evaluated by the Disabilities of Arm Shoulder and Hand (DASH) questionnaire. This trial did not report the results in individual zones. There were 28 (54%) patients with injuries in zones VI and VII (Mowlavi et al., 2004). The patients treated with dynamic splinting of complex lacerations had significantly better TAM, grip strength and DASH scores at 4, 12 and 26 compared to static splinting. TAM of the injured digit in the dynamic group compared to the static group was improved at weeks 4 (191.6° +/- 12.4° versus 124.5° +/- 7.6° (p=0.001)), 12 (227° +/- 11.7^0 versus 194.8° +/- 14.6^0 (p=0.05)), as well as 6 months (268.3° +/- 10.5° versus 210.8° +/- 11.6° (p=0.05)). Similar trend and p-values were observed for all digits at 4 (p=0.001) and 12 weeks (p=0.05), and 6 months (p=0.001). The mean grip strength at 6 months of the injured hand was 38 (SD 2.9)kg in the dynamic splinting group and 26 (3.8) kg in the static splinting group (p=0.001). At 12 weeks the mean (SD) DASH score for dynamic splinting group was 27.4 (3.4) and 37.3 (3.1) for the static splinting group (p=0.01). A significant difference (p=0.001) was also reported at 6 months, noting better functional level in the dynamic splinting group.

Static versus Early Active Mobilization

Bulstrode et al., performed a prospective randomized trial of 42 patients with extensor tendon injuries in zones V-VII randomized

to three different rehabilitation regimens: (1) static splinting protocol; (2) early active mobilization with static MP joints and free IP joints; and (3) the Norwich early active mobilization protocol (Bulstrode, et al., 2005). The patients in groups 2 and 3 had significantly better TAMs at 4 and 6 weeks but at 8 weeks there was no difference. At a mean follow-up of 12 weeks grip strength was significantly reduced ($p<0.01$) compared to the uninjured hand after static splinting (1). There was no statistical difference in the grip strength for regimes 2 and 3.

Early Active Mobilization versus Dynamic splinting

Chester et al., performed a prospective, randomized, controlled, trial of 54 patients with extensor tendon injuries in zones IV-VIII randomized to Group A early active mobilization (EAM) and Group B early controlled mobilization/dynamic splinting (ECM) (Chester, et al., 2002). At a mean follow up of 3 months all patients treated with EAM and ECM with simple extensor tendons injuries in zones IV-VII had either excellent or good results as defined by Kleinert and Verdan (Table 2), i.e., there was no difference in the outcomes between these two methods.

In a similar prospective randomized trial Khandwala et al., studied146 patients with extensor tendon injuries in zones V and VI treated with a dynamic extension splint for and early active mobilization (Khandwala, et al., 2000). Miller's assessment of extensor tendon repairs and Kleinert and Verdan's TAM were used for evaluation (Tables 2). The results for both Miller's criteria and TAM were the same at a mean follow-up of eight weeks.

Because of the heterogeneous data it was not possible to perform a meta-analysis.

Table 2 Comparison of different scoring and classification of TAM.

	Miller's assessment *	Strickland-Glogovac assessment**	Kleinert and Verdan's assessment*	Dargan's evaluation
Excellent	Same ROM as opposite side	75%-100%	TAM=TAM of contralateral finger	No extension lag, no flexion lag
Good	Loss of 20° flexion and/or <10° extension lag	50%-74%	TAM>75% TAM of contralateral finger	Extension lag<15°, no flexion lag
Fair	Loss of 45° flexion and/or <45°-10° extension lag	25%-49%	TAM= 50%-75% TAM of contralateral finger	Extension lag 16°-45°, pulp to palm distance 2cm or less
Poor	>45° loss of flexion and/or >45° extension lag	0%-24%	TAM < 50% TAM of contralateral finger	Extension lag >45°, pulp to palm >2cm

TAM=(MP+PIP+DIP Flexion) – (MP+PIP+DIP Extension lag)
Strickland-Glogovac Assesment
[(Active PIPj+DIPj flexion) – extension lag]/175° x 100= % of normal active PIP and DIP motion

Extensor Pollicis Longus Rehabilitation

In a subset analysis of thumb extensor injuries in Verdan zones I-III, Neuhaus et al., reported on patients treated with static splinting at night and dynamic extension splinting during the day starting after 7 days (Neuhaus et al., 2012). After 3 weeks active motion was allowed during the day with continued static splinting at night until 6 weeks post-operatively when all splinting was discontinued. Of the six thumbs treated four had an excellent and two a good outcome based on Miller's criteria at a mean follow-up of 96 days (range, 43 – 215 days).

Discussion

This systematic review on the rehabilitation of repaired extensor tendons in zones VI-IX shows evidence that early controlled mobilization with dynamic splinting gives superior outcomes in the early post-operative period (Mowlavi et al., 2004; Bulstrode et

al.,2005). It should be noted that the published data included in this review shows that no single rehabilitation regimen in clearly the best for injuries in zones VI – VIII after 6 months (Chow et al., 1989) (Mowlavo et al.,2004; Bulstrode et al., 2005;Chester et al., 2002 ; Khandwala et al.,2000). It should be noted that our search yielded no reliable studies on injuries in extensor zone IX to yield a recommendation.

The comparison of two high quality randomized controlled trials, however, shows conflicting results for functional outcomes with dynamic splinting compared to immobilization with static splinting. Better outcomes at 6 months as evaluated by DASH scores, TAM and grip strength were seen in the study by Kitiş et al., but not Mowlavi et al., (Mowlavi et al.,2004; Kitiş et al., 2012). A retrospective study by Evans of 112 complex tendon injuries, which was not included in our systematic review, also showed an improvement in TAM with DES versus static splinting for zones V, VI and VII (Evans, 1989). Two other retrospective studies of 52 patients and of 21 patients, not included in our review, showed reasonably good outcomes with early dynamic splinting without any tendon ruptures (Browne Jr. and Ribik, 1989; Kerr and Burczak 1989). Compared to these two studies, which included simple extensor tendon injuries, Crosby et al., reported better outcomes with complex injuries but added a passive tendon mobilization program to dynamic splinting (Crosby and Wehbé, 1999). It has been shown that associated injuries or complex injuries worsen the results of extensor tendon repair (Ip and Chow, 1997; Newport et al., 1990). It is perhaps the addition of a passive mobilization program that yielded superior results even in complex extensor tendon injuries. Tendon injuries in zones VI, VII and VIII glide over the capsule of the wrist joint and through narrow compartments potentially making them more susceptible to adhesion formation. It is only speculation that a passive mobilization program helps reduce adhesions and contribute to superior outcomes; better studies are needed to address this question.

Studies reporting static splinting showed a moderate number of fair or poor outcomes especially in zone VI injuries (Newport et al., 1990; Carl et al., 2007). Comparing static splinting with EAM showed no difference in TAM but the grip strength, however, was

significantly reduced compared to the uninjured hand after static splinting at 12 weeks. (Bulstrode et al., 2005) It should be noted that the follow up periods in these studies were short and could account for the poor grip strength.

Given a small number of rigorously executed trials, as evaluated by CMS, we intentionally reported only those with high quality methodology yielding a limited number of studies to report (Coleman et al., 2000). It is very important to note that the reporting of data was not exclusively performed by zone and that extraction of meaningful data by zone of interest, in this case zones VI-IX, was not possible for most studies. In addition the data were not suitable for a meta-analysis and therefor a singular recommendation for treatment of individual zones cannot be stated.

Additionally, the generalizability and synthesis of the evidence is not possible given the variability in several key areas of extensor tendon repair, rehabilitation and reporting. There was variability in the severity and complexity of injuries included in the studies, variability in the repair of such injured tendons including the time to intervention as well as repair technique. Furthermore the specific regimes of rehabilitation varied from timing of splint application, type of splint, duration of splinting, frequency of active or controlled motion as well as variability in the follow up with certified hand or occupational therapist. In addition the assessment and reporting of TAM and ROM data was not consistent e.g. the studies used various classification systems: Dargan; Kleinert and Verdan; Strickland-Glogovac; Miller; Geldmacher and others (Kleinert and Verdan, 1983; Miller, 1942; Strickland and Glogovac, 1980). The expertise of the surgeons repairing the tendon, and the therapists overseeing the rehabilitation efforts were not reported. Reporting such data could help validate comparisons across similarly designed trials with disparate outcomes (Tang and Avanessian, 2015; Tang and Giddins, 2016).

Based on our review more studies and large prospective trials with uniform methodology and interventions are needed to determine further the optimal treatments. In addition to the methodology, and interventions, a standardized extensor tendon repair should be based of literature showing the best biomechanical characteristics for extensor tendons (Newport and Williams, 1992).

Only once a standardized system of evaluation for extensor zones VI-VIII has been established, will we be able to standardize care for such injuries. As noted before our search yielded no reliable studies on injuries in zone IX.

In our experience and based on literature review, we do not use dynamic splinting after primary repair of zone VI to VIII extensor tendons. We majorly use early passive motion with immobilization in the first 4 weeks (Figure 2), followed by active motion and night splinting (Figure 3). In the cases of tendon injury to the thumb or only a single finger, or repair of clean-cut tendon cuts with very reliable strong repair methods, active motion of the involved digits can be added to the passive motion program

Figure 2 The method currently used by the authors after repairs of the extensor tendons to the fingers cut proximal to the MCP joint. A palmar slab with 30° wrist extension with MCP and IP joints in extension. After proximal FPL tendon repair, a palmar splint including the proximal part of the thumb is used (not shown here), most often, IP joint motion is allowed, because the repair is proximal and IP joint motion would allow the repaired tendon to actively move for a short distance to prevent adhesions, without overloading the repaired site.

Figure 3 After 4 weeks, a palmar based splint with 30° wrist extension with MCP joints immobilized in extension and IP joints free for 3 to 4 weeks as necessary. Extensor tendons healed quite strongly after 4 weeks. Active motion exercise should be started after week 4. Therefore, this type of splinting is a protection, which may only need to wear when the patient goes out and during night. Gentle use of the hand during daily activities starts from week 5 or 6 depending on severity of injuries and patient compliance.

from week 3 and 4, to allow the repaired tendon(s) to have earlier recovery of gliding. After repair of multiple extensor tendons at the level of the extensor retinaculum or distal part of the proximal forearm, separate exercises for each digit are very important, and should be incorporated into motion regime. The therapists should always know how strongly these tendons have been repaired during the surgery, or any defects present after injury, so they can adjust the motion regimens for individual patients. Some modifications in regime appears always necessary to fit the difference complexity of injuries and patient compliance in any patients with zone VI to IX extensor tendon injuries. Our current method is to the protect wrist in functional position of mild extension, concentrating on passive finger and thumb MCP joint motion. Dynamic splinting appears unnecessary if these patients do not have complex injuries involving the carpal joints. Static splinting is much simpler which requires less therapy expertise without adversely affecting the outcomes

High quality studies with objective data outlining therapeutic measures aimed at thumb rehabilitation after extensor pollicis longus (EPL) injury are largely absent from the literature. It is hard to recommend the best rehabilitation protocols after primary EPL repair. However, it appears that early active motion should at least promote motion of the thumb joint and likely promote tendon healing. At present, early active motion with a strong EPL repair is our current practice. At this juncture all of our efforts should be directed to designing high quality randomized controlled trials before any recommendation about the ideal post-operative therapy.

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4.3. Comparison of Outcomes Following Nerve Transfers versus Nerve Grafting. A Systematic Review of Individual Participant Data for Restoration of Elbow Flexion after Adult Brachial Plexus Injuries.

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Introduction

For decades, nerve grafting has been the treatment of choice for peripheral nerve injuries (Narakas,1980; Hentz, 1988). The advent of nerve transfers dramatically changed the strategies and options available for peripheral nerve injury reconstruction (Oberlin et al., 1994). Several new nerve transfers have been described over the last decade (Bertelli and Ghizoni, 2010). One absolute indication for nerve transfers is the lack of axonal outflow (e.g., secondary to root avulsions or poor-quality stumps), since nerve grafting is then impossible. Controversy arises when treating nerve ruptures, since both techniques might be applicable (Ali et al., 2015; Garg et al., 2011; Yang et al., 2012). The main theoretical advantage of a nerve transfer is the proximity of the axonal source and the muscle (i.e. the neuromuscular plate) resulting in a shorter time of muscle denervation and less neuromuscular plate death (Brown, 2009; Bertelli and Ghizoni, 2006). Thus, nerve transfer techniques might be ideal for cases treated late and when the muscle target is quite

distant from the point of nerve injury (Carlsen et al., 2009; Bertelli et al., 2012). Another theoretical advantage of nerve transfers might be selective reinnervation of a muscle or function, which avoids the development of co-contractions and allows for easier patient post-operative re-education (Bertelli et al., 2015). Based on these advantages, nerve transfers might be more effective than nerve grafting for peripheral nerve reconstruction, resulting in better outcomes (Garg et al., 2011). However, no strong evidence is yet available to support this hypothesis, not least because no prospective randomized studies have been published (Ali et al., 2015; Garg et al., 2011; Yang et al., 2012).

Another advantage of nerve transfers and a powerful motivation for surgeons to use this technique is that they are generally less technically demanding than nerve grafting. Nerve transfers performed in non-scarred areas with normal anatomy are, in theory, more reproducible.

A vast number of factors influence outcomes following nerve reconstruction; these could be confounders when outcomes are compared between different groups of patients. The most important factors influencing outcomes might be the patient's age and the time delay between the injury and surgery (Narakas,1980; Bentolila et al., 1999; Chuang et al., 1993; Hentz, 1988). Other important factors include the pattern of injury among the nerve roots, the type of root injury (rupture vs avulsion), the quality of the available nerve roots (Mallessy et al., 1999), the distance between the donor nerve stump and the recipient nerve, the distance between the donor nerve and target muscle, the number and length of nerve grafts, the donor nerve used, the recipient nerve, and others (Narakas, 1980; Bentolila et al., 1999; Chuang et al., 1993; Hentz, 1988). Spontaneous reinnervation is also an important confounding factor (Bertelli et al., 2004).

Considering all these potentially outcome-influencing factors and to facilitate comparisons between outcomes following nerve transfers and nerve grafting, this chapter will focus on the analysis of single-function reconstruction in a particular peripheral injury. We have looked at the outcomes of nerve transfers versus nerve grafting for the reconstruction of elbow flexion in adults with a brachial plexus injury (BPI).

The most relevant specific questions that this chapter will aim to answer are:

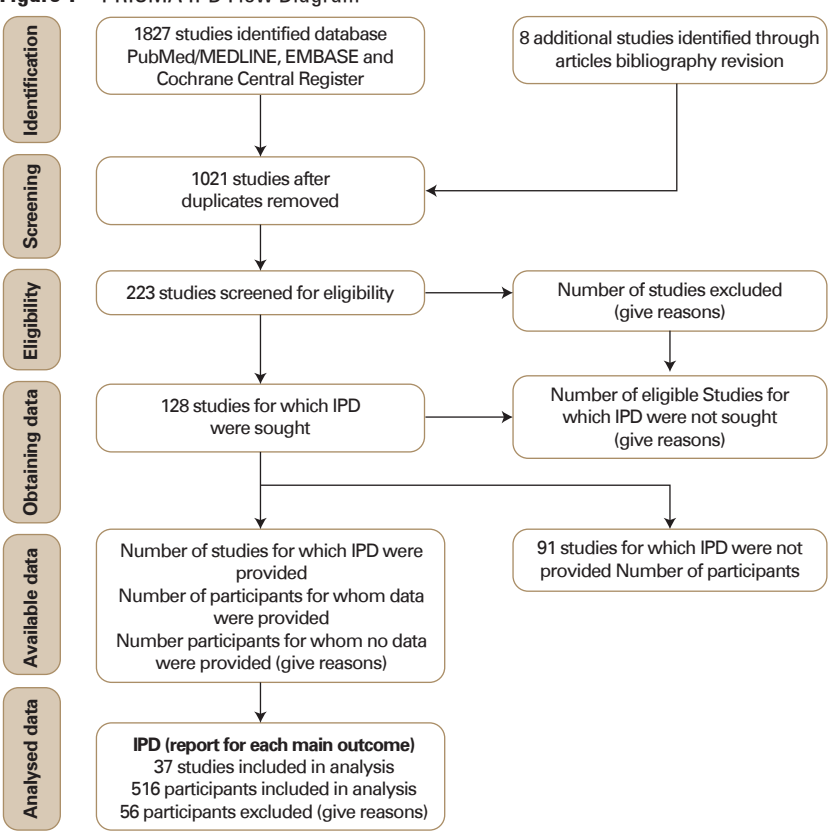
- Do nerve transfers generally yield better outcomes than nerve grafts?
- Do nerve transfers result in better outcomes than nerve grafts in patients whose injuries are treated late?
- Do nerve transfers result in better outcomes than nerve grafts in older patients?

Materials and methods

For this analysis, the PRISMA-IPD structure for the systematic review of individual patient data was employed (Stewart, 2015).

-Study selection process (Figure 1):

Figure 1 PRISMA IPD Flow Diagram



The PRISMA IPD flow diagram

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A search of the English-language literature using several databases (PubMed, EMBASE and Cochrane Central Register of Controlled Trials) was performed on the 15th of October, 2016. The following key words were used: "brachial plexus" or "brachial plexus injury" AND "surgery" or "nerve grafting" or "nerve transfers" AND "elbow flexion".

Eliminating duplicate search results produced 1021 articles. Reading of the title or abstract resulted in the rapid exclusion of unrelated articles. All the remaining papers were read in full and evaluated for pre-defined inclusion and exclusion criteria. A further manual reference check of these articles was performed to identify any additional studies for inclusion. Data extraction was performed from all of the papers ultimately selected as eligible for review.

Requisite patient data to be included in the study were: patient age; the interval between injury and surgery; and motor outcomes, as scored using the British Medical Research Council grading system (BMRC score). We also collected data on the pattern of injury; the type of treatment (graft or transfer); the donor and recipient nerves; graft length; and the duration of follow-up. A binary outcome of function was selected as the primary outcome of interest, with the surgical result considered *functional* if elbow flexion against gravity was achieved and *non-functional* if it were not.

Inclusion and exclusion criteria

We included full-text English-language articles on the treatment of brachial plexus injuries (BPI) to restore elbow flexion by nerve repair either by nerve grafting or nerve transfer. After reviewing titles and abstracts, we excluded any article that described a cadaveric study, laboratory experiment or anaesthetic techniques; peripheral nerve injuries outside the brachial plexus; literature reviews; descriptions of techniques other than within the context of a clinical trial or case series; expert opinions; and obstetrical and neonatal brachial plexus injuries (Fig. 1).

We further excluded articles that described only reconstruction of the shoulder, oncological cases and papers only reporting on sensory reconstruction. We also excluded articles that described secondary procedures and those in which nerve grafting and nerve

transfers were combined to restore elbow flexion.

We also only included articles with tables that provided individual patient data on the restoration of elbow function either by nerve grafting or nerve transfer. Articles without individual patient data were excluded. Furthermore, those papers that failed to report on patient age, the time interval between injury and surgery, or outcomes, were excluded. Patients younger than 14 years old were excluded. Patients treated with nerve transfers prolonged with nerve grafts were also excluded. In one instance in which individual patient data were not provided in a paper on nerve grafts, we asked the author for this information, which was provided and ultimately included in our pool of data (Bertelli and Ghizoni, 2010b).

Statistical methods

Descriptive data were summarized for every variable collected, as means with standard deviations for continuous variables and as proportions for categorical variables. We posed several questions:

1. **Does patient age at surgery influence the outcome and do older patients do better after a nerve transfer than after nerve grafting?**

We compared the percentage of patients who achieved a functional outcome among patients under 40 years old against those 40 years and over. We also estimated the mean age among patients who experienced a functional result compared to those who did not. Finally, we compared the results after nerve grafting versus nerve transfer selectively in patients 40 years old and older. For the first and third questions listed above, which involved a comparison of proportions, Pearson $\chi 2$ analysis was performed. When continuous variable means were compared (e.g., mean patient age), non-paired Student's t-tests were performed.

2. **Does the preoperative interval (i.e. the time from injury to surgery) influence the outcome? Specifically, do patients operated upon within 9 months of their injury do better after a nerve transfer or after nerve grafting?**

We compared the percentage of patients achieving a functional result among patients with a preoperative interval less than 9 months versus 9 months or greater. We assessed these data with a Pearson $\chi 2$ analysis. We compared the mean preoperative interval

among patients obtaining a functional result versus those not doing so with an unpaired Student's t test.

3. **Were the patterns of injury the same for patients treated with nerve grafts versus nerve transfer?**

We did this by calculating the proportion of patients with a partial versus complete BPI in each of the two treatment groups, comparing these proportions by Pearson $\chi 2$ analysis.

4. **Do nerve transfers result in better outcomes than nerve grafting procedures?**

We compared the proportion of patients obtaining a functional result between the nerve graft and nerve transfer groups. Within the subgroup of patients who obtained a functional result, we compared the percentage of patients who achieved BMRC-level 3 versus BMRC 4/5 strength between the graft and transfer groups. For these comparisons, we used multiple Pearson $\chi 2$ tests.

5. **Does the distance from the donor nerve to the target (muscle) influence the results of nerve transfers or nerve grafting?**

We compared the percentage of patients achieving a functional result after nerve transfer or nerve grafting to the musculocutaneous nerve (MCN).

6. **Does the severity of the injury affect the outcome of nerve transfer or nerve grafting?**

We compared the outcomes of nerve transfers and nerve grafting in patients with complete or incomplete BPI. This included comparisons between single and double Oberlin procedures, and between intra- and extra-plexal procedures.

7. **Does graft length influence outcomes after nerve grafting?**

We compared the percentage of patients achieving a functional outcome with grafts under 10 cm versus ≥10 cm in length and compared mean graft length in patients obtaining a functional versus a non-functional result.

8. **Does spontaneous re-innervation explain any of the enhanced results of nerve transfers versus nerve grafts?**

We addressed this by comparing the percentage of procedures achieving a functional result after a double Oberlin transfer versus nerve grafting in patients with an upper trunk BPI, and in patients undergoing a double versus single Oberlin transfer(s).

Results

Study retrieval

Patient information was extracted from 37 articles (Appendix 1). Seven articles provided information on nerve grafting, 29 articles on nerve transfers and one article on both techniques (Socolovsky et al., 2012). For every patient included in the study we have referred to the bibliographic source and patient number in the tables.

A total of 115 patients had undergone a nerve graft procedure and were included in analysis (Bertelli and Ghizoni, 2010; Bertelli and Ghizoni, 2010b; Fogarty and Brennen, 2002; Lusskin et al., 1973; Malessy, 1999; Malessy, 2004; Sedel, 1982). Four hundred patients with a nerve transfer were analysed; a variety of nerve transfers were identified, including transfer of the phrenic nerve (ten patients) (Bhandari et al., 2009; Monreal 2007; Siqueira et al., 2009; Xu et al., 2002; Xu et al., 2005); the intercostal nerves (113) (Arnal et al., 2016; Bhandari et al., 2009; Coulet et al., 2010; Friedman et al., 1990; Kakinoki et al., 2010; Krakauer and Wood, 1994; Ruch et al., 1995; Xiao et al., 2014); an Oberlin transfer (263) (Arnal et al., 2016; Bhandari et al., 2009; Coulet et al., 2010; Friedman et al., 1990; Kakinoki et al., 2010; Krakauer and Wood, 1994; Ruch et al., 1995; Xiao et al., 2014); the thoracodorsal nerve (5) (Novak et al., 2002; Richardson et al., 1997; Soldado et al., 2014); the medial pectoral nerve (5) (Brandt and Mackinnon, 1993; Richardson et al., 1997); and the ipsilateral C7 root (4) (Gu et al., 2003).

Five studies were retrospective, comparative studies (Level III), one comparing nerve grafting with nerve transfers (Socolovsky et al., 2012), two comparing different nerve transfer procedures (Coulet et al., 2010; Kakinoki et al., 2010), one comparing the transfer of two versus four intercostal nerves (Xiao et al., 2014) and one comparing single versus double Oberlin transfers (Barthel et al., 2014). The remaining studies were level IV evidence.

Statistical analysis

All statistical results are summarized in Appendix 1.

Appendix 1

Abbreviations used in the appendix

ADUT: Anterior division upper trunk, B: Brachialis branch, Bc: Biceps branch, BMRC: British Medical Research Council, F-U: Follow-up, G: Graft, IC: Intercostal nerve, iC7: Ipsilateral C7, LC: Lateral cord, MCN: Musculocutaneous nerve, Md: Median nerve, MPN: Medial pectoral nerve, Ph: Phrenic nerve, T: Transfer, TDN: Thoracodorsal nerve, Un: Ulnar nerve, UT: Upper trunk.

Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
1	1 Arnal 2016	23	total	T	IC	MCN	N/A	9	34	4	Y
2	2 Arnal 2016	21	total	T	IC	MCN	N/A	3	40	4	Y
3	3 Arnal 2016	22	total	T	IC	MCN	N/A	5	26	3	Y
4	4 Arnal 2016	20	total	T	IC	MCN	N/A	2	31	2	N
5	5 Arnal 2016	19	total	T	IC	MCN	N/A	2	27	4	Y
6	6 Arnal 2016	18	total	T	IC	MCN	N/A	5	24	4	Y
7	7 Arnal 2016	17	total	T	IC	MCN	N/A	4	10	3	Y
8	8 Arnal 2016	24	total	T	IC	MCN	N/A	2	12	4	Y
9	9 Arnal 2016	21	total	T	IC	MCN	N/A	9	21	4	Y
10	10 Arnal 2016	19	total	T	IC	MCN	N/A	8	30	2	N
11	11 Arnal 2016	16	total	T	IC	MCN	N/A	8	26	4	Y
12	12 Arnal 2016	31	total	T	IC	MCN	N/A	7	18	2	N
13	13 Arnal 2016	25	total	T	IC	MCN	N/A	4	13	0	N
14	14 Arnal 2016	21	total	T	IC	MCN	N/A	4	20	4	Y
15	15 Arnal 2016	17	total	T	IC	MCN	N/A	2	26	4	Y
16	16 Arnal 2016	25	total	T	IC	MCN	N/A	14	18	1	N
17	17 Arnal 2016	28	total	T	IC	MCN	N/A	1	16	4	Y
18	18 Arnal 2016	23	total	T	IC	MCN	N/A	2	12	2	N
19	19 Arnal 2016	22	total	T	IC	MCN	N/A	4	22	3	Y
20	1 Barthel 2014	19	C5-C7	T	Un	Bc	N/A	7	31	4	Y
21	2 Barthel 2014	47	C5-C6	T	Un	Bc	N/A	5	29	4	Y
22	3 Barthel 2014	17	C5-C6	T	Un	Bc	N/A	6	22	4	Y
23	4 Barthel 2014	25	C5-C6	T	Un	Bc	N/A	4.5	50	4	Y
24	5 Barthel 2014	18	C5-C7	T	Un	Bc	N/A	7	25	4	Y
25	6 Barthel 2014	16	C5-C7	T	Un	Bc	N/A	5	23	0	N
26	7 Barthel 2014	19	C5-C7	T	Un	Bc	N/A	6	41	4	Y
27	8 Barthel 2014	17	C5-C7	T	Un	Bc	N/A	4	39	4	Y
28	9 Barthel 2014	43	C5-C7	T	Un	Bc	N/A	7	19	0	N
29	10 Barthel 2014	48	C5-C7	T	Un	Bc	N/A	11	15	0	N
30	11 Barthel 2014	22	C5-C7	T	Un	Bc	N/A	5.5	15	3	Y
31	12 Barthel 2014	31	C5-C7	T	Un	Bc	N/A	3	25	3	Y
32	13 Barthel 2014	23	C5-C7	T	Un	Bc	N/A	5	93	3	Y
33	14 Barthel 2014	51	C5-C7	T	Un	Bc	N/A	2	60	4	Y
34	15 Barthel 2014	27	C5-C7	T	Un	Bc	N/A	23	65	4	Y
35	16 Barthel 2014	17	C5-C7	T	Un + Md	Bc + B	N/A	4	22	4	Y
36	17 Barthel 2014	43	C5-C7	T	Un + Md	Bc + B	N/A	7	20	0	N

>>>

Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
37	18 Barthel 2014	66	C5-C6	T	Un + Md	Bc + B	N/A	7	34	4	Y
38	19 Barthel 2014	21	C5-C7	T	Un + Md	Bc + B	N/A	6	21	2	N
39	20 Barthel 2014	21	C5-C6	T	Un + Md	Bc + B	N/A	3	36	4	Y
40	21 Barthel 2014	33	C5-C6	T	Un + Md	Bc + B	N/A	11	46	4	Y
41	22 Barthel 2014	32	C5-C7	T	Un + Md	Bc + B	N/A	2	29	4	Y
42	23 Barthel 2014	39	C5-C6	T	Un + Md	Bc + B	N/A	3	39	4	Y
43	24 Barthel 2014	16	C5-C7	T	Un + Md	Bc + B	N/A	6	33	4	Y
44	25 Barthel 2014	65	C5-C6	T	Un + Md	Bc + B	N/A	8	18	4	Y
45	26 Barthel 2014	27	C5-C7	T	Un + Md	Bc + B	N/A	4	48	4	Y
46	27 Barthel 2014	26	C5-C6	T	Un + Md	Bc + B	N/A	4	26	4	Y
47	28 Barthel 2014	22	C5-C6	T	Un + Md	Bc + B	N/A	4	54	4	Y
48	29 Barthel 2014	26	C5-C7	T	Un + Md	Bc + B	N/A	5	17	4	Y
49	1 Bhandari 2009	26	C5-C7	T	IC	MCN	N/A	4	37	4	Y
50	2 Bhandari 2009	22	C5-C7	T	IC	MCN	N/A	4	21	3	Y
51	3 Bhandari 2009	30	C5-C6	T	Un + Md	Bc + B	N/A	6	22	4	Y
52	4 Bhandari 2009	34	C5-C6	T	Un + Md	Bc + B	N/A	3	29	4	Y
54	6 Bhandari 2009	26	C5-C6	T	Un	Bc	N/A	4	20	3	Y
56	8 Bhandari 2009	41	C5-C6	T	Un + Md	Bc + B	N/A	4	27	4	Y
57	9 Bhandari 2009	21	C5-C6	T	Un	Bc	N/A	4	24	3	Y
58	10 Bhandari 2009	28	C5-C6	T	Un + Md	Bc + B	N/A	3	28	4	Y
59	11 Bhandari 2009	20	C5-C6	T	Un	Bc	N/A	3	28	3	Y
60	12 Bhandari 2009	29	C5-C6	T	Un + Md	Bc + B	N/A	5	21	4	Y
61	13 Bhandari 2009	22	C5-C7	T	IC	MCN	N/A	3	19	3	Y
62	14 Bhandari 2009	24	C5-C6	T	Un + Md	Bc + B	N/A	6	20	3	Y
63	15 Bhandari 2009	21	C5-C6	T	Un + Md	Bc + B	N/A	4	26	4	Y
64	16 Bhandari 2009	20	C5-C7	T	IC	MCN	N/A	3	18	2	N
65	17 Bhandari 2009	22	C5-C7	T	Un + Md	Bc + B	N/A	3	20	3	Y
66	18 Bhandari 2009	31	C5-C6	T	Un	Bc	N/A	4	20	3	N
67	19 Bhandari 2009	23	C5-C7	T	Un + Md	Bc + B	N/A	5	22	3	Y
68	20 Bhandari 2009	21	C5-C6	T	Un + Md	Bc + B	N/A	3	21	4	Y
69	1 Brandt 1993	36	C5-C6	T	MPN	MCN	N/A	4	37	4	Y
70	2 Brandt 1993	25	C5-C6	T	MPN	MCN	N/A	6	40	4	Y
71	3 Brandt 1993	21	C5-C6	T	MPN	MCN	N/A	3	32	4	Y
72	4 Brandt 1993	34	C5-C6	T	MPN	MCN	N/A	4	11	3	Y
73	5 Brandt 1993	48	C5-C6	T	MPN	MCN	N/A	5	5	0	N
74	1 Cho 2014	20	C5-C6	T	Un	Bc	N/A	5	23	4	Y
75	2 Cho 2014	22	C5-C6	T	Un	Bc	N/A	19	50	4	N
76	3 Cho 2014	24	C5-C7	T	Un	Bc	N/A	7	28	2	N
77	4 Cho 2014	29	C5-C6	T	Un	Bc	N/A	7	24	4	Y
78	5 Cho 2014	29	C5-C6	T	Un	Bc	N/A	6	18	3	Y
79	6 Cho 2014	27	C5-C7	T	Un	Bc	N/A	7	14	3	Y
80	7 Cho 2014	17	C5-C6	T	Un	Bc	N/A	10	6	3	Y
81	8 Cho 2014	18	C5-C7	T	Un	Bc	N/A	12	10	4	Y
82	9 Cho 2014	21	C5-C6	T	Md	Bc	N/A	19	21	4	Y
83	10 Cho 2014	19	C5-C6	T	Md	Bc	N/A	8	20	3	Y
84	11 Cho 2014	25	C5-C6	T	Md	Bc	N/A	11	43	4	Y
85	12 Cho 2014	30	C5-C7	T	Md	Bc	N/A	16	46	4	Y
86	13 Cho 2014	35	C5-C6	T	Md	Bc	N/A	11	26	4	Y
87	14 Cho 2014	23	C5-C7	T	Md	Bc	N/A	6	17	2	N
88	15 Cho 2014	26	C5-C7	T	Md	Bc	N/A	10	20	4	Y

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Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
89	16 Cho 2014	25	C5-C7	T	Md	Bc	N/A	10	15	3	Y
90	17 Cho 2014	39	C5-C7	T	Md	Bc	N/A	13	13	4	Y
91	18 Cho 2014	41	C5-C7	T	Md	Bc	N/A	10	14	4	Y
92	19 Cho 2014	34	C5-C6	T	Md	Bc	N/A	10	12	4	Y
93	20 Cho 2014	18	C5-C7	T	Md	Bc	N/A	11	13	4	Y
94	21 Cho 2014	42	C5-C7	T	Md	Bc	N/A	4	6	4	Y
95	22 Cho 2014	24	C5-C7	T	Md	Bc	N/A	12	8	3	Y
96	23 Cho 2014	49	C5-C6	T	Md	Bc	N/A	12	6	4	Y
97	1 Coulet 2010	18	C5-C6	T	IC	MCN	N/A	5	91	4	Y
98	2 Coulet 2010	16	C5-C6	T	IC	MCN	N/A	5.5	67	4	Y
99	3 Coulet 2010	15	C5-C7	T	IC	MCN	N/A	6	55	4	Y
100	4 Coulet 2010	17	C5-C6	T	IC	MCN	N/A	3	15	4	Y
101	5 Coulet 2010	26	C5-C6	T	IC	MCN	N/A	3	25	4	Y
102	6 Coulet 2010	16	C5-C7	T	IC	MCN	N/A	5	34	4	Y
103	7 Coulet 2010	26	C5-C7	T	IC	MCN	N/A	6	25	4	Y
104	8 Coulet 2010	38	C5-C7	T	IC	MCN	N/A	5	37	4	Y
105	9 Coulet 2010	32	C5-C7	T	IC	MCN	N/A	5	24	4	Y
106	10 Coulet 2010	30	C5-C7	T	IC	MCN	N/A	4	12	4	Y
107	11 Coulet 2010	26	C5-C7	T	IC	MCN	N/A	4	14	3	Y
108	12 Coulet 2010	22	C5-C7	T	IC	MCN	N/A	3	12	3	Y
109	13 Coulet 2010	18	C5-C7	T	IC	MCN	N/A	9	24	3	Y
110	14 Coulet 2010	45	C5-C7	T	IC	MCN	N/A	12	18	2	N
111	15 Coulet 2010	33	C5-C7	T	IC	MCN	N/A	6.5	42	2	N
112	16 Coulet 2010	26	C5-C7	T	IC	MCN	N/A	8	43	2	N
113	17 Coulet 2010	29	C5-C7	T	IC	MCN	N/A	7	13	1	N
114	18 Coulet 2010	20	C5-C6	T	Un	MCN	N/A	5	29	4	Y
115	19 Coulet 2010	32	C5-C6	T	Un	MCN	N/A	7	57	4	Y
116	20 Coulet 2010	22	C5-C6	T	Un	MCN	N/A	4	31	4	Y
117	21 Coulet 2010	19	C5-C6	T	Un	MCN	N/A	4	26	4	Y
118	22 Coulet 2010	34	C5-C6	T	Un	MCN	N/A	10.5	27	4	Y
119	23 Coulet 2010	32	C5-C7	T	Un	MCN	N/A	9	30	4	Y
120	24 Coulet 2010	16	C5-C6	T	Un	MCN	N/A	8	36	4	Y
121	25 Coulet 2010	42	C5-C6	T	Un	MCN	N/A	3	13	4	Y
122	26 Coulet 2010	20	C5-C6	T	Un	MCN	N/A	3	18	4	Y
123	27 Coulet 2010	19	C5-C6	T	Un	MCN	N/A	3	13	4	Y
124	28 Coulet 2010	20	C5-C7	T	Un	MCN	N/A	4	47	4	Y
125	29 Coulet 2010	34	C5-C6	T	Un	MCN	N/A	5	30	4	Y
126	30 Coulet 2010	24	C5-C6	T	Un	MCN	N/A	5	12	4	Y
127	31 Coulet 2010	29	C5-C6	T	Un	MCN	N/A	7	15	4	Y
128	32 Coulet 2010	21	C5-C6	T	Un	MCN	N/A	4.5	16	4	Y
129	33 Coulet 2010	41	C5-C6	T	Un	MCN	N/A	4	12	4	Y
130	34 Coulet 2010	18	C5-C6	T	Un	MCN	N/A	6	12	4	Y
131	35 Coulet 2010	30	C5-C7	T	Un	MCN	N/A	7	22	4	Y
132	36 Coulet 2010	31	C5-C6	T	Un	MCN	N/A	9	59	4	Y
133	37 Coulet 2010	36	C5-C7	T	Un	MCN	N/A	10	24	3	Y
134	38 Coulet 2010	22	C5-C7	T	Un	MCN	N/A	11	16	2	N
135	39 Coulet 2010	54	C5-C6	T	Un	MCN	N/A	12	15	2	N
136	40 Coulet 2010	47	C5-C6	T	Un	MCN	N/A	9	23	4	Y
137	1 Estrella 2011	40	C5-C7	T	Un	Bc	N/A	7	40	4	Y
138	2 Estrella 2011	17	C5-C7	T	Un	Bc	N/A	8	48	4	Y

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139	3 Estrella 2011	26	C5-C7	T	Un + Md	Bc + B	N/A	3	42	4	Y
140	4 Estrella 2011	47	C5-C7	T	Un + Md	Bc + B	N/A	6	18	4	Y
141	5 Estrella 2011	21	C5-C7	T	Un + Md	Bc + B	N/A	11	16	1	N
142	6 Estrella 2011	28	C5-C7	T	Un + Md	Bc + B	N/A	11	33	4	Y
143	7 Estrella 2011	39	C5-C7	T	Un + Md	Bc + B	N/A	6	12	4	Y
144	8 Estrella 2011	35	C5-C7	T	Un + Md	Bc + B	N/A	3	16	4	Y
145	9 Estrella 2011	34	C5-C7	T	Un + Md	Bc + B	N/A	4	24	4	Y
146	2 Friedman 1990	15	total	T	IC	MCN	N/A	9	36	4	Y
147	4 Friedman 1990	33	total	T	IC	MCN	N/A	3	17	1	N
148	5 Friedman 1990	19	total	T	IC	MCN	N/A	5	24	4	Y
149	7 Friedman 1990	24	total	T	IC	MCN	N/A	10	24	1	N
150	8 Friedman 1990	20	C5-C7	T	IC	MCN	N/A	9	36	1	N
151	9 Friedman 1990	43	total	T	IC	MCN	N/A	12	36	1	N
152	10 Friedman 1990	17	total	T	IC	MCN	N/A	4	36	2	N
153	11 Friedman 1990	17	C5-C7	T	IC	MCN	N/A	4	36	4	Y
154	12 Friedman 1990	18	C5-C7	T	IC	MCN	N/A	8	36	4	Y
155	13 Friedman 1990	19	total	T	IC	MCN	N/A	7	18	2	N
156	14 Friedman 1990	16	total	T	IC	MCN	N/A	4	24	4	Y
157	15 Friedman 1990	20	total	T	IC	MCN	N/A	8	12	4	Y
158	16 Friedman 1990	37	C5-C7	T	IC	MCN	N/A	7	24	1	N
159	1 Gu 2003	23	C5-C6	T	iC7	UT	N/A	2.5	22	4	Y
160	2 Gu 2003	49	C5-C6	T	iC7	UT	N/A	2	30	4	Y
161	3 Gu 2003	35	C5-C6	T	iC7	UT	N/A	5	24	4	Y
162	4 Gu 2003	23	C5-C6	T	iC7	UT	N/A	50	12	4	Y
163	1 Kakinoki 2010	65	C5-C6	T	Un	Bc	N/A	4	92	4	Y
164	2 Kakinoki 2010	30	C5-C6	T	Un	Bc	N/A	4	38	4	Y
165	3 Kakinoki 2010	30	C5-C7	T	Un	Bc	N/A	5	39	4	Y
166	4 Kakinoki 2010	45	C5-C6	T	Un	Bc	N/A	5	26	4	Y
167	5 Kakinoki 2010	28	C5-C6	T	Un	Bc	N/A	5	12	5	Y
168	6 Kakinoki 2010	31	C5-C6	T	Un	Bc	N/A	6	14	4	Y
169	7 Kakinoki 2010	56	C5-C6	T	Un	Bc	N/A	6	28	3	Y
170	8 Kakinoki 2010	18	C5-C6	T	Un	Bc	N/A	5	14	5	Y
171	9 Kakinoki 2010	35	C5-C7	T	IC	Bc	N/A	4	38	4	Y
172	10 Kakinoki 2010	58	C5-C7	T	IC	Bc	N/A	5	35	4	Y
173	11 Kakinoki 2010	19	C5-C8	T	IC	Bc	N/A	4	30	4	Y
174	12 Kakinoki 2010	56	C5-C7	T	IC	Bc	N/A	5	19	3	Y
175	13 Kakinoki 2010	62	C5-C8	T	IC	Bc	N/A	4	51	3	Y
176	14 Kakinoki 2010	31	C5-C8	T	IC	Bc	N/A	4	14	4	Y
177	15 Kakinoki 2010	24	C5-C8	T	IC	Bc	N/A	3	25	4	Y
178	16 Kakinoki 2010	22	C5-C8	T	IC	Bc	N/A	3	28	4	Y
179	2 Krauker 1994	17	?	T	IC	Bc	N/A	3	48	4	Y
180	3 Krauker 1994	23	?	T	IC	Bc	N/A	5	22	3	Y
181	4 Krauker 1994	21	?	T	IC	Bc	N/A	5	18	4	Y
182	5 Krauker 1994	30	?	T	IC	Bc	N/A	7	30	1	N
183	6 Krauker 1994	20	?	T	IC	Bc	N/A	6	24	0	N
184	7 Krauker 1994	50	?	T	IC	Bc	N/A	6	15	3	Y
185	1 Leechavengvong 1998	19	C5-C6	T	Un	Bc	N/A	3	?	4	Y
186	2 Leechavengvong 1998	23	C5-C6	T	Un	Bc	N/A	11	?	4	Y
187	3 Leechavengvong 1998	22	C5-C6	T	Un	Bc	N/A	7	?	4	Y
188	4 Leechavengvong 1998	26	C5-C6	T	Un	Bc	N/A	5	?	4	Y

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189	5 Leechavengvong 1998	20	C5-C6	T	Un	Bc	N/A	6	?	4	Y
190	6 Leechavengvong 1998	26	C5-C6	T	Un	Bc	N/A	5	?	4	Y
191	7 Leechavengvong 1998	36	C5-C6	T	Un	Bc	N/A	3	?	4	Y
192	8 Leechavengvong 1998	44	C5-C6	T	Un	Bc	N/A	4	?	3	Y
193	9 Leechavengvong 1998	28	C5-C6	T	Un	Bc	N/A	9	?	4	Y
194	10 Leechavengvong 1998	27	C5-C6	T	Un	Bc	N/A	12	?	4	Y
200	11 Leechavengvong 1998	20	Lat + Post cord	T	Un	Bc	N/A	4	?	4	Y
201	12 Leechavengvong 1998	27	C5-C6	T	Un	Bc	N/A	3	?	4	Y
202	13 Leechavengvong 1998	22	Lat + Post cord	T	Un	Bc	N/A	3	?	4	Y
198	14 Leechavengvong 1998	20	C5-C7	T	Un	Bc	N/A	5	?	4	Y
199	15 Leechavengvong 1998	30	C5-C6	T	Un	Bc	N/A	6	?	4	Y
200	16 Leechavengvong 1998	33	C5-C6	T	Un	Bc	N/A	4.5	?	4	Y
201	17 Leechavengvong 1998	21	C5-C6	T	Un	Bc	N/A	8	?	4	Y
202	18 Leechavengvong 1998	36	C5-C6	T	Un	Bc	N/A	4	?	4	Y
203	19 Leechavengvong 1998	40	C5-C6	T	Un	Bc	N/A	6	?	4	Y
204	20 Leechavengvong 1998	35	C5-C7	T	Un	Bc	N/A	12	?	0	N
205	21 Leechavengvong 1998	17	C5-C6	T	Un	Bc	N/A	3	?	4	Y
206	22 Leechavengvong 1998	46	C5-C6	T	Un	Bc	N/A	2	?	4	Y
207	23 Leechavengvong 1998	22	C5-C6	T	Un	Bc	N/A	3	?	4	Y
208	24 Leechavengvong 1998	37	C5-C6	T	Un	Bc	N/A	4	?	4	Y
209	25 Leechavengvong 1998	24	C5-C6	T	Un	Bc	N/A	3	?	4	Y
210	26 Leechavengvong 1998	25	C5-C7	T	Un	Bc	N/A	7	?	4	Y
211	27 Leechavengvong 1998	34	C5-C6	T	Un	Bc	N/A	4	?	4	Y
212	28 Leechavengvong 1998	20	C5-C6	T	Un	Bc	N/A	2	?	4	Y
213	29 Leechavengvong 1998	33	C5-C6	T	Un	Bc	N/A	5	?	4	Y
214	30 Leechavengvong 1998	28	C5-C6	T	Un	Bc	N/A	4	?	4	Y
215	31 Leechavengvong 1998	23	C5-C7	T	Un	Bc	N/A	3	?	4	Y
216	32 Leechavengvong 1998	24	C5-C6	T	Un	Bc	N/A	2	?	4	Y
217	1 Leechavengvong 2006	31	C5-C6	T	Un	Bc	N/A	3	?	4	Y
218	2 Leechavengvong 2006	22	C5-C6	T	Un	Bc	N/A	10	?	4	Y
219	3 Leechavengvong 2006	19	C5-C6	T	Un	Bc	N/A	8	?	4	Y
220	4 Leechavengvong 2006	35	C5-C6	T	Un	Bc	N/A	6	?	4	Y
221	6 Leechavengvong 2006	22	C5-C6	T	Un	Bc	N/A	8	?	4	Y
222	7 Leechavengvong 2006	35	C5-C6	T	Un	Bc	N/A	4	?	4	Y
223	8 Leechavengvong 2006	19	C5-C6	T	Un	Bc	N/A	5	?	4	Y
224	9 Leechavengvong 2006	62	C5-C6	T	Un	Bc	N/A	7	?	3	Y
225	10 Leechavengvong 2006	21	C5-C6	T	Un	Bc	N/A	3	?	4	Y
226	11 Leechavengvong 2006	19	C5-C6	T	Un	Bc	N/A	6	?	4	Y
227	12 Leechavengvong 2006	23	C5-C6	T	Un	Bc	N/A	7	?	4	Y
228	13 Leechavengvong 2006	35	C5-C6	T	Un	Bc	N/A	6	?	3	Y
229	14 Leechavengvong 2006	30	C5-C6	T	Un	Bc	N/A	6	?	4	Y
230	15 Leechavengvong 2006	17	C5-C6	T	Un	Bc	N/A	8	?	4	Y
231	1 Liverneaux 2006	17	C5-C6	T	Un + Md	Bc + B	N/A	11	11	4	Y
232	2 Liverneaux 2006	32	C5-C6	T	Un + Md	Bc + B	N/A	2	19	4	Y
233	3 Liverneaux 2006	30	C5-C6	T	Un + Md	Bc + B	N/A	3.5	18	4	Y
234	4 Liverneaux 2006	43	C5-C6	T	Un + Md	Bc + B	N/A	12	12.5	4	Y
235	5 Liverneaux 2006	31	C5-C6	T	Un + Md	Bc + B	N/A	4	24	4	Y
236	6 Liverneaux 2006	21	C5-C6	T	Un + Md	Bc + B	N/A	6	11	4	Y
237	7 Liverneaux 2006	21	Infraclavicular	T	Un + Md	Bc + B	N/A	7	8	4	Y
238	8 Liverneaux 2006	29	C5-C7	T	Un + Md	Bc + B	N/A	3.5	16	4	Y

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239	9 Liverneaux 2006	18	C5-C7	T	Un + Md	Bc + B	N/A	6	11.5	4	Y
240	10 Liverneaux 2006	30	C5-C7	T	Un + Md	Bc + B	N/A	11	19	4	Y
241	1 Maricq 2014	26	C5-C6	T	Un	Bc	N/A	10	81	4	Y
242	2 Maricq 2014	19	C5-C6	T	Un + Md	Bc + B	N/A	2	22	4	Y
243	3 Maricq 2014	48	C5-C7	T	Un + Md	Bc + B	N/A	4	36	3	Y
244	4 Maricq 2014	47	C5-C7	T	Un	Bc	N/A	2	77	3	Y
245	5 Maricq 2014	21	Infraclavicular	T	Un + Md	Bc + B	N/A	7	18	4	Y
246	1 Oberlin 1994	29	C5-C6	T	Un	Bc	N/A	4	24	4	Y
247	2 Oberlin 1994	28	C5-C6	T	Un	Bc	N/A	6	9	3	Y
248	4 Oberlin 1994	18	?	T	Un	Bc	N/A	4	10	4	Y
249	1 Ray 2011	19	C5-C6	T	Un + Md	Bc + B	N/A	5	25	5	Y
250	2 Ray 2011	47	C5-C6	T	Un + Md	Bc + B	N/A	7	18	3	Y
251	3 Ray 2011	17	Infraclavicular	T	Un + Md	Bc + B	N/A	5	25	5	Y
252	5 Ray 2011	29	C5-C6	T	Un + Md	Bc + B	N/A	3	68	5	Y
253	6 Ray 2011	17	Infraclavicular	T	Un + Md	Bc + B	N/A	1	14	4	Y
254	7 Ray 2011	53	C5-C7	T	Un + Md	Bc + B	N/A	5	32	4	Y
255	8 Ray 2011	68	C5-C6	T	Un + Md	Bc + B	N/A	6	16	3	Y
256	9 Ray 2011	29	C5-C6	T	Un + Md	Bc + B	N/A	0	17	4	Y
257	10 Ray 2011	17	C5-C6	T	Un + Md	Bc + B	N/A	4	16	4	Y
258	11 Ray 2011	18	C5-C6	T	Un + Md	Bc + B	N/A	8	11	3	Y
259	12 Ray 2011	37	C5-C6	T	Un + Md	Bc + B	N/A	7	32	4	Y
260	13 Ray 2011	30	C5-C6	T	Un + Md	Bc + B	N/A	9	12	4	Y
261	14 Ray 2011	36	C5-C6	T	Un + Md	Bc + B	N/A	5	11	5	Y
262	15 Ray 2011	26	C5-C7	T	Un + Md	Bc + B	N/A	3	26	5	Y
263	16 Ray 2011	51	C5-C7	T	Un + Md	Bc + B	N/A	6	8	4	Y
264	17 Ray 2011	21	C5-C7	T	Un + Md	Bc + B	N/A	3	23	4	Y
265	18 Ray 2011	26	C5-C7	T	Un + Md	Bc + B	N/A	5	26	5	Y
266	20 Ray 2011	21	C5-C6	T	Un + Md	Bc + B	N/A	4	8	5	Y
267	21 Ray 2011	22	C5-C6	T	Un + Md	Bc + B	N/A	3	8	4	Y
268	22 Ray 2011	63	C5-C6	T	Un + Md	Bc + B	N/A	11	25	0	N
269	23 Ray 2011	51	C5-C6	T	Un + Md	Bc + B	N/A	?	12	1	N
270	24 Ray 2011	58	C5-C7	T	Un + Md	Bc + B	N/A	6	12	4	Y
271	25 Ray 2011	38	C5	T	Un + Md	Bc + B	N/A	3	8	4	Y
272	26 Ray 2011	26	C5-C6	T	Un + Md	Bc + B	N/A	6	17	4	Y
273	28 Ray 2011	48	C4-C7	T	Un + Md	Bc + B	N/A	9	15	4	Y
274	29 Ray 2011	55	C5-C7	T	Un + Md	Bc + B	N/A	4	8	4	Y
275	1 Ruch 1995	19	?	T	IC	MCN	N/A	9	24	1	N
276	2 Ruch 1995	20	total	T	IC	MCN	N/A	5	96	2	N
277	3 Ruch 1995	21	C5-C6	T	IC	MCN	N/A	5	48	4	Y
278	4 Ruch 1995	20	C5-C6	T	IC	MCN	N/A	3	120	4	Y
279	5 Ruch 1995	18	C5-C7	T	IC	MCN	N/A	4	30	4	Y
280	6 Ruch 1995	22	total	T	IC	MCN	N/A	4	36	4	Y
281	7 Ruch 1995	37	C5-C7	T	IC	MCN	N/A	7	120	2	N
282	8 Ruch 1995	18	C5-C7	T	IC	MCN	N/A	6	120	1	N
283	9 Ruch 1995	42	total	T	IC	MCN	N/A	12	120	0	N
284	10 Ruch 1995	18	C5-C7	T	IC	MCN	N/A	4	120	4	Y
285	11 Ruch 1995	33	total	T	IC	MCN	N/A	4	48	0	N
286	12 Ruch 1995	17	total	T	IC	MCN	N/A	9	108	2	N
287	13 Ruch 1995	25	total	T	IC	MCN	N/A	10	48	2	N
288	14 Ruch 1995	16	total	T	IC	MCN	N/A	4	48	4	Y

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Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
289	16 Ruch 1995	15	total	T	IC	MCN	N/A	9	24	4	Y
290	17 Ruch 1995	20	total	T	IC	MCN	N/A	12	36	0	N
291	1 Siqueira 2009	23	total	T	Ph	MCN	N/A	8	53	3	Y
292	2 Siqueira 2009	25	total	T	Ph	MCN	N/A	6	46	3	Y
293	3 Siqueira 2009	14	total	T	Ph	MCN	N/A	6	25	3	Y
294	4 Siqueira 2009	25	total	T	Ph	MCN	N/A	8	53	3	Y
295	5 Siqueira 2009	34	total	T	Ph	MCN	N/A	4	33	1	N
296	6 Siqueira 2009	20	total	T	Ph	MCN	N/A	7	40	0	N
297	7 Siqueira 2009	43	total	T	Ph	MCN	N/A	9	36	1	N
298	8 Siqueira 2009	24	total	T	Ph	MCN	N/A	5	24	3	Y
299	9 Siqueira 2009	18	total	T	Ph	MCN	N/A	3	46	4	Y
300	10 Siqueira 2009	22	total	T	Ph	MCN	N/A	4	58	4	Y
301	1 Socolovsky 2012	34	C5-C6	T	Un	Bc	N/A	2.5	24	3	Y
302	2 Socolovsky 2012	25	C5-C7	T	Un	Bc	N/A	10.3	24	3	Y
303	3 Socolovsky 2012	56	C5-C6	T	Un	Bc	N/A	6.1	24	0	N
304	4 Socolovsky 2012	27	C5-C6	T	Un	Bc	N/A	3	24	3	Y
305	5 Socolovsky 2012	20	C5-C6	T	Un	Bc	N/A	6.1	25	3	Y
306	6 Socolovsky 2012	40	C5-C6	T	Un	Bc	N/A	6.3	24	4	Y
307	7 Socolovsky 2012	18	C5-C7	T	Un	Bc	N/A	5.5	24	3	Y
308	8 Socolovsky 2012	34	C5-C6	T	Un	Bc	N/A	6.5	33	4	Y
309	9 Socolovsky 2012	28	C5-C7	T	Un	Bc	N/A	8	36.5	4	Y
310	10 Socolovsky 2012	30	C5-C7	T	Un	Bc	N/A	9.6	48	1	N
311	11 Socolovsky 2012	26	C5-C7	T	Un	Bc	N/A	10	36	4	Y
312	12 Socolovsky 2012	39	C5-C6	T	Un	Bc	N/A	7	28	3	Y
313	13 Socolovsky 2012	27	C5-C7	T	Un	Bc	N/A	15	39	3	Y
314	14 Socolovsky 2012	34	C5-C6	T	Un	Bc	N/A	11.5	30	4	Y
315	15 Socolovsky 2012	31	C5-C6	T	Un	Bc	N/A	5	32	4	Y
316	16 Socolovsky 2012	32	C5-C6	T	Un	Bc	N/A	4.3	26	3	Y
317	17 Socolovsky 2012	28	C5-C6	T	Un	Bc	N/A	8	34	3	Y
318	18 Socolovsky 2012	19	C5-C6	T	Un	Bc	N/A	10	26	3	Y
319	1 Soldado 2014	42	Infraclavicular	T	TDN	Bc	N/A	9	28	4	Y
320	2 Soldado 2014	28	Infraclavicular	T	TDN	Bc + B	N/A	7	36	4	Y
321	3 Soldado 2014	50	Infraclavicular	T	TDN	Bc	N/A	8	16	4	Y
322	4 Soldado 2014	22	Infraclavicular	T	TDN	Bc + MCN	N/A	6	14	4	Y
323	5 Soldado 2014	23	Infraclavicular	T	TDN	Bc	N/A	10	14	4	Y
324	1 Teboul 2004	29	C5-C6	T	Un	Bc	N/A	4	24	4	Y
325	2 Teboul 2004	18	C5-C6	T	Un	Bc	N/A	12	74	4	Y
326	3 Teboul 2004	17	C5-C7	T	Un	Bc	N/A	6	60	4	Y
327	4 Teboul 2004	19	C5-C7	T	Un	Bc	N/A	8	18	3	Y
328	5 Teboul 2004	23	C5-C6	T	Un	Bc	N/A	4	13	2	N
329	6 Teboul 2004	40	C5-C7	T	Un	Bc	N/A	28	48	0	N
330	7 Teboul 2004	19	C5-C7	T	Un	Bc	N/A	75	15	0	N
331	8 Teboul 2004	34	C5-C6	T	Un	Bc	N/A	4	27	3	Y
332	9 Teboul 2004	25	C5-C6	T	Un	Bc	N/A	27	9	2	N
333	10 Teboul 2004	24	C5-C6	T	Un	Bc	N/A	8	35	3	Y
334	11 Teboul 2004	25	C5-C7	T	Un	Bc	N/A	8	15	0	N
335	12 Teboul 2004	39	C5-C7	T	Un	Bc	N/A	8	32	4	Y
336	13 Teboul 2004	19	C5-C7	T	Un	Bc	N/A	6	16	2	N
337	14 Teboul 2004	32	C5-C7	T	Un	Bc	N/A	2.5	25	4	Y

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Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
338	15 Teboul 2004	23	C5-C6	T	Un	Bc	N/A	4	36	4	Y
339	16 Teboul 2004	43	C5-C6	T	Un	Bc	N/A	7	42	4	Y
340	17 Teboul 2004	47	C5-C7	T	Un	Bc	N/A	2	36	4	Y
341	18 Teboul 2004	24	C5-C6	T	Un	Bc	N/A	6.5	42	4	Y
342	19 Teboul 2004	51	C5-C7	T	Un	Bc	N/A	7	14	2	N
343	20 Teboul 2004	26	C5-C7	T	Un	Bc	N/A	2	22	4	Y
344	21 Teboul 2004	66	C5-C6	T	Un	Bc	N/A	4.5	30	4	Y
345	22 Teboul 2004	17	C5-C7	T	Un	Bc	N/A	5	22	4	Y
346	23 Teboul 2004	33	C5-C7	T	Un	Bc	N/A	2	24	4	Y
347	24 Teboul 2004	15	C5-C7	T	Un	Bc	N/A	12	32	4	Y
348	25 Teboul 2004	30	C5-C7	T	Un	Bc	N/A	7	22	4	Y
349	26 Teboul 2004	20	C5-C7	T	Un	Bc	N/A	3	52	4	Y
350	27 Teboul 2004	21	C5-C7	T	Un	Bc	N/A	1.5	36	3	Y
351	28 Teboul 2004	24	C5-C7	T	Un	Bc	N/A	7	57	4	Y
352	29 Teboul 2004	22	C5-C7	T	Un	Bc	N/A	2	40	4	Y
353	30 Teboul 2004	24	C5-C7	T	Un	Bc	N/A	3	36	4	Y
354	31 Teboul 2004	27	C5-C7	T	Un	Bc	N/A	7	24	4	Y
355	32 Teboul 2004	25	C5-C7	T	Un	Bc	N/A	2	18	0	N
356	1 Venkatramani 2008	50	C5-C6	T	Un	Bc	N/A	6	36	4	Y
357	2 Venkatramani 2008	48	C5-C6	T	Un	Bc	N/A	3	34	4	Y
358	3 Venkatramani 2008	27	C5-C6	T	Un	Bc	N/A	4	30	4	Y
359	4 Venkatramani 2008	42	C5-C6	T	Un	Bc	N/A	4	26	4	Y
360	5 Venkatramani 2008	52	C5-C7	T	Un	Bc	N/A	2	25	4	Y
361	6 Venkatramani 2008	20	C5-C7	T	Un	Bc	N/A	3	23	4	Y
362	7 Venkatramani 2008	47	C5-C6	T	Un	Bc	N/A	3	22	4	Y
363	8 Venkatramani 2008	45	C5-C6	T	Un	Bc	N/A	2	20	4	Y
364	9 Venkatramani 2008	38	C5-C6	T	Un	Bc	N/A	4	20	3	Y
365	10 Venkatramani 2008	15	C5-C6	T	Un	Bc	N/A	5	18	4	Y
366	11 Venkatramani 2008	43	C5-C6	T	Un	Bc	N/A	2	17	4	Y
367	12 Venkatramani 2008	35	C5-C6	T	Un	Bc	N/A	4	15	4	Y
368	13 Venkatramani 2008	22	C5-C6	T	Un	Bc	N/A	4	14	4	Y
369	14 Venkatramani 2008	24	C5-C6	T	Un	Bc	N/A	3	13	4	N
370	15 Venkatramani 2008	26	C5-C6	T	Un	Bc	N/A	3	12	3	Y
371	1 Xiao 2014	48	C5-C7	T	IC	MCN	N/A	1	27	4	Y
372	2 Xiao 2014	43	total	T	IC	MCN	N/A	1	74	3	Y
373	3 Xiao 2014	31	total	T	IC	MCN	N/A	1	31	4	Y
374	4 Xiao 2014	34	C5-C7	T	IC	MCN	N/A	1.5	80	3	Y
375	5 Xiao 2014	47	C5-C7	T	IC	MCN	N/A	2	32	0	N
376	6 Xiao 2014	17	total	T	IC	MCN	N/A	2	24	3	Y
377	7 Xiao 2014	23	total	T	IC	MCN	N/A	2	54	3	Y
378	8 Xiao 2014	42	C5-C6	T	IC	MCN	N/A	3	54	3	Y
379	9 Xiao 2014	30	C5-C7	T	IC	MCN	N/A	3	56	4	Y
380	10 Xiao 2014	47	C5-C7	T	IC	MCN	N/A	3	24	4	Y
381	11 Xiao 2014	46	C5-C7	T	IC	MCN	N/A	3	43	2	N
382	12 Xiao 2014	19	total	T	IC	MCN	N/A	3	50	3	Y
383	13 Xiao 2014	16	C5-C7	T	IC	MCN	N/A	4	55	3	Y
384	14 Xiao 2014	33	C5-C7	T	IC	MCN	N/A	4	24	3	Y
385	15 Xiao 2014	35	C5-C7	T	IC	MCN	N/A	4	43	3	Y
386	16 Xiao 2014	25	C5-C7	T	IC	MCN	N/A	4	45	4	Y
387	17 Xiao 2014	19	total	T	IC	MCN	N/A	4	60	3	Y

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Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
388	18 Xiao 2014	33	total	T	IC	MCN	N/A	4	54	4	Y
389	19 Xiao 2014	43	total	T	IC	MCN	N/A	4	48	3	Y
390	20 Xiao 2014	38	C5-C7	T	IC	MCN	N/A	5	104	4	Y
391	21 Xiao 2014	42	total	T	IC	MCN	N/A	5	65	2	N
392	22 Xiao 2014	45	C5-C7	T	IC	MCN	N/A	6	57	3	Y
393	23 Xiao 2014	49	total	T	IC	MCN	N/A	6	29	1	N
394	24 Xiao 2014	33	C5-C7	T	IC	MCN	N/A	9	46	4	Y
395	25 Xiao 2014	45	total	T	IC	MCN	N/A	9	50	0	N
396	26 Xiao 2014	21	total	T	IC	MCN	N/A	11	52	4	Y
397	27 Xiao 2014	20	C5-C7	T	IC	MCN	N/A	12	49	3	Y
398	28 Xiao 2014	20	total	T	IC	MCN	N/A	12	63	2	N
399	29 Xiao 2014	20	total	T	IC	MCN	N/A	12	61	3	Y
400	30 Xiao 2014	48	total	T	IC	MCN	N/A	12	62	0	N
1	1 Bertelli 2008	22	Total	G	C5	ADUT	6	3	42	4	Y
2	2 Bertelli 2008	18	Total	G	C5	ADUT	4	3	48	4	Y
3	3 Bertelli 2008	18	Total	G	C5	ADUT	4	4	42	4	Y
4	4 Bertelli 2008	43	Total	G	C5	ADUT	6	9	27	4	Y
5	5 Bertelli 2008	23	Total	G	C5	ADUT	10	6	36	3	Y
6	6 Bertelli 2008	28	Total	G	C5	ADUT	10	8	36	2	N
7	7 Bertelli 2008	22	Total	G	C5	ADUT	6	2	36	4	Y
8	8 Bertelli 2008	19	Total	G	C5	ADUT	5	2	30	3	Y
9	9 Bertelli 2008	32	Total	G	C5	ADUT	12	6	36	4	Y
10	10 Bertelli 2008	22	Total	G	C5	UT	7	5	36	4	Y
11	11 Bertelli 2008	24	Total	G	C5	ADUT	7	6	33	3	Y
12	12 Bertelli 2008	21	Total	G	C5	ADUT	6	4	34	2	N
13	1 Fogarty 2002	14	C5-C6	G	?	C6	?	10	?	4	Y
14	2 Fogarty 2002	18	C5-C6	G	C5	LC	?	8	?	4	Y
15	3 Fogarty 2002	24	C5-C6	G	?	C6	?	24	?	4	Y
16	4 Fogarty 2002	46	C5-C6	G	C5	?	?	9	?	4	Y
17	5 Fogarty 2002	19	C5-C6	G	C5,C6	UT	?	26	?	4	Y
18	6 Fogarty 2002	26	C5-C6	G	C5	LC	?	8	?	4	Y
19	7 Fogarty 2002	23	C5-C6	G	C5	LC	?	32	?	0	N
20	9 Fogarty 2002	23	C5-C6	G	C6	LC	?	28	?	0	N
21	1 Mallesy 1999	17	Total	G	C5	MCN	16	17	30	0	N
22	3 Mallesy 1999	20	C5-C7	G	C5	UT	7	7	40	3	Y
23	5 Mallesy 1999	17	Total	G	C5	LC	32	1	42	3	Y
24	6 Mallesy 1999	17	Total	G	C5	MCN	16	6	44	4	Y
25	7 Mallesy 1999	26	Total	G	C5	MCN	20	2	25	0	N
26	8 Mallesy 1999	25	Total	G	C6	UT	3	10	30	3	Y
27	9 Mallesy 1999	20	Total	G	C5	MCN	?	1	48	5	Y
28	10 Mallesy 1999	22	Total	G	C5	LC	6	4	70	5	Y
29	11 Mallesy 1999	28	Total	G	C5	LC	14	3	74	2	N
30	12 Mallesy 1999	16	C5-C7	G	C5	MCN	9	2	36	4	Y
31	13 Mallesy 1999	20	Total	G	C5	LC	12	3	36	5	Y
32	14 Mallesy 1999	28	Total	G	C5	LC	12	2	34	3	Y
33	15 Mallesy 1999	23	Total	G	C6	MCN	6	5	36	1	N
34	17 Mallesy 1999	18	C5-C6	G	C5	UT	6	3	27	4	Y
35	19 Mallesy 1999	41	C5-C7	G	C6	MCN	7	3	27	3	Y
36	21 Mallesy 1999	16	C5-C8	G	C6	MCN	6	3	26	5	Y
37	23 Mallesy 1999	20	Total	G	C6	MCN	11	4	24	1	N

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Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
38	24 Mallesy 1999	32	Total	G	C6	LC	7	2	24	4	Y
39	25 Mallesy 1999	17	Total	G	C5	MCN	14	5	24	4	Y
40	3 Table 1 Mallesy 2004	24	Total	G	C6	ADUT	?	4	?	3	Y
41	4 Table 1 Mallesy 2004	34	Total	G	C7	ADUT	?	4	?	2	N
42	5 Table 1 Mallesy 2004	18	C5-C6	G	C6	LC	?	6	?	3	Y
43	6 Table 1 Mallesy 2004	23	C5-C6	G	C5	MCN	?	9	?	3	Y
44	7 Table 1 Mallesy 2004	22	Total	G	C5	LC	?	1	?	4	Y
45	9 Table 1Mallesy 2004	54	Total	G	C5	LC	?	3	?	3	Y
46	10 Table 1Mallesy 2004	17	Total	G	C5	ADUT	?	5	?	1	N
47	11 Table 1 Mallesy 2004	19	Total	G	C5-C6	ADUT	?	4	?	0	N
48	1 Table 2 Mallesy 2004	32	Total	G	C6	LC	?	2	?	5	Y
49	3 Table 2 Mallesy 2004	16	Total	G	C6	MCN	?	3	?	5	Y
50	4 Table 2 Mallesy 2004	38	C5-C7	G	?	LC	?	12	?	2	N
51	5 Table 2 Mallesy 2004	26	Total	G	C6	LC	?	4	?	0	N
52	6 Table 2 Mallesy 2004	20	C5-C6	G	C6	MCN	?	4	?	0	N
53	7 Table 2 Mallesy 2004	24	C5-C6	G	C6	MCN	?	3	?	3	Y
54	10 Table 2 Mallesy 2004	23	Total	G	C6	LC	?	5	?	1	N
55	12 Table 2 Mallesy 2004	27	Total	G	C6	MCN	?	5	?	0	N
56	13 Table 2 Mallesy 2004	17	Total	G	C6	LC	?	2	?	4	Y
57	1 Table 3 Mallesy 2004	26	Total	G	C5	LC	?	4	?	4	Y
58	3 Table 3 Mallesy 2004	28	Total	G	C5	LC	?	3	?	2	N
59	5 Table 3 Mallesy 2004	16	C5-C8	G	C6	MCN	?	3	?	3	Y
60	6 Table 3 Mallesy 2004	16	Total	G	C5	MCN	?	1	?	5	Y
61	7 Table 3 Mallesy 2004	28	Total	G	C5	MCN	?	2	?	3	Y
62	11 Table 3 Mallesy 2004	27	C5-C6	G	C5	ADUT	?	5	?	3	Y
63	13 Table 3 Mallesy 2004	22	Total	G	C5	LC	?	4	?	5	Y
64	18 Table 3 Mallesy 2004	16	C5-C7	G	C5	MCN	?	2	?	4	Y
65	9 Sedel 1982	27	Total	G	C5	LC	?	12	48	4	Y
66	11 Sedel 1982	18	Total	G	C5	LC	?	3	36	3	Y
67	17 Sedel 1982	18	Total	G	C5	UT	?	12	70	4	Y
68	18 Sedel 1982	16	Total	G	C5	UT	?	5	36	4	Y
69	20 Sedel 1982	21	Total	G	C5	LC	?	3	48	5	Y
70	21 Sedel 1982	22	Total	G	C5-C6	UT	?	6	36	2	N
71	22 Sedel 1982	24	Total	G	C5-C6	UT	?	3	70	0	N
72	33 Sedel 1982	23	C5-C6	G	C5-C6	UT	?	6	28	4	Y
73	34 Sedel 1982	44	C5-C6	G	C5-C6	UT	?	5	36	3	Y
74	40 Sedel 1982	29	C5-C7	G	C5	UT	?	8	48	4	Y
75	41 Sedel 1982	23	C5-C7	G	C5	UT	?	6	24	4	Y
76	43 Sedel 1982	20	C5-C7	G	C5	UT	?	8	36	4	Y
77	1 Socolovsky 2012	30	C5-C7	G	C5	ADUT	?	6	38	0	N
78	2 Socolovsky 2012	19	C5-C6	G	C5	ADUT	?	8	35	2	N
79	3 Socolovsky 2012	27	C5-C6	G	C5	ADUT	?	5	27	3	Y
80	4 Socolovsky 2012	28	C5-C7	G	C5	ADUT	?	8	26	0	N
81	5 Socolovsky 2012	24	C5-C7	G	C5	ADUT	?	10	35	3	Y
82	6 Socolovsky 2012	50	C5-C7	G	C5-C6	ADUT	?	7	28	0	N
83	7 Socolovsky 2012	28	C5-C7	G	C5-C6	LC	?	8	47	3	Y
84	8 Socolovsky 2012	18	C5-C7	G	C6	ADUT	?	9	20	0	N
85	9 Socolovsky 2012	42	C5-C6	G	C5	ADUT	?	5	24	0	N
86	10 Socolovsky 2012	29	C5-C6	G	C5	ADUT	?	10	83	4	Y
87	11 Socolovsky 2012	18	C5-C6	G	C5	ADUT	?	12	22	3	Y

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Patient #	Pt number / Source	Age (y-o)	injury pattern	Graft/ Transfer	Donor nerve	Recipient nerve	graft length	Preop. Interval (Months)	F-U (Months)	BMRC (M)	Functional result (Y/N)
88	12 Socolovsky 2012	24	C5-C6	G	C5	UT	?	6	26	2	N
89	13 Socolovsky 2012	19	C5-C6	G	C5	UT	?	10	61	0	N
90	14 Socolovsky 2012	31	C5-C7	G	C5	LC	?	7	30	4	Y
91	15 Socolovsky 2012	21	C5-C6	G	C5-C6	UT	?	9	28	0	N
92	16 Socolovsky 2012	25	C5-C6	G	C5-C6	UT	?	4	34	3	Y
93	17 Socolovsky 2012	23	C5-C6	G	C5-C6	UT	?	5	63	4	Y
94	1 Bertelli 2010	22	Total	G	C5	MCN	10	6	?	4	Y
95	2 Bertelli 2010	29	Total	G	C5	MCN	17	4	?	4	Y
96	3 Bertelli 2010	47	Total	G	C5	MCN	17	10	?	3	Y
97	4 Bertelli 2010	20	Total	G	C5	MCN	18	5	?	3	Y
98	5 Bertelli 2010	16	Total	G	C5	MCN	15	11	?	3	Y
99	6 Bertelli 2010	21	Total	G	C5	MCN	20	3	?	4	Y
100	7 Bertelli 2010	18	Total	G	C5	MCN	17	11	?	4	Y
101	8 Bertelli 2010	23	Total	G	C5	MCN	20	4	?	2	N
102	9 Bertelli 2010	23	Total	G	C5	MCN	16	4	?	3	Y
103	10 Bertelli 2010	22	Total	G	C5	MCN	23	5	?	4	Y
104	11 Bertelli 2010	23	Total	G	C5	MCN	20	5	?	2	N
105	12 Bertelli 2010	24	Total	G	C5	MCN	15	5	?	4	Y
106	13 Bertelli 2010	19	Total	G	C5	MCN	17	3	?	4	Y
107	14 Bertelli 2010	23	Total	G	C5	MCN	13	5	?	4	Y
108	15 Bertelli 2010	33	Total	G	C5	MCN	16	6	?	3	Y
109	16 Bertelli 2010	34	Total	G	C5	MCN	19	4	?	3	Y
110	17 Bertelli 2010	15	Total	G	C5	MCN	20	4	?	3	Y
111	18 Bertelli 2010	23	Total	G	C5	MCN	18	5	?	4	Y
112	19 Bertelli 2010	22	Total	G	C5	MCN	17	2	?	4	Y
113	20 Bertelli 2010	23	Total	G	C5	MCN	15	5	?	3	Y
114	21 Bertelli 2010	20	Total	G	C5	MCN	17	4	?	4	Y
115	22 Bertelli 2010	19	Total	G	C5	MCN	19	5	?	4	Y

Patient age

The mean age of all the patients was 28 years (SD = 10.9). The mean percentage of patients experiencing a functional result among those under age 40 years was 83%, versus 75% in those 40 years old and older (p= 0.052) (Table and diagram 1). The mean age among patients obtaining a functional result was 28 years (10.9), versus 29 years (11.1) in those who did not (p = 0.26) (Table 2). The mean percentage of patients 40 years old and over achieving a functional result was 75% after nerve grafting and 75% after a nerve transfer (p = 0.68). (Table and diagram 2)

Table and diagram 1 Functional results and age (<40 vs >40 y-o)

Age > 40 * Funtional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
Age > 40	<40	Count	363	73	436
		% within Age > 40	83,3%	16,7%	100,0%
	>40	Count	59	20	79
		% within Age > 40	74,7%	25,3%	100,0%
Total		Count	422	93	515
		%	81,9%	18,1%	100,0%

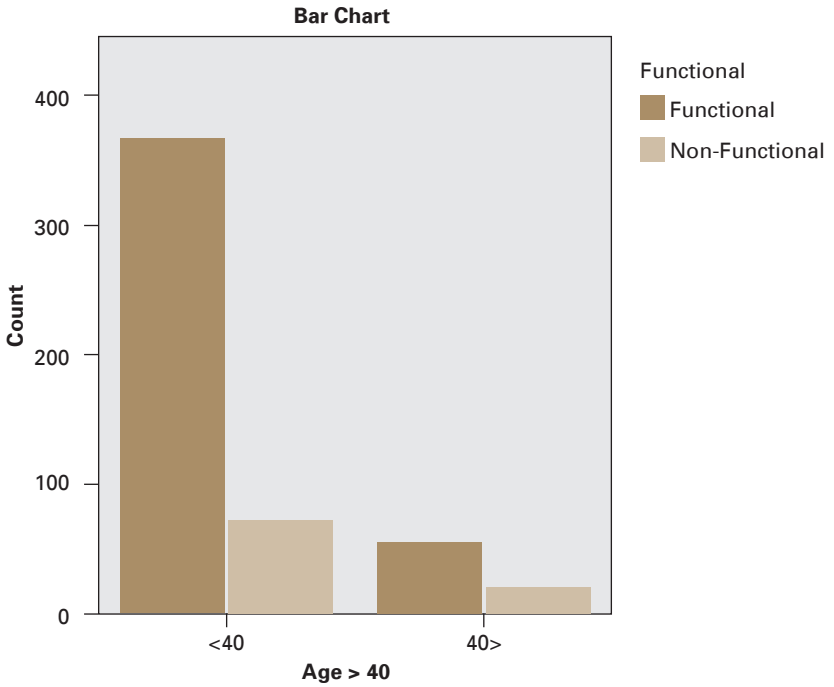


Table 2 Age and functional vs non-functional results

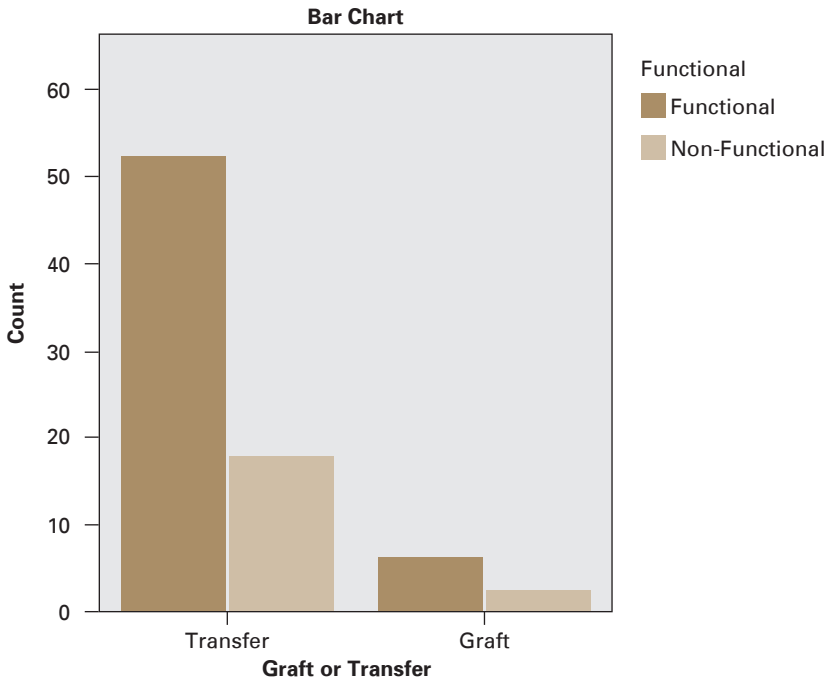
Group Statistics

	Funtional	N	Mean	Std. Deviation	Std. Error Mean
Age	Functional	422	27,86	10,941	,533
	Non-functional	93	29,27	11,085	1,149

Table and diagram 2 Age: Older versus younger than 40y-o

Graft or Transfer * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Graft or Transfer	Transfer	Count	53	18	71
		% within Transfer	74,6%	25,4%	100,0%
	Graft	Count	6	2	8
		% within Graft	75,0%	25,0%	100,0%
Total		Count	59	20	79
		% within Graft or Transfer	74,7%	25,3%	100,0%



Injury-to-surgery interval

Treatment within 9 months yielded a functional result in 84%, versus just 68% amongst those treated beyond 9 months (p=0.001) (Table and diagram 3). Among patients treated beyond 9 months, there was no difference in the percentage of functional outcomes between these patients undergoing nerve grafting and those undergoing nerve transfer (71% of 17 vs. 67% of 58, respectively; p =

0.52) (Table and diagram 4). The mean delay to treatment among those who achieved a functional result was 5.7 months (SD 3.9) versus 8.6 months (8.8) among those who did not ($p < 0.001$) (Table and diagram 5).

Table and diagram 3 Injury-to-surgery interval: before 9 months vs after 9 months

Interval >9 months * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Interval >9 months	<9 months	Count	369	69	438
		% within Interval >9 months	84,2%	15,8%	100,0%
	>9 months	Count	51	24	75
		% within Interval >9 months	68,0%	32,0%	100,0%
Total		Count	420	93	513
		%	81,9%	18,1%	100,0%

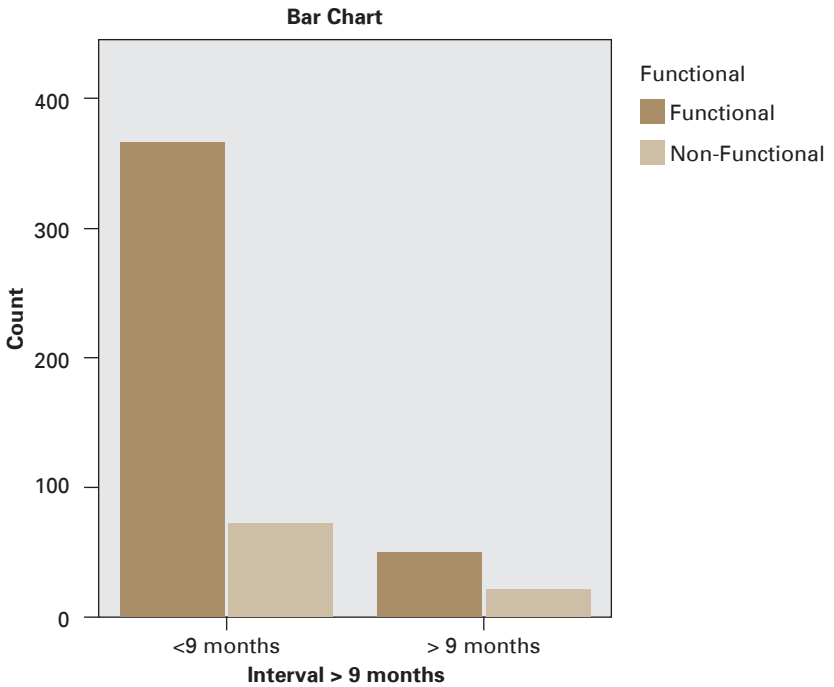


Table and diagram 4 Injury-to-surgery interval >9 months: Grafting vs transfer

Graft or Transfer * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Graft or Transfer	Transfer	Count	39	19	58
		% within Transfer	67,2%	32,8%	100,0%
	Graft	Count	12	5	17
		% within Graft	70,6%	29,4%	100,0%
Total		Count	51	24	75
		% within Graft or Transfer	68,0%	32,0%	100,0%

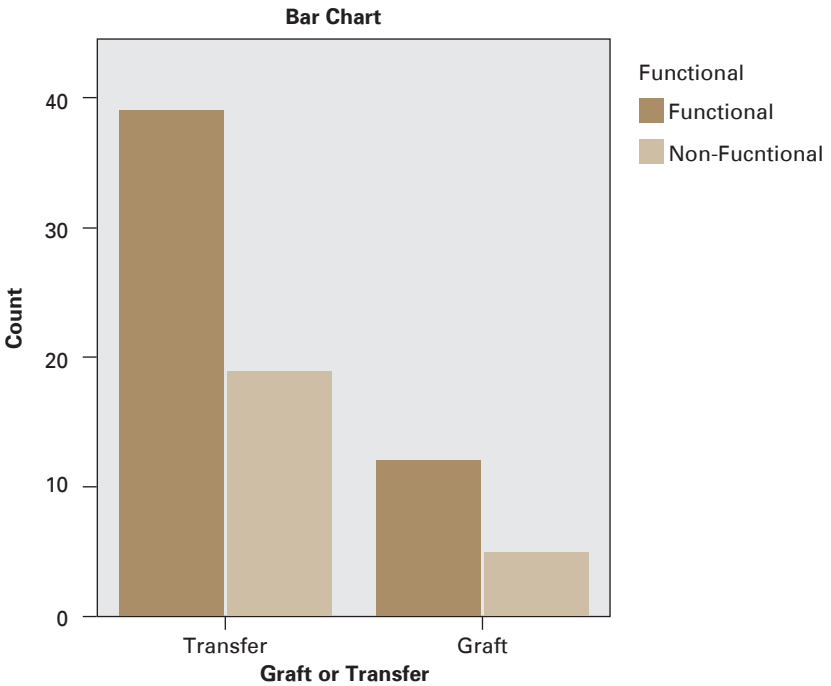
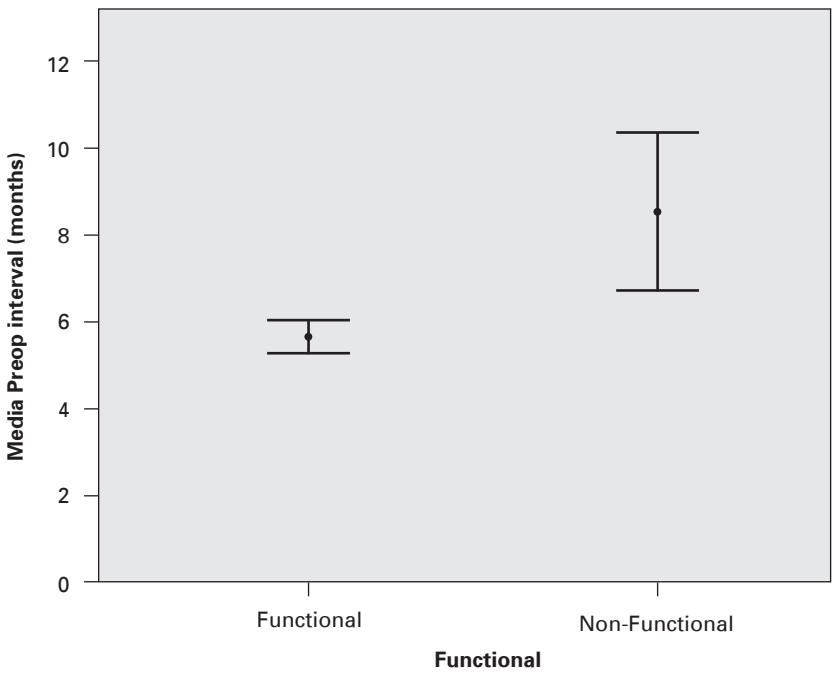


Table and diagram 5 Injury-to-surgery interval: functional vs non-functional results

Group Statistics

	Functional	N	Mean	Std. Deviation	Std. Error Mean
Preop interval (months)	Functional	420	5,68	3,958	,193
	Non-functional	93	8,59	8,836	,916

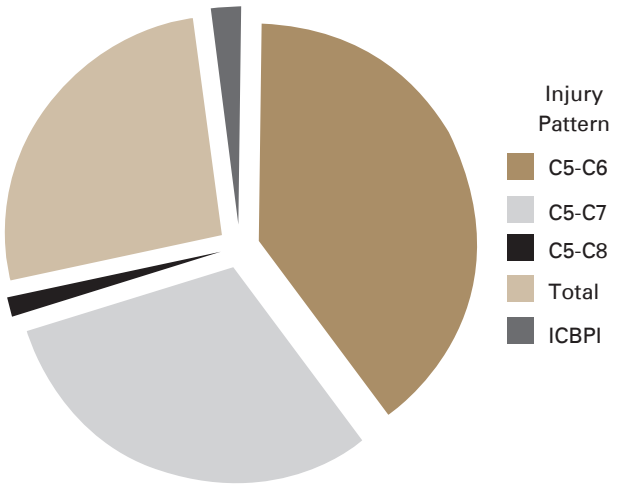


Error Barr: 95% Confident Interval

Injury level

Thirty-nine percent of the injuries were C5 and C6 (upper trunk) injuries, while 30% were C5-C7, 1.4% were C5-C8, 1.6% were infraclavicular and 26% were complete BPI (Diagram 6). The levels of injury differed significantly between patients treated with nerve grafts versus transfers. Of the patients treated with a nerve transfer, 80% had an upper-type injury (C5-C6 ±C7) and 16% had total BPI. Of the patients treated with a nerve graft, 36% had an upper-type injury (C5-C6 ±C7) and 63% had total BPI ($p<0.001$).

Diagram 6 Injury patterns distribution



Comparing outcomes following nerve transfer versus nerve grafting

Eighty-five percent of the patients who underwent a nerve transfer obtained functional elbow flexion, versus 73% following nerve grafting (p = 0.005) (Table and diagram 7). Among upper-type injuries (C5-C6 +/- C7), 89% of patients treated with a nerve transfer obtained a functional result versus 68% with a nerve graft (p=0.01) (Table and diagram 8). Amongst patients who achieved a functional result, 80% scored M4 or M5 after a nerve transfer, but just 57% after nerve grafting (p = 0.006). Conversely, among patients with complete BPI, 75% of patients who had a nerve graft experienced a functional result versus just 60% who had a nerve transfer (e.g., intercostal or phrenic nerve transfer) (p = 0.056) (Table and diagram 9).

Table and diagram 7 Nerve grafting vs transfer and functional results

Graft or Transfer * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Graft or Transfer	Transfer	Count	338	62	400
		% within Transfer	84,5%	15,5%	100,0%
	Graft	Count	84	31	115
		% within Graft	73,0%	27,0%	100,0%
Total		Count	422	93	515
		%	81,9%	18,1%	100,0%

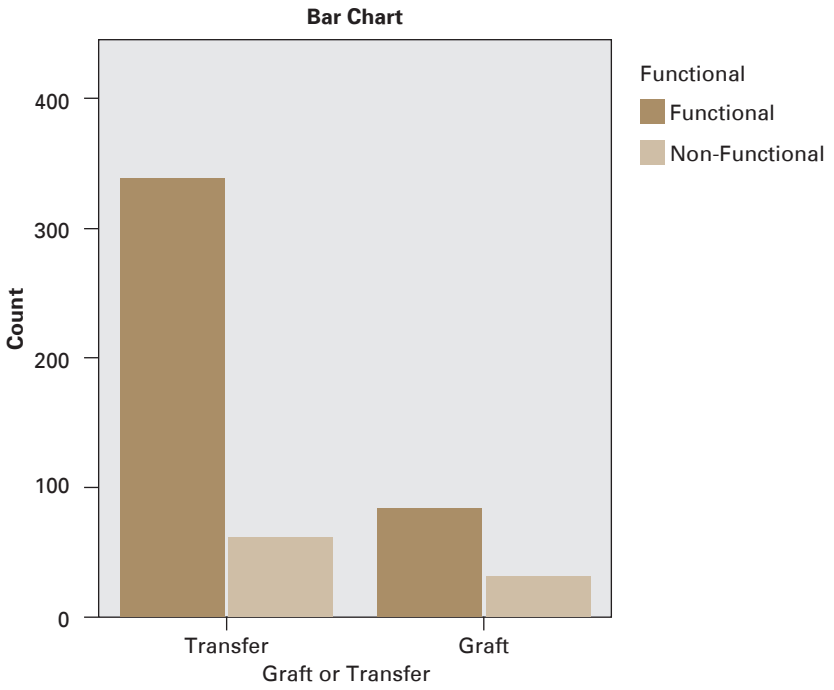


Table and diagram 8 Upper-type injuries: Nerve grafting vs transfer and functional results

Graft or Transfer * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Graft or Transfer	Transfer	Count	280	35	315
		% within Transfer	88,9%	11,1%	100,0%
	Graft	Count	28	13	41
		% within Graft	68,3%	31,7%	100,0%
Total		Count	308	48	356
		% within Graft or Transfer	86,5%	13,5%	100,0%

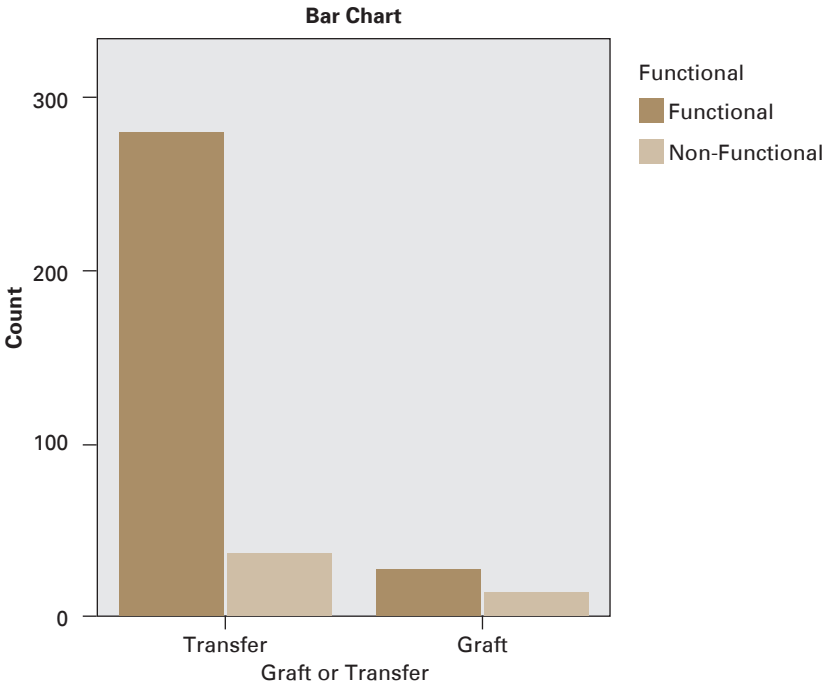
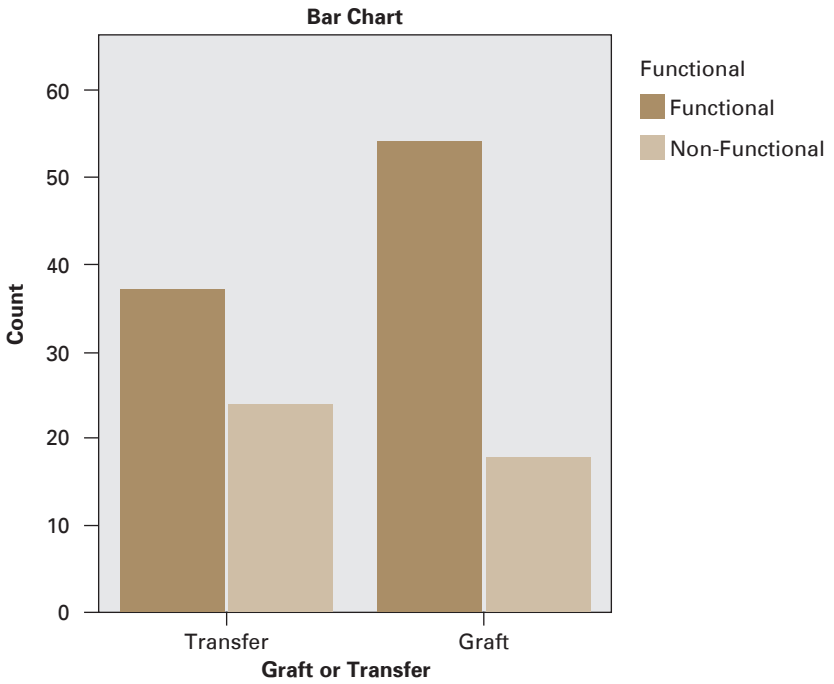


Table and diagram 9 Nerve grafting vs transfer and functional results in complete palsies

Graft or Transfer * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Graft or Transfer	Transfer	Count	37	24	61
		% within Transfer	60,7%	39,3%	100,0%
	Graft	Count	54	18	72
		% within Graft	75,0%	25,0%	100,0%
Total		Count	91	42	133
		% within Graft or Transfer	68,4%	31,6%	100,0%



Distance from the recipient nerve to the target

Ninety-two percent of the 259 patients who underwent a nerve transfer to the nerve to the biceps/brachialis obtained a functional result, compared to just 71% when the MCN was the recipient nerve ($p<0.001$) (Table and diagram 10). There was no statistically-significant difference between the 137 patients who had a nerve transfer to the MCN and achieved a functional result (71%) and the 41 patients who had the MCN grafted (80% functional results) ($p = 0.15$) (Table and diagram 11).

There was a trend ($p= 0.078$) towards superiority of nerve grafting to the MCN versus grafting to the upper trunk/anterior division of the upper trunk, with 81% and 64 % achieving a functional result, respectively (Table and diagram 12).

Table and diagram 10 Nerve transfer to Biceps/Brachialis vs MCN and functional results

Recipient * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Recipient	biceps/brachialis	Count	237	22	259
		% within Recipient	91,5%	8,5%	100,0%
	MCN	Count	97	40	137
		% within Recipient	70,8%	29,2%	100,0%
Total		Count	334	62	396
		% within Recipient	84,3%	15,7%	100,0%

Table and diagram 11 Nerve transfer vs grafting to MCN and functional results

Graft or Transfer * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Graft or Transfer	Transfer	Count	97	40	137
		% within Transfer	70,8%	29,2%	100,0%
	Graft	Count	33	8	41
		% within Graft	80,5%	19,5%	100,0%
Total		Count	130	48	178
		% within Graft or Transfer	73,0%	27,0%	100,0%

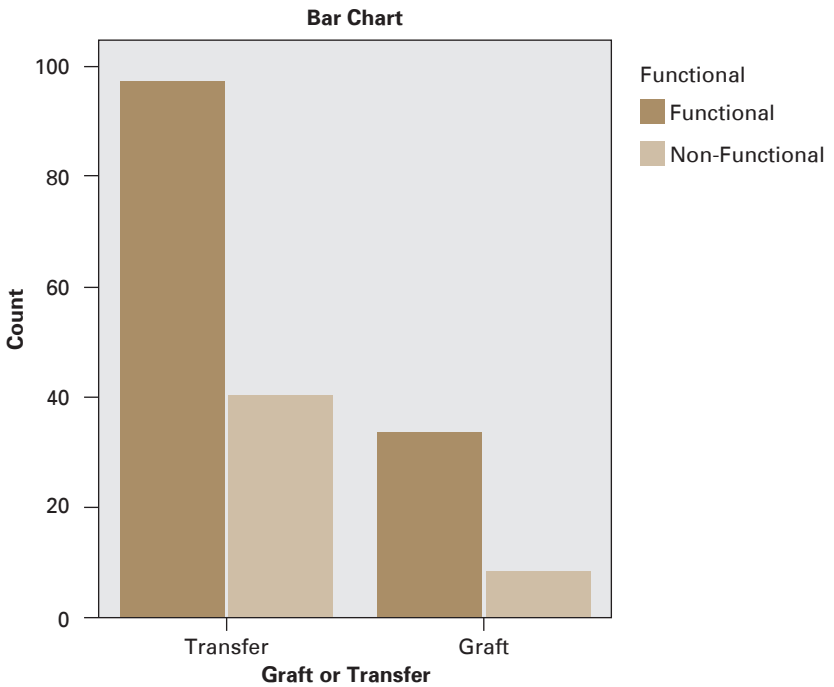
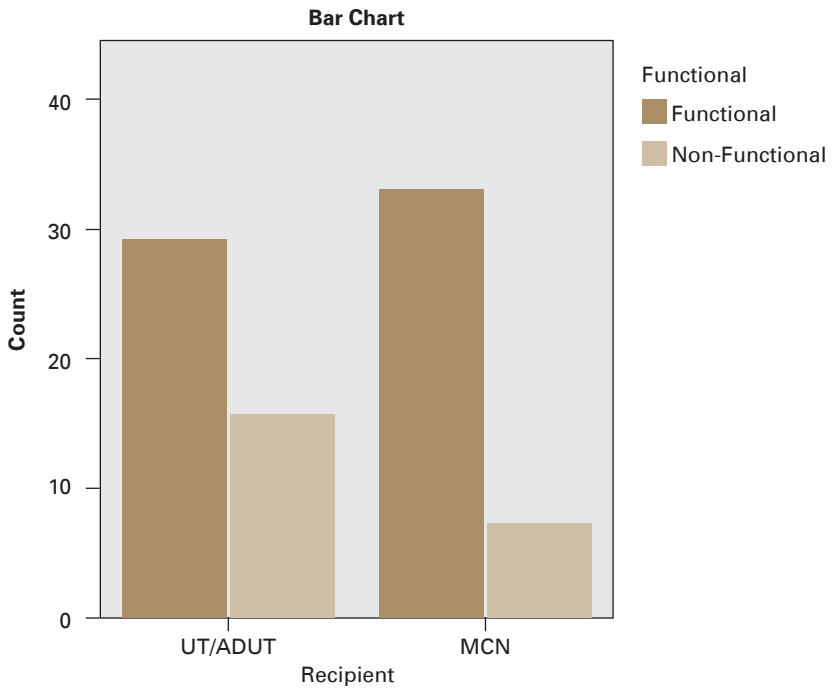


Table and diagram 12 Nerve grafting to UT/ADUT vs MCN and functional results

Recipient * Functional Crosstabulation

			Functional		Total
			Functional	Non-functional	
Recipient	UT/ADUT	Count	29	16	45
		% within Recipient	64,4%	35,6%	100,0%
	MCN	Count	33	8	41
		% within Recipient	80,5%	19,5%	100,0%
Total		Count	62	24	86
		% within Recipient	72,1%	27,9%	100,0%



Outcomes after nerve transfers or grafting in complete versus partial BPI

Sixty-one percent of the patients with a complete BPI who underwent a nerve transfer achieved a functional result, versus 89% patients with a partial BPI ($p < 0.001$) (Table and diagram 13). Among patients treated with nerve grafting, 75% of patients with a complete BPI and 69% with a partial BPI achieved a functional result ($p = 0.34$) (Table and diagram 14).

Table and diagram 13 Nerve transfers in complete vs partial BPI and outcomes

Total Injury Pattern * Funtional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
Total Injury Pattern	Nontotal	Count	301	38	339
		% within Partial Injury	88,8%	11,2%	100,0%
	Total	Count	37	24	61
		% within Total Injury	60,7%	39,3%	100,0%
Total		Count	338	62	400
		%	84,5%	15,5%	100,0%

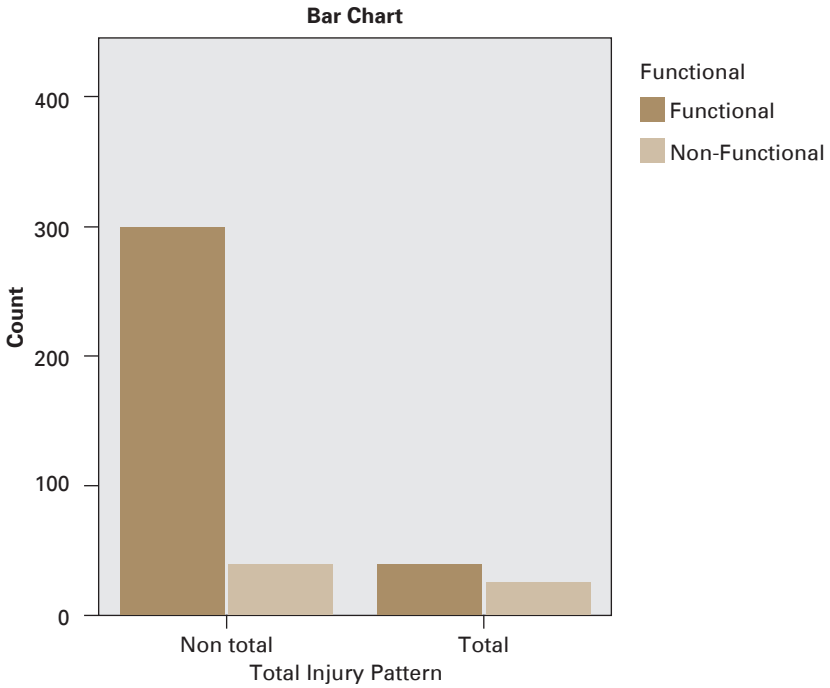
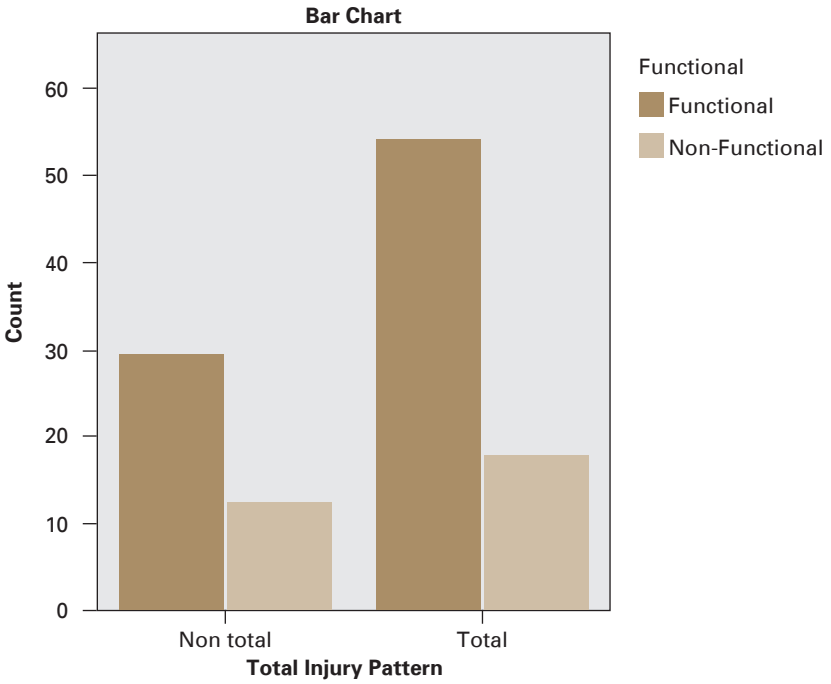


Table and diagram 14 Nerve grafting in complete vs partial BPI and outcomes

Total Injury Pattern * Funtional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
Total Injury Pattern	Nontotal	Count	30	13	43
		% within Partial Injury	69,8%	30,2%	100,0%
	Total	Count	54	18	72
		% within Total Injury	75,0%	25,0%	100,0%
Total		Count	84	31	115
		%	73,0%	27,0%	100,0%



Double Oberlin procedure

Among patients with a partial BPI, 94% who had a double Oberlin procedure achieved a functional result compared to 68% who underwent nerve grafting ($p < 0.001$) (Table 15). Ninety percent treated with a single Oberlin procedure achieved a functional result, a rate that was no different overall than among those who

underwent double Oberlin transfer (p = 0.477) (Table and diagram 16). Intra-plexal nerve transfers (Oberlin, MPN, TDN) were statistically more effective than) extra-plexal nerve transfers (IC and Ph) with 92% versus 68% achieving functional recovery respectively (p < 0.001) (Table and diagram 17).

Table and diagram 15 Oberlin vs nerve grafting in partial BPI

UlnarMed vs Graft * Functional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
UlnarMed vs Graft	Graft	Count	28	13	41
		% within Graft	68,3%	31,7%	100,0%
	Un+Md	Count	67	4	71
		% within UlnarMed	94,4%	5,6%	100,0%
Total		Count	95	17	112
		% within UlnarMed vs Graft	84,8%	15,2%	100,0%

Table and diagram 16 Single vs Double Oberlin

Un+Md vs Un * Functional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
Un+Md vs Un	Un+Md	Count	67	4	71
		% within Un+Md vs Un	94,4%	5,6%	100,0%
	Un	Count	160	17	177
		% within Un+Md vs Un	90,4%	9,6%	100,0%
Total		Count	227	21	248
		% within Un+Md vs Un	91,5%	8,5%	100,0%

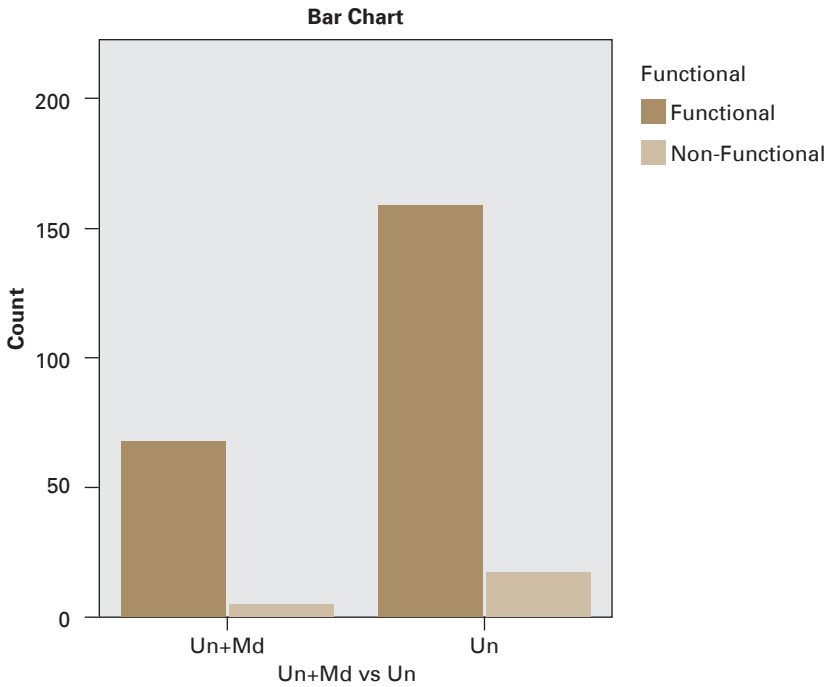
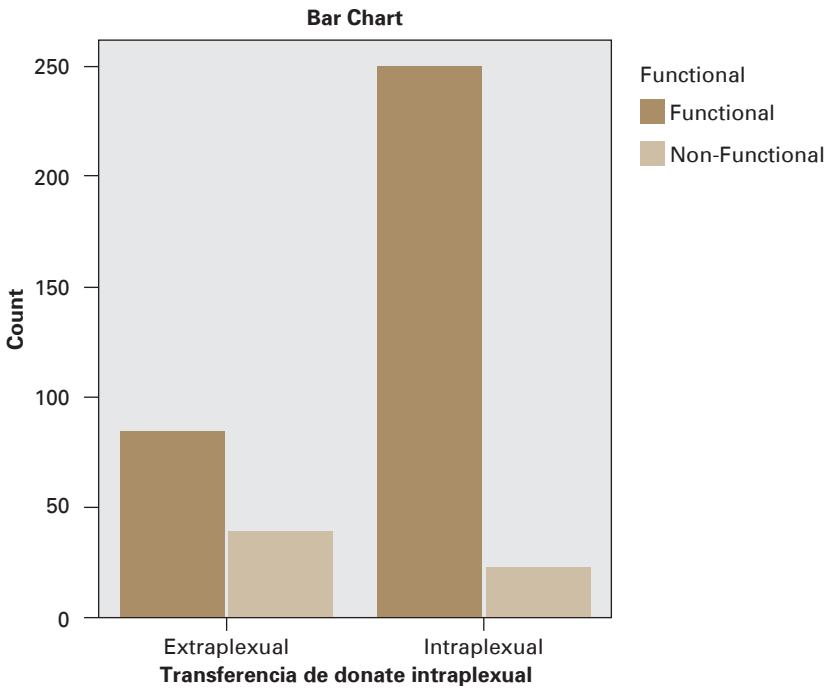


Table and diagram 17 Intraplexual vs Extraplexual nerve transfer and outcomes

Transferencia de donante intraplexual * Functional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
donor transfer intraplexual	Extraplexual	Count	84	39	123
		% within extraplexal transfer	68,3%	31,7%	100,0%
	Intraplexual	Count	250	23	273
		% within intraplexal transfer	91,6%	8,4%	100,0%
Total		Count	334	62	396
		%	84,3%	15,7%	100,0%



Graft length

The mean nerve graft lengths in patients who achieved a functional result after nerve grafting was 12.6 cm (SD = 6.2) and 13.7cm (5.7) when a functional result was not obtained (p = 0.64) (Table and diagram 18). Similarly, there was no significant difference in the percentage achieving functional recovery with nerve grafts shorter than 10 cm (21 patients; 86% success rate) versus 10 cm or longer (31; 81%) (p = 0.47) (Table and diagram 19).

Table and diagram 18 Graft lenght in functional vs non-fuctional groups

Group Statistics

	Funtional	N	Mean	Std. Deviation	Std. Error Mean
Graftlength (cm)	Functional	43	12,581	6,2877	,9589
	Non-functional	9	13,667	5,7446	1,9149

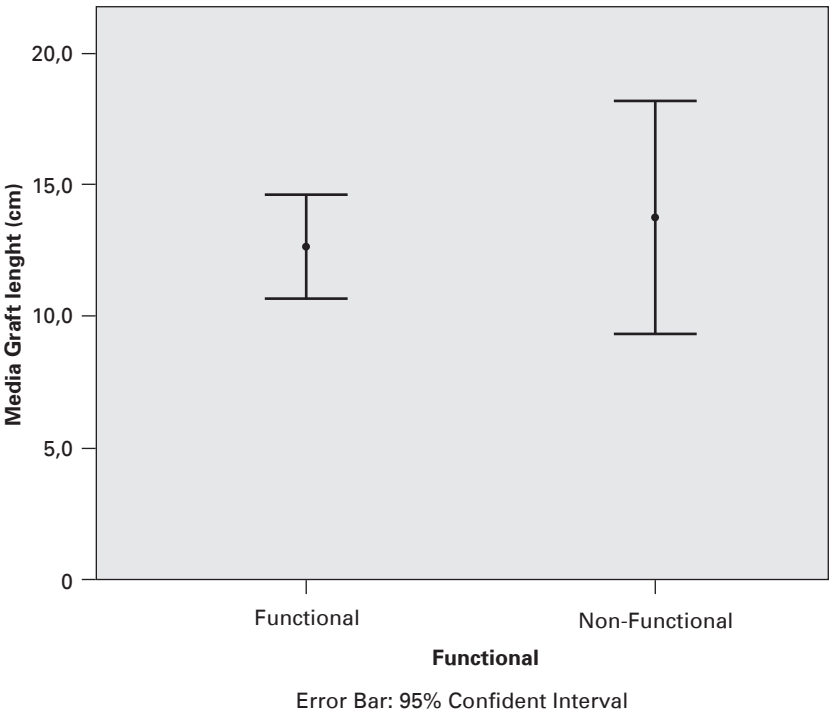
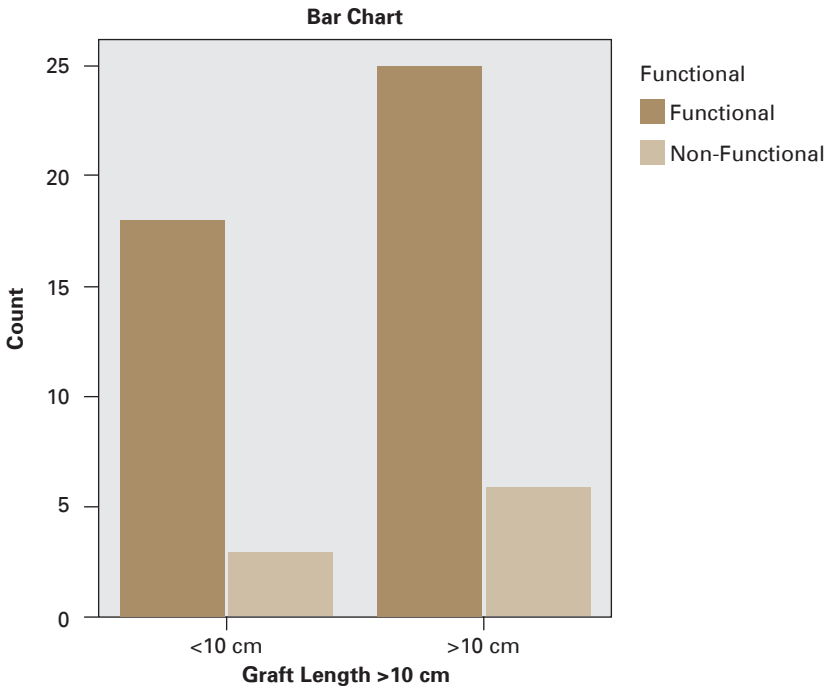


Table and diagram 19 Graft lenght <10cm vs >10cm and outcomes

Graft Length >10cm * Funtional Crosstabulation

			Funtional		Total
			Functional	Non-functional	
Graft Length >10cm	<10cm	Count	18	3	21
		% within Graft Length >10cm	85%	14%	100,0%
	>10cm	Count	25	6	31
		% within Graft Length >10cm	80%	19%	100,0%
Total		Count	43	9	52
		%	82%	17%	100,0%



Discussion

There is a general lack of robust, supportive scientific evidence in the field of peripheral nerve and brachial plexus surgery. This includes the lack of any prospective controlled studies. Several systematic reviews have been published in which the authors have sought to compare nerve transfers and nerve grafting for the reconstruction of BPI; all of these reviews used aggregated data (Ali et al., 2015; Garg et al., 2011; Yang et al., 2012). Individual data enable more flexible and robust analysis than is possible with aggregate analyses, including the ability to deal appropriately with time-to-event and longitudinal data (Stewart et al., 2015). Therefore, we believe that our study has scientific merit relative to previous systematic reviews.

Our study investigated and compared the outcomes achieved with nerve transfers versus nerve grafting in patients with traumatic BPI and also analysed the influence of the distance between the nerve repair and target muscle, the patient's age and the time from injury to surgery.

Since partial and complete BPI cannot be treated with the same type of nerve transfer (e.g., complete BPI is only amenable to extra-plexal nerve transfers), the results of nerve transfers and nerve grafts were compared independently for these two specific injuries. There was a significant difference between the two procedures, but only amongst patients with upper trunk (C5, 6 +/- C7) injuries. Nerve transfers performed better than nerve grafts in upper trunk BPI with a higher incidence of functional recovery (89% vs. 68%, respectively) and of M4-M5 level recovery (80% vs. 57%, respectively). These results are similar to those identified in other systematic reviews (Garg et al., 2011; Ali et al., 2015; Yang et al., 2012).

Conversely, extra-plexal nerve transfers did not fare better than nerve grafting in patients with a complete BPI. There are several potential explanations for this. First, with the latter there is a longer distance between the axonal outflow and the target, as the recipient nerve used for complete palsies was usually the MCN, compared to the nerve to the biceps or brachialis utilized for partial BPI. A second reason could be the reduced axon count in the phrenic and intercostal nerves (Bulstra and Shin, 2016; Narakas 1980). Finally, functional re-education is more difficult in patients who have undergone an extra-plexal versus intra-plexal transfer; in particular an intercostal nerve transfer requires complex retraining (Xu et al., 2002; Xu et al., 2005).

To investigate the influence of the distance between the axonal outflow and target, we compared the outcomes of nerve transfers involving two different recipient nerves for partial BPI: the biceps ± brachialis and the MCN. Our analysis suggests that the benefit of nerve transfers over grafts vanishes when the recipient nerve is not a terminal motor branch. This is, however, currently only conjecture that requires further research for confirmation.

Our results did not confirm the generally-held beliefs that outcomes are worse in older patients and that transfers are preferable in this population (Narakas, 1980). Patients who failed to achieve a functional result were no older than those who did. In addition, transfers performed no better than grafts in patients older than 40 years.

Delayed treatment has also been considered to be of paramount importance to outcomes, so that nerve repair has typically been recommended for patients treated late (more that 9 to 12 months after the injury)(Bentolila et al., 1999; Chuang et al., 1993; Hentz, 1988; Carlsen et al., 2009; Brown et al., 2009). Our analysis supports the concept that better results are generally achieved if surgery is performed earlier than 9 months. Patients operated upon within 9 months of their injury obtained better outcomes than those operated upon later. In addition, the mean injury-to-surgery interval was significantly shorter in patients who achieved functional recovery than those who failed to do so (5.7months vs. 8.6 months). One way in which our results conflict with conventional wisdom is that nerve transfers were not found to be significantly better than nerve grafting in patients treated later than 9 months post injury.

The basic theoretical concept that supports the superiority of nerve transfers over nerve grafting relates to closer axonal outflow to the target, thereby resulting in faster re-innervation and decreased neuromuscular endplate death (Garg et al., 2011). However, in the current data set, this superiority was only evident for partial BPI in which terminal or muscular branches are the recipient nerves. The time needed for axons to reach the muscle might explain this benefit. However, as previously mentioned, no differences were found between nerve transfers and grafts in patients treated later than 9 months after their injury.

Our hypothesis is that the benefits of nerve transfers, rather than being explained by the relative proximity of the axonal outflow to the muscle, might be better explained by more selective muscle re-innervation (as the donor nerve is a terminal motor branch), which would result in easier patient re-education, since axonal dispersion into antagonistic muscles would not occur (Bertelli et al., 2015). This concept is similar to the principle of one tendon/one function in tendon transfers (Kozin, 2008). This hypothesis could be tested by comparing nerve grafts versus nerve transfers to terminal motor branches supplying elbow flexor muscles. Unfortunately, we could not specifically extract this dataset from the papers we reviewed. However, nerve grafts with the MCN as a

recipient nerve tended towards better outcomes than grafts to the upper trunk, which might support the concept of more selective or less-dispersed re-innervation.

Spontaneous re-innervation is a confounding factor that might explain the better outcomes we observed following nerve transfers versus nerve grafts for partial BPI (Bertelli 2004 et al.,). A double source of re-innervation might exist in elbow flexor muscles after a single nerve transfer: both through transfer to the neurotized muscle and through the neuroma to the remaining elbow flexors. Re-innervation through the neuroma might explain elbow flexion restoration rather the nerve transfer. Thus, we compared the double Oberlin procedure (with which spontaneous re-innervation is impossible, except for the brachioradialis muscle, since both the brachialis and biceps are disconnected) against nerve grafting. Again, the results were superior for nerve transfers.

Nerve grafting, contrary to classical principles, did not result in worse outcomes than nerve transfers in patients with either complete BPI or partial BPI when the recipient nerve was not a terminal muscular branch. In addition, the outcomes after nerve grafting were no worse in older patients (≥ 40 years) or patients treated late. We also found that the length of nerve graft did not influence outcomes, which is contrary to generally-held beliefs, albeit recently the subject of debate (Bentolila et al., 1999; Hentz, 1988; Socolovsky et al., 2011). No differences were found between nerve grafts longer or shorter than 10 cm.

Our analysis has limitations beyond those that have already been mentioned. One such limitation is that we could not analyse several potentially influential factors like the role of co-contractions, the level of performance, motor re-education, the time it took the muscle to show signs of re-innervation and the number of nerve grafts, since most papers lacked this information (Dy et al., 2015). In addition, though the literature describes thousands of patients with BPI treated with nerve grafts, only a few reports provide individual data. This is contrary to what has happened in recent literature on nerve transfers. Thus, our analysis is fraught with disequilibrium

in the number of patients with nerve transfers and nerve grafts, limiting statistical power especially when comparing subgroups of patients. In addition, with few exceptions (e.g., patient age, the injury-to-surgery time interval and outcomes), most variables had considerable missing data, further limiting the power of statistical analysis. This also caused some potentially important factors to be eliminated from analysis, e.g. although information on the pattern of injury was provided for most patients, the type of root lesion (i.e., rupture vs. avulsion) was typically not provided. Our analysis also only focused on one function — active elbow flexion against gravity — meaning that the results we obtained comparing nerve grafts and transfers should not be extrapolated to other functions, like shoulder elevation and external rotation. Two final problems are statistical. The first relates to the issue of multiple comparisons, for which we did not adjust, given the exploratory nature of our study. We do note, however, that many of the differences we identified were significant at $p = 0.001$ or less, which indicates that the likelihood of type II error in those comparisons is minimal, even given the multiple comparisons. The second statistical issue pertains to the tremendous diversity between studies in the variables collected, which meant that multivariate analysis was virtually impossible. Such analysis will require prospective studies that provide enough that data on the same variables are collected across a large enough sample to render multivariate analysis meaningful and of sufficient statistical power.

Despite these limitations, we still feel that our analysis questions many classically held beliefs regarding nerve transfers and generates some novel ideas for future consideration and study. From our analysis, we believe that nerve transfers are superior to nerve grafts only in patients with a partial BPI and only when the donor nerve is a terminal motor branch. Selective neurotization might be a major reason for the observed benefits of nerve transfers, rather than the proximity of the axonal donor source (Bertelli et al., 2015). Finally, our analysis fails to support the belief that nerve transfers out-perform nerve grafts in patients beyond 9 to 12 months from injury, older patients and patients with a complete BPI.

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4.4 Evidence in Compression Neuropathies

4.4.1 Evidence in Carpal Tunnel Syndrome

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Introduction

The aim of this section is to review the recent findings in the literature and to assess which of the most common beliefs concerning CTS are supported by an evidence-based approach and which ones are not. The PRISMA algorithm was implemented to select the relevant articles and to assess their quality.

Materials and Methods

The MEDLINE database (http://www.ncbi.nlm.nih.gov/), the Cochrane Register of Controlled Trials (http://www.cochranelibrary.com/) and Google Scholar (https://scholar.google.com/) were searched on 20th April 2017. Carpal tunnel AND diagnosis, Carpal tunnel AND risk factor(s), Carpal tunnel AND treatment(s) OR management and finally Carpal tunnel AND complication(s) were used as search words. The scientific community has been

very prolific on this topic so the authors decided that only articles that were published in the last 5 years were included in this study. The total number of published articles was 2078. When only systematic reviews and meta-analyses were included in this search the number of total articles was 100. Of those 100 articles 45 were excluded for not being directly related to the original query. The remaining 55 articles were then checked using the PRISMA protocol; 46 were included in this review (Table 1) (Liberati et al., 2009).

Table 1 Summary of the selective process to include studies in the current section.

Inclusion Criterion	Number of articles
Articles related to "Carpal Tunnel" that were found on the databases	9962
Articles published in the last 5 years	2078
Meta-analysis and systematic reviews	100
Articles directly related to the topic	55
Articles that responded to the PRISMA protocol	46

Results

Risk factors and associations

A recent meta-analysis performed with the same PRISMA protocol that was used to select the studies for this review showed that there is no correlation between computer use and CTS (Mediouni et al., 2014). The authors concluded that there is no evidence that computer use constitutes a risk factor for CTS. A contrary opinion emerged from the analysis of Shiri and Falah 2015 (Shiri and Falah, 2015); they found a little evidence that exposure to computer use could be considered a minor risk factor, although in the conclusion the authors state that this evidence cannot yet be confirmed.

Several studies nevertheless have found a correlation between the development of CTS and exposure to vibration, repetitive use and high sustained hand forces (Barcenilla et al., 2012; Giersiepen et al., 2011). All the meta-analyses that were included in the present review agreed on this evidence, pointing out how manufactur-

ing and construction workers are appreciably more likely to suffer CTS (Kozak et al., 2015). The studies also noted that particular wrist positions lead to CTS more than others (You et al., 2014).

A recent meta-analysis conducted on over 14 studies. It concluded that there was an association between smoking and CTS in cross-sectional studies (Pourmemari et al., 2014) but not in meta-analyses of case controlled studies. Even though there is a common belief that smoking is a risk factor for CTS there is currently insufficient scientific evidence to support this thesis.

Attention has been placed to the association between Raynaud's Syndrome and CTS (Hartmann et al., 2012). Although the authors of the most recent systematic review on this topic confirm that there is great heterogeneity in the clinical studies that they reviewed, they came to the conclusion that there is a possible correlation between the Raynaud's syndrome and CTS. A possible explanation for the high disparity in results among clinical studies was offered by the authors; they believe that climate conditions and the subjective diagnostic criteria for Raynaud's syndrome, which varied amongst the studies included in this work, are very likely to skew the data.

The links between osteoarthritis (OA) and rheumatoid arthritis (RA) were also investigated in 2015 (Shiri, 2016). The authors included 23 papers in their meta-analysis. They found that both OA and RA were directly related to CTS. The stronger evidence was in favour of RA but OA was proven to be a cause of CTS. In particular, they reported that they tried to exclude studies with potential scientific or selection bias in this meta-analysis.

Twenty-five studies were included in a recent meta-analysis that aimed to assess the evidence of a correlation between both type I and type II diabetes and CTS. The authors (Pourmemari and Shiri, 2015) concluded that there is a strong evidence that these two conditions are both linked to CTS.

Hypothyroidism was also investigated as a potential risk factor for carpal tunnel; the most recent systematic review on the topic showed no link (Shiri, 2014).

Diagnosis

Electromyography is considered the best test to diagnose CTS, although the current European guidelines clearly state that the diagnosis is primarily based on the clinical examination and electromyography should be requested only to confirm or refute the clinical suspicion of CTS (Huisstede et al., 2014). The classic clinical tests such as the Tinel's sign and Phalen's test are both reported to have limited specificity and sensibility as diagnostic tools (de Krom et al., 1990; Hansen et al., 2004; Mondelli et al., 2001).

As well as neurophysiological tests, there has been a focus in recent years on ultrasound as an alternative test for the diagnosis of CTS. A meta-analysis published in 2011, conducted on 19 studies stated the sensitivity and the specificity expressed in percentages with 95% confidence intervals for clinical examination, ultrasound and electromyography; the results are summarized in Table 2 (Fowler et al., 2011). There is no evidence at the moment to support ultrasound over the electrodiagnostic testing for the diagnosis of CTS (Duckworth et al., 2014), rather the opposite. The sensitivity and the specificity of ultrasound as a diagnostic tool for CTS was also confirmed by a second and broader systematic review published in 2012; this also supported neurophysiology as the best method to diagnose CTS (Tai et al., 2012). Further confirmation comes from the work of Descatha et al., (2012) and Roll et al., (2011). They noted that ultrasound scanning is complementary to but not an alternative to neurophysiology. This is also reflected in the guidelines of the American Association of Neuromuscular and Electrodiagnostic Medicine (Cartwright et al., 2012).

Table 2 Sensitivity and specificity of the most common diagnostic approaches to CTS. C.I. stands for Confidence Interval. Results are expressed in percentages.

Diagnostic technique	Sensitivity (%) (95% C.I)	Specificity (%) (95% C.I.)
Clinical Examination	77.3 (62.1-84.6)	92.8 (81.3-100)
Ultrasound	77.6 (71.6-83.6)	86.8 (78.9-94.8)
Electromyography	80.2 (71.3-89.0)	78.7 (66.4-94.8)

Recently Wang et al., (Wang et al., 2016) published a meta-analysis which assessed the evidence regarding the use Magnetic

Resonance Imaging (MRI) for the diagnosis of CTS. They studied diffusion tension imaging (DTI) MRI. This technique has been shown to be valid for diagnosing cerebral pathology but there is little evidence to support its role in assessing peripheral neuropathies. The authors of this meta-analysis concluded that there is enough evidence to consider DTI MRI as a potential tool for diagnosing CTS (sensitivity 83%, specificity 78%), although they do not recommend it as the new reference for the diagnosis of CTS.

Conservative treatment

A systematic review published in 2016 assessed the clinical course and the prognostic factors of patients affected by CTS and treated conservatively (Burton et al., 2016). This study reported that there was no evidence of an improved outcome after three years of conservative treatment, and that a worsening of the CTS was present in a too wide range (23%-89%) to come to a significant conclusion. Moreover more than half the patients included underwent surgery (57%-66%) over the period.

The Cochrane Library study which reported on 19 studies with over 1190 patients concluded that there is a limited evidence that night splinting is better than no treatment (Page et al., 2012). The authors could not detect any benefit of splinting over any other form of conservative treatment. The same meta-analysis also stated that there is no evidence of a one splint being better than another, although the possible benefits of ergonomic splinting have been assessed in another systematic review with limited evidence to support any one type of splint (Buchan and Amirfeyz, 2013).

Therapeutic ultrasound has been shown to be of no benefit in treating CTS. Page et al., (2012) published a systematic review on this topic concluding that there is no evidence supporting the benefits of therapeutic ultrasounds over placebo, either for short- or long-term symptom improvement. In addition there was no evidence to support this treatment against any other conservative treatment (Page et al., 2012).

There is strong evidence for the short-term benefits of local corticosteroid injections into the carpal tunnel especially in order

to reduce symptoms of pain (Huisstede et al., 2014; Lyon et al., 2016). A recent meta-analysis included 633 patients and concluded that there is enough evidence to consider that corticosteroid injections are better than placebo for both symptom reduction and functional recovery in the short term (Chen et al., 2015). The same authors compared ultrasound-guided injections with non-guided injections finding enough evidence to suggest that the ultrasound-guided approach is more effective but reports of the techniques of non-ultrasound guided injections are rarely specific enough to assess their likely reliability. Currently there is no good evidence that ultrasound guided injection are better than well performed non-ultrasound guided injections.

A systematic review published in 2012 reveals that there is limited and very low quality evidence of benefit for the diverse range of reported exercises and mobilization interventions for CTS (Page et al., 2012). Nevertheless, mobilization exercises and nerve gliding exercises represent the first line of treatment for patients with very mild and sporadic symptoms according to the European guidelines on CTS (Huisstede et al., 2014).

A systematic review has shown that there is weak evidence that low-level laser therapy has a positive effect on cases of CTS that present with mild symptoms (Li et al., 2016); but the authors stated that there is no evidence of benefit in more advanced cases.

Surgical treatment

As stated in the Cochrane Library review conducted by Verdugo et al., (2008) there is strong evidence that the surgical treatment for CTS gives better results than splinting. These authors also stated that they could not find enough evidence to clearly recommend surgical treatment over steroid injections.

A meta-analysis published in 2012 that included 22 studies showed evidences that endoscopic CTR (ECTR) gives better outcomes than open CTR (OCTR) for outcomes, speed of recovery and post-operative pain (Sabesan et al.,2012) but this has not been confirmed in more recent analyses (Kohanzadeh et al., 2015). One of the most common beliefs about ECTR is that this technique

enables patients to recover faster, with less loss of grip strength and an earlier return to work. Two meta-analyses published in 2014 (Chen et al., 2014; Vasiliadis et al., 2014) agreed that there is strong evidence to confirm these beliefs. Vasiliadis et al., (2015) showed in a systematic review that ECTR has a lower rate of minor complications compared to OCTR, but no evidence that ECTR had fewer major complications. Hu et al., (2016) have recently confirmed these findings.

There is strong evidence that ECTR allows a faster return to work (Sayegh et al., 2015; Sanati et al., 2011). In a study performed by Sabesan et al., (2012), there was strong evidence that a surgeon with over 12 years' experience in ECTR had better results and fewer complications compared to the means in the published data. Nevertheless, Zuo et al., (2015) in their systematic review found no statistical difference in terms of complication rates and grip strength recovery between the two techniques. The studies are summarized in Table 3.

Table 3 Meta-analyses included in the present study comparing ECTR Vs OCTR. The Table shows evidences of one technique over the other in the selected feature. N.A. stands for not applicable.

Author	Outcome Difference	Minor Complications	Major Complications	Hand Pain Reduction	Faster return to work	Grip Streght Recovery
Sanati, 2011	N.A	N.A	N.A	N.A	ECTR	N.A
Kohanzadeh, 2012	ECTR	ECTR	OCTR	ECTR	ECTR	ECTR
Sabesan, 2012	N.A.	ECTR	ECTR	ECTR	N.A.	N.A.
Chen, 2014	NO EVIDENCE	ECTR	NO EVIDENCE	ECTR	ECTR	ECTR
Vasiliadis, 2014	NO EVIDENCE	ECTR	NO EVIDENCE	ECTR	ECTR	ECTR
Vasiliadis, 2015	NO EVIDENCE	ECTR	NO EVIDENCE	NO EVIDENCE	ECTR	N.A
Sayegh, 2015	NO EVIDENCE	OCTR	NO EVIDENCE	ECTR	ECTR	ECTR
Zuo, 2015	NO EVIDENCE	OCTR	NO EVIDENCE	ECTR	NO EVIDENCE	NO EVIDENCE
Hu, 2016	NO EVIDENCE	NO EVIDENCE	NO EVIDENCE	ECTR	ECTR	NO EVIDENCE

From these studies it appears clear that ECTR gives an earlier return to work (better results within the first three months) but there are no other differences between the outcomes in the long-term (Louie et al., 2012).

There appears to be a link between carpal tunnel release and post-operative trigger finger but the evidence is at best weak (Cheng et al., 2015).

Considerable attention has been placed on the treatment of primary CTS but few studies have focused on the treatment of recurrent and persistent CTS. Soltani et al., (2013) performed a systematic review. In their meta-analysis conducted on 14 studies they concluded that decompression and nerve coverage with a vascularized flap (294 patients) offers better results than repeated decompressions (364 patients).

Discussion

Traditionally the idea that CTS is linked to computer use has been widespread, both amongst the general public and healthcare professionals; there is no evidence to sustain this idea. It can be described as nothing more than a myth. On the contrary, repetitive manual work and vibration, conditions that can be easily found in many factories, can lead to the development of CTS. Diabetes, RA and OA can be considered to be risk factors for CTS. Raynaud's phenomenon is also clearly linked to CTS even although less strongly. Surprisingly hypothyroidism and smoking are not proven to be linked to CTS.

For diagnosis of CTS, the only recent evidence supporting novel techniques is that the DTI MRI may be an alternative to the classical techniques that are commonly used at present. So far, electromyography remains the best option for the diagnosis of CTS. US can be a useful method for diagnosing or confirming the diagnosis of CTS; this procedure is still particularly in those cases where an anatomic alteration of the wrist is present e.g. after a distal wrist fracture or suspected.

There is considerable although variable evidence about conservative treatment of CTS. Manipulation, nerve gliding exercises and therapeutic ultrasound are common therapies that do with no supportive evidence. There is good evidence that both night splinting and steroid injections reliably help CTS. Although there is evidence that the conservative treatment does not work in the long term, it works in the short term and is indicated at the early stages of the disease.

According to the published evidence a carpal tunnel release is the most reliable solution for a patient suffering from CTS, as the surgical approach offers the best long term outcomes. The debate over the superiority of ECTR over OCTR remains open. The evidence supporting better outcome for ECTR are poor; there is much stronger evidence that in the long term the two procedures give similar outcomes. Nonetheless there is clear evidence that there is a faster recovery and earlier return to work following ECTR. Vascularized flaps appear to be the best option for the treatment of recurrent/persistent CTS.

Conclusion

Much of the above evidence is not new. There has been some good quality research but as in much of hand surgery the bulk of the published papers have appreciable flaws. To make progress we recommend that multicentre, possibly international studies should be carried out in order to provide the best possible evidence on what should and what should not be done for patients with CTS. The creation of a European Register for carpal tunnel syndrome may provide the help needed to gather less fragmented information on this topic.

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4.4.2 Evidence-Based Approach to the Treatment of Cubital Tunnel Syndrome

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Introduction

Ulnar neuropathy is the second most common entrapment neuropathy. Despite having been treated for decades there is limited high quality information to guide our clinical practice.

The aim of this study was to perform a systematic review looking at the various options in the management of ulnar neuropathy in order to establish what is known and what not proven.

Methods

Search Strategy

AA comprehensive search of the following databases: PubMed, Embase, Science Direct, Web of Science Core Collection, Scopus, Cochrane Library, was conducted by the authors to identify all published meta-analyses and systematic reviews on the treatment of cubital tun-

nel syndrome. The search was completed on 1st October 2016. No date range or language restrictions were applied to the search. The search strategy used for PubMed is summarized in Table 1.

Table 1 Search Strategy for PubMed

#1	((((cubital tunnel[Title/Abstract]) OR ulnar neuropathy[Title/Abstract]) OR ulnar neuritis[Title/Abstract]) OR ulnar nerve entrapment[Title/Abstract]) OR ulnar nerve palsy[Title/Abstract]
#2	(Ulnar Nerve[Title/Abstract]) OR Cubital Tunnel[Title/Abstract]
#3	(((((((((open release[Title/Abstract]) OR endoscopic release[Title/Abstract]) OR transposition[Title/Abstract]) OR open decompression[Title/Abstract]) OR simple decompression[Title/Abstract]) OR in situ decompression[Title/Abstract]) OR endoscopic decompression[Title/Abstract]) OR arthroscopic decompression[Title/Abstract]) OR mini invasive approach[Title/Abstract])
#4	#2 AND #3
#5	#1 OR #4
#6	((Review[Title/Abstract]) OR Systematic Review[Title/Abstract]) OR Meta-Analysis[Title/Abstract]
#7	#5 AND #6

Study Selection

All potentially relevant systematic reviews and meta-analyses were assessed for eligibility with inclusion criteria established a priori. Eligibility assessments were performed independently by two authors using the full-text of the manuscripts. In all cases where updated versions of a systematic review (SR) were available, only the most recent version of the SR was used. The inclusion criteria for the study were: a systematic reviews or meta-analyses of randomized controlled trials (RCTs) or observational studies (prospective or retrospective) comparing treatment options for cubital tunnel syndrome. The exclusion criteria were: systematic reviews or meta-analyses without any systematic search of at least one database; the failure to perform a quality assessment or risk of bias assessment of included RCTs; systematic reviews that did not perform a meta-analysis or pooling of data; systematic reviews or meta-analyses including case studies in their statistical analysis; and narrative or expert reviews, abstracts or letters to the editor. Any disagreement among the authors during the study selection process were resolved by a consensus among the entire review team. The PRISMA guidelines were upheld throughout (Moher et al., 2009).

Data Extraction

The following parameters were extracted from the included studies: title; authors; year; original study design; level of evidence; databases searched; total number of studies; date ranges of included studies; statistical software; methodological variables (primary and secondary outcomes); pooled results; and heterogeneity for each primary and secondary outcome. Furthermore, each study was checked to determine if a sensitivity analysis or a subgroup analysis was performed to explore the sources of heterogeneity. Heterogeneity in the meta-analyses were assessed with the reported I^2 statistic value for each outcome as follows in accordance to the guidelines in Cochrane Handbook: 0 - 40% might not be important; 30 - 60% might indicate moderate heterogeneity; 50 - 90% may indicate substantial heterogeneity; and 75 - 100% may represent considerable heterogeneity (Higgins and Green, 2011).

Google Scholar was used to determine the total number of citations for each review. To compare the overlap of studies included in the meta-analyses, we compared the articles cited between meta-analyses on the same treatment topic.

Quality Assessment

The methodological quality of the included systematic reviews or meta-analyses were assessed independently by two authors using the eleven item Assessment of Multiple Systematic Reviews (AMSTAR) tool. Any disagreements amongst the authors were solved by a consensus with a third author. The AMSTAR tool is a measurement scale inclusive of 11 items that has been previously validated for this purpose (Shea et al., 2007). The results of the AMSTAR assessment of each systematic review or meta-analysis were summarized as either “yes” (+), “no” (-), or “cannot be assessed” (0).

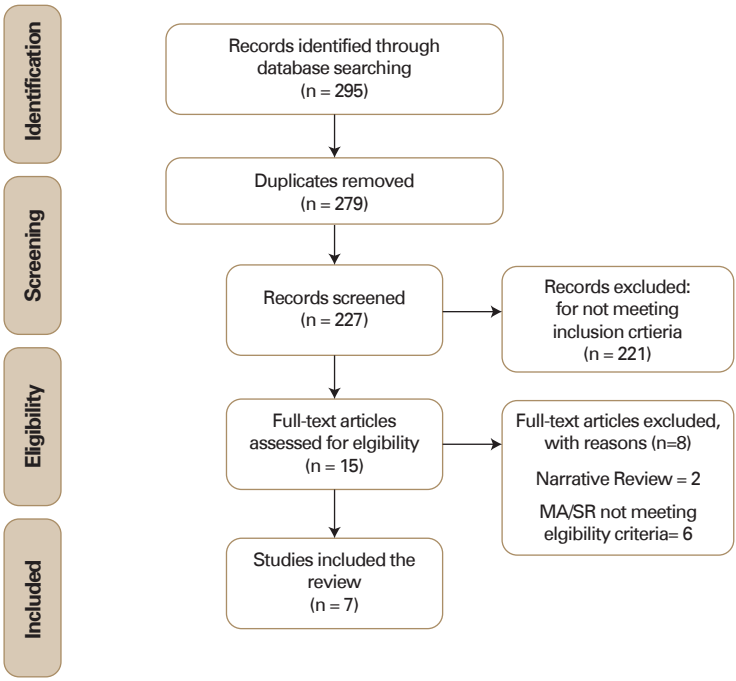
Results

Study Identification

A total of 295 articles were identified in the initial search. After removal of duplicates and preliminary screening, 15 articles were assessed for possible inclusion in the review. After applying the

exclusion criteria, two meta-analyses and five systematic reviews combined with meta-analyses were included. Of the rejected articles, one was a narrative review and seven did not meet our set criteria. A flowchart summarizing the selection of studies is found in Figure 1.

Figure 1 Flow of studies through the review



Characteristics of Included Meta-Analyses

A summary of the characteristics of the included studies is presented in Table 2. The included meta-analyses were conducted on as few as three studies (190 patients) to as many as 13 (1009 patients). The most common comparisons were between decompression and transposition, followed by open versus endoscopic release and subcutaneous versus submuscular transposition. Table 3 lists the primary sources for each meta-analysis included in this study and overlap in the included studies between the meta-analyses.

Table 2 Characteristics of Included Meta-Analysis

Study	Journal	Date of Last Search	Date of publication	Comparisons	Number of studies included* (number of patients)*	Number of Citations
Aldekhayel 2016	Hand (New York)	2014	January 2016	Endoscopic vs open decompression	3 (190)	0
Caliandro 2012	Cochrane Database	February 2012	July 2012	Simple decompression vs transposition,	6 (454)	109
Chen 2014	Clinical Neurology and Neurosurgery	December 2013	August 2014	Simple decompression vs anterior transposition	13 (1009)	6
Liu 2015a	PLOS ONE	December 2014	June 2015	Subcutaneous vs submuscular transposition	3 (352)	0
Liu 2015b	Medicine (Baltimore)	February 2015	June 2015	Subcutaneous vs submuscular transposition	9 (249)	1
Ren 2016	International Journal of Surgery	April 2016	September 2016	Open vs endoscopic	6 (527)	0
Zlowodzki 2007	Journal of Bone and Joint Surgery	November 2006	December 2007	Transposition vs decompression	3 (261)	131

* number of studies/patients included in the meta-analysis only

Search Methodology Included Meta-Analyses

The search strategies used in the included meta-analyses or systematic reviews were analyzed and reviewed. A summary of the databases used in each meta-analysis or systematic review can be found in Table 4. Medline, EMBASE and the Cochrane Library were used in nearly all the studies, with two studies conducting searches through individual journal archives related to the subject.

Methodological Quality Assessment

Table 5 summarizes the methodologies employed in each of the included studies. Most the studies consisted primarily of randomized controlled trials and observational studies. Two consisted strictly of randomized controlled trials. All were Level II evidence.

Table 3 Primary studies included in Meta-Analyses/Systematic Reviews

	Endoscopic vs. Open		Simple decompression vs. Transposition (overall)			Simple decompression vs. Subcutaneous Transposition		Simple decompression vs. Submuscular Transposition		Subcutaneous vs. Submuscular Transposition	
Study	**Aldekhayel 2016**	**Ren 2016**	**Chen 2014[16]**	**Caliandro 2012**	**Zlowodzki 2007**	**Caliandro 2012**	**Chen 2014**	**Caliandro 2012**	**Chen 2014**	**Liu 2015a**	**Liu 2015b**
Adelaar 1984	-	-	+	-	-	-	+	-	+	-	+
Bacle 2014	-	+	-	-	-	-	-	-	-	-	+
Bartels 2005	-	-	+	+	+	+	+	-	-	-	-
Biggs 2006	-	-	+	+	+	-	-	+	+	-	-
Bimmler 1996	-	-	+	-	-	-	-	-	+	-	-
Bolster 2014	+	+	-	-	-	-	-	-	-	-	-
Chan 1980	-	-	+	-	-	-	+	-	-	-	-
Charles 2009	-	-	-	-	-	-	-	-	-	-	+
Davies 1991	-	-	+	-	-	-	+	-	-	-	-
Dutzmann 2013	+	+	-	-	-	-	-	-	-	-	-
Foster 1981	-	-	+	-	-	-	+	-	-	-	-
Gervasio 2005	-	-	+	+	+	-	-	+	+	-	-
Geutjens 1996	-	-	-	+	-	-	-	-	-	-	-
Heikenfeld 2013	-	+	-	-	-	-	-	-	-	-	-
Jaddue 2009	-	-	-	-	-	-	-	-	-	+	+
Keiner 2009	-	-	+	-	-	-	-	-	+	-	-
Kosse 2007	-	-	-	-	-	-	-	-	-	-	+
Luo 2010	-	-	-	-	-	-	-	-	-	-	+
Mitsionis 2010	-	-	+	-	-	-	+	-	-	-	-
Nabhan 2005	-	-	-	+	+	-		-	-	-	-
Paine 1970	-	-	+	-	-	-	+	-	-	-	-
Saint-Cyr 2013	-	+	-	-	-	-	-	-	-	-	-
Sarah 2015	-	+	-	-	-	-	-	-	-	-	-
Stuffer 1992	-	-	-	-	-	-	-	-	-	-	+
Svernlov 2009	-	-	-	+	-	-	-	-	-	-	-
Taha 2004	-	-	+	-	-	-	+	-	-	-	-
Watts 2009	+	+	-	-	-	-	-	-	-	-	-
Zarezadeh 2012	-	-	-	-	-	-	-	-	-	+	+
Zhong 2011	-	-	-	-	-	-	-	-	-	+	-
Zhou 2012	-	-	-	-	-	-	-	-	-	-	+

Furthermore, each study was reviewed for its quality and reliability using the AMSTAR tool. Table 6 summarizes the findings of the AMSTAR assessment. The highest scoring study was Caliandro et al., (2012) The one question most studies could not answer was an assessment of the conflict of interest of each individual study within the meta-analysis or systematic review.

Table 4 Databases Searched by Included Meta-Analysis

Study	Databases Searched							
	Medline	Scopus	Embase	Cochrane	BIOSIS	Google Scholar	EBSCO	Others
Aldekhayel 2016	+	+	+	-	-	-	-	*
Caliandro 2012	+	-	-	+	-	-	+	CENTRAL, LILACS, PEDpro, AMED
Chen 2014	+	-	+	+	-	+	-	Springer, Science Direct
Liu 2015a	+		+	+	+	-	+	AMED,**
Liu 2015b	+	-	+	+	-	-	-	-
Ren 2016	+	-	+	+	-	-	-	CNKI
Zlowodzki 2007	+	-	+	+	-	-	+	Controlledtrials.com, Conference proceedings

* Indicates the authors searched through archives of the following journals: American Society of Plastic Surgeons (2002-2014), Canadian Society of Plastic Surgeons (2007-2014), American Association of Plastic Surgeons (2006-2014), American Association of Hand Surgeons (2007-2014), American Society for Surgery of the Hand (2000-2014), American Association of Neurological Surgeons (2009-2014), and Canadian Orthopedic Association (2003-2014).

** Indicates the following journals were checked for gray literature: Journal of Hand Surgery, American Society for Surgery of the Hand, American Association of Hand Surgeons and International Clinical Trials Registry Platform.

Overview of primary and secondary outcomes

An overview of the combined primary and secondary outcomes of surgical intervention for cubital tunnel syndrome is shown in Table 7. Most studies demonstrated that all techniques used to approach cubital tunnel syndrome were equally effective when it came to primary outcomes. Significant differences only arose in the secondary outcomes like complications, reoperation, scar formation and wound infection.

Table 5 Methodological characteristics of included studies

Study	Primary study design	Level of evidence	Software	Sensitivity analysis	Subgroup analysis	GRADE evidence profiles
Aldekhayel 2016	RCTs and observational studies	Level II	RevMan 5.2	NO	YES	NO
Caliandro 2012	RCTs	Level II	RevMan 5.1	YES	YES	YES
Chen 2014	RCTs and observational studies	Level II	RevMan 5.1, STATA 11.0	YES	YES	NO
Liu 2015a	RCTs and observational studies	Level II	RevMan 5.3	YES	YES	YES
Liu 2015b	RCTs and observational studies	Level II	STATA 12.0	YES	YES	YES
Ren 2016	RCTs and observational studies	Level II	RevMan 5.1	NO	NO	NO
Zlowodzki 2007	RCTs	Level II	Not Reported	YES	YES	NO

Table 6 AMSTAR assessment

AMSTAR Item	Aldekhayel 2016	Caliandro 2012	Chen 2014	Liu 2015a	Liu 2015b	Ren 2016	Zlowodzki 2007
'A priori' design provided	+	+	+	+	+	+	+
Duplicate selection and extraction	+	+	+	+	+	+	+
Comprehensive search	+	+	+	+	+	+	+
Grey literature inclusion	-	+	+	+	0	+	0
List of studies	+	+	+	+	+	+	+
Included study characteristics	+	+	+	+	+	+	+
Assessment of included studies	+	+	+	+	+	+	+
Study quality addressed in conclusion	+	+	+	+	+	+	+
Heterogeneity	+	+	+	+	+	+	+
Bias assessment	-	+	+	+	+	+	+
Conflict of interest mentioned	-	+	-	-	0	-	+

(+) - Was included in the study
(-) - Was not found in the study
(0) - Could not be determined

Table 7 Primary and secondary outcomes

	Endoscopic vs. Open		Simple decompression vs. Transposition (overall)			Simple decompression vs. Subcutaneous Transposition		Simple decompression vs. Submuscular Transposition		Subcutaneous vs. Submuscular Transposition	
Primary outcomes	**Aldekhayel 2016**	**Ren 2016**	**Chen 2014**	**Caliandro 2012**	**Zlowodzki 2007**	**Caliandro 2012**	**Chen 2014**	**Caliandro 2012**	**Chen 2014**	**Liu 2015a**	**Liu 2015b**
Clinical improvement (overall)	RR: 1.10 (95 % CI: 0.95-7-1.25)		OR: 0.91 (95% CI: 0.67-1.23)	RR: 0.93 (95% CI: 0.80-1.08)	SMD: -0.04 (95% CI: -0.36-0.28)	RR: 0.92 (95% CI: 0.74 - 1.14)	OR: 0.99 (95% CI: 0.69-1.43)	RR: 0.95 (95% CI: 0.77 - 1.17)	OR: 0.76 (95% CI: 0.45-1.29)	RR: 1.04 (95% CI: 0.88 - 1.25)	-
Clinical improvement (RCTs)										RR: 1.00 (95% CI: 0.98 - 1.02)	RR: 1.16 (95% CI: 0.68 - 1.98
Clinical improvement (Observational studies)										RR: 1.50 (95% CI: 0.95 - 2.37)	RR: 1.01 (95% CI: 0.95 - 1.08)
Clinical improvement (1 year of follow-up)										RR: 1.16 (95% CI: 0.68 - 1.98)	
Clinical improvement (2 years of follow-up)										RR: 1.00 (95% CI: 0.99 - 1.01)	
Bishop score		RR: 0.99 (95 % CI: 0.88-1.12)									

>>>

	Endoscopic vs. Open		Simple decompression vs. Transposition (overall)			Simple decompression vs. Subcutaneous Transposition	Simple decompression vs. Submuscular Transposition	Subcutaneous vs. Submuscular Transposition
Postoperative satisfaction		RR: 0.98 (95 % CI: 0.89-1.08)						
Secondary outcomes								
Complications	RR: 0.44 (95 % CI: 0.23-0.85)	RR: 0.88 (95 % CI: 0.24-3.29)	OR: 0.32 (95% CI: 0.17-0.60)					RR: 0.54 (95% CI: 0.33-0.87
Post-operative motor nerve conduction velocity				RR: 1.47 (95% CI: -0.94-3.87)	SMD: 0.24 (95% CI: -0.15-0.63)			
Wound infection				RR: 0.32 (95% CI: 0.12-0.85)				
Scar tenderness/ elbow pain	RR: 0.08 (95% CI: 0.02-0.40)							
Hematoma	RR: 3.64 (95% CI: 0.40-31.9)							
Ulnar nerve subluxion	RR: 9.64 (95% CI: 0.53-175.07)							
Reoperation	RR: 5.36 (95% CI: 0.26-109.17)							

Heterogeneity

Table 8 summarizes the heterogeneity of the outcomes described in each study. In our assessment we used the standard set forth by the Cochrane Handbook. According to this scale, the study of Liu et al., showed considerable heterogeneity in the reported primary outcomes in both studies (Liu et al., 2015a,b). The study of Ren et al., also showed substantial heterogeneity (68%) in reporting complications (Ren et al., 2016).

Discussion

This review of the current data on surgical treatment of cubital tunnel syndrome was developed to provide the most up-to-date evidence on which approach and technique is most beneficial for the patient. After a thorough search and subjection to proper a priori determined criteria, seven relevant meta-analyses or systematic reviews were included. Due to a small number of meta-analyses on the subject, meta-analyses including both randomized control trials and observational studies were considered in our inclusion criteria. Studies including case studies or lacking a form of quality assessment or statistical analysis were excluded.

Conservative vs. surgical therapy

Conservative treatment, usually reserved for patients presenting with only sensory symptoms, mostly consists of activity modification, non-steroidal anti-inflammtory drugs (NSAIDs) and the use of night time splinting or elbow pads (Wojewnik and Bindra, 2009). Despite it being only effective for about 50% of patients, it is still recommended for three months prior to any surgical intervention (Wojewnik and Bindra, 2009).

Only one of the included systematic reviews included compared conservative to surgical treatment. However, only one study within that meta-analysis included conservative treatment; therefore the authors could not provide statistical evidence for this review. It was concluded that conservative treatment offers no improvement of muscle strength and that the most effective method of conservative treatment was education of the patient to avoid provocative

Table 8 Heterogeneity of each outcome reported in the Meta-Analyses

	Endoscopic vs. Open		Simple decompression vs. Transposition (overall)			Simple decompression vs. Subcutaneous Transposition		Simple decompression vs. Submuscular Transposition		Subcutaneous vs. Submuscular Transposition	
Primary outcomes	**Aldekhayel 2016**	**Ren 2016**	**Chen 2014**	**Caliandro 2012**	**Zlowodzki 2007**	**Caliandro 2012**	**Chen 2014**	**Caliandro 2012**	**Chen 2014**	**Liu 2015a**	**Liu 2015b**
Clinical improvement (overall)	0%		-	0%	34.2%	-	-	0%	-	79%	
Clinical improvement (RCTs)										1%	81%
Clinical improvement (Observational studies)										-	0%
Clinical improvement (1 year of follow-up)										81%	
Clinical improvement (2 years of follow-up)										-	
Bishop score		0%									
Postoperative satisfaction		0%									
Secondary outcomes											
Complications	0%	68%	-								0%
Post-operative motor nerve conduction velocity				0%	0%						
Wound infection				-							
Scar tenderness/elbow pain	0%										
Hematoma	-										
Ulnar nerve subluxion	-										
Reoperation	-										

* % is calculated the I^2 statistic reported for each pooled outcome

movements and positions, with the addition of night-time splinting offering little to no improvement of symptoms (Calindro et al., 2012). Aside from these conclusions no meta-analysis has been performed comparing conservative treatment to surgical treatment to our knowledge.

Endoscopic vs. open cubital tunnel release

In the two studies that compared endoscopic and open techniques for decompression in cubital tunnel syndrome, the primary outcomes were nearly the same. Bishop scores, patient postoperative satisfaction and overall clinical improvement did not show statistically significant differences, with relative risks for postoperative satisfaction being 0.98 (CI 0.89 - 1.08), 0.99 (95 % CI: 0.88-1.12) for the Bishop score and 1.10 (95 % CI: 0.95-7-1.25) for overall clinical improvement (Ren et al., 2016; Aldekhayel et al., 2016).

There were statistically significant differences for some secondary outcomes. Open approaches were far more prone to scarring and elbow pain with a relative risk of 0.08 (95% CI: 0.02-0.40) (Aldekhayel et al., 2016). Meanwhile, patients undergoing endoscopic procedures were more likely to develop hematomas, ulnar nerve subluxation and were at a higher risk of reoperation (Aldekhayel et al., 2016).

Simple decompression vs. transposition (overall)

Three studies assessed the outcomes of simple decompression and transposition. As with most procedures, the measured primary outcomes of overall clinical improvement were not statistically different. Chen et al., (2014) noticed that there was a higher risk for complications in general with transposition procedures OR: 0.32 (95% CI: 0.17-0.60). Caliandro et al., (2012) found that there was a higher risk of developing a wound infection with transposition RR: 0.32 (95% CI: 0.12-0.85). Nerve conduction velocities were reported in two studies and showed faster nerve conduction after simple decompression (Zlowodzki et al., 2007; Chen et al., 2014).

Simple decompression vs. subcutaneous transposition

Two studies by Chen et al., (2014) and Caliandro et al., (2012)

compared the primary outcomes of simple decompression and subcutaneous transposition. Neither study showed any significant difference in primary outcome i.e. overall clinical improvement with Chen reporting an odds ratio of 0.99 (95% CI: 0.69-1.43) and Caliandro et al., (2012) reporting a relative risk of 0.92 (95% CI: 0.74 - 1.14). Neither study reported data on the secondary outcomes. It could be concluded that both simple decompression and subcutaneous transposition can be considered equally successful, however, this conclusion and comparison is limited due to a lack of data on secondary outcomes.

Simple decompression vs. submuscular transposition

The same studies also compared simple decompression with submuscular transposition. Again, both studies only reported the primary outcome of clinical improvement (Caliandro et al., 2012; Chen et al., 2014). However, it was found that submuscular transposition yielded slightly better primary outcomes than simple decompression with an odds ratio of 0.76 (95% CI: 0.45-1.29), though the significance was marginal (Chen et al., 2014).

Subcutaneous vs. submuscular transposition

The final two studies by Liu et al., (2015a,b) comparing subcutaneous vs submuscular transposition did not show any statistically significant difference in primary outcomes. A difference was noticed in secondary outcomes. Submuscular transpositions were found to have a higher relative risk, 0.54 (95% CI: 0.33-0.87), of complications (Liu et al., 2015b).

Summary of Evidence and Future Directions

When compared by primary outcome, no one surgical approach to ulnar nerve entrapment at the elbow can be considered better than its competitors. However, with secondary outcomes, each approach has been found to have a disadvantage. In general complications are seen more commonly in open approaches and in transposition techniques. Though we found endoscopic procedures were less prone to complications, they were found to be more prone to needing reoperation.

It is important to note that conservative therapy, despite not being compared in any meta-analysis form, is still the first line treatment prior to any surgical intervention (Wojewnik and Bindra, 2009).

Our goal was to find the most recent meta-analyses and systematic review and provide a comprehensive review of the data they presented. Despite our efforts however, we were limited in many ways. As mentioned above, few meta-analyses have been designed on the topic of surgical treatment of cubital tunnel syndrome. Most of the studies included contained valuable data, however, aside from general clinical improvement, few studies reported the same primary and secondary outcomes. Many valid systems of assessing outcomes including the Bishop score, McGowan score and Dellan classification exist; currently a uniform standard of comparison is difficult.

With none of the current options standing clearly better than another, there appears to be an opportunity to development of a new, reliable, minimally invasive approach in order to achieve better outcomes with minimal complications.

Conclusions

The choice of surgical treatment for cubital tunnel syndrome remains a disputed topic among surgeons. With the options of endoscopic and open approaches, as well as decompression and translocation techniques, it can be difficult to choose the correct procedure for each patient. Taking into account both primary and secondary outcomes is paramount to the success of the procedure, regardless of the approach taken.

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4.5 Injection Therapy in Hand Surgery

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Introduction

Steroid and other injections are used widely in hand surgery. Their efficacy is disputed. In this chapter we have reviewed the most recent literature.

We have divided the results into the treatment of: osteoarthritis; enthesopathies; entrapment neuropathies; de Quervain's syndrome and trigger digits. We have not considered the role of collagenase as that is assessed in another chapter.

Osteoarthritis

The PubMed database was searched for the terms "wrist, trapezio-metacarpal, finger, osteoarthritis, injection" in combinations. There were 143 articles in the search results. After removal of duplications the articles were filtered by title and by abstracts. Eighteen relevant articles were selected for review; 13 of them were rejected because of an unclear study setup or retrospective design. The five most valuable articles are summarized here. Three of them were prospective trials (Heyworth et al., 2008; Meenagh et al., 2004; Roux et al., 2007) and two were randomized control trials (Day et al., 2004; Fuchs et al., 2006). Altogether 256 patients

were followed after injection treatment of arthritic changes of the thumb carpo-metacarpal joint or finger proximal interphalangeal (PIP) joint. The injections included hyaluronic acid, triamcinolone, lidocaine or placebo. The results of these articles are not comparable because of the huge divergence in the stages of arthritis and the evaluation criteria. There is only one article from Heyworth comparing the four different injections (hyaluronic acid, steroid, lidocaine and placebo) in one study. Overall these articles showed no significant benefit from steroid or hyaluronic acid above placebo or lidocaine. Currently the evidence for benefit from steroid or other injections to treat osteoarthritis is limited although clinical experience suggests otherwise.

Enthesopathies

With the search terms "tennis elbow, injection, and epicondylitis" in combinations we found 1724 results. After removing duplications, and filtering the results by titles, there were 300 original research papers and 81 reviews. We selected six prospective randomized controlled trials with level I evidence (Arik et al., 2014; Bellapianta et al., 2011; Guatam et al., 2015; Jindal et al.,2013; Krogh et al., 2013; Wolf et al., 2011). From these articles, we have information about 248 patients. The mean follow-up time was 4.2 (range 6 weeks to 6 months) months. Thirty patients had placebo treatment, 74 received autologous blood injections, 35 received platelet rich plasma injections and 109 were treated with corticosteroid injections. In all the studies the placebo was saline solution; the chosen steroid was methylprednisolone acetate. The blood or platelet rich plasma injections were 2 or 3 ml drawn from the ipsilateral forearm. All these patients received only a single shot of injection.

During the follow-up, the patients treated with steroids reported reduced pain scores in the first three months, but this treatment had no affect after 90 days. The positive affect of the blood and plasma injections developed later (6-12 weeks), but lasted longer or were associated with long term resolution of symptoms.

In a meta-analysis Arirachakaran et al., (2016) reported also that both autologous blood injections and platelet rich plasma in-

jections were better than steroid injections, although the autologous blood injections had more adverse effects. The platelet rich plasma appears to be better for reducing pain; the risk of adverse effects is very low.

Entrapment neuropathies

With the search terms "carpal tunnel and steroid" we found 378 papers; and "carpal tunnel and injection" gave 477 more. After elimination of duplications and filtering by title we found 66 relevant papers. We found five prospective randomized trials (Agarwal et al., 2005; Atroshi et al., 2013; Dammers et al.,2006; Eslamian et al., 2017; Ustün et al., 2013) reporting on 295 patients. We were searching for answers to three questions: are steroid injections useful in carpal tunnel syndrome? Does the dose of the steroid injection matter? Does ultrasound guidance improve the outcomes of steroid injections? Placebo: compared to the placebo group (n=37) the steroid therapy group (n=258) had significantly better results in carpal tunnel symptoms severity scores at 3 month. At one year the results were without significant difference ($p > 0.05$).

Dose: There is no significant difference between high and low doses at 3 months and at 6 months, but there is a trend in favour of the highest dose (80 mg methyl prednisolone).

Ultrasound guidance: 53 patients had a steroid injection was aimed by landmarks and 53 patients with ultrasound. The short-term results, and the 12 weeks results were not significantly different in the two groups. The rate of adverse effects was also similar. There is no evidence that ultrasonographic guidance is needed for steroid injections in carpal tunnel syndrome.

For ulnar nerve entrapment syndromes there are only six relevant publications from the last five years. One of them is a review of the current evidence (Rinkel et al., 2013). They conclude that steroid injections are not superior to placebo. Therefore, the efficacy of this treatment is not established; steroid injections are not recommended to treat cubital tunnel syndrome.

De Quervain's syndrome

We searched the PubMed database with the term "de Quervain". Out of 95 articles published on de Quervain's syndrome we found only three relevant papers (Anderson et al., 1991; Orlandi et al., 2015; Peters-Veluthamaningal et al., 2009) with clear study setups, prospective designs and detailed description of results; they reported 126 patients treated with steroid injection. They received their injection in two different ways: 50 of them by ultrasound guidance; and 76 without ultrasonography. The results showed highly significant reduction in the pain visual analogue scale scores ($p < 0.01$). There is no good evidence that ultrasound guidance improves the outcome of well-directed steroid injections performed without use of ultrasound.

Trigger finger

We searched the PubMed database using the terms "trigger finger" and "injection". Out of 179 papers we found 20 relevant articles. We selected the four most valuable studies (Castellanos et al., 2015; Cecen et al., 2015; Hansen et al., 2017; Peters-Veluthamaningal et al., 2008) (prospective randomized controlled trials with evidence level I) as data sources; they treated a total of 360 patients. Steroid injections (one or two injections of methyl prednisolone, or triamcinolone) have been compared to placebo in 50 patients. This study found that 88% of patients was free of symptoms at three months after steroid injection; only 20% were satisfied with placebo treatment.

Some authors used ultrasound guidance for injecting steroid, but everybody agreed that this technique merely takes more time and gives no better results. Compared to open surgery, steroid injections reduce the pain level and stop triggering at similar rates at 3 months (99% for open surgery, 86% for steroid). After one year only half of the patients (49%) treated with a steroid injection were symptom-free. Steroid injection appears to be more effective for thumbs (81% remission) than for fingers (56% remission).

Further investigation is necessary on the use of hyaluronic acid for trigger finger. While some preliminary results are available, a randomized controlled trial to compare it to corticosteroid would be very informative.

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CHAPTER 5

MISCELLANEOUS

5.1 Complex Regional Pain Syndrome (CRPS) Treatment. A Systematic Review.

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Introduction

Complex regional pain syndrome (CRPS) is a complex of symptoms typically occurring following trauma of the extremity. At present the "Budapest criteria" for diagnosis are commonly accepted and frequently used in scientific studies (Harden et al., 2010) although subjective and open to exaggeration. There is no definitive single test for confirming or excluding CRPS. The diagnosis relies on clinical assessment with the requirement for a sufficient number of symptoms and signs to be present. A lack of understanding of the underlying pathophysiology for CRPS contributes to the difficulty in developing definitive treatments. A large number of treatments have been investigated but major multicentre randomized controlled trials are lacking and the primary outcome parameters (pain, function) are subjective. There is consensus concerning the fundamental role of early therapeutic intervention as it may prevent the disease transition from acute to a chronic form, although it is not yet proven how this changes the course of CRPS (Birklein and Schlereth, 2015).

Methods

This systematic review is a follow-up to earlier reviews of randomized controlled trials (RCTs) of CRPS treatment published between 1966 and 2014. Five studies were considered and used in this analysis:

- Review of 18 RCTs published from 1966 to 2000 (Forouzanfar at al., 2002).
- Review of 21 RCTs published from 1980 to 2000 (Perez et al., 2001).
- Review of 35 RCTs published from 1980 to 2005 (Perez et al., 2010).
- Review of 41 RCTs published from 1950 to 2009 (Tran et al., 2010).
- Review of 29 RCTs published from 2000 to 2012 (Cossins et al., 2013).

Three other reviews of randomized, controlled trials that focused on specific CRPS treatments, published between 2012 and 2016 were analysed:

- Review of 18 RCTs focused on physiotherapy, published from 1999 to 2014 (Smart et al., 2016).
- Review of 3 RCTs focused on ketamine infusions, published from 1999 to 2014 (Azari et al., 2012).
- Review of 12 RCT focused on the efficacy of local anaesthetic sympathetic blocks, published from 2005 to 2015 (O'Connell et al., 2016).

No other, relevant studies have been found up to the completion of this review in March 2017.

In this review CRPS is considered "early" when it had lasted less than 6 months or "chronic" (long-standing) when it had lasted more than 6 months. It is likely these criteria will change as diagnosis becomes swifter and more reliable not least as 6 months is quite late to initiate treatment.

Results

The following therapeutic interventions were assessed in these studies:

Calcitonin.

It has been used in CRPS because of its analgesic properties through release of ß-endorphin in the central nervous system and its inhibition of bone resorption. Four RCTs investigated the effect of calcitonin in a nasal spray (three) or subcutaneous (s.c.) injections (one) in the treatment of 163 patients with acute and chronic CRPS. Nasal calcitonin spray was administered in doses of 200-400 U/day for 3-4 weeks, whereas s.c. calcitonin 100 U/day was given for 8 weeks. In two studies, calcitonin was combined with an intensive physiotherapy regimen, which was the same in the treatment and placebo groups. All but one trial were small, including fewer than 30 patients in one study arm. At a mean follow-up of 2 (range 1-2) months, statistically significant differences were noted in pain scores (using a four-point pain scale) and in ranges of motion, favouring the treatment (nasal calcitonin, 300 U/day for 3 weeks) group in one study (Gobelet et al., 1992). The other studies showed no intergroup differences in terms of pain relief, improvement of ranges of motion and grip strength, reduction of oedema, stiffness or vasomotor changes (Bickerstaff and Atkins, 1991; Cossins et al., 2012; Tran et al., 2010).

There is conflicting evidence with respect to the efficacy of calcitonin for the treatment of CRPS. This treatment is relatively simple, safe and therefore frequently used in clinical practice. Its efficacy is confined to early CRPS i.e. lasting less than 6 months. One disadvantage of use calcitonin is intolerance which occurs in about 30% of patients; in particular they may experience unpleasant adverse symptoms during first 1-2 days of calcitonin administration.

Biphosphonates.

They have been used in CRPS because of their potential to inhibit bone resorption. Four RCTs investigated the effect of bisphosphonates in a total of 118 patients with acute and chronic CRPS (du-

ration 3 to 22 months) affecting the upper or lower limb. Three types of biphosphonates: alendronate, pamidronate and clondronate were used in i.v. infusions (three) or orally (one). Aledronate 7.5 mg/day was administered intravenously (i.v.) for 3 days and after 14 days (Adami et al., 1997); aledronate 40 mg/day was administered orally for 8 weeks followed by 4 weeks nontherapeutic period and 8 weeks open extension (Manicourt et al., 2004); clodronate 300 mg/day was administered i.v. for 10 days (Varenna et al., 2000); pamidronate 60 mg was given in single i.v. infusion (Robinson et al., 2004). In all studies drug therapy was combined with formal physiotherapy. At a mean follow-up of 6 (range 1-13) months, all four studies showed statistically significant differences in pain relief, improvement of function and overall improvement favouring the treatment groups.

In one trial biphosphonate (parecoxib) combined with clonidine and lidocaine was given in a regional intravenous regional block (Bier block). This therapy decreased pain more than either i.v. parecoxib with regional lidocaine and clonidine, or a control group, without biphosphonate (Frade et al., 2005).

There is not strong evidence for the efficacy of bisphosphonates, with no high-quality trials although positive findings from one on i.v. pamidronate and one on oral alendronate. Oral alendronate administered in high dose is not licensed in some countries. The trials differed with regard to disease duration and included patients with early and chronic CRPS. In spite of positive but not very strong evidence for the effectiveness of this therapy, it is not frequently used in clinical practice. Two ongoing trials should be published in 2017/2018 providing further evidence.

Free radical scavengers.

They have been used in CRPS because of their anti-inflammatory potential. This therapy is based on the assumption that CRPS is caused by an exaggerated inflammatory response to trauma, mediated by an overproduction of toxic oxygen and hydroxyl free radicals (16). Four RCTs investigated the effect of these drugs involving 210 patients with acute and chronic CRPS (Zuurmond

et al., 1996; Perez et al., 2003; Perez et al., 2008; Geertzen et al., 1994)). Three free radical scavengers were used: dimethyl sulfoxide (DMSO) (topical for 2 months), N-acetylcysteine (oral for 4 months) and mannitol (i.v. for 5 days). In one study, the intervention (topical DMSO for 3 weeks) was compared to another intervention - intravenous regional blockade with guanethidine (twice per week for three weeks) (Geertzen et al., 1994) and in the other study, two interventions were compared, topical DMSO vs oral N-acetylcysteine, both for 4 months (Perez et al., 2003). The others were compared against placebo. In all studies drug therapy was combined with formal physiotherapy. At a mean follow-up of 4 (range 2-12) months follow-up statistically significant differences were noted in a scoring system based on pain, disability, oedema, skin colour and ranges of motion, favouring treatment with DMSO vs guanethidine in one study. This study involved only patients with early CRPS, lasting < 3 months (Geertzen et al., 1994). The other studies showed no intergroup differences in terms of pain relief, improvement of ranges of motion and grip strength or reduction of other features of CRPS.

There is moderate evidence for the effectiveness of topical 50% DMSO cream in reducing the symptoms of early CRPS. Likewise, there is moderate evidence for the effectiveness of oral N-acetylcysteine in reducing the symptoms of chronic CRPS. Free radical scavengers have been used frequently in clinical practice, mostly in the Netherlands.

Intravenous regional sympathectomy.

This therapy is based on the assumption that CRPS is associated with a dysfunction of the sympathetic nervous system. Thus, sympathetic interruption using intravenous regional blocks (Bier blocks) consisting of local anesthetic and an anti-sympathetic drug might have a beneficial effect. Five RCTs have investigated the effect of this therapy (Blanchard et al., 1990; Jadad et al., 1995; Livingstone and Atkins, 2002; Kettler et al., 1988; Hanna et al., 1989), involving a total of 101 patients with acute and chronic CRPS. Three drugs were tested: guanethidine (an inhibitor of the

presynaptic release of norepinephrine; three trials); droperidol (an alpha adrenergic antagonist; one trial); and ketanserin (a serotonin type 2 receptor antagonist; one trial). In three studies the active drugs and placebo were diluted in normal saline and in one study the drug (guantehidine) and placebo were diluted in 0.5% prilocaine (Livingstone and Atkins, 2002). The treatment consisted of 2-4 blocks administered at weekly intervals. In all studies drug therapy was combined with formal physiotherapy. At a mean follow-up of 9 (range 1-24) weeks follow-up no benefits were found from adding intravenous regional anti-sympathetic comparing to intravenous regional saline or prilocaine (placebo).

There is relatively weak evidence for the effectiveness of i.v. regional sympathectomy for treatment of CRPS. At present this treatment is not popular and, if used, is confined to patients responding positively to a phentolamine test.

Two other RCTs compared different anti-sympathetic modalities: regional intravenous blocks with guanethidine vs regional intravenous blocks with reserpine (an agent inhibiting norepinephrine synthesis and depleting norepinephrine stores) vs plain 1% lidocaine; and regional intravenous blocks with guanethidine vs stellate ganglion blocks with lidocaine (Rocco et al., 1989; Bonelli et al., 1983). In the former study, every subject underwent treatment with all three solutions in a randomized fashion at weekly intervals. Both trials were small, including 12 and nine patients respectively.

At mean follow-ups of 24 and 2 months, respectively, no significant differences were noted between the treatment groups in terms of pain relief and functional improvement. Three of 12 patients receiving guanethidine or reserpine blocks obtained significant pain relief lasting 12 months (Rocco et al., 1989).

Sympathetic ganglion blocks.

The stellate and lumbar sympathetic ganglia are responsible for the sympathetic innervation of the upper and lower limbs, respectively. Blocking of these ganglia results in inhibition of sympathetic efferent action in the affected limb. Four RCTs involving 90 patients

with early and chronic CRPS investigated the effect of sympathetic ganglion blocks. One low-quality RCT involving seven patients with chronic CRPS investigated the effect of sympathetic blocks performed with 1% lidocaine vs normal saline for stellate ganglion blockade and with 0.125% bupivacaine vs normal saline for lumbar sympathetic chain blockade. The two therapeutic or saline blocks were separated by an interval of 7-10 days. Immediately after the injections no differences were found between the analgesic effects of the two types of injection. The duration of pain relief was greater with lidocaine/bupivacaine than saline blocks (5 days vs 12 hours) (Price et al., 1998). One high-quality RCT involving 15 patients with early CRPS who responded to a single stellate ganglion block (>50% pain relief) compared the effect of the addition of a series of five stellate ganglion blockades over 1 month to a combination of oral drug therapy and physiotherapy. At a follow-up of one month after the last injection no intergroup differences were observed (Rodriguez et al., 2006). One high-quality RCT involving 25 patients with early and chronic CRPS compared the effect of three interventions: stellate ganglion block with 1% lidocaine (9 patients) vs stellate ganglion ultrasound block (9) and vs stellate ganglion saline block (7). A total of ten therapeutic blocks with 1% lidocaine were performed. The ultrasound block consisted of 5 minutes of intermittent ultrasound application at 3 watt/cm^2 over the stellate ganglion. A total of ten „sham" saline blocks were performed. All groups had further rehabilitation. At a follow-up all one month after the last blocade, no intergroup differences in pain relief or functional improvement were observed (Aydemir et al., 2006).

One high-quality RCT involving 43 patients with early and chronic upper limb CRPS compared the effect of three interventions: stellate ganglion block with 1% lidocaine (14 patients) vs stellate ganglion block with 1% lidocaine plus 30 µg clonidine (15) and vs regional intravenous block with 1% lidocaine plus 30 µg clonidine (14). A series of five stellate ganglion/regional intravenous blockades were preformed at weekly intervals. At a follow-up all one month after the last blockade, no intergroup dif-

ferences in pain relief or functional improvement were observed (Nascimento et al., 2010).

Other two low-quality RCTs involving 24 patients with chronic lower limb CRPS investigated the effect of lumbar sympathetic chain lesions with 7% phenol or thermal radiofrequency application. At a mean follow-up of 3 (range 2 -4) months, a reduction in pain scores compared with baseline was noted in both groups, but no intergroup differences were observed (Haynsworth et al., 1991; Manjunath et al., 2008).

Likewise with intravenous regional sympathectomy, there is relatively weak evidence supporting the effectiveness of sympathetic ganglion blocks in CRPS. At present this treatment is rarely used, and, if so, mostly in patients with chronic lower limb CRPS.

Steroids.

They have been used in CRPS because of their anti-inflammatory action. The underlying rationale was same as in use of free radicals scavengers. Four RCTs investigated the effect of steroids administered over a period form 4 to 12 weeks in 148 patients with chronic CRPS. In two of the studies the patients had specific post-stroke CRPS (so called shoulder-hand syndrome). Two of four trials were small, including 12 and 17 patients in one study arm (Christensen et al., 1982; Braus et al., 1994). Three types of steroids were used: prednisone (10 mg/day orally until clinical response or maximum of 12 weeks) (Chrirstensen et al., 1982) and methylprednisolone (8 mg/day orally, then taper dose for two weeks) (Braus et al., 1994); and in one study involving 60 patients, prednisolone (40 mg/day orally for two weeks tapering to a dose of 10 mg/week) was compared with piroxicam 20 mg/day (Kalita et al., 2006). All these three trials were of relatively low quality. Immediately after treatment there were statistically significant differences in pain relief, reduction in signs of CRPS features and improvement favouring the treatment groups in three trails. The results of the most recent high-quality RCT, showed that the efficacy of 60-100 mg oral prednisone administered for 2-3 weeks was statistically significant but limited in treating CRPS of more than 3 months duration not responding to previous treatment (Barbalinardo et al., 2015).

One high-quality RCT investigated the effect of three regional intravenous blocks of 40 mg methylprednisolone in 10 ml of 2% lidocaine vs saline blocks, given as one block per week for 3 weeks. At follow-up at 4 weeks therapeutic blocks were no more effective than saline in treating early CRPS (Taskaynatan et al., 2004).

In spite of relatively weak evidence for the effectiveness of steroids for treatment of CRPS, they are frequently used in clinical practice, especially in early CRPS (a type 1 error is likely to be present) Steroids appear to be useful in chronic CRPS for patients after stroke, but less so in post-traumatic/injury CRPS.

Anticonvulsants.

The use of anticonvulasants is based on the assumption that pain in CRPS may be (at least in part) neuropathic. Anticonvulsants (gabapentin, pregabalin) with proven analgesic effects in other neuropathic pain syndromes, might be beneficial in pain control. One high-quality RCT investigated the effect of gabapentin (1800 mg/daily given over 3 weeks) in a double-blind randomized cross-over trial involving 46 patients with chronic CRPS. There were no differences in pain scores (the primary outcome measure in the trial) between the treatment and control groups. However, using global perceived pain relief, more patients receiving gabapentin reported an improvement in pain control (van de Vusse et al., 2004). It is noticeable that gabapentin dose that was used (1800 mg/daiy) is not the maximum (2400mg/day) recommended for the treatment of neuropathic pain.

There is moderate evidence for the effectiveness of gabapentin reducing some of the pain symptoms (including hyperaesthesia and allodynia) in CRPS patients. Although frequently used, anticonvulsants appear not to be particulary useful in clinical practice.

Physiotherapy (various types).

Various methods of physiotherapy are recommended as part of the multimodal treatment of CRPS. It seems obvious that exercises are beneficial in restoration of ranges of motion, strength and in improving function of the affected hand. However, the underlying

mechanisms of physical therapy in pain control remain obscure. There are several theories explaining this, including release of endorphins in the central nervous system, stimulation of sensory nerve endings of peripheral afferent nerves, spinal cord-mediated analgesia and anti-inflammatory effects. Graded motor imagery (GMI) and mirror therapy may reduce pain and increase mobility by ameliorating maladaptive somatosensory and motor cortex reorganization (Moseley, 2004; Moseley, 2006). In general, physiotherapy is aimed at better adaptation to pain, improving posture, movement, activities of daily living and psychosocial functioning (Oerlemans et al., 1999).

Eighteen RCTs have investigated the effect of various (dozens) kinds of physiotherapy involving a total of 739 patients with acute and chronic CRPS. They treated a mean of 41 (range 13-135) patients per study (Smart et al., 2016). Two broadly similar types of rehabilitation, graded motor imagery (6 week programme) and mirror therapy (4 week programme) might be useful for reducing the pain and disability associated with post-traumatic and post-stroke CRPS. This benefcial effect has been maintained up to 6 months after therapy (Moseley, 2004; Moseley, 2006; Cacchio et al., 2009a, Cacchio et al., 2009b). However only the patients following uncomplicated distal radial fractures with early CRPS had proven benefit. The two low-quality trials were conducted in the same centre setting (Moseley, 2004; Moseley, 2006); the effectiveness of this therapy has not been reproduced by other studies. The two low-quality RCTs involving 72 patients with early post-stroke CRPS investigated the effect of mirror therapy vs placebo (covered mirror). At a mean follow-up of 6 months, a meaningful reduction of pain and functional improvement were seen in the treatment groups (Cacchio et al., 2009a, Cacchio et al., 2009b).

Oerlemans et al., (1999) employed multimodal physiotherapy in the treatment of 135 patients with CRPS lasting <12 monts. After initial drug therapy with free radical scavengers (DMSO or N-acethylcysteine), vasodilators and trigger point lidocaine injections, the patients were randomized to physiotherapy, occupational therapy or minimal “social work” intervention (control thera-

py). After a mean follow-up of one year, no significant differences were observed in the reduction of pain or improvement of function between the three groups. There is no convicting evidence supporting the effectiveness of other physiotherapy treatments (Smart et al., 2016).

There is moderate evidence of effectiveness of GMI and mirror therapy in CRPS, however, a type II error is likely to be present. Physiotherpay in general is likely to have a positive effect on the impairment level in patients with chronic CRPS but less effect on pain reduction. It is commonly accepted as a part of the standard treatment of CRPS.

Spinal cord stimulation.

This therapy is based on the assumption that electrical stimulation of the spinal cord (SCS) engenders spinal cord-mediated analgesia and anti-inflammatory effects (Taylor et al., 2006). One low-quality RCT studied the use of spinal cord stimulation and physiotherapy vs physiotherapy alone in 54 patients with chronic CRPS; these patients have been reported further at follow-ups of 2 and 5 years (Kemler et al., 2000). At follow-up of 2 years, statistically significant differences were noted in pain scores and seven-point global perceived effect scale, favouring the treatment group. No differences were found for the changes in functional status and quality of life (Kemler et al., 2000). At 5 years follow-up the difference between the intervention and control groups was lost (Kemler et al., 2008).

There is moderate evidence for the effectiveness of the spinal cord stimulation in giving some reduction in pain symptoms in CRPS patients. SCS has no effect on function, it is an invasive procedure and its effect is unpredictible and appears only to be temporary. Regardless it enjoys increasing popularity, particularly for patients with chronic CRPS and has been recommended by the National Institute for Clinical effectiveness (NICE) in the UK, which has a reasonably high bar to acceptance.

Ketamine.

The use of ketamine for the treatment of CRPS is based the role of glutaminergic N-methyl-D-aspartate receptor (NMDA) in the process of "sensitization" in the central nervous system. There is some evidence that ketamine has strong NMDA-receptor blocking (antagonist) properties resulting in inhibition of the central sensitization mechanism. Three low-level RCTs have investigated the effect of of intravenous (two studies; 60 and 19 patients) or topical (one trial; 20 patients) ketamine, involving patients with acute and chronic CRPS (Azari et al., 2012). Two studies showed statistically significant differences in pain relief, favouring the treatment (i.v. ketamine) groups. This effect was, however, transient: the lowest pain scores were one week after the ketamine treatment. No positive effect on function was observed. In one study, the application of topical 10% ketamine did not lead to pain relief but it reduced allodynia. The level of evidence of these studies was 2B, suggesting only a weak recommendation and moderate-quality evidence for the use of ketamine in the treatment of CRPS (Azari et al., 2012).

Regardless of this conclusion, i.v. ketamine treatment enjoys increasing popularity, particularly for patients with chronic CRPS, resistant to any other therapy. It offers at least temporary relief from severe, debilitating pain, however it does not improve the function of the affected limb.

Fentanyl.

Opioid drugs, including fentanyl, are commonly used to treat neuropathic pain and are considered effective. There is some evidence that pain in CRPS may have, at least in part, a neuropathic component (Birklein and Schlereth, 2015). One study has investigated the effect of fentanyl in patients suffering from various types of neuropathic pain, including postherpetic neuralgia, chronic postoperative pain and CRPS. Transdermal fentanyl (one-day fentanyl patch) was titrated over 10 to 29 days to establish the maximum tolerated and effective dose (12.5 to 50 µg/h). One hundred and sixty three patients who responded to this therapy were then entered into a randomized withdrawal phase. The number of partic-

ipants completing the study was 47/84 (56%) with fentanyl and 28/79 (35%) with placebo. Nearly 60% of participants taking fentanyl were satisfied and very satisfied with their treatment at the end of the study, compared with about 40% with placebo (Arai et al., 2015). There is insufficient evidence to support or refute the suggestion that fentanyl works for any neuropathic pain condition.

Amputation

Amputation of the limb is a definitive treatment that may be considered in so-called "end-stage" CRPS. Fortunately this is seen rarely. In this long-standing, therapy-resistant disease, apart from intractable, debilitating pain, several new problems may be encountered such as a totally dysfunctional limb, severe recurrent infections and chronic trophic ulcers. Therefore amputation of the limb may be appropriate for pain relief and improving patients' quality of life. Twenty-six studies, involving 111 amputations in 107 patients have investigated the effect of amputation on pain relief and patients' satisfaction. None of these 26 studies was an RCT. The primary reasons cited for amputation were pain (80%) or a dysfunctional limb (72%). Recurrence of CRPS in the stump was reported in twelve studies and occurred in 31 of 65 patients (48%); phantom pain occurred in fifteen patients (23%). Thirty-six patients were fitted with prostheses; 14 of these patients used the prosthesis. Patient satisfaction was reported in eight studies, but the nature of the satisfaction was not clearly explained. Changes in patient quality of life were reported in three studies (15 patients): quality of life improved in five patients and the joy of life improved in another six patients (Bodde et al., 2011). Available evidence does not clearly delineate the beneficial and adverse effects of an amputation for long-standing, therapy-resistant CRPS. Whether to amputate or not remains an unanswered question.

Vitamin C for prevention CRPS.

Vitamin C has been suggested as a low-risk intervention that might limit excessive soft tissue injury and prevent CRPS. The mechanism of action of vitamin C is thought to be by inhibiting local in-

flammatory cascades via antioxidant mechanisms. Four high-quality RCTs have investigated the effect of vitamin C for preventing the development of CRPS. The studies compared vitamin C with placebo in a total of 1081 patients following distal radial fractures (the studies assessed 123, 195, 427 and 336 patients respectively) (Zollinger et al., 1999; Cazeneuve et al., 2002; Zollinger et al., 2007; Ekrol et al., 2014). All four trials included predominantly older women and a mix of intra- and extra-articular fractures of the distal radius. In two trials, patients were treated with operative and nonoperative techniques, whereas the two other trials included only nonoperative management. In two trials patients were randomized to 500 mg of vitamin C daily for 50 days versus placebo (1:1), in one study a dose of 1000 mg of vitamin C was used in the same manner, whereas one randomized patients to 200, 500, or 1500 mg of vitamin C daily for 50 days versus placebo (3:1). All studies showed a statistically significant reduction in CRPS incidence in groups receiving vitamin C vs placebo at a follow-up of one year. Therefore, a general conclusion from these studies is that it is likely that oral administration of 500-1000 mg of vitamin C per day for 50 days from the date of the injury reduces the incidence of CRPS in patients following distal radial fractures. Following this conclusion, it is frequently used in clinical practice and is also recommended by the American Association of Orthopedic Surgery for patients following distal radial fractures (Malay and Chung, 2014).

However, all of the studies have numerous limitations, including: (1) use of non-Budapest criteria of diagnosis of CRPS, instead using the older criteria of Veldman et al.(1993) and Atkins et al., (1990); (2) two of the studies had statistically significant dichotomous primary outcomes and their fragility indices were each one event or fewer (Zollinger et al., 1999; Zollinger et al., 2007); (3) all studies reported surprisingly high incidence of CRPS in the control groups of 10-12%, at a mean follow-up of one year, suggesting use of invalid diagnotic criteria; and (4) there were 103 patients lost to follow-up across the four trials. The scenario in which all missing patients were assumed to have CRPS is improbable, but it

is equally improbable that none of these patients developed CRPS, as was assumed in these studies. Bearing in mind above limitations, the most recent systematic review by Evaniew et al., (2015) suggests that the literature is conflicting and fails to demonstrate a statistically significant effect for vitamin C in preventing CRPS in patients with distal radius fractures.

Discussion

The review of RCTs showed that only biphosphonates were found to give uniformly statistically significant effects over placebo but the studies were not high quality. Some improvement has been reported with topical DMSO, systemic steroids, spinal cord stimulation and graded motor imagery/mirror therapy programmes. The available evidence does not support the use of other treatments in CRPS. This conclusion is typical and common for many meta-analyses in this topic. This may prompt one to reflect that there is a lack of good evidence for or against any treatment of CRPS and lead to therapeutic nihilism.

As mentioned in the introduction, CRPS comprises a broad spectrum of clinical forms which may be driven by different patophysiological mechanisms. The degree to which individual mechanisms contribute to CRPS may differ between patients and even within one patient over time (Perez et al., 2010; Bussa et al., 2015; Birklein et al., 2015). These facts may explain the difficulty in achieving an evidence-based treatment of CRPS. These studies suggest that there is not and cannot be one, universal treatment for all forms of CRPS; rather treatment should be targeted to the particular clinical manifestation (i.e. different for early or for chronic CRPS).

Clinically appreciable CRPS is a rare disease, therefore, it is difficult to recruit large numbers of patients to conduct a randomized study. Likewise, it is difficult to select patients with uniform disease pattern in order to avoid a heterogeneous patient population, typical of many studies (Cossins et al., 2013; Bussa et al., 2015) which further biases the results of the clinical trials

In addition the studies use heterogeneous primary outcome

measures, e.g. some are focused on pain, other on improvement of function. It is very uncommon to use "recovery from CRPS" as a primary outcome measure because full recovery is rare and there is also no commonly accepted definition of recovery.

Conclusion

The review of RCTs showed that only bisphosphonates were found to give uniformly positive effects, statistically significantly better than placebo. Improvement has been reported with topical DMSO, systemic steroids, spinal cord stimulation and graded motor imagery/mirror therapy programmes. The available evidence does not support the use of other treatments in CRPS, however they are frequently used in clinical practice. This discrepancy shows that available evidence does not necesserily reflect what is truely effective and what is sham in the management of CRPS.

Table 1 Coleman analysis of the quality of the studies (Coleman et al., 2000)

Study	Intervention/Drug	Number of patients	Follow-up (months)	CMS
Bickerstaff and Atkins, 1991	Calcitonin nasal spray	38	3	61
Gobelet et al., 1992	Calcitonin, nasal spray	66	2	68
Adami et al., 1997	Aledronate, i.v.	20	1	63
Manicourt et al., 2004	Aledronate, p.o.	39	3	68
Varenna et al., 2000	Clodronate, i.v.	31	1.5	53
Robinson et al., 2004	Pamidronate, i.v.	27	3	68
Geertzen et al., 1994	Topical DMSO vs IVRB guanethidine	26	2	74
Zuurmond et al., 1996;	Topical DMSO	31	2	72
Perez et al., 2003;	Topical DMSO vs N-acetylcysteine, p.o	112	12	65
Perez et al., 2008	Mannitol, i.v.	41	2	69
Blanchard et al., 1990;	IVRB, guanethidine vs IVRB reserpine	21	3	61
Jadad et al., 1995	IVRB, guanethidine	9	1	54
Livingstone and Atkins, 2002	IVRB, guanethidine	56	6	66
Kettler et al., 1988	IVRB, droperidol	6	1/2	54

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Study	Intervention/Drug	Number of patients	Follow-up (months)	CMS
Hanna et al., 1989	IVRB, ketanserin	9	1	59
Rocco et al., 1989	IVRB, guanethidine vs IVRB reserpine	12	24	51
Bonelli et al., 1983	IVRB, guanethidine vs stellate ganglion block	19	3	55
Price et al., 1998	stellate ganglion block vs lumbar sympathetic block	7	1/4	56
Rodriguez et al., 2006)	stellate ganglion blocks	15	1	56
Aydemir et al., 2006	stellate ganglion lidocaine block vs stellate ganglion US block vs stellate ganglion saline block	25	1	60
Nascimento et al., 2010	stellate ganglion lidocaine block vs stellate ganglion lidocaine/ clonidine block vs IVRB lidocaine/ clonidine	43	1	60
Chrirstensen et al., 1982	Prednisone, p.o	23	3	63
Braus et al., 1994	Methyplrednisolone, p.o	34	6	63
Kalita et al., 2006)	Prednisolone, p.o. vs piroxicam, p.o.	60	1	61
Barbalinardo et al., 2015	Prednisolone, p.o.	31	1.5	74
Taskaynatan et al., 2004	IVRB, methylprednisolone	22	1.5	58
van de Vusse et al., 2004	Gabapentin, p.o.	46	2	58
Moseley, 2004	Graded motor imagery vs conventional physio	13	3	64
Moseley, 2006	Graded motor imagery vs mirror therapy	20	3	65
Cacchio et al., 2009a, Cacchio et al., 2009b	Mirror therapy	72	6	68
Oerlemans et al., 1999	Physiotherapy vs occupational therapy vs minimal „social work" therapy	135	12	89
Kemler et al., 2000	Spinal cord stimulation	54	24	78
Schwartzman et al., 2009	Ketamine, i.v.	19	1	70
Sigtermans et al., 2009	Ketamine, i.v.	60	3	77
Finch et al., 2009	Ketamine, topical	20	1/4	74
Zollinger et al., 1999	Vitamin C	123	6	56

CMS - Coleman Methodology Score
IVRB - Intravenous regional block

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5.2 The Future for Evidence Based Data in Hand Surgery

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In the last decade, hand surgery research has grown considerably. A recent analysis of original articles and reviews from the four major hand surgery journals revealed that the number of scientific articles published between 2005 and 2014 doubled (Mei et al., 2016). Furthermore, these articles gained in quality. In the European Journal of Hand Surgery (JHS Eur), the number of randomised controlled trials (RCTs) increased from zero in 1991 to 5% in 2008-2011 (Post et al., 2014). A similar trend was seen with the JHS American volume. Despite the trend to publish more RCTs, most papers still present case series or case reports and the quality of RCTs is often insufficient either due to poor study planning or issues in reporting the trial (Post et al., 2014; Rosales, 2015).

How to generate high quality evidence based data?

Systematic study planning

The basis for publishing high quality papers is a thorough and systematic study plan: the study protocol, the target population and an adequate sample size must be defined. Feasible and measurable

hypotheses have to be defined *a priori* as well as the primary endpoint. Appropriate outcome measures have to be chosen carefully to test these hypotheses. The use of standardised and validated outcome measures is essential to compare results between studies, e.g. in a meta-analysis. Outcome measures should comprise all domains of interest to comprehensively assess the health status of a patient. If available, core sets assessing the clinical and patient-reported outcomes as well as complications should be used, e.g. the core set for patients with distal radius fractures (Goldhahn et al., 2014) or for patients with hand osteoarthritis (OA) (Kloppenburg et al., 2014).

To ensure patient safety, the entire study protocol needs to be approved by an ethics committee and/or competent authority. Registration in a public trials registry, such as *www.clinicaltrials.gov,* is paramount before the study can begin.

Data processing

Other important aspects include data collection, data management and statistical analysis. Researchers should use a professional database that conforms with international laws and regulations, and protects patient data. The use of Excel for research is outdated, since data can easily be manipulated or accidentally misplaced. A statistical plan covering suitable methods of data analysis to answer the research question has to be developed *a priori*. To ensure data quality, a person independent of the study should do a systematic and thorough data control. This monitor checks the completeness of case report forms and worksheets, correct data transfer into the database (if applicable) and ascertains that the study was conducted according to good clinical practice and the predefined study protocol. After completing the study, an experienced statistician is responsible for data checks, e.g. for completeness and confirmability. After finishing these steps and necessary data corrections (with date, reason, and signature), data analysis can begin.

In the data analysis, one should be cautious when interpreting p-values. Even small, clinically meaningless changes in a condi-

tion can be "significant", if the sample size is high. In contrast, an effect can be overlooked, if the sample size is small (Wasserstein and Lazar, 2016). Interpretation of the data should also be based on confidence intervals, Minimal Important Changes (MIC) and Minimal Important Differences (MID). The MIC is the smallest change in a score which an individual patient perceives as important, whereas the MID is the smallest difference between patients that is considered relevant (Mokkink et al., 2010). Since the MIC and MID vary between different patient groups, interventions and outcome measures, only sparse data are available to date (Rodrigues et al., 2015). Therefore, the calculation of these parameters should be promoted.

Challenge the assumptions

Having discussed the issue of data collection and its importance, one needs to realise that many former studies, which are still cited in the literature, were done under different conditions and with a completely different understanding of statistics and methodology. It might therefore be adequate and worthwhile to re-analyse keystone papers according to our modern understanding of the standards of care and research. A classic example is the 1986 study of Knirk and Jupiter (1986). It is one of the most cited manuscripts in the orthopaedic surgical literature, has high impact on the treatment recommendation for distal radius fractures and continues to generate hypotheses for outcome studies. The authors themselves re-evaluated the data in 2009 (Haus and Jupiter, 2009) and concluded that some of the important radiographic parameters were incorrectly interpreted. In addition, the study failed to use intra- and inter-observer agreement in its analysis. Last but not least, some newer diagnostic tools such as computerised tomography and wrist arthroscopy were much less readily available in the 1980s. The authors recommended generating new data and re-evaluating the study hypothesis. There are a number of similar studies from the 1980s and 1990s, which still have impact on hand surgery research and literature, which perhaps deserve reassessment.

Study report

Summarising research results in a scientific manuscript is challenging. Most of the peer-reviewed journals require manuscripts to follow the CONSORT (Schulz et al., 2010), STROBE (von Elm et al., 2007) or PRISMA (Moher et al., 2009) statements for RCTs, observational studies or systematic reviews and meta-analyses, respectively. These statements comprise checklists and explanations of essential items that should be included in study reports. Consulting an experienced medical writer, who is familiar with these tools, can enhance the quality of the manuscript to be submitted.

Resources

The planning and conduct of high quality studies is quite complex and time-consuming. It is impossible for all this to be done by a hand surgeon alone. A multidisciplinary team consisting of the principal investigator, hand surgeon(s), project leader, statistician, study nurse, medical writer, monitor and a librarian (for reviews) is necessary. A clear definition of the different roles and the inclusion of different professionals enhances the quality of the studies. As a consequence, the administrative complexity as well as associated costs increase. Therefore, doing research without adequate funding is barely feasible.

Which evidence based data do we need in future?

In the future, the following points need to be addressed in order to strengthen the impact of hand surgery and its research:

Study types

Reviews and meta-analyses are required to show the best available evidence. The basis for these analyses are RCTs. Therefore, one should aim at increasing the number of well-conducted RCTs. However, performing an RCT is sometimes not feasible or useful, for example, due to a lack of resources, few patients when studying rare diseases, interventions that cannot be randomised due to different indications (e.g. surgical treatment versus collagenase injection in patients with Dupuytren disease) and where patients are unwilling to be randomised or due to ethical considerations.

If enough RCTs investigating a specific condition/intervention are available, reviews and meta-analyses can be initiated, e.g. in collaboration with the Cochrane group.

Expert opinions and guidelines

How should we deal with expert opinions and case reports in the future? Despite reviews and meta-analyses being the gold standard in research, expert opinion, at least in daily practice, plays an important role. The patient-doctor relation is highly influenced by expert opinion, mainly due to the asymmetric level of knowledge concerning many medical questions. Therefore, expert opinions should still have a place in research questions, especially if a practical and clinical question is investigated. A possible approach to enhance the scientific level of expert opinions is to run a Delphi study in which different expert opinions are summarised using a scientifically accepted method (Hasson et al., 2000). In an iterative process, experts (ideally of different specialties) give their opinion on a specific topic that is merged into a consensus, e.g. to develop guidelines or definitions (Felici et al., 2014; Huisstede et al., 2013; Huisstede et al., 2014a; Huisstede et al., 2014b; Huisstede et al., 2014c; Kloppenburg et al., 2014).

Special types of guidelines are decision trees; a decision tree includes relevant clinical and patient information, e.g. age, gender, stage of disease, affected joint, etc., which support the clinician in choosing the appropriate evidence based treatment as well as providing information about the expected outcome or cost-effectiveness (Kerrigan and Stanwix, 2009; Shauver et al., 2011; Song et al., 2012). Such a tool may facilitate decision-making between a surgeon and their patient prior to the intervention.

Large samples - registries

Research needs to include large sample sizes. Studies investigating only 20 patients or fewer under ideal conditions are not very meaningful for clinical practice. Therefore, a greater number of patients, particularly from the daily clinical setting, should be evaluated. The best approach is to collect data from all patients with a certain condition in a dedicated registry, as exist worldwide for hip

and knee arthroplasty. In hand surgery, however, national or international registries are rare. Registries should not only include the type of intervention, but also the short- and long-term outcomes, measured with standardised outcome measures. In the digital age, collaboration between international research partners is easy and enables high sample sizes to be achieved, even for rare diseases. However, in daily practice, the multicentre and multi-disciplinary approach is often not easy to follow. Clear study protocols have to be defined from the whole research group. Project managers in all participating centres are needed to ensure data quality. Furthermore, the varied financial positions of the individual centres must be taken into consideration, and if possible, balanced out.

Evaluation of long-term results

For several conditions, long-term follow-ups are essential. Using the example of thumb carpometacarpal (CMC) joint osteoarthritis (OA), short-term evidence suggests removal of the trapezium alone is the preferred surgical treatment because it is associated with fewer complications compared to ligament reconstruction with tendon interposition. However, there are an insufficient number of high quality RCTs to compare the long-term outcomes of the many available interventions (Zafonte and Szabo, 2014).

Establish outcome core sets

In the field of outcome measures, core sets for the most common hand disorders need to be defined, including a comprehensive evaluation of all areas concerning the patient`s health. Within these core sets, standardised and validated outcome measures have to be used to enable the comparison of study results in RCTs and meta-analyses. Current standardisation of outcome measures is poor, since even simple measurements such as ranges of motion are completed and reported in many different ways (Pratt and Ball, 2016). Another challenge is the standardised and comprehensive reporting of complications requiring further investigation (Audige et al., 2014).

Analysis of cost-effectiveness

Although, for some areas in hand surgery, a lot of good research has been done to prove the effectiveness of interventions, there is lack of cost-effectiveness or cost-utility studies. Due to the increasing costs of the healthcare system, it is essential not only to compare treatment methods for their effectiveness but also for economic aspects. In these types of studies, knowledge about the direct treatment costs is important for the health insurance system, but further costs as a result of sick leave affects society and should also be analysed. A good example is the report of Chen et al., (2011), who analysed the cost of the different treatment regimens for Dupuytren disease in various clinical scenarios. The authors provided clear recommendations for the price of the new collagenase medication in order for it to be cost-effective. In future, more of these questions will be addressed by different healthcare providers including insurance companies. The use of such health technology assessments is becoming widely popular and in some countries, national institutes have already been set up (e.g. the National Institute for Health and Care Excellence (NICE) in the UK and the Institute for Quality and Efficiency in Health Care (IQWIG) in Germany). The hand surgical community would be well advised to take the lead in such research questions before outsiders do it first.

Prognostic research

It is self-evident that an accurate indication substantially defines the outcome of an intervention. However, there are several clinical and patient-related parameters that also influence outcome. In order to understand the determinants of a good or poor outcome and their mechanisms, prognostic research is useful. Knowledge of these determinants enables the development of algorithms for predicting outcome, e.g. in terms of a risk or benefit calculator. A risk calculator may determine the probability of recurrence, revision surgery or severe complications. The American College of Surgeons developed such a surgical risk calculator, although this tool does not yet consider orthopaedic interventions of the hand. From a positive point of view, a benefit calculator could estimate, for instance, the anticipated pain reduction or improved range of motion or a certain patient-reported outcome score at a specified time after treatment.

Patient expectations

A further relevant aspect of decision making is the assessment of preoperative patient expectations. We know that fulfilment of expectations is associated with improved outcomes (Rossi et al., 2015; Waljee et al., 2014). To gather this information, the patient could fill out a standardised and validated electronic questionnaire prior to consultation, such as that already existing for thumb CMC joint OA (Kang et al., 2016). Knowledge about prognostic factors and patient expectations will better guide the patient towards more realistic assumptions of the outcome.

Translational research

Besides all the aforementioned suggestions for improving research in hand surgery, we must not forget how to translate research results into practice. It is important that hand surgeons have the time to review as well as understand the scientific literature. Therefore, every clinician should have at least a basic understanding of methodology and statistical analyses in order to interpret the research. In addition, newer search engines and more selective information providers are needed to select the important and valid information. With the steadily increasing number of publications comes more research of dubious or invalid information. Social networks and more community-based exchange channels could be the future in order to circulate validated and important knowledge.

Conclusion

In hand surgery, there is increasing need for evidence based data and high quality publications. Well-conducted RCTs are the basis for attaining high evidence when they are compared in meta-analyses. However, RCT research is complex and requires a qualified multidisciplinary team with sufficient funding. Despite all the potential barriers, high quality studies are worth the invested time and resources because they support a greater recognition of our speciality in society, are important for demonstrating the effectiveness of our interventions to insurance companies and health policy-makers and last but not least, they improve the general health of our patients.

KEY POINTS

- The basis for publishing high quality papers is thorough and systematic study planning.
- A professional database is required for data processing. Data should not only be analysed based on p-values; confidence intervals and the MIC and MID should also be considered.
- A re-analysis of former keystone papers according to modern understanding on the standards of care and research is worthwhile.
- Study reporting is worth doing according to guidelines and checklists.
- High quality studies require a multidisciplinary team.
- Reviews and meta-analyses are supposed to show the best evidence available. The basis for these analyses are RCTs.
- Expert opinions can be summarised in a Delphi study to develop guidelines or definitions.
- Decision trees support the clinician in choosing the appropriate evidence based treatment.
- High sample sizes can be achieved through multicentre registries.
- Evaluation of long-term results is important for several hand conditions.
- The use of standardised and validated outcome measures enhances the comparability of study results.
- Cost-effectiveness analyses are important to contain the ever-increasing healthcare costs.
- Prognostic research enables the identification of determinants of patient outcome, which serve as a basis for developing prediction tools.
- Fulfilment of expectations is associated with improved outcomes. Therefore, surgeons should guide the patient towards realistic assumptions of the expected outcome.
- In conjunction with all these suggestions for improving research in hand surgery, we must not forget to translate research results into practice by facilitating the scientific knowledge of surgeons and sharing relevant research results within the community.

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