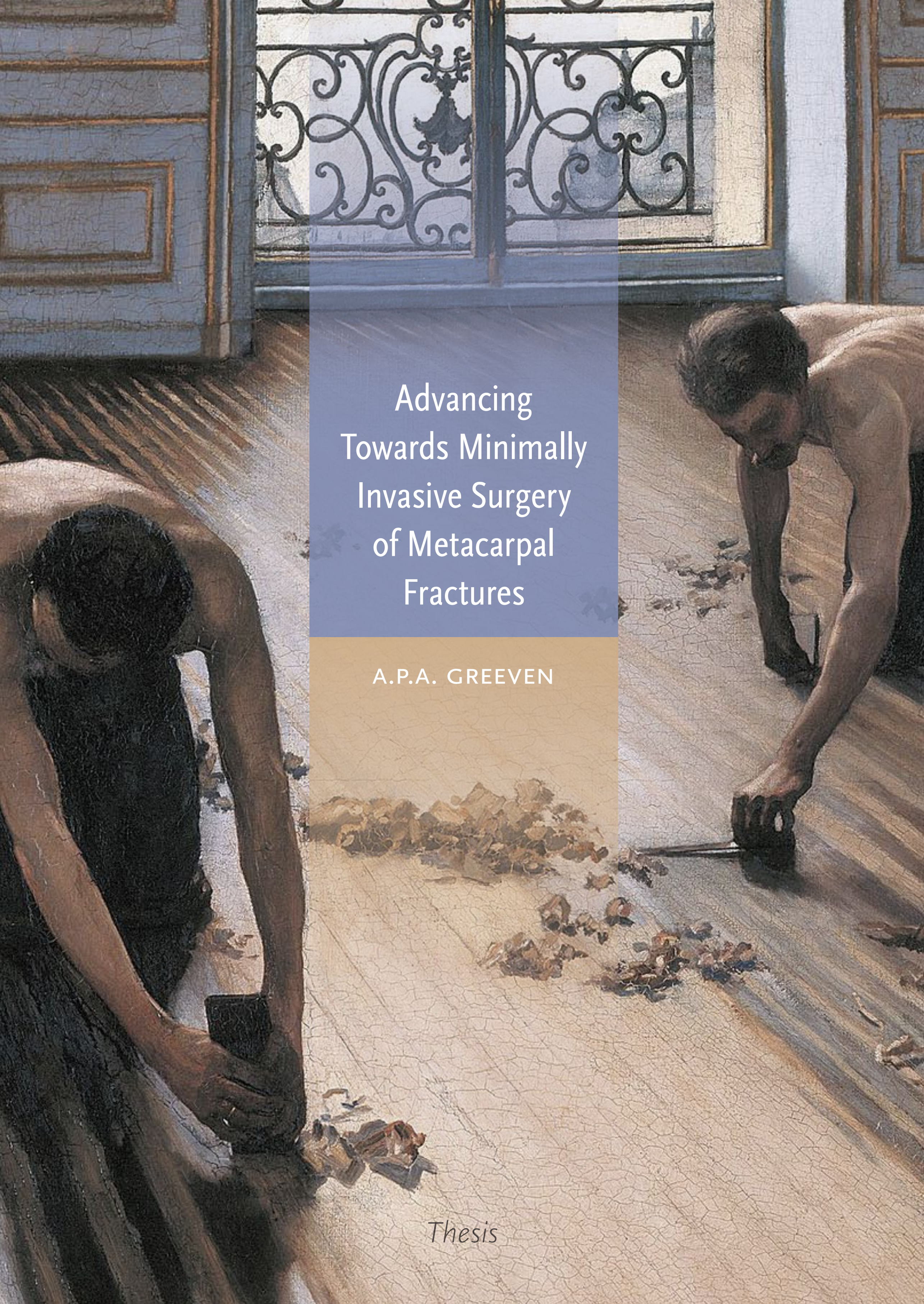

Advancing Towards Minimally Invasive Surgery of Metacarpal Fractures

A.P.A. GREEVEN

Thesis

Advancing Towards Minimally Invasive Surgery of Metacarpal Fractures

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Cover image

Raboteurs de parquet (1875)

Gustave Caillebotte (Paris 19 august 1848 – Petit Gennevilliers 21 februari 1894)

Layout and printed by: Optima Grafische Communicatie (www.ogc.nl)
ISBN: 978-94-6361-414-6

Advancing Towards Minimally Invasive Surgical Treatment of Metacarpal Fractures

Minimaal invasieve operatieve behandeling van metacarpale fracturen

Proefschrift

ter verkrijging van de graad van doctor aan de
Erasmus Universiteit Rotterdam
op gezag van de rector magnificus
Prof.dr. R.C.M.E. Engels
en volgens het besluit van het College voor Promoties.
De openbare verdediging zal plaatsvinden op

dinsdag 20 oktober 2020 om 13.30 uur

Alexander Pieter Antony Greeven

geboren te Doetinchem

Erasmus University Rotterdam

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“We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.“

T.S. Eliot, *Little Gidding*

CONTENT

I Introduction and outline

I

Background & fracture classification

Epidemiology

Fractures in the hand are very common. Between 17 and 19% of all fractures seen on Accident and Emergency Departments (A&E) are located in the hand [1-4]. Metacarpal fractures account for 30–40 % of these hand fractures [5]. Most frequently fractures in the hand are located in the first and second ray (**Figure 1**) [1, 3, 4]. For metacarpal bone specifically, the most commonly affected is the fifth metacarpal. About 20-22% of all metacarpal fractures is a subcapital fifth metacarpal fracture is, also known as “boxer’s fracture” [6, 7].

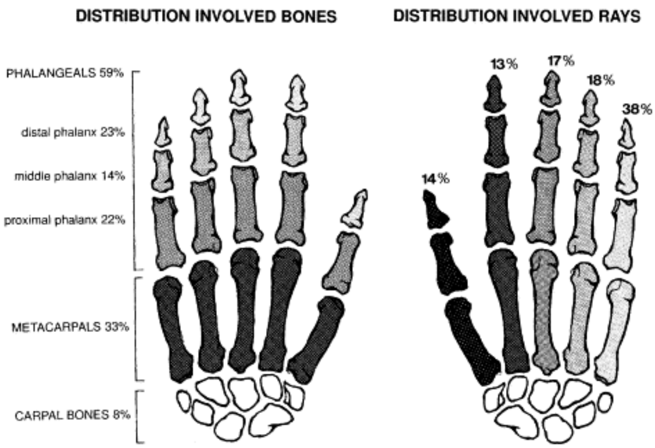

Figure 1. Distribution of metacarpal fractures (from: Prevalence and distribution of hand fractures. E.B.H. van Onselen, R.B. Karim, J.J. Hage, M.J.P.F. Ritt; J. Hand Surg (Eur), Oct 2003, Vol 28, pages 491-495) [1]

Patient characteristics

The majority of patients with metacarpal fractures are between 15 and 40 years old (**Figure 2**) [2]. A predominance exists for male patients, the male:female ratio varies from 1.8:1 to 3:1 [1, 4]. This male predominance exists up to the 6th decade of age and is explained by men doing heavy manual labour up to the age of retirement, sports and fighting [8, 9]. In the female population osteoporosis combined with an increased fall incidence later in life and a longer life expectancy results in an increase in metacarpal fractures in the 6th decade in comparison to males (**Figure 2**) [1].

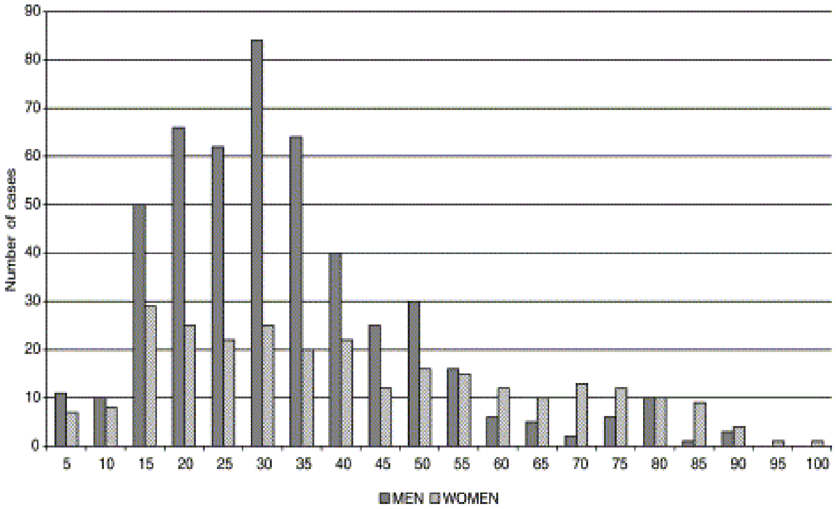

Figure 2. Incidence of metacarpal fractures (from: Prevalence and distribution of hand fractures. E.B.H. van Onselen, R.B. Karim, J.J. Hage, M.J.P.F. Ritt; J. Hand Surg (Eur), Oct 2003, Vol 28, pages 491-495) [1]

Fracture classification

The classification of metacarpal fractures is based on the anatomical location of the fracture. A first distinction is the metacarpal in which the fracture is located. A second distinction can be made based on the location of the fracture, i.e. the base, shaft, neck or head of the metacarpal (**Figure 3**). Metacarpal shaft fractures can be further classified into spiral, oblique or comminuted fractures [10]. First metacarpal base fractures can be reported as intra-articular (Bennett, Rolando, comminuted), extra-articular and epiphyseal fractures (**Figure 4**) [11].

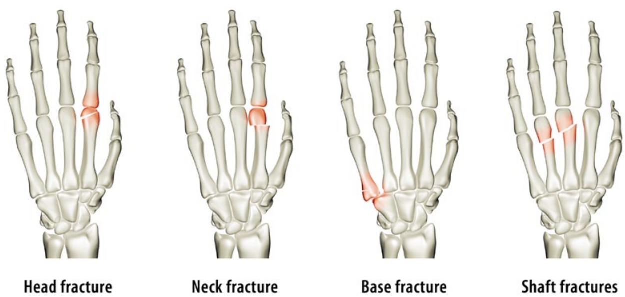

Figure 3. Classification of Metacarpal Fractures based on its anatomical location

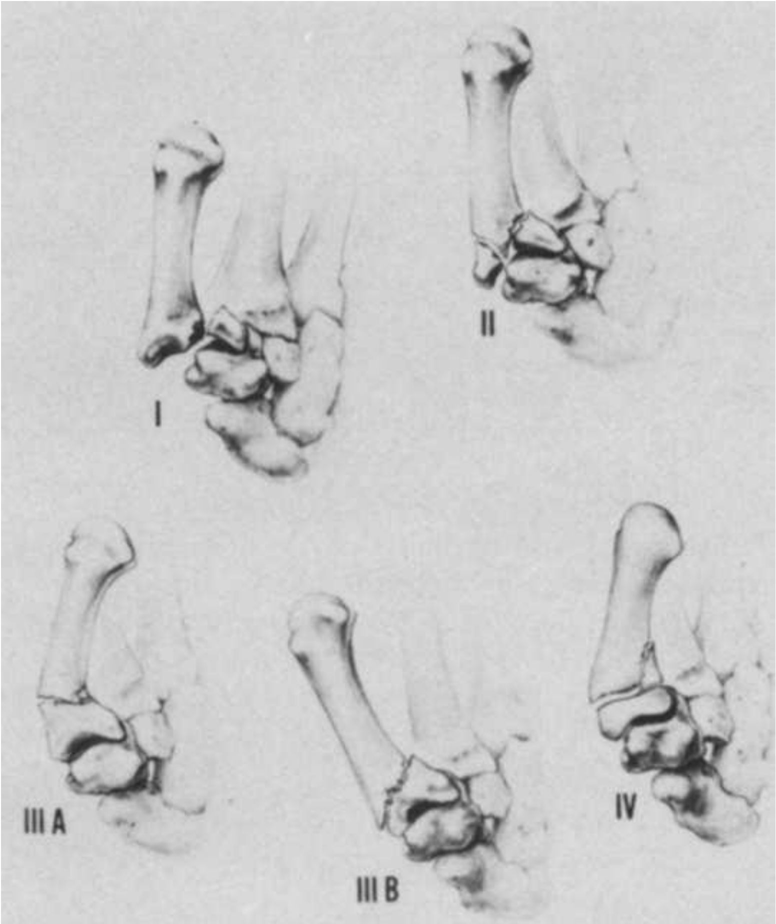

Figure 4. Classification of thumb fractures
Type I Bennett's fracture
Type II Rolando's fracture
Type IIIA Transverse extra-articular fracture
Type IIIB Oblique extra-articular fracture
Type IV Epiphyseal fracture
(Re-printed with kind permission from Elsevier Publisher® from "Fractures of the base of the first metacarpal bone: results of surgical treatment. J.L.M. van Niekerk, R. Ouwens; Injury, Vol 20, Issue 6, p 359-262 (Nov) 1989.)

Treatment

The majority of fractures in the hand can be treated non-operatively. The method of treatment of metacarpal fractures depends on the stability of the fracture. Surgical goals of treatment are restoration of length, alignment and correction of rotation. Isolated, stable fractures can be treated with non-operative immobilization for several weeks [5, 6, 12, 13]. The injured hand is immobilized in so-called "position of protection", in which the meta-carpo-phalangeal joint flexed as near 90 degrees as possible and the interphalangeal joints almost straight [14].

Unfortunately, not all fracture types are suitable for non-operative treatment. For malrotation, angulation, longitudinal shortening, multiple metacarpal fractures and fractures with associated tissue injury or bone loss surgical treatment is indicated [15-18]. Each of these factors, negatively influences long-term functional outcome when treated non-operatively. Shortening or angulation of the metacarpal can biomechanically influence function and strength of the hand, i.e. Pinch and Grip strength [19]. Rotational deformity of the metacarpal causes scissoring of the fingers which results in loss of functional use of the scissoring fingers and can lead to functional loss of part of the hand.

Unstable intra-articular fractures will also benefit from operative fixation in which the fracture is stabilized and the position in which the fracture heals is controlled. Secondly, by intra-articular fracture reduction the development of post-traumatic arthrosis might be prevented. However, it is still debated if the intra-articular step-off and gap after fixation in such cases should be smaller than 2 mm or that an anatomical reduction without step-off and gap would be more beneficial in preventing post-traumatic arthrosis in metacarpal fractures ***(Figure 5)*** *[20-22]*.

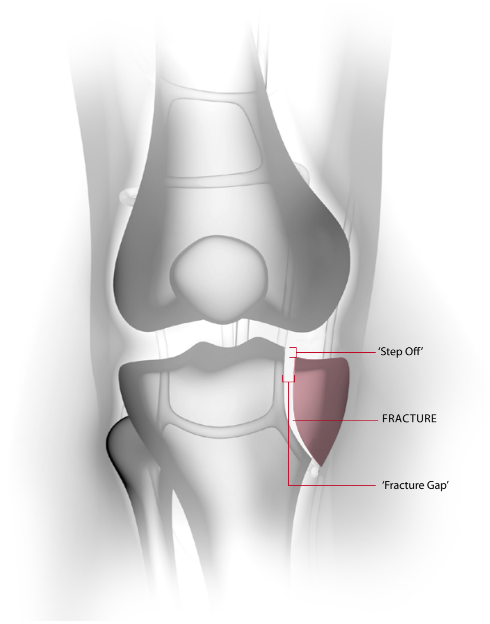

Figure 5. Intra-articular Tibia Plateau Fracture illustrating Step-off and Gap (i.e. step-off is displacement of fracture fragment in relation to the articular surface; gap is distance between two fracture fragments at articular level)

Introduction - What is the problem?

Unfortunately, it is currently unknown what type of operative treatment is preferable in the surgical treatment of different types of metacarpal fractures.

Up until the 1940's surgical treatment of metacarpal fractures consisted of closed reduction percutaneous fixation (CRIF) [23]. In 1950, Wagner et al. reported on CRIF in the treatment of first metacarpal fractures for the first time [24]. In the same decade Iselin et al. and Wiggins et al. reported on different CRIF techniques in first metacarpal surgery [25, 26]. During the same years the first reports of successfully applied open reduction internal fixation (ORIF) techniques in specific intra-articular fractures of the hand are reported [27, 28]. The introduction of new mini screw and plate systems in the 1990's has further promoted ORIF for surgical treatment of the hand.

Parallel to these developments CRIF was also still applied and in 1989 Van Niekerk et al. reported on 23 patients who had been successfully treated for first metacarpal fractures [11]. This has been the start of a revival in the scientific research into CRIF for the surgical treatment of metacarpal fractures [29-31].

CRIF - *Minimal tissue dissection vs. post-operative immobilization?*

Closed reduction and internal fixation (CRIF) is also referred to as closed reduction percutaneous fixation (CRPF). CRIF implies that the fixation of the fracture is performed with a percutaneous technique, for instance percutaneous Kirschner wire fixation, after indirect reduction of the fracture. Fluoroscopy is used to confirm fracture reduction and fixation during surgery.

The advantage of CRIF is that no surgical dissection is necessary leaving the fracture hematoma intact. The fracture hematoma has developed while the fracture occurred by blood loss from the fractured bone. The bone marrow contributes to the fracture hematoma, thereby pluripotent stem cells are part of the fracture hematoma. These stem cells are essential for the formation of new bone. Over time, fibrinous tissue and later bony depositions called "callus formation" are formed in the fracture hematoma. This bone healing process is known as "secondary bone healing". During this process small movements at the fracture site are allowed and even contribute to callus formation and strong bone healing.

Another advantage of CRIF is that it is a minimal invasive technique, which requires minimal tissue dissection. CRIF may possibly be associated with a smaller risk of iatrogenic injury in comparison with ORIF.

Possible disadvantages of CRIF might be that without direct vision of the fracture a less adequate reduction is achieved. While treating an intra-articular fracture this might result in a higher change of post-traumatic arthrosis at long-term follow-up. Furthermore, during closed surgical technique, radiographic instruments are used to assess fracture reduction. Some authors believe these to be less accurate in the assessment of fracture reduction in comparison with direct vision during open surgical reduction [32].

Another possible disadvantage of CRIF might be that the percutaneous fracture fixation is less stable in comparison to internal fixation after open reduction. For this reason, percutaneous fixated fractures are often additionally immobilized in a plaster cast. A period of immobilization of several weeks may negatively influence long-term functional outcome because of adhesion formation between anatomical layers in the hand thereby restricting movement.

The Kirschner-wires can be removed after consolidation of the fracture. In most cases this can be facilitated in the outpatient clinic, if necessary under local anaesthetics.

ORIF - *Anatomical reduction vs. soft tissue dissection?*

During open reduction and internal fixation, the tissues surrounding the fracture are dissected and the fracture fragments are explored. During open surgery fracture reduction can be directly visualized, which may contribute to an anatomical reduction of the fracture. Fracture fixation occurs with screws and/or plate fixation. Fluoroscopy is additionally used to assess fracture reduction and position of osteosynthesis material. Consequently, the fracture hematoma is released during dissection. Therefore, after open surgical treatment the fracture hematoma is lost for future contribution to the fracture healing process.

After ORIF the fracture healing process is based on a process called "primary bone healing". Because of the loss of the fracture hematoma consolidation of the fracture occurs by osteoblasts crossing the fracture site, while creating bone bridges that cross the fracture. No movement is allowed at the fracture site during this process not to damage this bone bridge formation. Therefore, ORIF requires a rigid fixation of the fracture.

The rigid fixation necessary for direct bone healing has the advantage that no post-operative immobilization is required. The soft tissue dissection necessary for ORIF contributes to possibly more adhesion formation in comparison to CRIF. However, direct mobilization of the patient after ORIF theoretically reduces this risk of adhesion formation again by allowing movement between dissected layers.

ORIF allows anatomical reduction with no persistent intra-articular step-off and gap therefore theoretically preventing the development of post-traumatic arthrosis. During fixation of intra-articular fractures a persistent step-off and gap up to 2 mm is sometimes accepted, based on a study reporting on distal radial fractures in which a persistent step-off and gap larger than 2 mm was associated with post-traumatic arthrosis formation [33]. However, it is still debated what the allowed step-off and gap after fixation of intra-articular fractures of the hand might be without increasing the risk of post-traumatic arthrosis formation [20-22].

Another disadvantage of ORIF is the required soft tissue dissection for exposure of the fracture, resulting in an increased risk of iatrogenic injury during surgery [34]. The osteosynthesis material is removed when necessary, mostly because of local discomfort experienced by the patient. The removal is done during a second operation, which also increases the risk of iatrogenic injury.

Outcome measures

To assess long term functional outcome in the hand Grip and Pinch strength are usually used [35]. With Grip strength the force of the entire hand is tested. The greater part of force in Grip strength is produced by the thumb and the second and third ray of the hand [35]. Pinch strength tests the specific force of one single ray by measuring the Pinch force between the thumb and the tested digit. Because Grip and Pinch tests are different outcome measures, correlation between the two scores can be poor. For instance, a fourth metacarpal fracture which is consolidated in a shortened position might not affect the Grip strength of this hand but may affect Pinch strength.

Because strength of the injured hand before trauma is unknown, the Pinch and Grip strength of the injured hand are compared with the patients uninjured hand. A complicating factor is the fact that hand strength is not similar for left and right. In general, the dominant right hand is 10% stronger than the left hand [35]. Interestingly, left hand dominance results in equal strength in both hands in half of the patients [35].

To detect clinically important functional deficit a minimally clinical important difference (MCID) is used comparing Grip and Pinch strength. This MCID is usually set at a difference of 20% in comparison with the contra-lateral side and adjusted for hand dominance as suggested by Crosby et al [35].

The Visual Analogue Scale (VAS) is used to evaluate pain experienced by the patient. This analogue scale ranges from 0cm (no pain) to 10cm (worst imaginable pain). The patient is asked to mark the experienced pain on the 10cm scale.

For injuries of the hand the Disability of the Arm, Shoulder and Hand (DASH) questionnaire can also be used to assess functional outcome [36]. The DASH is a 30-item, self-report questionnaire which is designed to measure physical function and symptoms in patients with musculoskeletal disorders of the upper limb. The score it generates describes the disability experienced by people with upper-limb disorders and also monitors changes in symptoms and function over time.

Post-traumatic arthrosis is also an important long-term measure. Radiographs are used to evaluate post-traumatic arthrosis by using the Van Niekerk and Owens modification of the Eaton and Littler classification of thumb carpometacarpal joint arthrosis [11, 37]. On the radiographs the following is scored; Stage I: no clear arthritic changes, Stage II: osteophytes smaller than 2 mm, Stage III: osteophytes larger than 2 mm or joint narrowing and Stage IV: joint space more or less disappeared [11, 37].

Indications for operative treatment of first metacarpal base and shaft fractures

First metacarpal base fractures frequently involve the carpo-metacarpal joint (CMC). Intra-articular caput fractures by definition involve the metacarpal joint (MCP). Both types of intra-articular fractures are most frequently unstable, resulting in secondary dislocation during non-operative treatment. The instability of the fractured joint and the intact muscle insertion around the fracture causes dislocation of the fracture fragments. For instance, Bennett's fracture instability results from the insertion of the abductor pollicis muscle, which causes a specific fracture dislocation. In Rolando's fracture and comminuted fractures similar effects cause instability of these intra-articular first metacarpal base fractures. In case of metacarpal head fractures a combination of tendon insertions of the injured finger together with the intrinsic hand muscles (i.e. interosseous muscle) can cause dislocation and instability. Surgical treatment aims to reduce and maintain reduction during fracture healing and subsequently preventing post-traumatic arthrosis in the long run [27, 28].

Extra-articular first metacarpal fractures may be impacted and clinically stable when they occur from direct trauma. Stable fractures can be treated non-operatively. Neck fractures are most frequently relative stable fractures. The majority is treated conservatively, based on fracture angulation.

Metacarpal shaft fractures require reduction in case of severe angulation (10–20° dorsal angulation for the second metacarpal and third metacarpal and 30° for the fourth and fifth metacarpal), shortening of more than 5 mm, or malrotation. The upper limit of rotation accepted is 10°, though 5° of mal-rotation can lead to 1.5 cm of overlap on flexion of the digits resulting in scissoring of the fingers [10]. Operative treatment is indicated with unstable patterns (spiral, oblique, comminuted), inadequate reductions, or multiple metacarpals fractures. Fixation can be achieved with inter-fragmentary screw fixation, mini-fragment plate fixation, external fixation or cross-pinning with K-wires [10]

Hypothesis

The hypothesis of this thesis is that a minimal invasive surgical technique is preferable in the treatment of metacarpal fractures compared with open reduction and internal fixation.

Long term outcome has significantly improved with the introduction of surgical treatment of metacarpal fractures in the 1950's [27]. Since then, different surgical techniques have been introduced and added to the surgeon's therapeutic arsenal. In an attempt to prevent post-traumatic arthrosis from occurring, anatomical reduction has been advocated [31, 32]. Together with the introduction in the 1990's of mini-screws and -plates open reduction and internal fixation has recently more frequently been applied in comparison with closed (percutaneous) surgical techniques aiming to prevent post-traumatic arthrosis and allowing early mobilization [38-41].

However, it is debatable whether these new open treatment strategies are correctly applied, or that closed reduction and percutaneous fixation should be preferred. We hypothesised in this thesis that a closed reduction and percutaneous fixation technique is preferable in the treatment of metacarpal fractures compared with open reduction and internal fixation.

Outline of this thesis

Part A

The first half of this thesis focusses on the clinical assessment of surgically treated patients with metacarpal fractures. To prevent biased outcome specific fracture types are separately assessed.

Outcome of surgical treatment of unstable first metacarpal fractures and second to fifth metacarpal fractures are evaluated. Surgical techniques applied can be classified as closed reduction and internal (percutaneous) fixation (CRIF) or open reduction and internal fixation (ORIF).

Chapter II reports the outcome of first metacarpal base fractures that have all been treated with CRIF. Functional assessment included Grip- and Pinch-strength during an outpatient assessment and radiological assessment of post-traumatic arthrosis using the Eaton-Littler score at 24-months follow-up.

In **Chapter III** the combined results of multiple studies are assessed via a systematic review into the surgical treatment of one specific type of first metacarpal base fracture, i.e. the Bennett's fracture. Longer, 10-year follow-up assessment of surgically treated Bennett's fractures is reported in **Chapter IV**. Differences in outcome and complications after surgery are discussed for ORIF and CRIF.

To assess possible benefit for second to fifth metacarpal fractures from minimally invasive surgical treatment is compared with open surgical technique in **Chapter V.** Outcome, re-operations and complications of different surgical techniques are discussed, based on the reported results of five studies combined in one systematic review.

To determine stability of fixation, chances of re-operation and complications after CRIF and ORIF in the treatment of single, as well as multiple, metacarpale second to fifth shaft fractures, the results of 142 surgically treated patients are evaluated in **Chapter VI**.

Part B

The second part of this thesis focuses on technical aspects of first to fifth metacarpal surgery.

In **Chapter VII** the adequacy of fluoroscopy in the assessment of fracture reduction during closed reduction and percutaneous fixation is assessed. The persistent step-off and gap after closed reduction assessed with fluoroscopy is compared with radiography and direct visualization after dissection.

Anatomical considerations regarding surgery on the first metacarpal are described in **Chapter VIII**. The anatomical route of the sensory branch of the radial nerve (SBRN) and the dorsal branch of the radial artery (DBRA) is assessed during cadaveric dissection and via computed assisted surgery anatomy mapping (CASAM) a possible safe zone for future surgery is suggested.

Finally, this thesis will conclude with a general discussion and give future perspectives based on the present findings.

Étude pour les Raboteurs de parquet
Gustave Caillebotte (1848-1894)
Study of a Kneeling Floor-Scraper, Bare-Chested, Viewed from the Front
Source Kirk Vaebedoe: Gustave Caillebotte, 1987 Author
HYPERLINK "/wiki/Gustave_Caillebotte"Gustave Caillebotte

Part A

II

Closed reduction intermetacarpal Kirschner wire fixation in the treatment of unstable fractures of the base of the first metacarpal

Injury. 2012 Feb;43(2):246–251

A.P.A. Greeven
T.D. Alta
R.E. Scholtens
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F.M. van der Linden

Abstract

The purpose of this study was to describe the results of extra-articular and intra-articular fractures, at the base of the first metacarpal, treated with closed reduction and percutaneous fixation with intermetacarpal Kirschner wires. Outcome was evaluated by experienced pain, functional outcome and radiographic indications for arthritis. In total, 25 patients with unstable fractures at the base of the first metacarpal underwent closed reduction and percutaneous fixation of the fracture. Prospectively collected data of 25 consecutive patients were evaluated retrospectively, assessing stability of fixation, operation time and the occurrence of fracture dislocation during and after treatment. All patients were assessed at 1, 3, 6 and 24 months. Follow-up included questionnaires: functional tests including Grip and Pinch measurement and Radiographic analysis for post-traumatic arthritis, using the modified Eaton–Littler classification. In total, 15 patients with extra-articular fractures and 10 patients with intra-articular fractures were treated with this technique. In the group of extra-articular fractures of 15 patients, only one patient had loss of Grip strength greater than 20% in comparison with the contra-lateral side (corrected for hand dominance). No clinically important difference was found for Pinch strength. One patient experienced functional limitations and was unable to return to a previous hobby. In the patients' group with intra-articular fractures, seven patients had a Bennett's fracture and three a Rolando's fracture. One patient with a Bennett's fracture had a loss of Pinch strength greater than 20% corrected for hand dominance. One of the three patients with a Rolando's fracture had Grip loss greater than 20%. None of the patients with intra-articular fractures experienced any functional limitations. The described fixation procedure results in a stable fixation of the fracture fragments, and no secondary dislocation of the fracture occurred. Fractures consolidated within 32 (26–50) days and no new fractures were observed. These results suggest that this technique can be safely used in the treatment of extra-articular fractures as well as intra-articular fractures at the base of the first metacarpal.

Level of Evidence: **Therapeutic study, Level III**

Introduction

Unstable first metacarpal base fractures are usually treated surgically; however, it is still debated whether closed or open reduction gives optimal results [20, 28, 31, 42, 43]. Various surgical procedures have been described, including intra-articular positioned osteosynthesis [29, 30, 32, 44-48]. In the late 1980's, a retrospective study described the treatment of fractures at the base of the first metacarpal bone with parallel extra-articular positioned Kirschner wires [11]. In the article by van Niekerk, two of the 23 included patients could not be treated with closed reduction and K-wire fixation, and open reduction and Kirschner wire fixation were necessary. The treatments of three other patients were not defined. During follow-up (6.25 years, range 1.5–9 years), nine patients reported slight complaints of which three patients reported these complaints to interfere with daily activities, hobby or sport. On the basis of these results, the authors advocated the closed reduction and fixation method, as open reduction and fixation would be more difficult.

Several other percutaneous fixations have been described placing the Kirschner wires through the base of the first metacarpal and into the trapezium [49, 50]. Intra-articular Kirschner wires give additional damage to the articular surface. This seems contradictory in the treatment of intra-articular fractures with the aim of anatomical reduction and preventing the development of post- traumatic arthritis.

As the reported results by van Niekerk are incomplete and nine out of 23 patients reported complaints, the current study evaluated the closed reduction and extra-articular fixation method to see if there is still medical evidence for its wide use in the Netherlands. The purpose of this study was to evaluate the clinical and radiological outcomes of the closed reduction and percutaneous fixation method described by van Niekerk in patients with intra- and extra-articular fractures of the base of the first metacarpal.

Materials and methods

The medical ethics committee of the Groene Hart Hospital approved this study. Prospectively collected data of patients presenting with unstable fractures of the base of the first metacarpal at our Accident and Emergency Department between 1998 and 2008 were retrospectively reviewed. The 1972 Green and O'Brien classification was used to describe all fractures (**Figure 1**) [51].

In total, 25 patients were operated for unstable fractures at the base of the first metacarpal. Under fluoroscopy, closed reduction was achieved by longitudinal traction, abduction and extension of the thumb in combination with pronation of the metacarpus. By keeping traction on the thumb, the reduction was maintained allowing two parallel 1.6 mm Kirschner wires to be placed. The K-wires were positioned approximately 2 cm apart, through the first metacarpal with a 90° angle and also through the second metacarpal (**Figure 2**).

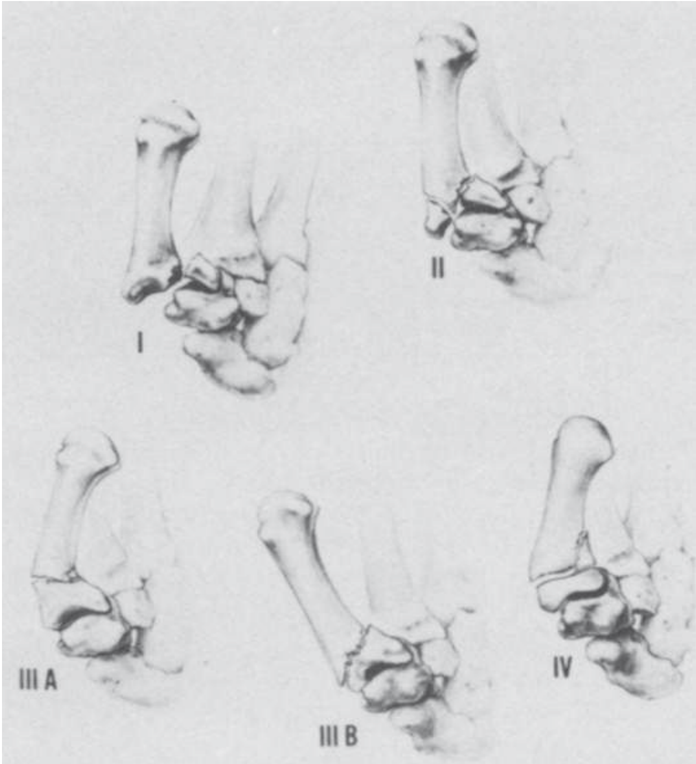

Figure 1. Classification of thumb fractures; Type I Bennett's fracture, Type II Rolando's fracture, Type IIIA Transverse extra-articular fracture, Type IIIB Oblique extra-articular fracture, Type IV Epiphyseal fracture. (Re-printed with kind permission from Elsevier Publisher® from "Fractures of the base of the first metacarpal bone: results of surgical treatment. J.L.M. van Niekerk, R. Ouwens; Injury, Vol 20, Issue 6, p 359-262 (Nov) 1989.)

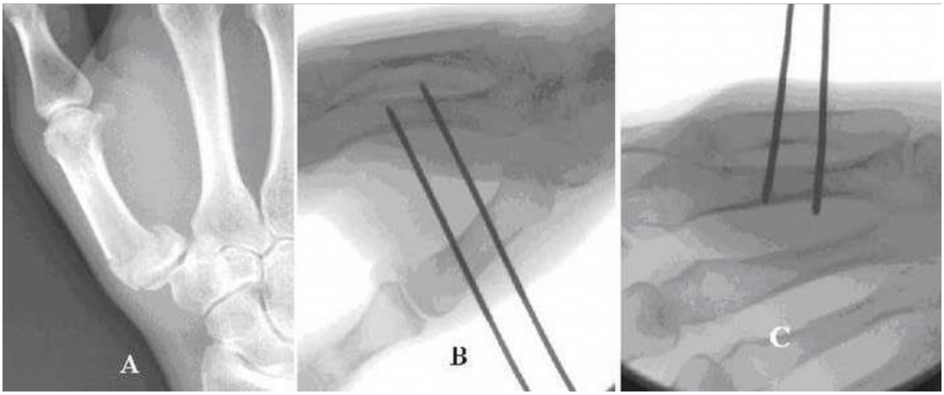

Figure 2. Extra-articular fracture and its surgical treatment.
(A) Oblique view of the fracture. (B, C) Oblique views after treatment (same patient)

A maximal intra-articular step-off of 2 mm was accepted. Stability of the fixation was evaluated under fluoroscopy by moving the thumb. In patients where movement in the fracture was still possible, whilst maintaining adequate reduction, an additional cast was applied. Patients were operated by one of the staffs (trauma) surgeons and a surgical resident within 24 hours after trauma.

Patients were seen for follow-up after 1, 3, 6 and 24 months. At 1-month follow-up, radiographs were made to confirm consolidation. When callus formation was present, the K-wires were removed under local anaesthesia. In the absence of callus formation, the patient was re-examined with radiographs 1 or 2 weeks after the first evaluation.

At 3- and 6-month follow-up, wound healing and functional recovery were evaluated.

At 24-month follow-up, patients were asked to answer a questionnaire describing pain and function. To evaluate pain, a visual analogue scale, ranging from 0 cm (no pain) to 10 cm (worst imaginable pain), was used. In addition, patients were asked to report limitations in performing their daily work or hobbies. Function was evaluated by measuring Pinch and Grip-strength using the Jamar® Hydraulic Hand Dynamometer and Jamar® Hydraulic Pinch Gauge (Fabrication Enterprises Inc., New York, NY, USA).

To compare the Pinch and Grip strength between the injured and non-injured hand, a minimally clinically important difference (MCID) was set at a difference of 20%, compared with the contralateral side and adjusted for hand dominance as suggested by Crosby et al [35].

Radiographs were made to evaluate post-traumatic arthritis using the Van Niekerk and Owens modification of the Eaton and Littler classification: Stage I: no clear arthritic changes, Stage II: osteophytes smaller than 2 mm, Stage III: osteophytes larger than 2 mm or joint narrowing and Stage IV: joint space more or less disappeared [11, 37].

The Statistical Package for Social Sciences (SPSS) version 14.0 was used for all statistical analyses. A non-parametric Mann–Whitney test was used to compare the functional results between the injured and non-injured hand.

Results

Twenty-five consecutive patients with a mean age of 31 years (±14 (SD), range 10–63 years), with 25 closed unstable first metacarpal base fractures were treated. Twenty-one patients were injured after a fall (**Table I**). All patients were male except one 10-year old girl, who was treated for an epiphyseal fracture. Of the 25 patients, 10 patients had an intra-articular fracture (e.g. seven Bennett's and three Rolando's fractures).

Five patients were lost to follow-up after 6 months. At 24- month follow-up, 20 patients were evaluated (80%), and in 17 patients control radiographs were made (68%). None of the patients reported a visual analogue score (VAS) higher than 4 (**Figure 3**). Patients described no loss or restriction of function. All patients returned to their former work. One patient, with an extra-articular fracture, was unable to carry out a previous hobby.

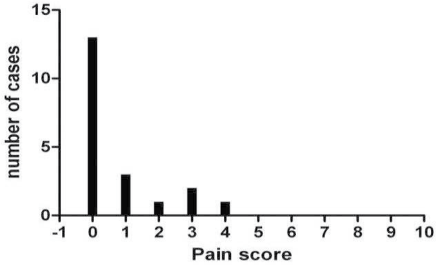

Figure 3. Pain rating (Visual Analogue Score). Pain scoring at 24-months follow-up.

Table I Patient Characteristics

	Sex	Age	Fracture side	Trauma Mechanism	Fracture Type	Operation time (min)	Cast Immobilisation	K-wire removal (days)	Complications
1	M	31	R	fighting	Extra Oblique	30	Yes	31	none
2	M	20	L	fall	Rolando Y	8	Yes	37	none
3	M	16	L	fall	Extra Transverse	25	Yes	28	none
4	M	16	R	fighting	Extra Transverse	20	No	29	none
5	M	63	R	fall	Extra Transverse	10	No	26	none
6	F	10	L	fall	Epiphyseal	32	Yes	32	none
7	M	34	R	fall	Extra Oblique	11	No	50 [#]	Pintract infection
8	M	41	R	fall	Rolando T	9	No	31	none
9	M	43	R	motorcycle accident	Extra Oblique	26	Yes	33	none
10	M	44	L	fall	Extra Transverse	10	Yes	29	none
11	M	46	L	fall	Bennett	20	No	35	none
12	M	17	R	fall	Extra Transverse	13	No	30	none
13	M	26	L	fall	Extra Oblique	7	Yes	38	none
14	M	35	R	fall *	Extra Transverse	113	Yes	41	none
15	M	24	L	fall	Extra Oblique	15	No	26	none
16	M	28	R	fall	Bennett	17	No	29	none
17	M	19	R	fall	Extra Oblique	45	No	30	Pintract infection
18	M	34	R	fighting	Extra Oblique	9	No	31	Pintract infection
19	M	52	R	fall	Extra Transverse	25	Yes	31	none
20	M	43	R	motorcycle accident *	Rolando T	190	Yes	37	none
21	M	49	L	fall	Bennett	20	Yes	28	none
22	M	18	R	fall	Bennett	5	No	30	none
23	M	16	L	fall	Bennett	11	Yes	32	none
24	M	18	L	fall	Bennett	8	No	30	none
25	M	39	L	fall	Bennett	6	No	30	none
	Age	31			Average operation time	27 min		32 days	
					Adjusted for Multi-trauma patients	17 min			

*= multi-trauma patient

II

Technique

The average operation time was 27 minutes (range 5–190 minutes). Of the 25 patients, two patients had multiple fractures and injuries and operation time for the procedure of the metacarpal fracture was not documented individually. Average operation time corrected for these two multi-trauma patients was 17 minutes (range 5–45 minutes). The type of fracture did not influence the duration of the operation (**Table I**).

Twelve patients received additional cast immobilisation after fixation because of instability of the fracture after testing with fluoroscopy. None of the fractures showed dislocation at 1-month follow-up. K-wires were removed after a mean of 32 days (range 28–50 days). No new fractures were observed during follow-up.

Step-off

All intra-articular fractures were treated with closed reduction and percutaneous fixation. A 2mm step-off was accepted during surgery. No secondary dislocation occurred. Fluoroscopy images were not saved digitally and fluoroscopy images of most of these patients were untraceable. Consequently, the exact accepted step-off of the fracture during surgery cannot be reported, other than smaller than 2 mm.

Function

Functional testing with the Jamar® Dynamometer showed no significant difference in Pinch or Grip strength between the injured and non-injured hand of each patient (**Figure 4**). Reported pain did not influence the functional outcome. The difference in Pinch and Grip strength adjusted for hand dominance showed that 90% of patients in the extra-articular group and 71% of patients in the intra-articular group had no clinically important difference (**Tables II and III**).

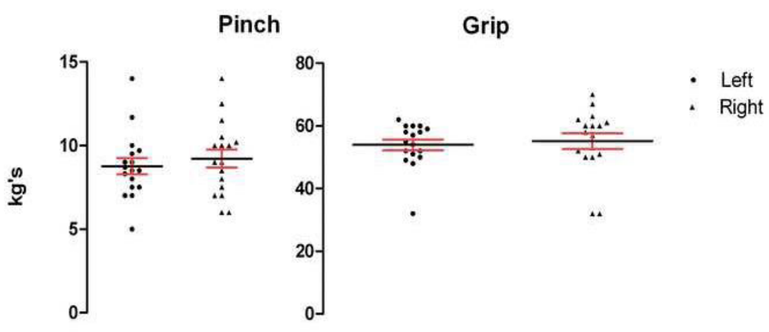

Figure 4. Functional results at 24-months follow-up

Extra-articular fractures

In the group of 15 patients with extra-articular fractures (**Table II**), all patients returned to their previous work. One patient was unable to carry out a previous hobby. In one patient, the Grip strength of the injured hand showed a loss of 25.7% in comparison with the contra-lateral side. This patient did not experience any loss of function and reported a subjective force of 8 out of 10. None of the patients with extra-articular fractures showed arthrotic changes on radiographs (modified Eaton and Littler classification: Stage I: no clear arthrotic changes).

Intra-articular fractures

In the group of patients with intra-articular fractures, seven patients had a Bennett's fracture and three patients had a Rolando's fracture. All patients were able to return to their work and hobbies (**Table III**).

In the group of patients with Bennett's fractures, one patient had a loss of Pinch strength of 22.2% in comparison with the contra-lateral side. The patient did not experience any pain or functional limitations and reported a subjective force of 9 out of 10. In one patient with a Bennett's fracture, the radiographs showed osteophytes smaller than 2mm (modified Eaton and Littler classification Stage II). This patient reported a VAS score of 3.

Of the patients with Rolando's fracture, one patient showed a difference in Grip strength of 38.5%. The patient reported a subjective force of 8 out of 10 and a VAS score of 1.

Table II Extra-articular fractures at 24 months follow-up

	Age	Fracture	Hand dominance	Difference % Pinch	Difference % Grip	Pain (VAS)	Force (subjective)	Work return	Hobby return	Pinch L (kg)	Pinch R (kg)	Grip L (kg)	Grip R (kg)	Arthritis Eaton-Littler Class.
17	19	Extra Obli	R	4,9%	5.0%	3	7	Yes	Yes	9,7	10,2#	60	63#	1
18	34	Extra Obli	R	*	*	0	4	Yes	**No**	*	*	*	*	*
19	52	Extra Trans	*	*	*	*	*	Yes	Yes	*	*	*	*	*
12	17	Extra Trans	R	5,9%	-18,0%	0	10	Yes	Yes	9	8,5#	49	60#	1
13	26	Extra Obli	R	6,8%	**-25,7%**	0	8	Yes	Yes	11,7#	12,5	52#	70	1
14	35	Extra Trans	R	16,7%	4,8%	0	10	Yes	Yes	7,5	9#	59	62#	1
15	24	Extra Obli	*	*	*	*	*	Yes	Yes	*	*	*	*	*
3	16	Extra Trans	R	*	*	0	8	Yes	Yes	*	*	*	*	*
4	16	Extra Trans	R	0,0%	3,8%	0	10	Yes	Yes	7,5	7,5#	51	53#	1
5	63	Extra Trans	R	0%	24%	0	10	Yes	Yes	10	10#	48	50#	1
6	10	Epifysiolyse	L	-16,7%	0%	0	8	Yes	Yes	5#	6	32#	32	1
7	34	Extra Obli	*	*	*	*	*	Yes	Yes	*	*	*	*	*
1	31	Extra Obli	R	17,4%	0%	0	10	Yes	Yes	8,5	11,5#	60	60#	1
9	43	Extra Obli	R	5%	6,9%	0	8	Yes	Yes	9,5	10#	54	58#	1
10	44	Extra Trans	R	5,9%	8,5%	1	10	Yes	Yes	8,5#	8	58#	61	1
	31								Average:	8,7	9,3	52	57	

*= lost to follow-up

Table III Intra-articular fractures and Difference in Pinch and Grip

	Age	Fracture	Hand dominance	Work Return	Hobby Return	Pain (VAS)	Force (subjective)	Pinch L (kg)	Pinch R (kg)	Grip L (kg)	Grip R (kg)	Difference % Pinch	Difference % Grip	Arthritis Eaton-Littler Class.
21	49	Bennett	L	Yes	Yes	4	10	7,0#	6,0	58#	50	14,3%	13,8%	1
22	18	Bennett	*	Yes	Yes	*	*	*	*	*	*	*	*	*
23	16	Bennett	R	Yes	Yes	0	9	7,0#	9,0	57#	60	-22,2%	5,0%	1
24	18	Bennett	*	Yes	Yes	*	*	*	*	*	*	*	*	*
25	39	Bennett	L	Yes	Yes	1	7	8,0#	7,0	62#	52	12,5%	16,1%	1
11	46	Bennett	L	Yes	Yes	3	10	9,0#	10	55#	57	-10,0%	-3,5%	2
16	28	Bennett	R	Yes	Yes	2	10	8,7	10,5#	50	51#	17,1%	2,0%	1
2	20	Rolando Y	R	Yes	Yes	0	9	*	*	*	*	*	*	*
8	41	Rolando T	L	Yes	Yes	0	10	14	14#	60	67#	0,0%	10,4%	1
20	43	Rolando T	R	Yes	Yes	1	8	8,3	7,0#	52	32#	-15,6%	-38.5%	1
	32						Average:	8,9	9,1	56	53			

*= lost to follow-up

II

Complications

In three patients, pin-tract infections occurred requiring treatment with oral antibiotics. In one of these patients, K-wire removal was delayed (50 days) compared to the average (32 days) of all 25 patients (**Table I**). One patient complained of a cosmetic deformity of the thumb. Neither clinical examination nor radiographic imaging showed an objective deformity (**Table I**); the patient was referred to another hospital for a second opinion.

Lost to follow-up

In total, five patients (20%) were lost to follow-up at 24 months, three of these patients had an extra-articular fracture. Two patients had returned to work and hobbies at previous follow- up. One patient was unable to carry out a previous hobby. This was the patient who was referred to another hospital for a second opinion. One other patient had been successfully treated with antibiotics for a pin-tract infection. Two patients with extra- articular fractures were interviewed on the telephone because they were unable to visit the hospital for clinical examination at 24months. Both patients did not report any pain, but one experienced loss of force (**Table II**).

Two patients with intra-articular fractures were lost to follow-up at 24 months. Both patients had returned to work and hobby during earlier follow-up. One other patient did not visit the hospital at 24-month follow-up and was interviewed on the telephone reporting no pain and a subjective force of 9 out of 10.

Discussion

The purpose of this study was to evaluate if extra-articular as well as intra-articular fractures could be treated successfully with Van Niekerk's closed reduction and percutaneous fixation [11].

The described technique gave adequate fixation of the fracture in all 25 patients. No dislocations of the fractures occurred during treatment. All patients with intra-articular fractures returned to their former work and hobby. Only one patient, with an extra-articular fracture, was unable to return to a previous hobby.

Ninety percent of the patients with extra-articular fractures had no clinically important difference in Pinch or Grip strength. The difference in Pinch and Grip strength showed that 71% of patients with an intra-articular fracture did not have a clinically important difference.

The treatment of articular fractures and fracture dislocations at the base of the first metacarpal are challenging [47]. Previous authors have stated that the quality of the reduction is correlated with the development of arthritis, although it had developed in almost all cases, even after exact reduction [20]. The amount of anatomic incongruity that can be accepted is still debated. Several authors accept an intra-articular step-off of 2mm [43, 52]. Other authors will not accept any displacement and choose open reduction and internal fixation to achieve this. Extensive dissection for open reduction can result in further damaging of the already injured hand [37].

Percutaneous techniques cause less damage to the surrounding soft tissues and are associated with less infections and ligament damage [34, 52, 53]. Huang and Fernandez stated that in most cases Bennett's fractures can be treated with closed reduction with Kirschner wire fixation [46]. Other authors reported good results in treating Rolando's fractures with external fixators [54]. Niempoog and Waitayawinyu reported very good results when an external fixator was applied in combination with Kirschner wires [55]. The position of these Kirschner wires is similar to the intermetacarpal Kirschner wires in the current technique.

In this study, all patients with an intra-articular fracture (Bennett's and Rolando's fracture) returned to their work and hobbies, and only one patient showed modified Eaton and Littler classification Stage II on radiographs. In three patients, pin-tract infections occurred which were successfully treated with oral antibiotics. All pin-tract infections occurred in patients with extra- articular fractures. Fracture consolidation took longer than average in one of these patients. If this was caused by the infection is unknown. In all three cases no additional casting was applied. Maybe cast immobilisation protects pin tracts from becoming infected.

A limitation of this study is the 20% loss to follow-up at 24 months. Secondly, the study is a case series and consequently there is no control group. Although the data is prospectively collected, analysis is done retrospectively. All unstable fractures at the base of the first metacarpal were treated similarly. Within the intra-articular group, seven Bennett fractures and three Rolando fractures were treated. Another limitation is that the exact accepted intra-articular step-off after fixation was not exactly known per patient, other than smaller than 2 mm.

In addition, no standardised questionnaire was used. And for optimal evaluation of radiographic arthritis longer follow-up could be beneficial [37].

For future studies it could be interesting to focus on larger groups of patients with similar fractures. It would also be valuable to compare this closed technique with open reduction and internal fixation.

In this study we show that closed reduction intermetacarpal Kirschner wire fixation can be safely used in the treatment of extra- articular fractures at the base of the first metacarpal. Intra-articular fractures at the base of the first metacarpal can be treated with this technique provided there is a maximal intra-articular step-off of 2 mm after closed reduction and percutaneous fixation.

III

Open reduction and internal fixation versus closed reduction and percutaneous fixation in the treatment of Bennett Fractures: a systematic review

Injury. 2019 Aug;50(8):1470–1477.

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Abstract

Purpose

Open reduction and internal fixation (ORIF) of Bennett fractures is increasingly preferred over closed reduction and percutaneous fixation (CRIF) in an attempt to prevent the development of post-traumatic arthrosis. The aim of this systematic review was to determine whether the preference for ORIF is justified based on the available literature regarding functional outcome and complications after surgery.

Methods

A systematic review was performed in Medline, Embase, Cochrane CENTRAL, Web of science, and Google scholar. Duplicates were removed and title and abstract were screened after which full text articles were analysed. The reference lists of selected articles were screened for additional relevant studies. Study characteristics were recorded and methodological qualities were assessed after which data was extracted from the included articles. The Eaton-Littler score for post-traumatic arthrosis on follow-up X-rays was used as primary outcome. Secondary outcomes were Grip strength, Pinch strength, persistent pain, fixation failure, functional impairment, infection and surgery time.

Results

Ten studies were included; three retrospective comparative studies and seven retrospective case series. Of the 215 patients in these studies, 138 had been treated using an open technique and 77 by a closed percutaneous technique. The pooled rate of post-traumatic arthrosis was 57.5% (26.6-85.5) in the ORIF group versus 26.1% (3.9-59.0) in the CRIF group. The pooled means Grip strength was 48.3kg (95% CI; 39.7-56.9) versus 43.4kg (95% CI; 22.9-63.8) for ORIF and CRPF, respectively. Persistent pain was seen in 32.9% (0.6-83.1) in ORIF patients versus 22.3% (8.1-41.1) in the CRIF patients. Fixation failure was significantly more often seen in the ORIF patients, 8.2% (0.7-22.8) vs. 2.9% (0.8-9.1), Risk Ratio 1.132 (0.01-176.745); p=0.048. Functional impairment was similar between the two groups, 1.4% (0.1-4.4) vs 1.8% (0.1-5.7) respectively. Infection was only seen in 5 CRIF patients. Mean surgical operation time was 71.9 minutes for ORIF and 30.2 minutes for percutaneous patients.

Conclusion

The analysed data do not confirm ORIF to prevent post-traumatic arthrosis, secondly more fixation failure and pain was seen in the ORIF group. The pooled data show percutaneous fixation to be preferable over ORIF in the surgical treatment of Bennett fractures.

Level of Evidence: **Therapeutic study, Level II-B**

Introduction

Ever since the 1950's there has been an ongoing debate regarding the best treatment of Bennett fractures [11, 22, 27, 49, 56]. Together with the introduction of new techniques, recent research has reported on outcome after several types of surgical treatment [39, 41, 57-59]. Closed reduction and percutaneous fixation (CRIF) give good clinical results, although complications such as pintract infections and secondary dislocation have been reported [56, 60]. Open reduction and internal fixation (ORIF) is also reported to provide good results and has the advantage of anatomical reduction of the fracture under direct visualisation [22, 38, 61]. Anatomical fracture reduction aims to prevent the development of post-traumatic arthrosis [20]. Secondly, the advantage of open reduction and internal fixation is the possibility of early mobilisation [62]. One of the reasons for the ongoing debate is the quality of the evidence in hand surgery in general and more specific the lack of randomized controlled trials regarding this topic [63, 64].

Part of the discussion is the suggestion that an anatomical reduction might prevent the development of post-traumatic arthrosis. Some authors found a relationship while others were not able to correlate accuracy of fracture reduction with post-traumatic arthrosis [20, 22, 56, 65]. To improve anatomical reduction arthroscopically assisted percutaneous techniques have been introduced to combine visualisation of anatomical reduction with minimally invasive techniques [31, 59].

There is lack of consensus because most studies only describe one surgical technique or only a small sample of patients [64]. This paucity in evidence stresses the importance to evaluate open and closed techniques in a systemic review [66, 67]. Combining results from multiple studies might provide additional insight into the pros and cons for each treatment type.

Therefore, this systematic review aimed to determine the functional outcome and post-operative complications for both techniques in the treatment of Bennett fractures.

Materials and methods

A systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, including (1) a systematic search of the literature, (2) selection of studies, (3) recording of study characteristics, (4) assessment of methodological quality of studies, and (5) extraction and comparison of clinical outcomes [68, 69].

Search strategy

The literature search was conducted on April 6, 2018. The search strategies were developed by a medical librarian and included combinations of different terms and synonyms for Bennett fractures and its surgical treatment. The searches were performed in Medline, Embase, Cochrane central, Web of science, and Google scholar. The detailed search strategies are described in the "***Appendix***".

Selection of studies

After removal of duplicate studies, the title and abstract of the remaining studies were screened to evaluate if they met the following criteria: (1) Language: English. (2) Study design: trial (randomized) or observational (case series or cohort, prospective or retrospective). (3) Population: Humans with Bennett fractures with no additional injury. (4) Intervention: ORIF and/or Percutaneous K-wire fixation. (5) Outcome: post-traumatic arthrosis, hand function, consolidation, or complications. (6) Period: Publication after 2000 [70].

Following screening of title and abstract, the full text articles were screened using the same inclusion criteria. The reference lists of selected articles were screened for additional relevant studies which had not been identified during the search process [71].

Recording of study characteristics

The following study characteristics were extracted from the selected articles: author, title, publication year, country of origin, study design, number of participants, type of surgical treatment and follow-up period. All corresponding authors of the included articles were contacted by email for additional data.

Assessment of methodological quality

The risk of bias was assessed following the instructions by Spindler *et al*. within and between studies and the level of evidence of the selected studies was assessed [72].

Data extraction

As primary outcome, post-traumatic arthrosis was scored by radiological evaluation using the Eaton-Littler classification [11, 37]. Secondary outcomes were surgical time, fixation failure, infection, Grip strength, Pinch strength, persistent pain, functional impairment. Two researchers (APAG and JVG) performed steps 2-6 independently. During step 2, disagreement about selection of studies for full text analysis was resolved by inclusion of the study for full text reading. This way no disputed article was excluded on title and abstract alone. Disagreement during steps 3-5 was resolved by discussion.

Statistical analysis

Meta-analysis of the collected data for either ORIF or percutaneous treatment was performed using MedCalc for Windows, version 16.4.3 (MedCalc Software bvba, Ostend, Belgium; https://medcalc.org;2016 MedCalc). The pooled risk ratios are reported with their 95% confidence intervals (CI) and p-value. Heterogeneity was quantified with Cochran's Q test and I^2 statistic, a fixed effects model was used when the I^2 was < 40%. A random effects model was used for the pooled analysis when the I^2 was ≥ 40%. A p-value less than 0.05 was considered statistically significant.

Since many studies did not provide a mean with standard deviation for continuous outcome measures (which would be needed for a formal meta-analysis), a weighted average was also calculated for the two treatment options. The sample size was used as weighting factor.

Results

Study selection

The search identified a total of 809 articles in Medline, Embase, Cochrane CENTRAL, Web of science and Google scholar (**Figure 1**). After removing 273 duplicate studies, the title and abstract of the remaining 536 articles were screened. Ten articles were included in the systematic review. The corresponding author of one study replied to an email and provided additional information (*i.e.*, Pinch and Grip strength in kilograms instead of % of uninjured side) [73].

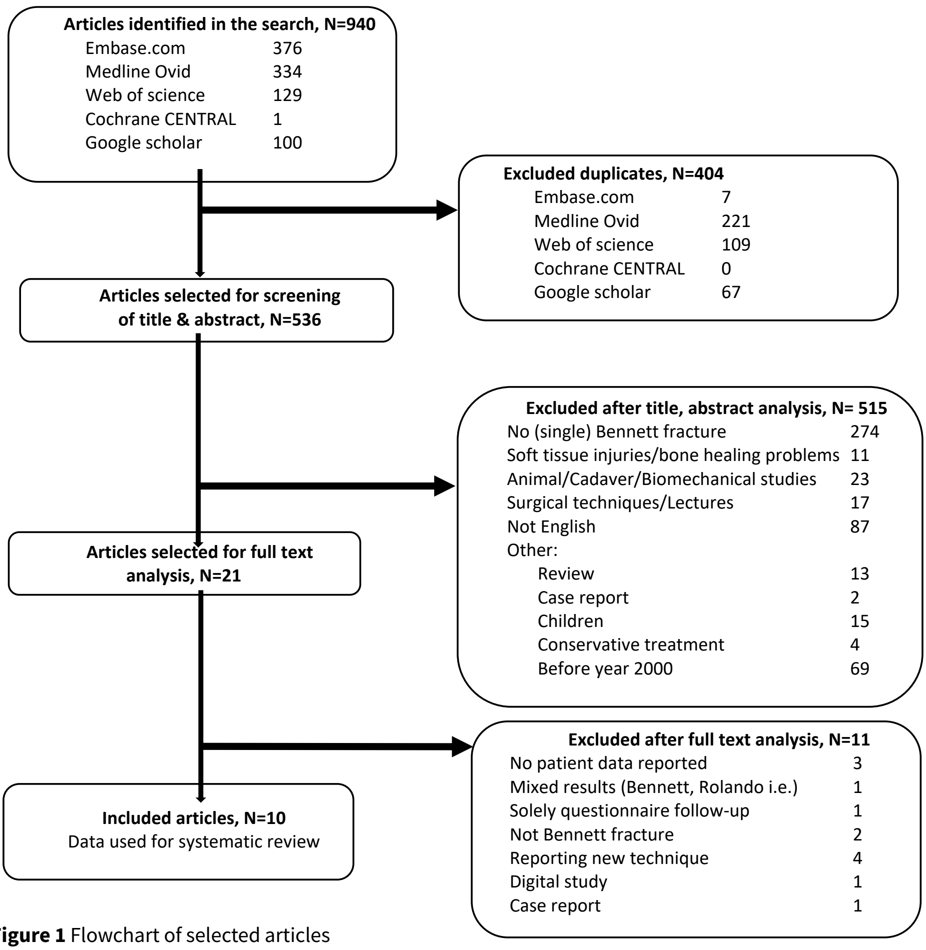


Figure 1 Flowchart of selected articles

Risk of bias and level of evidence

The graded evidence of the included studies is described in **Table I** [72]. All included articles were retrospective studies [22, 30, 39, 41, 42, 56, 57, 59, 62, 73]. Three of the included articles were retrospective comparative studies [42, 57, 59]. The remaining seven studies were retrospective case series, four studies on open reduction and internal fixation (ORIF) and three studies on closed reduction and percutaneous fixation (CRIF) [22, 30, 39, 41, 56, 62, 73].

Table I Study characteristics of included articles

Nr.	Study	Year	Country	Design	Fixation	No. of patients	Follow-up (months)	Level of Evidence
1	Fischborn *et al. [41]*[#]	2018	Germany	Retrospective cohort	ORIF	3	41.9 (30.5-74.9)	IV
2	Levy *et al.[39]*	2018	Argentina	Retrospective cohort	ORIF	21	8 (3-10)	IV
3	Pomares *et al.[59]*	2016	France	Retrospective cohort	ORIF vs CRIF	21 (10 vs 11)	33 vs 27	III
4	Uludag *et al.[62]*	2015	Turkey	Retrospective cohort	ORIF	9	14 (10-24)	IV
5	Adi *et al.[73]*	2014	France	Retrospective cohort	CRIF	7	14 (9-22)	IV
6	Greeven *et al.[56]*	2012	Netherlands	Retrospective cohort	CRIF	7	24	IV
7	Leclerc *et al.[22]*	2012	France	Retrospective cohort	ORIF	24	83 (54-154)	IV
8	Zhang *et al.[57]*	2012	China	Retrospective cohort	ORIF vs CRIF	79 (56 vs 23)	39 (21-47) vs 35 (31-41)	III
9	Sawaizumi *et al.[30]*	2005	Japan	Retrospective cohort	CRIF	12	26 (8-54)	IV
10	Lutz *et al. [42]*	2003	Austria	Retrospective cohort	ORIF vs CRIF	32 (15 vs 17)	84 (36-216)	III
					Total	215 (138 vs 77)		

ORIF = Open Reduction and Internal Fixation
CRIF = Closed Reduction and Percutaneous Fixation
[#] 3 patients included who had been treated by Open Reduction and Internal Fixation

Study characteristics

No multicentre randomized studies were found (**Table I and II**). One article reported on a mixed group of patients who had been treated with open reduction after which some were fixed with K-wires and others with internal fixation. In order to prevent contamination only the patients who had primarily been treated with ORIF were included in this systematic review [41]. The ten articles included a total of 215 patients. ORIF was performed in 138 patients and CRIF was performed in 77 patients. Open surgery consisted of open reduction and internal fixation using screw, plate fixation or tension band wiring (**Table II**).

Table II Data collected from comparative studies (Open vs Percutaneous)

Studies	*Pomares et al.*		*Zhang et al.*		*Lutz et al.*	
	10 x ORIF	11 x CRIF + Arthroscopy	56 x ORIF	23 x CRIF	15 x ORIF	17 x CRIF
Mean age (years)	30	37	32 (19-51)	35 (21-47)	37	28
Follow-up (months)	33 (28-36)	28 (24-31)	39 (36-42)	35 (31-41)	84 (36-204)	84 (36-204)
Fracture classification	>30% joint	>30% joint	Gedda I	Gedda I	Gedda I	Gedda I
Fixation type	Screw(s)	Screw(s)	Tension band wiring	K-wire	Screw	Wagner method
Surgery time (minutes)	56.6 (45-64)	42.6 (26-70)	-	-	-	-
Immobilization (weeks)	7.1	3.9	0.2	5 (4-6)	4	6
Pain (VAS)	-	-	0 (0-2)	0 (0-5)	-	-
Persistent Pain	6/10 (60%)	1/11 (9.1%)	1/56 (1.8%)	1/23 (4.3%)	4/15 (26.7%)	2/17 (11.8%)
Grip (% of contralateral)	52 kg (-)	48.7 kg (-)	43 (22-48) kg	39 (21-45) kg	89 kPa$	87 kPa$
Pinch (% of contralateral)	10.7 kg (-)	9.3 kg (-)	7.4 (3.9-8.2) kg	5.8 (3.1-7.5) kg	42 kPa$	40 kPa$
(Quick) DASH	9.5	3.1	-	-	-	-
Consolidation time (weeks)	-	-	4 (3-6)	4 (3-5)	-	-
Arthritis Stage 1/2/3/4*	-	-	-	-	4/9/3/0	5/10/0/0
Additional information/ Complications	1 loss of strength 1 mal-union 1 paraesthesia 4 screw migration 2 inadequate reduction	1 x CRPS	100% 2nd operation for removal of tension band at 8 months	3 pain + reoperation 2 patients excluded after loss of reduction in percutaneous group were re-operated£		

Results are presented as mean (range)
- = Not reported
ORIF = Open Reduction and Internal Fixation
CRIF = Closed Reduction and Percutaneous Fixation
CRPS = Complex Regional Pain Syndrome
£ = excluded from follow-up
* = Eaton Littler classification [11]
$ = Balloon Dynamometer

One comparative study compared ORIF with an arthroscopically assisted percutaneous fixation (**Table III**) [59]. Closed reduction and percutaneous fixation consisted of percutaneous K-wire fixation according to Iselin, parallel K-wire fixation according to Van Niekerk *et al.* or leverage pinning using Wagner's technique [11, 30, 73].

Primary outcome: post-traumatic radiographic arthrosis

For 79 patients, post-traumatic arthrosis was scored using the Eaton Littler score. Post-traumatic arthrosis (Eaton-Littler score 2 and higher) was more common in patients treated with ORIF (pooled mean 52.8%; CI 30.0-75.0) than in patients treated with CRIF (pooled mean 28.0%; 95% CI 2.9-65.7) (**Table IV**).

Secondary outcomes: Surgical time, Fixation failure, Infection, Pain, Grip, Pinch, and Functional impairment (results of the weighted and pooled analyses are shown in **Table IV**). The associated forest plots are shown in **Supplemental Table SI**)

Operation time was reported in 37 ORIF patients and 25 CRIF patients. A weighted average could be calculated of 71.9 minutes for the ORIF patients and 30.2 minutes for the CRIF patients (**Table IV**).

Fixation failure (i.e. screw migration, inadequate reduction and loss of reduction) could be pooled and analysed in 206 patients. Statistical analysis showed a pooled proportion for ORIF patients was 8.2% (0.7-22.8) versus 2.9% (0.8-9.1), which was statistically significant (p= 0.048).

Post-operative infections could be pooled and analysed in 129 ORIF patients and 77 CRIF patients. Infection only occurred in 5 CRIF patients. The pooled proportion for ORIF patients was 1.0% (0.1-3.3) versus 7.0% (0.80-18.7) for CRIF patients.

Pain was scored using the Visual Analogue Score (VAS) in 75 ORIF patients and 60 CRIF patients. A VAS of 2 and more was seen in 12 ORIF patients and 11 CRIF patients. The weighted average of a VAS of 2 and more within each group was 32.9% (0.6-83.1) vs 22.3% (8.1-41.1) respectively and was not statistically significant (p=0.627).

Grip strength could be pooled and analysed in 167 patients. Statistical analysis showed pooled mean for ORIF patients was 43.4 kg (95% CI; 22.9-63.8) versus 48.3 kg (95% CI; 39.7-56.9) for CRIF patient, a difference of 0.70 kg.

Pinch strength was reported in 37 ORIF treated patients and 25 CRIF patients. The weighted average was 10.35 kg vs 8.76 kg respectively. For 27 of the ORIF patients the standard deviation (SD) was not reported. No further statistical analysis could therefore be performed.

Functional impairment data was pooled for 108 ORIF treated patients and 77 CRIF patients. One ORIF patients was reported with functional impairment versus no patients in the CRIF group. Statistical analysis showed a pooled proportion of 1.4% (0.1-4.4) for ORIF patients and 1.8% (0.1-5.7) for CRIF patients.

Overall complications and reoperations for all patients

An overview of all complications and reoperations is reported separately (**Table V**).

Table III Data collected from single treatment studies

Studies	*Fischborn et al.*	*Levy et al.*	*Uludag et al.*	*Adi et al.*	*Greeven et al.*	*Leclerc et al.*	*Sawaizumi et al.*
	3 x ORIF[#]	21 x ORIF	9 x ORIF	7 x CRIF	7 x CRIF	24 x ORIF	12 x CRIF
Age (years)	38 (27-47)	32 (22-52)	33 (16-56)	31 (16-60)	31 (16-49)	40 (24-64)	36 (18-79)
Follow-up (months)	41.9 (30.5-74.9)	8 (3-10)	14 (10-24)	14 (9-22)	24	83 (54-154)	26 (8-54)
Fracture classification	-	Gedda I / II	-	2 Gedda I 5 Gedda II	-	10 Gedda I 14 Gedda II	9 x Gedda I 3 x Gedda III
Fixation type	Screws	Pins or screws	8 x Screw / 1x Plate	K-wire, Iselin + connector	K-wire parallel	Screws	K-wire, leverage pinning
Surgery time (minutes)	67 (52-82)	-	-	29 (16-40)	12 (6-20)	79	-
Immobilization (weeks)	-	5	1.4	0	4	2	-
Pain (VAS)	2	0 (1-1.5)	1.2 (0-3)	0 (0-3)	2 (0-4)	1.4 (1.0-1.8)	-
Persistent Pain (%)	-	-	5/9 (56%)	2/7 (28.6%)	4/7 (57.1%)	-	3/12 (25.0%)
Grip (kg)	48.5	30.8 (12-45)	-	-	56.6 (51-62)	48.6	40 (29-44)
Pinch (kg)	27.3	-	-	-	8.3 (7.0-10.5)	10.2	-
(Quick) DASH	1.7 (0-38)	15	12 (10-12)	4.5 (0-13.6)	-	-	-
Arthritis Stage 1/2/3/4	-	-	-	7/0/0/0	4/1/0/0[^]	14/9/1/0	10/2/0/0
Additional information / Complications	-	1 secondary dislocation and re-operation	-	2 mal-union no secondary dislocation	3 pintract infection 1 cosmetic deformity 2 cast immobilization	1 secondary dislocation and re-operation	2 pin-tract infection 1 arthroplasty 1 hyperaesthesia

Results are presented as mean (range)

[#] = 3 of 8 patients with Bennett fracture included who have had open reduction and internal fixation

[^] = 2 patients lost to follow-up

Table IV Post-traumatic arthrosis, Fixation failure, Infection, Grip strength and pain

	Post-traumatic arthrosis		Fixation failure		Infection		Pain		Grip (kg)	
Author	ORIF	CRIF	ORIF	CRIF	ORIF	CRIF	ORIF	CRIF	ORIF	CRIF
Fischborn et al. (2018)	-	-	0/3 (0%)	-	0/3 (0%)	-	-	-	45.80 (-, n=3)	-
Levy et al. (2018)	-	-	1/21 (4.8%)	-	0/21 (0%)	-	-	-	30.80 (9.38, n=21)	-
Pomares et al. (2016)	-	-	6/10 (60%)	0/11 (0%)	0/10 (0%)	0/11 (0%)	6/10 (60%)	1/11 (9.1%)	52.00 (2.30, n= 10)	48.70 (3.50, n=11)
Uludag et al. (2015)	-	-	-	-	-	-	4/7 (57.1%)	-	-	-
Adi et al. (2014)	-	0/7 (0%)	-	0/7 (0%)	-	0/7 (0%)	-	2/7 (28.6%)	-	-
Greeven et al. (2012)	-	1/5 (20%)	-	0/7 (0%)	-	3/7 (42.9%)	-	4/7 (57.1%)	-	56.60 (4.00, n=7)
Leclerc et al. (2012)	10/24 (41.7%)	-	1/24 (4.2%)	-	0/24 (0%)	-	-	-	48.60 (-, n=24)	-
Zhang et al. (2012)	-	-	0/56 (0%)	2/23 (8.7%)	0/56 (0%)	0/23 (0%)	1/56 (1.8%)	1/23 (4.3%)	43.00 (-, n=56)	39.00 (-, n=23)
Sawaizumi et al. (2005)	-	2/12 (16.7%)	-	0/12 (0%)	-	2/12 (16.7%)	-	3/12 (25.0%)	-	39.70 (5.00, n=12)
Lutz et al. (2003)	10/15 (66.7%)	12/16 (75%)	0/15 (0%)	0/17 (0%)	0/15 (0%)	0/17 (0%)	-	-	-	-
Weighted average	20/39 (51.3%)	15/40 (37.5%)	8/129 (6.2%)	2/77 (2.6%)	0/129 (0%)	5/77 (6.5%)	12/75 (16.0%)	11/60 (18.3%)	42,79 (n=114)	43.50 (n=53)
Pooled proportion (95% CI) ‡	52.8% (30.0-75.0)	28.0% (2.9-65.7)	8.2% (0.7-22.8)	2.9% (0.8-9.1)	1.0% (0.1-3.3)	7.0% (0.80-18.7)	32.9% (0.6-83.1)	22.3% (8.1-41.1)	43.4 (22.9-63.8%)	48.3 (39.7-56.9)
Risk Ratio	N.A.		1.132 (0.01-176.745)		N.A.		1.956 (0.130-29.375)			
p-value			p= 0.048				p= 0.627			

SD= Standard deviation

n = number of patients

= Visual Analogue Score of 2 or higher

95% CI = 95% confidence interval

N.A. = Not available

‡ = forest plots for these analyses are shown in **Supplemental Table S1**

Reoperations in ORIF patients was 1.4% and 3.9% in the CRIF patients. An additional 56 (69%) patients were re-operated in the ORIF group for planned hardware removal.

Table V Overall complications and reoperations for all included patients

	ORIF (n=138)		CRIF (n=77)	
	No. with complications	No. with reoperations	No. with complications	No. with reoperations
Delayed Union	0	0	0	0
Fixation failure	8 (5.8%)[#]	2 (1.4%)	2 (3.9%)[*]	2 (3.9%)[*]
Functional impairment	1 (0.7%)	0	0	0
CRPS	0	0	1 (2%)	0
Infection	0	0	5 (6.5%)	0
Pain	16 (11.6%)	0	11 (14.3%)	0
Cosmetic deformity	0	0	1 (1.3%)	0
New fracture	0	0	0	0
Planned removal	0	56 (69%)	0	0

[#] = fixation failure: screw migration and inadequate reduction
[*] = loss of reduction in percutaneous group were all re-operated
ORIF = Open Reduction and Internal Fixation
CRIF = Closed Reduction and Percutaneous Fixation

Discussion

The difference in primary outcome between the two groups of patients is the most important finding in this systematic review. A higher percentage of post-traumatic arthrosis was seen in the ORIF patients compared to CRIF patients, 52.8% vs 28.0 % respectively.

In this systematic review, the follow-up period of the included studies was long enough for post-traumatic arthrosis to develop. Especially in the comparative studies with a follow-up period of 84 months (range 36-204) and 83 months (range 54-154) an advantage of ORIF over CRIF in preventing post-traumatic arthrosis was not found [22, 42].

Based on the pooled data in this systematic review the choice for ORIF in the surgical treatment of Bennett fractures should not be made based on the claim that doing so reduces the chance of post-traumatic arthrosis [20, 38, 40]. The current evidence cannot confirm this statement and seems to confirm the opposite. Possibly, persistent step-off and gap after reduction and fixation should not exceed 2mm, therefore not requiring exploration of the fracture site [11, 56].

The second important finding is the significant difference in fixation failure. Failure occurred in 8.2% ORIF patients versus 2.9% CRIF patients. The additional findings in similar Grip strength, more frequently reported pain and longer surgical time suggest ORIF to be the less preferable technique in treating Bennett fractures.

Infections were more frequently seen in the CRIF group. These pin-tract infections were reported to have been successfully treated with antibiotics and removal of K-wires after consolidation. No additional effect of these infections has been reported. Pain was more frequently seen in the open treated patients, 32.9% versus 22.3%, respectively.

For this systematic review, several limitations should be considered. Unfortunately, only retrospective studies, mostly case series rather than comparative studies could be included.

Secondly, there was considerable heterogeneity in subtypes of Bennett fractures (**Table III**), surgical techniques as well as in choice of outcome measures and follow-up duration across the studies. Because of these limitations detailed subgroup analysis was not possible.

Another limitation is that data presentation per study was sometimes/often incomplete; the lack of standard deviation for instance, hampered the possibilities for a formal meta-analysis and to present the results in forest plots for all outcomes. Unfortunately, most authors of the included studies were unresponsive to a request for additional data.

For the three comparative studies a selection bias might be considered. But because all included patients were included for surgery based on the same surgical indication; Bennett fracture with a Gedda I classification which is similar to an involvement of > 30% of the joint surface, a comparison of these three reported results is possible (**Table II**) (**Supplement II**).

Secondly, within the ORIF and CRIF groups different surgical techniques were used. Although different techniques were used, less invasive techniques have less failure of fixation without the additional risk of pain after open surgery.

It can be debated if a planned removal of osteosynthesis should be seen as a re-operation. A second operation exposes the patient for a second time to risks such as infection, wound healing difficulties, additional adhesion formation, and a possible set back in mobilization. Therefore, the risk of a secondary operation should be compensated by significant benefits from the open technique in comparison with a closed percutaneous technique. In the reported results from all ten included articles no such important difference in outcome for patients treated by open technique were found.

Possibly, these benefits do exist for other intra-articular first metacarpal base fractures (i.e. Rolando, comminuted fractures). Because studies mainly report on a specific surgical technique applied on a variety of intra-articular fractures the focus is on the surgical technique presented. Fracture type specific outcome and comparison is less likely to result in difference in outcome in these studies because of the small sample size. Therefore, the lack of large studies reporting on solely Bennett fractures treated with ORIF and CRIF underlines the importance of assessing the available evidence with a systematic review.

Finally, a closed percutaneous technique was found to take shorter surgical operation time. Further research is necessary to determine if this makes a percutaneous technique more cost effective than an open technique.

These findings warrant the suggestion that first choice of treatment should be a closed percutaneous technique. Only, when no acceptable closed reduction and percutaneous fixation can be reached, an open technique is warranted. Because of the Level of Evidence (III and IV) of the included articles and the limitations mentioned further research is necessary and the current results should be interpreted with caution. The research should focus on the comparison between ORIF and percutaneous fixation for Bennett fractures, preferably in a randomized clinical trial.

Appendix: Search strategies

Embase.com

('bennett fracture'/de OR (((('fracture'/de OR 'intraarticular fracture'/de OR 'joint fracture'/de) AND ('metacarpal bone'/de)) OR 'metacarpal bone fracture'/de) AND ('thumb'/de OR 'thumb injury'/de)) OR ((bennet* NEAR/3 fracture*) OR (fracture* NEAR/10 (metacarp* OR bas*-joint*) NEAR/10 (thumb* OR first))):ab,ti) AND ('surgery'/exp OR surgery:lnk OR 'orthopedic fixation device'/exp OR (surg* OR operative* OR fixat* OR wire* OR orif OR screw* OR plate* OR ((close* OR open) NEAR/3 reduc*) OR osteosynthes* OR approach* OR repair*):ab,ti)

Medline Ovid

(((((Fractures, Bone[mh] OR Intra-Articular Fractures[mh]) AND (Metacarpal Bones[mh] OR Metacarpus[mh]))) AND (thumb[mh])) OR ((bennet*[tiab] AND fracture*[tiab]) OR (fracture*[tiab] AND (metacarp*[tiab] OR base-joint*[tiab] OR basal-joint*[tiab]) AND (thumb*[tiab] OR first[tiab])))) AND (Surgical Procedures, Operative[mh] OR surgery[sh] OR Orthopedic Fixation Devices[mh] OR (surg*[tiab] OR operative*[tiab] OR fixat*[tiab] OR wire*[tiab] OR orif[tiab] OR screw*[tiab] OR plate*[tiab] OR ((close*[tiab] OR open[tiab]) AND reduc*[tiab]) OR osteosynthes*[tiab] OR approach*[tiab] OR repair*[tiab]))

Cochrane CENTRAL

(((bennet* NEAR/3 fracture*) OR (fracture* NEAR/10 (metacarp* OR bas*-joint*) NEAR/10 (thumb* OR first))):ab,ti) AND ((surg* OR operative* OR fixat* OR wire* OR orif OR screw* OR plate* OR ((close* OR open) NEAR/3 reduc*) OR osteosynthes* OR approach* OR repair*):ab,ti)

Web of science

TS=((((bennet* NEAR/2 fracture*) OR (fracture* NEAR/10 (metacarp* OR bas*-joint*) NEAR/10 (thumb* OR first)))) AND ((surg* OR operative* OR fixat* OR wire* OR orif OR screw* OR plate* OR ((close* OR open) NEAR/2 reduc*) OR osteosynthes* OR approach* OR repair*)))

Google scholar

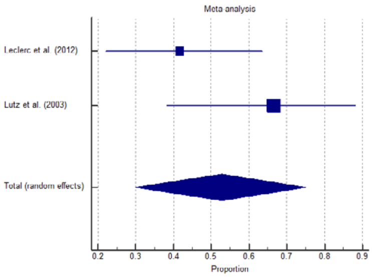
"bennet|bennett fracture|fractures"|"bennet|bennett*fracture|fractures" surgery|surgical|operative|fixation|"closed|open reduction"|osteosynthesis|repair

Supplemental Table S1

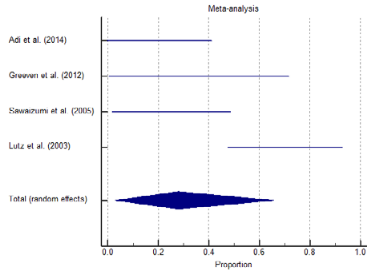
Forest plots for the pooled analysis regarding post-traumatic arthrosis, fixation failure, infection, pain, and grip

A. Post-traumatic arthrosis

ORIF

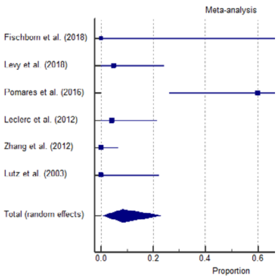


CRIF

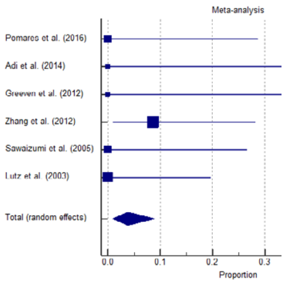


B. Fixation failure

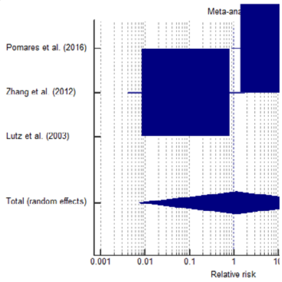
ORIF



CRIF

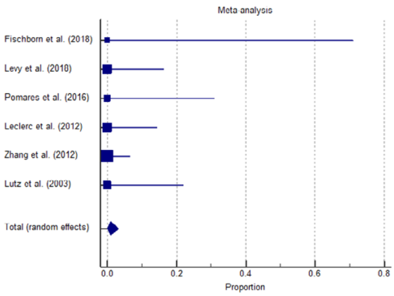


Risk Ratio

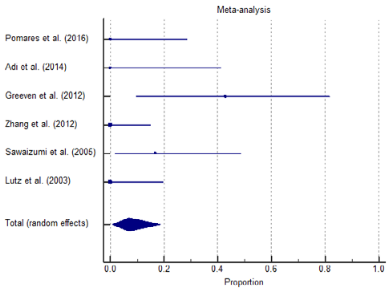


C. Infection

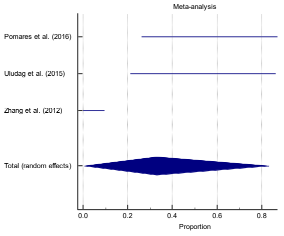
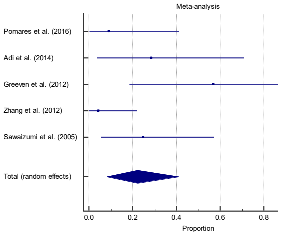
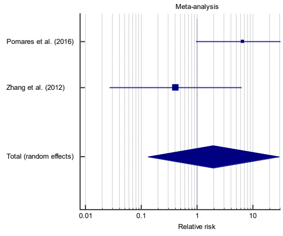
ORIF



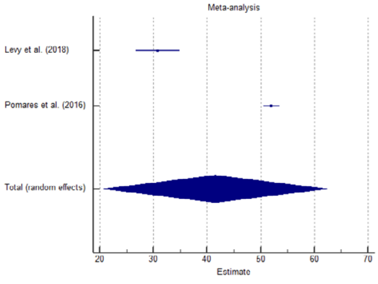
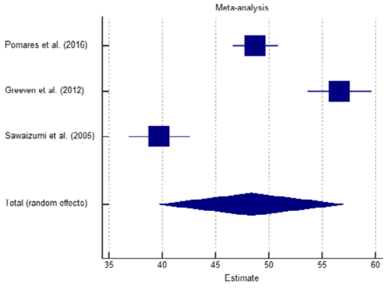
CRIF



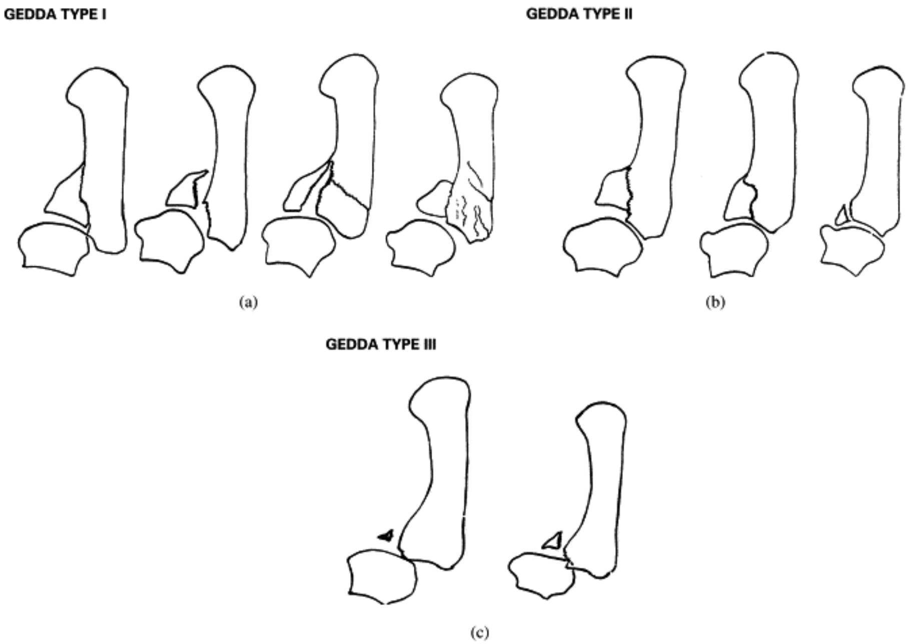
D. Pain

ORIF	CRIF	Risk Ratio
		

E. Grip (kg)

ORIF	CRIF
	

Supplement II: Gedda Classification of Bennett Fractures [27]



Type 1 Large single ulnar fragment and subluxation of the metacarpal base

Type 2 Impaction fracture without subluxation of the thumb metacarpal

Type 3 Small ulnar avulsion fracture fragment in association with metacarpal dislocation

IV

Bennett's fracture: comparative study between open and closed surgical techniques

La fracture de Bennett : étude comparative entre l'ostéosynthèse directe et ostéosynthèse percutaneé

Hand Surg Rehabil. 2019 Apr;38(2):97-101.

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Abstract

Objectives

Aim of this study was to compare outcome after long term follow-up of Bennett fractures treated with Open Reduction and Internal Fixation (ORIF) or Closed Reduction Percutaneous Fixation (CRIF).

Material and methods

Patients treated between 1994 and 2010 were retrospectively assessed during an outpatient clinic appointment using a validated questionnaire (i.e. DASH, VAS), sensory tests, Grip- and Pinch-strength and Radiographic analysis for post-traumatic arthrosis.

Results

Fifty patients were included. Mean follow-up was 10 years. Mean age at trauma was 34 years. ORIF was applied in 35 patients. CRIF was used in 15 patients. No clinical difference in Grip- and Pinch-strength was found. Pain was significantly negatively correlated with decreased strength. Re-operations were performed in 5 ORIF treated patients. Change of sensation of the thumb was found in 13 patients, of which 11 had been treated by ORIF. High pain scores (VAS) were seen in ORIF patients. No correlation was found between post-traumatic arthrosis, surgical technique and functional outcome. A persistent Step-off or Gap larger than 2mm after surgery was significantly correlated with post-traumatic arthrosis.

Conclusion

The necessity to choose for anatomical reduction via open reduction and internal fixation seems to be less important in preventing post-traumatic arthrosis to develop as a persistent step-off or gap exceeding 2mm was found to be significantly correlated with the development of post-traumatic arthrosis. Secondly, both techniques give good functional results, although persistent pain was seen in the ORIF treated patients. Bennett fractures can therefore be safely treated with CRIF, when persistent step-off and gap after fixation does not exceed 2mm.

Level of Evidence: **Therapeutic study, Level III**

Introduction

Fractures at the base of the first metacarpal are classified using the 1972 Green and O'Brien classification. Five fractures can be recognized, i.e. Bennett's fracture, Rolando's fracture, Transverse extra-articular, Oblique extra-articular and Epiphyseal fracture (**Figure 1**) [11].

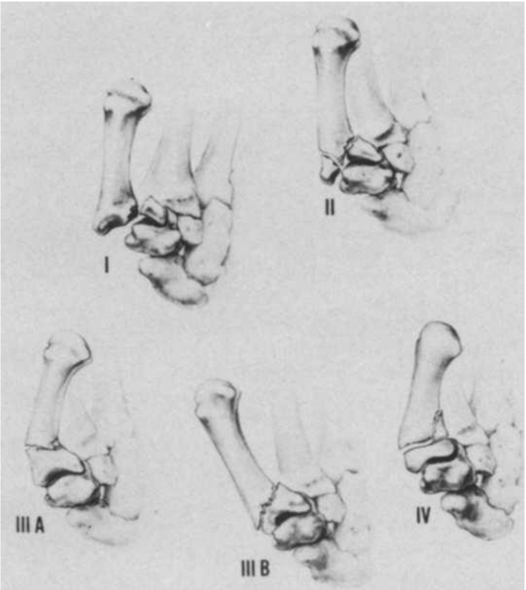

Figure 1. Classification of thumb fractures:
Type I Bennett's fracture
Type II Rolando's fracture
Type IIIA Transverse extra-articular fracture
Type IIIB Oblique extra-articular fracture
Type IV Epiphyseal fracture.
(Re-printed with kind permission from Elsevier Publisher® from "Fractures of the base of the first metacarpal bone: results of surgical treatment. J.L.M. van Niekerk, R. Ouwens; Injury, Vol 20, Issue 6, p359-262 (Nov) 1989.)

Bennett's fracture is named after Edward Hallaran Bennett, Professor of Surgery (1837–1907), who first described it in 1882 [74]. The specific fracture he described; "passed obliquely across the base of the bone, detaching the greater part of the articular surface and the piece of bone that was resting on this surface was projected toward the palm of the hand. The separated fragment was very large, and the deformity that resulted therefrom seemed more a dorsal subluxation of the first metacarpal".

This specific fracture dislocation occurs as a result of the abductor pollicis muscle and adductor pollicis muscle which displace the larger fracture fragment, i.e. the first metacarpal shaft. The smaller, volar fracture fragment is transfixed to the palmar oblique ligament.

The result is an abduction of the first metacarpal shaft within the CMC joint and an adduction of the first metacarpal shaft towards the second metacarpal, making it an unstable fracture.

In the 1950's the first reports were published showing better results when this unstable fracture is treated surgically [27, 28]. In the following years several surgical techniques have been suggested and new techniques have been introduced [11, 22, 27, 39, 41, 49, 56-59].

Open reduction and internal fixation (ORIF) is reported to give good results and has the advantage of anatomical reduction of the fracture under direct vision [22, 38, 61]. The anatomical reduction aims to prevent post-traumatic arthrosis [20]. Secondly, the advantage of open reduction and internal fixation is the possibility of early mobilisation [62].

Closed reduction and percutaneous fixation (CRIF) is also reported to give good clinical results [11, 56]. During CRIF fluoroscopy is used to assess fracture reduction. One study suggested fluoroscopy to be inadequate to assess step-off and gap during closed surgery [32]. Consequently, arthroscopy assisted surgery or ORIF is suggested for this fracture [59]. Fortunately, a more recent study confirmed that fluoroscopy can be safely used to assess Step-off and Gap in the closed surgical treatment of intra-articular fractures at the base of the first metacarpal [75].

Currently, no consensus is reached which type of surgery should be preferred in treating Bennett fractures. One reason for the ongoing discussion is the assumption that an anatomical reduction prevents the development of post-traumatic arthrosis. Some authors suggest a relationship while others were not able to correlate accuracy of fracture reduction with post-traumatic arthritis [20, 22, 56, 65]. To improve anatomical reduction arthroscopically assisted percutaneous techniques have even been suggested to combine visualisation of anatomical reduction with minimally invasive techniques [31, 59].

Lack of consensus also exists regarding the best surgical treatment as most outcome is based on research of only one technique or of very small groups of patients at short term follow-up [63, 64]. This paucity in evidence for one technique stresses the importance to evaluate ORIF and CRIF in a large group of patients, after a long follow-up period in which post-traumatic changes have likely occurred and long-term complications can be detected [66]. Therefore, the purpose of the current study is to evaluate clinical and radiological outcome and report complications at 10-year follow-up of Bennett fractures treated by ORIF or CRIF.

Material and methods

This retrospective study was performed in two Level I Trauma Centres, after both institutions' ethical committee's approval was given to reassess all treated patients with Bennett fractures in the period 1994 and 2010. Procedures were performed in accordance with the 1975 Declaration of Helsinki.

An electronic search in the Digital Patients Medical Database was performed using diagnostic codes, treatment codes and (erroneous) spelling varieties of "Bennett". Only patients treated between 1994 and 2010 were included to guarantee long time follow up. All medical files were screened for eligibility (i.e. no other hand injuries). Previous radiological examinations were assessed to confirm type of fracture Bennett fractures. Inclusion criteria were Bennett fractures (Gedda type I); surgically treated with K-wire fixation or open reduction internal fixation; minimum age of 15 years at time of injury [42]. Patients who did not meet the inclusion criteria were excluded. When patients met all inclusion criteria they were invited to the outpatient clinic. Baseline characteristics were noted from the patient's medical record together with any additional injuries and the type of surgery applied.

During the outpatient's assessment subjective strength of the hand was scored. A scale from 0 to 10 was used to score the experienced strength as experienced by the patient in comparison with strength before trauma. To evaluate pain, we used a Visual Analog Scale (VAS) ranging from 0 cm (no pain) to 10 cm (worst imaginable pain). Post-operative complications and re-operations were documented.

Sensory examination of the radial side of the operated thumb was compared with the patient's non-injured hand and classified as normal intact sensation, tingling or numbness.

Grip- and Pinch-strength of both hands was assessed. Grip- and Pinch-strength were expressed in kilograms (Baseline® Hydraulic Hand Dynamometer and Baseline® Mechanical Pinch Gauge, Fabrication Enterprises, White Plains, NY, USA). The mean of three separate measurements was documented for each hand. To compare the Pinch- and Grip-strength between the injured and the non-injured hand, a percentage was calculated. A minimally clinically important difference (MCID) was set at a difference of 20%, compared with the Pinch- and Grip-strength of the contralateral side and adjusted for hand dominance as suggested by Crosby et al. and Greeven et al [35, 56].

Radiographic images were made in two separate directions to evaluate post-traumatic arthrosis of the first carpo-metacarpal joint using the Van Niekerk and Owens modifications of the Eaton and Littler classification: stage I: no clear arthritic changes, Stage II: osteophytes smaller than 2 mm, Stage III: osteophytes larger than 2 mm or joint narrowing and Stage IV: joint space more or less disappeared [11, 37].

All radiographs were examined by two researchers (SK and TG, respectively Consultant Orthopaedic Trauma Surgery, Level of Experience III and IV respectively). If no consensus could be reached, a third researcher had the deciding vote (MV, Consultant Trauma Surgeon, Level of Experience V) [76].

Statistical analysis

All statistical analysis and comparison have been performed by one of the authors, a professional in medical statics. Normality of data was evaluated using a Shapiro-Wilk test. Continuous data are shown as mean with standard deviation (if normally distributed) or as median with P_{25}-P_{75} (if non-normal). Categorical data are shown as numbers with percentage. Statistical significance of difference between the ORIF and Percutaneous group was tested using Student's T-test or Mann-Whitney U-test (if normal or non-normal, respectively) or using a Chi-squared or Fisher's Exact test (for categorical variables). Correlation between outcome scores was tested using a Spearman rank correlation. A 2-sided p-value less than 0.05 was considered statistically significant.

IV

Results

The electronic search in the Digital Patients Medical Database identified eighty-three possible patients. After assessment of date of trauma, eligibility and radiological examination fifty patients, with a Gedda I fracture, met the inclusion criteria and were included for outpatient assessment. All fifty patients were clinically and radiologically assessed during the outpatient clinic visit. Mean follow-up time was 10 (±4) years. The average age at trauma was 34 (±12) years. Forty-two patients were male.

The dominant hand was injured in 34 patients. Mechanism of injury varied from sports injuries, (motor) cycle accidents, car accidents, to involvement in a fight and a fall on an outstretched hand. Medical history showed no relevant injuries or illnesses prior to the treatment of the Bennett's fracture.

ORIF was performed in 35 patients and consisted of mini-fragment screw fixation via a radio-palmar approach, followed by a release of the thenar. CRIF was performed in 15 patients and consisted of trans-metacarpal fixation between metacarpal I and II or with metacarpo-trapezoidal K-wires.

The average time between trauma and surgery was 7 days; ORIF was done in 6 days and CRIF in 8 days after trauma. Post-operative management varied from cast immobilization and removable splint to functional after treatment. Significantly more often the right side was treated with CRIF ($p = 0.011$, **Table I**)

Table I Patient characteristics

ID	Sex	Age	Follow up (yr.)	Fracture side	Trauma mechanism	Fixation type	Additional injury	Days to Surgery	Cast immobilization
1	M	18	8	R	(motor)cycle accident	ORIF	none	6	another#
2	M	38	18	R	sports	ORIF	none	14	none
3	M	24	17	R	(motor)cycle accident	ORIF	none	1	none
4	M	31	17	L	(motor)cycle accident	ORIF	none	1	cast immobilization
5	M	41	17	L	sports	ORIF	none	1	none
6	M	42	12	R	(motor)cycle accident	ORIF	metatarsal fracture	4	cast immobilization
7	M	32	17	L	(motor)cycle accident	ORIF	trapezium fracture	1	none
8	M	37	13	L	(motor)cycle accident	ORIF	none	6	none
9	M	19	14	R	(motor)cycle accident	ORIF	none	2	removable splint
10	F	28	14	R	fall	ORIF	metacarpal II-IV fracture	0	cast immobilization
11	F	26	12	R	sports	ORIF	none	21	cast immobilization
12	F	54	12	R	(motor)cycle accident *	ORIF	cerebral contusion	7	cast immobilization
13	M	15	10	R	fighting	ORIF	none	9	none
14	M	23	9	R	sports	ORIF	none	11	none
15	M	17	10	L	(motor)cycle accident	CRIF	none	0	cast immobilization

Table I Patient characteristics (continued)

ID	Sex	Age	Follow up	Fracture	Trauma mechanism	Fixation type	Additional injury	Days to	Cast immobilization
16	M	45	9	R	sports	ORIF	none	4	cast immobilization
17	M	32	9	R	fall	ORIF	none	4	cast immobilization
18	F	54	9	L	fall	CRIF	cerebral contusion	20	cast immobilization
19	M	46	8	R	(motor)cycle accident *	CRIF	tib fib fracture, lung contusion	6	cast immobilization
20	M	33	8	R	fighting	ORIF	IP displacement	3	cast immobilization
21	M	36	8	R	fighting	ORIF	none	10	cast immobilization
22	M	43	6	L	sports	CRIF	none	8	cast immobilization
23	M	23	6	R	fighting	ORIF	none	9	none
24	M	38	7	R	fall	ORIF	none	7	removable splint
25	M	26	6	R	sports	ORIF	none	1	cast immobilization
26	M	34	6	L	(motor)cycle accident	ORIF	none	3	cast immobilization
27	M	20	6	L	fall	ORIF	none	5	cast immobilization
28	M	18	6	R	(motor)cycle accident *	CRIF	clavicle fracture	23	cast immobilization
29	M	48	7	R	fall	ORIF	none	1	cast immobilization
30	M	45	6	R	(motor)cycle accident	ORIF	none	2	cast immobilization
31	M	21	5	R	fighting	ORIF	none	0	cast immobilization
32	M	47	5	L	fighting	CRIF	none	3	cast immobilization
33	M	24	16	R	(motor)cycle accident	ORIF	none	10	none
34	F	27	18	L	(motor)cycle accident	ORIF	none	4	none
35	F	19	7	R	hockey ball versus hand	ORIF	none	20	none
36	M	50	12	L	fall	ORIF	none	1	removable splint
37	M	54	10	L	sports	CRIF	none	0	none
38	M	22	10	R	(motor)cycle accident	ORIF	none	10	cast immobilization
39	M	30	8	R	(motor)cycle accident	CRIF	none	3	cast immobilization
40	F	46	7	R	sports	ORIF	none	8	none
41	M	55	8	L	(motor)cycle accident	CRIF	none	5	cast immobilization
42	M	22	7	R	fall	ORIF	none	7	cast immobilization
43	F	39	9	L	(motor)cycle accident	CRIF	none	1	cast immobilization
44	M	34	6	L	(motor)cycle accident	ORIF	none	6	cast immobilization
45	M	28	7	L	car accident	CRIF	cerebral contusion	3	cast immobilization
46	M	38	14	R	fighting	CRIF	head wound	27	cast immobilization
47	M	64	7	R	fall	CRIF	subdural haematoma	7	cast immobilization
48	M	35	6	R	(motor)cycle accident	ORIF	none	14	cast immobilization
49	M	28	18	L	fall	CRIF	shoulder displacement	4	cast immobilization
50	M	17	11	L	(motor)cycle accident	CRIF	none	7	cast immobilization

* multi trauma patient
# bandage for 1 week
M = male, F =female, R =right, L = left, ORIF = Open Reduction Internal Fixation; CRIF = Closed Reduction and Percutaneous Fixation

IV

Functional outcome

The median DASH score for all patients was 5 (P_{25}-P_{75} 0-8). Selected by treatment type the DASH score was 0 (P_{25}-P_{75} 0-6) and 4 (P_{25}-P_{75} 0-12), for ORIF and CRIF respectively. Grip- and Pinch-strength were good in majority of patients in comparison to the non-injured hand for both techniques. A MCID of 20% in Grip- and Pinch-strength in comparison with the uninjured hand was found in 7 patients (**Table II and III**). Four had been treated with ORIF and three with CRIF.

In total eleven patients reported pain at follow-up. Four patients were found to report a VAS of 3 or higher. All 4 patients had been treated with ORIF. Statistical analysis showed a significant correlation between DASH and pain score (Spearman's rho = 0.540, p <0.001) and also a significant correlation between pain (VAS) and strength (Spearman's rho = -0.533, p < 0.01). A higher pain score correlated significantly with a higher DASH and also with loss of strength.

Table II Overall outcome

Item	Overall N=50	ORIF N=35	CRIF N=15	p-value
Age	34 (12)	32 (10)	39 (15)	0.123*
Male	42 (84)	29 (83%)	13 (87%)	1.000#
Right side affected	31 (62%)	26 (74%)	5 (33%)	0.011#
Right side dominant	41 (82%)	29 (83%)	12 (80%)	1.000#
Dominant side affected	16 (32%)	9 (26%)	7 (47%)	0.191#
Eaton Littler class				
1	24 (48%)	19 (54%)	5 (33%)	0.078^
2	18 (36%)	11 (31%)	7 (47%)	
3	6 (12%)	5 (14%)	1 (7%)	
4	2 (4%)	0 (0%)	2 (13%)	
Sensory dysfunction	13 (26%)	11 (31%)	2 (13%)	0.294#
Re-operation	27 (54%)	12 (34%)	15 (100%)	<0.001#
VAS	0 (0-0)	0 (0-0)	0 (0-0)	0.285~
DASH	0 (0-8)	0 (0-6)	4 (0-12)	0.135~
DASH work	0 (0-0)	0 (0-0)	0 (0-10)	0.257~
DASH hobbies	0 (0-10)	0 (0-6)	0 (0-16)	0.893~
Strength	10 (9-10)	10 (8-10)	10 (9-10)	0.949~
Pinch (kg) affected side	11 (9-12)	11 (10-12)	10 (8-12)	0.112~
Pinch (kg) contralateral side	10 (8-12)	10 (9-11)	10 (7-13)	0.86~
Pinch difference	0 (-1 to 1)	1 (0-1)	-1 (-1 to 0)	0.012~
Grip (kg) affected side	47.9 (11.0)	48.6 (10.4)	46.3 (12.7)	0.516∞
Grip (kg) contralateral side	47.7 (11.5)	48.6 (11.0)	45.4 (12.9)	0.366∞
Grip difference	0.2 (6.4)	-0.1 (7.1)	0.9 (4.8)	0.612∞

Data are shown as mean (SD), median (P_{25}-P_{75}) or N (%).
* Student's T-test with unequal variance assumed
# Fisher's Exact test ^ Chi-squared test
~ Mann-Whitney U-test ∞ Student's T-test with equal variance assumed

Table III Minimally Clinically Important Difference (MCID) of Pinch- and Grip-strength

ID	Surg.	Injured	Dominant	Pain	DASH	Work	Hobby	Strength	Pinch	Pinch	Grip	Grip	Diff.	Diff.	Arthritis
				(VAS)		DASH	DASH		R (kg)	L (kg)	R (kg)	L (kg)	%Pinch	% Grip	Eaton-Littler class
8	ORIF	L	R	3	4	0	0	8	12.3	10.0#	43	31#	-18.7%	-38.7%	2
10	ORIF	R	R	0	3	0	13	8	4.7#	6.0	29#	27	-27.7%	6.9%	2
18	CRIF	L	R	0	0		0	10	6.7	2.7#	31	25#	-148%	-4%	4
29	ORIF	R	L	0	0	0	0	10	13.7	11.3#	59	52#	-21.2%	-13.5%	1
36	ORIF	L	R	6	28	19		6	11.2	9.0#	51	33#	-19.6%	-54.50%	3
41	CRIF	L	R	0	3	0	0	7	12.7	9.8#	41	41#	-29.6%	0%	2
50	CRIF	L	R	0	4	0		10	12.7	8.7#	74	73#	-31.4%	1.4%	1
							average	8							

Minimally Clinically Important Difference (MCID) was set at a difference of 20% versus contralateral side and adjusted for hand dominance (*after Crosby et al. & Greeven et al.* [35, 56], MCID larger than 20% are underlined in table.
Surg. = type of surgery, i.e. ORIF or CRIF
ORIF = Open Reduction Internal Fixation
CRIF = Closed Reduction and Percutaneous Fixation
L = Left
R = Right
VAS = Visual Analogue Score
Diff. = Difference (in % Pinch and % Grip)

IV

Complications

Complications were reported in 12 (34%) ORIF treated patients and 4 (27%) CRIF treated patients (**Table IV**). Loss of reduction was reported in one ORIF and one CRIF patient. Both patients were successfully re-operated with the same technique.

Pin-tract infection occurred in one CRIF treated patient and was successfully treated with oral antibiotics and K-wire removal after fracture healing.

Sensory examination of the operated hand in comparison to the patient's non-injured hand showed normal sensation in 37 patients. Tingling was found in 4 patients and numbness was found in 9 patients (**Table IV**). Of these 13 patients, 11 were treated with ORIF and 2 had been treated with CRIF.

Seven ORIF patients (20%) were re-operated. Reasons for re-operation were loss of reduction, functional impairment and complaints of osteosynthesis material. One CRIF patient was re-operated because of loss of reduction. All other CRIF patients were re-operated for K-wire removal after fracture consolidation.

Radiographs

In 13 patients the radiographs showed an Eaton Littler Grade III or IV at follow-up. Seven patients had been treated by ORIF and 6 patients had been treated by CRIF.

Table IV Complications at follow-up

Surgical Technique	ID	Sex	Age	Injured side	Days to Surgery	Re-operations	Complications
ORIF	1	M	18	R	6	yes	tingling
(N=12, 34%)	6	M	42	R	4	no	numbness
	9	M	19	R	2	no	numbness
	10	F	28	R	0	yes	numbness
	23	M	23	R	9	yes	tingling
	24	M	38	R	7	yes	Loss of reduction/numbness
	27	M	20	L	5	yes	tingling
	30	M	45	R	2	no	numbness
	34	F	27	L	4	no	numbness
	35	F	19	R	20	yes	adhesiolysis
	38	M	22	R	10	no	tingling
	48	M	35	R	14	yes	numbness
CRIF	22	M	43	L	8	yes	pin-tract infection
(N=4, 27%)	46	M	38	R	27	yes	Numbness of thumb
	47	M	64	R	7	yes	loss of reduction
	50	M	17	L	7	yes	Numbness of thumb

M= male, F= female, R= right, L= left

A persistent Step-off or Gap after surgical fixation larger than 2mm showed a significantly correlation with the development of post-traumatic arthrosis (**Table V**).

No statistically significant association could be found between the modified Eaton Littler classification and reported pain (VAS), functional outcome, or treatment type.

(**For detailed outcome please see *Supplement: Pinch- & Grip strength and Eaton-Littler Classification for all 50 patients***)

Table V Post-Traumatic Arthrosis and Quality of Reduction

		Eaton Littler classification			
Fracture reduction*		I	II	III	IV
0-2 mm	(n=43)	12	24	6	1
> 2mm	(n=7)	1	0	6	0
total	(n=50)	13	24	12	1

* = Step-off or Gap
Chi-Square test, p=0.001

Discussion

The first important finding of the current study is the significant correlation between a persistent Step-off and Gap of 2mm and the development of post-traumatic arthrosis. This warrants the question how much importance should be given to an anatomical reduction during surgery in an attempt to prevent these post-traumatic changes from developing [61, 73].

Previous research has shown that with fluoroscopy fracture reduction after percutaneous fixation can be adequately assessed [75]. The necessity for anatomical reduction via open reduction and internal fixation or even arthroscopy might be of less importance. Previous smaller studies also reported good results when step-off was smaller than 2mm [20, 77]. Furthermore, without the dissection necessary for ORIF the patient is less at risk to develop complications such as reported in the current study. Pain was mostly seen in ORIF patients as well as re-operations because of functional impairment and complaints of osteosynthesis material.

The second important finding of the current study is that similar functional outcome was found for both types of surgery after long term follow-up. In line with previous publications with shorter follow up, the current study confirms good clinical results for ORIF as well as for CRIF in the treatment of Bennett's fracture at 10-year follow up [22, 41, 56, 61, 62].

An important other finding in the current study are the high pain scores (VAS > 3) which were only seen in ORIF patients. A higher pain score was significantly correlated with a higher DASH and also with loss of strength. This makes these findings clinically important.

The authors are not aware of any previous research in which pain after surgical treatment of Bennett's fracture are reported at 10-year follow-up. The reported pain was not correlated with post-traumatic arthrosis (Eaton-Littler score). Other metacarpal studies have shown difference in complications between CRIF and ORIF techniques in the surgical treatment of second to fifth metacarpal fractures [16]. This was explained by the surgical dissection necessary for open reduction and internal fixation resulting in a higher chance of unintended damage to vital anatomical structures [16, 34]. This might be explanatory for the current study's finding, that all patients with a pain score (VAS) of 3 or higher had been treated by open technique. Future research should focus on persistent pain after surgical treatment of Bennett fractures.

Strengths/Limitations

One strength of the current study is the long term follow up of the included patients and the clinical and radiological assessment of outcome. But because of its retrospective nature, this study has several limitations. Selection bias will be present because the type of treatment was based on the personal preference of the surgeon. Secondly, the post-operative management is different between ORIF and CRIF. Thirdly, within the CRIF patients two types of percutaneous pinning was used, introducing extra bias.

In conclusion, the necessity to choose for anatomical reduction via open reduction and internal fixation seems to be less important in preventing post-traumatic arthrosis. And although both techniques result in similar functional outcome after 10-year follow-up, pain was only seen in ORIF patients. Based on these findings, a Bennett fracture can be safely treated with CRIF, when persistent step-off and gap after fixation does not exceed 2mm.

Supplement: Overall Functional Outcome and Eaton-Littler Classification

ID	Sex	Age	Fracture side	Dominant side	Pain (VAS)	DASH	Work DASH	Hobby DASH	Strength (subj.)	Pinch R (kg)	Pinch L (kg)	Grip R (kg)	Grip L (kg)	Difference % Pinch	Difference % Grip	Arthritis Eaton-Littler class
1	M	18	R	R	0	0	0	0	10	11,7#	12,3	50#	49	-5,1%	2,0%	1
2	M	38	R	R	0	0	0	0	10	12.0#	10,3	52#	50	14,1%	3,8%	1
3	M	24	R	R	0	0	0		10	12.7#	9,7	59#	69	23,6%	-16,9%	1
4	M	31	L	R	0	0	0		10	10.3	11.7#	52	50#	12,0%	-4,0%	1
5	M	41	L	R	0	0	0	0	10	11.0	11.0#	36	39#	0,0%	7,7%	2
6	M	42	R	R	0	0	0	0	9	10,3#	9,3	39#	41	9,7%	-5,1%	3
7	M	32	L	R	0	0	0		10	11,3	11,3#	43	47#	0,0%	8,5%	1
8	M	37	L	R	3	4	0	0	8	12,3	10,0#	43	31#	<u>-23.0%</u>	<u>-38,7%</u>	2
9	M	19	R	R	0	0	0		10	11,2#	11,3	53#	53	-0,9%	0,0%	1
10	F	28	R	R	0	3	0	13	8	4,7#	6	29#	27	<u>-27,7%</u>	6,9%	2
11	F	26	R	R	0	0	0		10	8,0#	7,3	35#	33	8,8%	5,7%	1
12	F	54	R	R	3	22		13	5	7,3#	7	31#	31	4,1%	0,0%	2
13	M	15	R	R	0	0	0	0	10	10,7#	10	61#	59	6,5%	3,3%	1
14	M	23	R	R	0	4	0	13	9	12,0#	10,7	59#	59	10,8%	0,0%	2
15	M	17	L	L	0	0	0	0	10	8,2	8,0#	52	55#	-2,5%	5,5%	1
16	M	45	R	R	0	8	6	6	10	13,7#	12	60#	39	12,4%	35,0%	2
17	M	32	R	R	0	0	0	0	10	10,8#	11,2	53#	57	-3,7%	-7,5%	3
18	F	54	L	R	0	0		0	10	6,7	2,7#	31	25#	<u>-148,0%</u>	<u>-24,0%</u>	4
19	M	46	R	R	0	11	0	19	9	10,7#	12,8	58#	51	-19,6%	12,0%	3
20	M	33	R	L	0	0	0		10	10,3	12,0#	40	49#	14,2%	18,4%	1
21	M	36	R	R	1	8	13		8	11,5#	12,2	43#	42	-6,1%	2,3%	2
22	M	43	L	R	0	0	0	0	10	13,2	11,7#	49	51#	-12.8%	3,9%	2

Supplement: Overall Functional Outcome and Eaton-Littler Classification (continued)

ID	Sex	Age	Fracture	Dominant	Pain	DASH	Work	Hobby	Strength	Pinch	Pinch	Grip	Grip	Difference	Difference	Arthritis
23	M	23	R	R	3	11	13		8	11,7#	11,2	45#	43	4,3%	4,4%	1
24	M	38	R	R	0	0	0		10	11,2#	10,2	51#	59	8,9%	-15,7%	3
25	M	26	R	R	0	0	0	0	10	11,8#	11,3	63#	55	4,2%	12,7%	1
26	M	34	L	R	0	0	0	0	10	10	12,7#	59	57#	21,3%	-3,5%	2
27	M	20	L	L	1	1		25	10	9	10,2#	36	41#	11,8%	12,2%	2
28	M	18	R	R	0	8	19	25	10	11,2#	11,8	50#	50	-5,4%	0,0%	2
29	M	48	R	L	0	0	0	0	10	13,7	11,3#	59	52#	-21,2%	-13,5%	1
30	M	45	R	R	0	0	0	0	10	12,0#	11,3	56#	58	5,8%	-3,6%	1
31	M	21	R	L	1	13	6	44	8	8,3	10,0#	60	60#	17,0%	0,0%	1
32	M	47	L	L	1	26	0		10	24,7	23,0#	50	48#	-7,4%	-4,2%	2
33	M	24	R	R	0	0	0	0	10	24,3#	23,3	55#	65	4,1%	-18,2%	1
34	F	27	L	L	0	4	0	0	5	6,7	5,8#	37	33#	-15,5%	-12,1%	2
35	F	19	R	R	0	33	0	0	10	6,0#	5,7	34#	35	5,0%	-2,9%	1
36	M	50	L	R	6	28	19		6	11,2	9,0#	51	33#	-24,4%	-54,5%	3
37	M	54	L	R	0	2	0	0	10	10	11,7#	52	56#	14,5%	7,1%	2
38	M	22	R	R	0	1	0	6	10	12,3#	10,3	59#	55	16,3%	6,8%	2
39	M	30	R	R	0	0	0	0	10	9,3#	7	29#	31	24,7%	-6,9%	1
40	F	46	R	R	0	3		0	10	9,7#	8,7	46#	39	10,3%	15,2%	3
41	M	55	L	R	0	3	0	0	7	12,7	9,8#	41	41#	-29,6%	0,0%	2
42	M	22	R	R	0	7	0	0	10	12,0#	12,2	60#	67	-1,7%	-11,7%	1
43	F	39	L	L	0	11	13	0	8	10	10,0#	32	33#	0,0%	3,0%	2
44	M	34	L	L	1	6			10	10,5	10,8#	51	59#	2,8%	13,6%	1
45	M	28	L	R	0	12	13	13	9	11,7	13,7#	63	53#	14,6%	-18,9%	2
46	M	38	R	R	1	16		25	8	7,3#	7	33#	28	4,1%	15,2%	1

Supplement: Overall Functional Outcome and Eaton-Littler Classification (continued)

ID	Sex	Age	Fracture	Dominant	Pain	DASH	Work	Hobby	Strength	Pinch	Pinch	Grip	Grip	Difference	Difference	Arthritis
47	M	64	R	R	0	12	6	0	10	9,3#	8	47#	41	14,0%	12,8%	4
48	M	35	R	R	1	1	0	6	8	8,7#	7,2	56#	51	17,2%	8,9%	1
49	M	28	L	R	0	0	0	0	10	6,2	5,7#	36	43#	-8,8%	16,3%	1
50	M	17	L	R	0	4	0		10	12,7	8,7#	74	73#	-46.0%	1,4%	1
Average		34			0	5	2	6	9	10,9	10,4	48	47			

V

Open reduction and internal fixation versus percutaneous transverse Kirschner wire fixation for single, closed second to fifth metacarpal shaft fractures: a systematic review

Eur J Trauma Emerg Surg. 2016 Apr;42(2):169-75

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Abstract

Purpose

Open reduction and internal fixation (ORIF) of single, closed metacarpal shaft fractures is increasingly preferred over closed reduction and percutaneous fixation (K-wire). The aim of this systematic review is to determine whether the preference for ORIF can be substantiated based on the available literature regarding the functional outcome and complications after surgery.

Methods

A systematic review was performed using a computer-based search on MedLine and Embase, following the preferred reporting items for systematic and meta- analyses guidelines.

Results

Five non-comparative studies were found. Two studies reported on 36 ORIF-treated patients. Three studies reported on 65 K-wire-treated patients. Complications were reported in 8 ORIF-treated patients (22 %) and in 23 K-wire-treated patients (35 %). Functional outcome was generally reported as good for both techniques. Nonetheless functional impairment requiring reoperation was reported in 6 ORIF-treated patients (17 %) and in none of the K-wire-treated patients.

Conclusions

Although for both techniques good functional outcomes were reported, the significance of the functional impairment after ORIF requiring reoperation suggests ORIF to be a less favorable technique for single, closed metacarpal shaft fractures.

Level of Evidence: **Therapeutic study, Level II-B**

Introduction

Metacarpal fractures are among the most common fractures of the skeletal system and account for 36 % of hand and wrist fractures [17, 78-80]. The peak incidence of metacarpal shaft fractures is between 20 and 40 years and results in significant societal costs [81]. The majority of metacarpal shaft fractures can be treated conservatively [17]. Numerous indications for operative treatment include malrotation, angulation, longitudinally shortening, multiple fractures and fractures with associated soft tissue injuries or bone loss [17, 45, 52, 78, 82-84]. With the introduction of new fixation techniques for metacarpal fractures in the last 25 years, open reduction and internal fixation (ORIF) gained increasing popularity, because stable ORIF fixation allows early mobilization [29, 85]. The reasons for surgeons to decide for open reduction and internal fixation also included the improvement of materials and instruments, better understanding of biomechanical principles of internal fixation, and the availability of antibiotics to reduce infection. A well-known alternative surgical treatment options is closed reduction and percutaneous fixation with Kirschner wires (K-wires) [17, 45].

This systematic review was performed to determine the functional outcome and post-operative complication for both these surgical techniques in the treatment of single, closed metacarpal shaft fractures. This review aims to determine whether the preference for ORIF can be substantiated based on available data in the literature in terms of functional outcome and complications.

Materials and methods

A systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta- Analyses guidelines, including (1) a systematic search of the literature, (2) selection of studies, (3) recording of study characteristics, (4) assessment of methodological quality of studies, and (5) extraction and comparison of clinical outcomes [68, 86].

Search strategy

The literature search was conducted in both MedLine and Embase on September 12th 2014. The search strategies were developed by a trained medical librarian and included combinations of different terms and synonyms for extra- articular metacarpal fractures and surgical treatment. The detailed search strategies are described in the "**Appendi**x".

Selection of studies

After removal of duplicate studies from the MedLine and Embase literature searches, the title and abstract of the remaining studies were screened to evaluate if they met the following criteria: (1) Language: English or German. (2) Study design: comparative (randomized or non-randomized), prospective or retrospective studies. (3) Population: Humans with a single shaft fracture located in the second, third, fourth or fifth metacarpal. (4) Intervention: ORIF and/or percutaneous transverse K-wires. (5) Out- come: hand function, consolidation and/or complications.

Of the selected abstracts, the full-text articles were screened using the same inclusion criteria. The reference lists of selected articles were screened for additional relevant studies (**Figure 1**).

Recording of study characteristics

The following study characteristics were extracted from the five selected full-text articles: author, title, publication year, country of origin, study design, number of participants, type of surgical treatment, complications and follow-up period (**Tables 1 and 2**).

Assessment of methodological quality

The risk of bias was assessed following the instructions by Spindler et al. within and between studies and the level of evidence of the selected studies was assessed [72].

Data-extraction and comparison of clinical outcomes were reviewed. The following data was extracted from the selected full-text articles: functional outcome, complications (reoperation, infection, delayed/non-union and failure of fixation) and postoperative cast immobilization. Delayed union and non-union were defined as lack of bony consolidation on radiographs at 3 and 6 months, respectively [34, 87].

Two researchers performed steps 2–5 independently. During step 2, disagreement about selection of studies was resolved by study inclusion. Disagreement during steps 3–5 was resolved by discussion.

Results

Study selection

The search identified 158 articles in Medline and 186 articles in Embase. After removing 174 duplicate studies, the title and abstract of the remaining 170 articles were screened. A total of 24 articles were selected for full-text reading. By screening of the references of these 24 articles another three potentially relevant articles were found. After full-text examination of these 27 articles, 22 articles were excluded as these articles did not provide patient data or did not meet the selection criteria. The remaining five articles were included in the systematic review and the reported data in these articles were used for analyses (**Figure 1**).

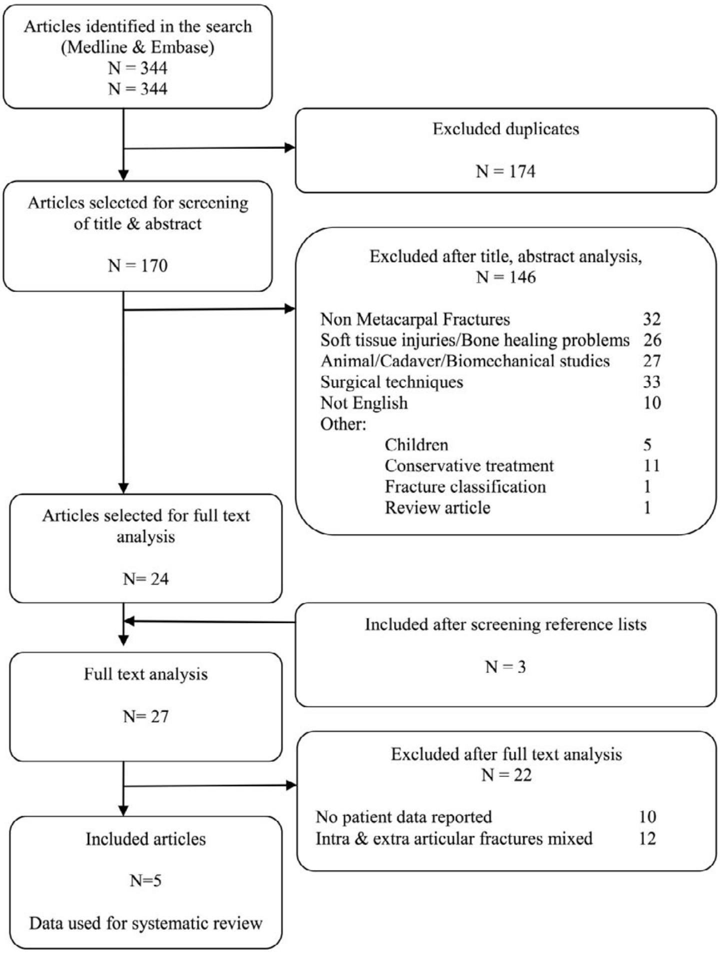

Figure 1 Flowchart of selected articles

Study characteristics

No randomized or non-randomized studies comparing ORIF with K-wire fixation were found. The selected articles described three retrospective and two prospective patient cohorts, including two that had been treated with ORIF [85, 88] and three with K-wires [29, 89, 90] (**Table 1**). One article reported on patients treated with intra-articular as well as on patients treated with metacarpal shaft fractures [85]. From this study the separate results of the meta- carpal shaft fractures could be extracted and were used for this review. In total, the five articles reported on outcomes of 36 metacarpal shaft fractures treated with ORIF in 36 patients and on 65 metacarpal shaft fractures treated with transverse K-wire fixation, in 65 patients (**Table I**).

All studies included patients with single, closed unstable metacarpal shaft fractures.

Table I Characteristics of included articles

	Study	Year	Country	Study design	Fixation	No. of Patients	Follow-up
1	Ozer	2008	USA	Prospective Cohort	ORIF	14	19 (12-219)
2	Westbrook	2008	United Kingdom	Retrospective Cohort	ORIF	22	180 (100-240)
3	Galanakis	2003	Greece	Retrospective Cohort	K-wire	11	12 (120)
4	Paul	1994	United Kingdom	Prospective Cohort	K-wire	22	*
5	Sletten	2012	Norway	Retrospective Cohort	K-wire	32	128 (68-156)

* = not specified, follow-up reported until full consolidation

Functional outcome

Functional outcome was reported in all five studies and measured by total active motion (TAM, normal range 290–310) or by a disability arm shoulder (DASH) score (**Table II**). The functional outcome of patients treated with ORIF was reported to be generally good, with a TAM between 150° and 270° or a DASH score between 1 and 44 (**Table II**). All K-wire-treated patients were reported to have good functional outcome, except one. This patient was reported to have an extension loss of 10°. The other 64 patients were reported to have full function or to have a range of motion (ROM) and grip strength equalling that of the contra-lateral, uninjured hand (**Table II**).

Complications

In the ORIF-treated patients a total of 8 patients (22 %) were reported to have had a complication after operative treatment (details provided in **Table III**). Six of these patients (17 %) experienced major functional impairment from these complications and required a reoperation. In the K-wire-treated patients a total of 23 (35 %) were reported to have encountered a complication (**Table III**). None of these complications resulted in functional impairment or required reoperation.

Table II Data extracted from included articles

Study	1 (n=14)	2 (n=22)	3 (n=11)	4 (n=22)	5 (n=32)
Mean age (yrs)	28 (19-47)	25 (14-79)	43 (18-64)	*	30 (19-50)
Pre-operative angulation °	14 (0-82)	29 (16-62)	37 (32-42)	36 (32-40)	35 (1-69)
Fracture location					
MC II	0	0	*	4	0
MC III	0	0		2	0
MC IV	3	0		8	11
MC V	11	22		8	21
Fixation	Plate-Screw	Plate-Screw	Transverse K-wire (size 1.4mm)	Transverse K-wire (size 1.4mm)	Transverse K-wire (size *)
Immobilization (days)	Bulky dressing (13 (12-14)	Not applied 0	Cast 7 (7)	Not applied 0	Cast 35 (28-49)
Follow-up (weeks)	19 (12-219)	180 (100-240)	12 (12)	*	128 (68-156)
Post-operative angulation	0	*	0	2.2 (0-10)	10 (2-19)
Post-operative shortening (mm)	0	*	0	*	0
TAM / Function	225 (150-270)	*	Full function	Full function	264 (250-296)
DASH	8.07 (1-28)	5 (1-44)	*	*	1 (0-39) ^
Complications					
Infection	0	2	0	8	8
Impairment	2	3	0	0	0
Pain	0	1	0	0	0
Other	0	0	0	0	3 ‡

* not specified
° as measured on lateral X-ray
^ patients with higher DASH scores had suffered other injuries in their upper limbs during follow-up period
‡ Fracture at former K-wire site in uninjured metacarpal

V

Infections

In the ORIF group infections occurred in 2 patients (6 %). Both patients were treated with oral antibiotics (**Table III**). In the K-wire-treated patients superficial skin infection was reported in 16 patients (25 %). Nine of those were treated with oral antibiotics (14 %) and 7 with removal of K-wires (11 %) (**Table III**).

Table III: Details on Complications & Re-operations per treatment

	ORIF (36 fractures)		K-wire (65 fractures)	
Complication	**No. with complication**	**No. of reoperations**	**No. with complication**	**No. of reoperations**
Delayed union	*0*	*0*	0	0
Non-union	*0*	*0*	0	0
Fixation failure	*0*	*0*	0	0
Stiffness / tenolysis	5 (14%)	5 (14%)	0	0
CRPS	0	0	0	0
Infection	2 (6%)	0	16 (25%)	0
Pain	1 (3%)	1 (3%)	0	0
Skin irritation	Not reported	Not reported	4	0
Cosmetic deformity	Not reported	Not reported	0	0
New fracture	0	0	3* (5%)	0
Total	**8 (22%)**	**6 (17%)**	**23 (35%)**	**0**

*= fracture after new trauma, at former K-wire location in non- fractured metacarpal
‘’ 0 ‘’ = articles report no such complication occurred
‘’ Not reported ’’ = no mention was made in the reviewed article about the type of Complication or Re-operation mentioned.

Non-union/delayed union

Non-union or delayed union was not reported in any of the five studies (**Table III**).

Failure of fixation

In none of the ORIF and K-wire-treated patients did a failure of fixation occur (**Table II**).

Stiffness/tenolysis

In the ORIF group impairment of function as a result of stiffness was reported for 5 patients (14 %) (**Table II**). Causes for stiffness were not specified. In all 5 patients (14 %) this impairment was reported to require a reoperation because of persistent functional deficit. No functional impairment was reported for the K-wire-treated patients. Open reduction and internal fixation versus percutaneous transverse Kirschner wire fixation

Other findings

One ORIF study reported on bulky dressing for 12–14 days postoperatively [88]. Postoperative immobilization by a splinting cast was only applied for K-wire-treated patients (**Table II**). No complications correlated to cast immobilization were reported in the K-wire-treated patients.

In one study three K-wire-treated patients were reported to have fractured a previously non-injured neighbouring metacarpal after a new trauma at a former K-wire site during follow-up period [90].

Risk of bias and level of evidence

None of the selected studies compared two types of treatment. All five studies reported on cohorts of patients treated by one type of fixation. All five studies were therefore graded levels of evidence 4 (**Table I**) [72]. Relevant types of potential bias within these studies included selection bias and follow-up bias.

Although all five studies only report on one type of surgical technique a selection bias might be considered. Because all included patients in this review were included for surgery based on the same surgical indication; a single, closed metacarpal shaft fractures with rotational deformity, comparison of the reported results is possible.

Follow-up bias might be considered in the selected studies, as the follow-up period was not reported in one study [89]. As all patients in this study were reported to have a full function outcome this possible bias does not influence comparison of the reported results.

Discussion

No randomized or non-randomized study comparing ORIF with K-wire fixation was found. Based on the data from the included literature, reporting on a total of 101 patients operated for a single, closed unstable metacarpal shaft fracture, complication rates are more frequently found in the K-wire-treated patients (22 vs. 35 % respectively). However, the reported complications after ORIF are more frequently related to functional impairment and more often require reoperation (15 %), whereas most complications after K-wire fixation involved superficial infection, which could be treated conservatively.

Secondly, Fusetti et al. suggests that exploration for ORIF results in loss of the fracture hematoma, which may give rise to delayed union and non-union [91]. As no consolidation problems were reported this suggestion cannot be confirmed. On basis of the included data there does not seem to be any evidence for fracture healing problems in the treatment of a single, closed metacarpal shaft fractures with ORIF or with K-wire fixation.

Although the general functional outcome was reported to be good for both techniques, the data shows one ORIF-treated patient with a DASH score of 44 [85]. Such a DASH score is likely to be associated with loss of function. Unfortunately, no further specifications are made and no explanation is given for this finding by the authors. Similarly, one K-wire patient also scored a relative high DASH score of 39. The authors suggest a plausible reason by explaining the patient had encountered additional injuries to the upper limb, non-related to the operated hand, but therefore possibly resulting in a biased DASH score.

One of the limitations of this systematic review is the lack of comparative studies on outcomes after ORIF and K-wire fixation of single, closed metacarpal shaft fractures of the second to fifth metacarpal. Comparison of outcome between the data from the included articles is appropriate as similar indications for surgery have been applied in all five articles. A second limitation is the lack of patients treated solely with screw fixation. Possibly less dissection is required for this type of fixation in comparison to plate fixation.

In contrast to earlier publications postoperative immobilization did not influence postoperative functional repair in the reported studies. Postoperative cast immobilization was only applied after K-wire fixation and was reported to be associated with good functional results. None of the ORIF-treated patients were immobilized with casts (**Table II**). Therefore, cast immobilization cannot have been a reason for the development of functional impairment requiring reoperations as found in these ORIF- treated patients. Also cast immobilization can be safely applied, without increased chance of functional impairment, in K-wire-treated patients for support of soft tis- sue and fracture healing the first weeks after surgery (**Tables II and III**).

No specification was made about the type of fracture, other than shaft fractures located in the second, third, fourth or fifth metacarpal (**Table II**). All fractures were operated because of instability, angulations' or rotational deformity. No comparison can therefore be made between fracture type (i.e. spiral, oblique) and functional results. As all studies reported identical indication for surgical fixation a comparison between type of fixation and functional result can be made.

Based on the reported results there is no level I evidence to suggest one fixation technique over another. The reported complications however for ORIF and K-wire fixation in the treatment of single, closed metacarpal shaft fractures are unmistakably different for the two types of fixation. ORIF was associated with a considerable number of functional restricting complications and consequent reoperations, whereas K-wire fixation resulted frequently in superficial infection treated conservatively. The significance of these reported findings suggest ORIF might be a less preferable surgical technique in comparison to K-wire fixation in the treatment of a single metacarpal shaft fracture. To confirm this finding further research is warranted and should focus on the comparison between ORIF and K-wire fixation for single, closed metacarpal shaft fractures, preferably in a randomized clinical trial.

Appendix: Search strategies

MedLine: ("Metacarpal Bones"[Mesh] OR "metacarpal"[all fields] OR "metacarpus"[all fields]) AND ("Fractures, Bone"[Mesh] OR fracture[all fields] OR fractures[all fields] OR "Fracture Fixation"[Mesh] OR "Fracture Healing"[Mesh]) AND ("midshaft"[all fields] OR "shaft"[all fields] OR "mid-shaft"[all fields] OR "middle third"[all fields] OR "diaphysis"[all fields] OR "extra-articular"[all fields]) AND ("Surgical Procedures, Operative"[Mesh] OR "surgery"[all fields] OR "surgical"[all fields] OR "operative"[all fields] OR "Orthopedic Fixation Devices"[Mesh] OR "fixation"[all fields] OR "fixator"[all fields] OR "fixators"[all fields]).

Embase: (((metacarpal bone/OR "metacarpal".mp. OR "metacarpus".mp.) AND (exp fracture/OR fracture.mp. OR fractures.mp. OR exp fracture fixation/OR fracture treatment/OR fracture healing/OR fracture reduction/)) OR metacarpal bone fracture/) AND ("midshaft".mp. OR "shaft".mp. OR "mid-shaft".mp. OR "middle third".mp. OR "diaphysis".mp. OR "extra-articular".mp.) AND (exp surgery/OR "surgery".mp. OR "surgical".mp. OR "operative".mp. OR fixation device/OR exp fracture fixation/OR "fixation".mp. OR "fixator".mp. OR "fixators".mp.).

VI

Comparison of closed and open surgical technique for second to fifth metacarpal shaft fractures, based on 10-year comparison of 142 surgically treated patients

Submitted

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Abstract

Objectives

Assess surgical treatment of multiple metacarpal shaft fractures to determine if multiple second to fifth metacarpal shaft fractures can be safely treated with Closed Reduction and Internal Fixation (CRIF), without higher risk of complications and re-operation in comparison with Open Reduction and Internal Fixation (ORIF).

Material and methods

Consecutively treated patients in the period January 1, 2007 to December 31, 2017, were retrospectively analysed. Fracture type, surgery time, loss of reduction, rotational deformity, infection, pain, functional impairment, and re-operations were recorded from the patients' medical files.

Results

One-hundred-forty-two patients were included. Median age was 35 years. Single and multiple shaft fractures were treated, 105 and 37, respectively. Fracture types were spiral, oblique, transverse, and comminuted. ORIF and CRIF were both used in all fracture types. ORIF was performed in 121 patients and CRIF in 21 patients. Median follow-up was 2 months (1-4). Significant shorter surgery time was found in CRIF patients, 21 vs 50 minutes. Pain during exercise and infection were seen in ORIF and CRIF. Loss of reduction, rotational deformity and functional impairment were only seen in ORIF patients. Re-operations were only performed after ORIF. Reasons for re-operations were loss of reduction, rotational deformity, infection, pain, functional impairment and hardware irritation as experienced by the patient.

Conclusion

Spiral, oblique, and transverse second to fifth metacarpal shaft fractures can be safely treated by CRIF resulting in good outcome, shorter operation time, and less re-operations than ORIF. Secondly, the results of CRIF for multiple metacarpal shaft fractures are as good as ORIF treated patients with less risk of complications.

***Level of Evidence*: Therapeutic study, Level III/IV**

Introduction

A large percentage of fractures of the skeletal system are metacarpal fractures and account for 36% of hand and wrist fractures [3, 8, 92-94]. Incidence of metacarpal shaft fractures is highest between 20 and 40 years and result in significant societal costs [16, 95]. The majority of metacarpal fractures are sub-capital fifth metacarpal (Boxer's) and first metacarpal base fractures. Shaft fractures of the second to fifth metacarpal represent a smaller percentage of hand fractures.

Non-operative treatment is applicable in a majority of these metacarpal shaft patients [17, 96]. Indication for operative treatment are malrotation, angulation, longitudinal shortening, multiple fractures and fractures with associated soft tissue injury or bone loss [15-18]. Open reduction and internal fixation (ORIF) gained popularity by the introduction of new stable fixation techniques allowing early mobilization post-operatively [29, 34, 85]. Combined with a better knowledge of biomechanical principles of internal fixation and the possibly the availability of antibiotics to reduce infection surgeons decided for ORIF more frequently than closed reduction and percutaneous fixation techniques (CRIF) [16-18, 97]. Parallel to this surge in open technique, multiple articles have been published reporting on different percutaneous techniques and their outcome in the last decade [17, 18, 90, 93, 98, 99]. What type of surgical fixation is preferable based on fracture pattern or the number of fractures is still unclear. Recent analysis in a systematic review suggested open reduction and intern fixation to be less favourable than percutaneous fixation in the treatment of single fractures [16]. Although a majority of patients were reported to have good functional outcome for both techniques a large percentage of the ORIF treated patients experienced functional impairment, which required reoperation in 17% of these patients. No reoperations were necessary for percutaneous treated patients. The systematic review debates ORIF might be a less preferable surgical technique in comparison to K-wire fixation in the treatment of a single metacarpal shaft fracture. Further research was suggested to focus on the comparison between ORIF and K-wire fixation for single and multiple metacarpal shaft fractures.

For multiple reasons, not least of which is the difficulty of recruiting patients willing to undergo surgical randomization, previous authors have suggested that a randomized clinical trial might not be performed in the near future [15, 100]. The current study was therefore designed to determine if the review's results could be substantiated in one large comparative single centre study and therefore confirming that closed percutaneous technique can be safely used in the treatment of second to fifth metacarpal shaft fractures.

Materials and methods

This retrospective study was performed in a single Level I Trauma Centre after the institution's ethics committee's approval was given.

An electronic search in the Digital Patients Medical Database was performed using diagnostic codes, treatment codes, and (erroneous) spelling varieties of "Metacarpal fracture". All patients treated between January 1, 2007 and December 31, 2017 were included. All medical files were screened for eligibility. Inclusion criteria were single or multiple second to fifth metacarpal shaft fractures surgically treated with Closed Reduction Percutaneous Fixation (CRIF) or Open Reduction Internal Fixation (ORIF) and minimum age of 16 years at time of injury. There were no exclusion criteria. Of all included patients baseline characteristics were noted from the patient's medical record together with any additional injuries and the type of surgery applied. Patients records, postoperative complications and reoperations were fully assessed and documented. All radiographs were examined by a panel of two researchers to determine fracture type and secondary dislocation (APAG and MK). Consensus was reached by discussion.

The Statistical Package for Social Studies (SPSS) Version 24.0 was used for all statistical analyses. Normality of data was evaluated using a Shapiro-Wilk test. Since all continuous data deviated from the Normal distribution, they are shown as median with P_{25}-P_{75}. Categorical data are shown as numbers with percentage. Statistical significance of difference between the ORIF and CRIF group was tested using Mann-Whitney U-test (for continuous variables) or using a Chi-squared or Fisher's Exact test (for categorical variables). A 2-sided p-value less than 0.05 was considered statistically significant.

Results

Patient characteristics

The search identified 142 patients, who were all included (**Table I**). The median age was 28 (P_{25}-P_{75} 22-46) years. Ninety-six (68%) were male. Median follow-up time was 2 (P_{25}-P_{75} 1-4) months. The dominant hand was injured in 79 (67%) patients.

Mechanism of injury was mostly frequently related to a fall from standing height (46%). Other trauma mechanisms were a strike (30%), crush injury (14%) and a traffic accident (9%). Thirty-three percent of the patients did smoke. Medical history showed no relevant injuries or illnesses prior to the treatment of the metacarpal shaft fracture.

Fracture characteristics

Hundred five patients were treated for a single metacarpal fracture (**Table II**). Thirty-seven patients were treated for multiple fractures. ORIF was applied in 121 patients and CRIF in 21 patients. Multiple fractures were not more frequently operated with open or closed technique, 26% vs 29%, respectively.

The most frequently treated type of fracture was a transverse type in 50 patients (34%). Spiral fractures were treated in 46 patients (32%). Less frequent were oblique fractures (26%) and comminuted fractures (8%). ORIF was used in all single second metacarpal fractures and 86% of the single third metacarpal fractures. Comminuted and open fractures were not more frequently treated using either one of the techniques.

Table I Patient Characteristics, Trauma Mechanism and Follow-up

	Total	CRIF	ORIF	p-value
	n=142	n=21	n=121	
Age (years)	28 (22-46)	31 (22-54)	27 (22-45)	0.426
Male	96 (67.6%)	14 (67%)	82 (67.8%)	1.000
Smoking*	48 (43.2%)	8 (40%)	40 (44.0%)	0.807
Right side fractured	88 62.0%)	13 (62%)	75 (62.0%)	1.000
Dominant side injured **	79 (66.9 %)	13 (68%)	66 (66.7%)	1.000
Multiple Fractures	37 (26.1%)	6 (29%)	31 (25.6%)	0.791
Trauma mechanism				
Fall	66 (46.5%)	12 (57%)	54 (44.6%)	0.182
Strike	43 (30.3%)	3 (14%)	40 (33.1%)	
Crush	20 (14.1%)	5 (23.8%)	15 (12.4%)	
Traffic accident	13 (9.2%)	1 (5%)	12 (9.9%)	
Follow-up (months)***	2.0 (1.0-4.0)	3.0 (2.0-5.0)	2.0 (1.0-4.0)	0.084

ORIF= Open Reduction Internal Fixation
CRIF= Closed Reduction and Percutaneous Fixation
Data are shown as median (P_{25}-P_{75}) or as N (%).
* Missing data for 1 patient in percutaneous and 20 in ORIF group.
** Missing data for 2 patients in percutaneous and 22 in ORIF group.
*** One patient (ORIF) lost to follow-up direct post-operatively

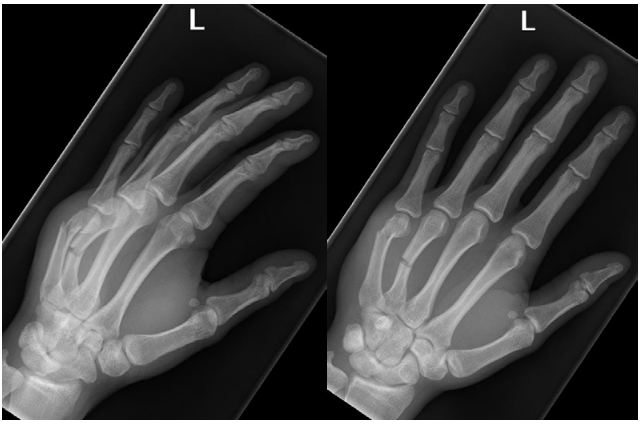
VI

Table II Fracture Classifications

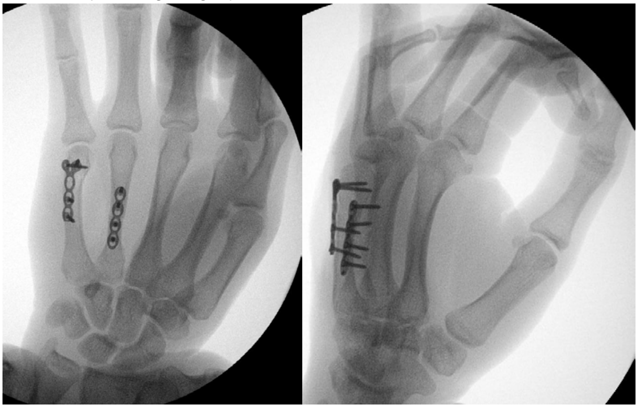
	Total	ORIF	CRIF	p-value
	n=142	n=121	n=21	
Fracture Type				0.633$
Spiral	45 (31.7%)	38 (31.4%)	7 (33.3%)	
Oblique	35 (24.6%)	28 (23.1%)	7 (33.3%)	
Transverse	50 (35.2%)	45 (37.2%)	5 (23.8%)	
Comminuted	12 (8.5%)	10 (8.3%)	2 (9.5%)	0.477^
Single Fracture				0.054$
MC II	7 (6.7%)	7 (7.8%)	0 (0%)	
MC III	7 (6.7%)	6 (6.7%)	1 (6.7%)	
MC IV*	38 (36.2%)	28 (31.1%)	10 (66.7%)	
MC V#	53 (50.5%)	49 (54.4%)	4 (26.7%)	
Multiple Fractures				0.018$
MC II + III + IV	3 (8.1%)	1 (3.2%)	2 (33.3%)	
MC II + III + IV + V	1 (2.7%)	1 (3.2%)	0 (0%)	
MC III + IV	11 (29.7%)	11 (35.5%)	0 (0%)	
MC III + IV + V	4 (10.8%)	3 (9.7%)	1 (16.7%)	
MC III + V	1 (2.7%)	0 (0.0%)	1 (16.7%)	
MC IV + V	17 (45.9%)	15 (48.4%)	2 (33.3%)	
Open Fracture	4 (2.8%)	3 (2.5%)	1 (5%)	

ORIF= Open Reduction Internal Fixation; MC= Metacarpal
CRIF= Closed Reduction and Percutaneous Fixation
Data are shown as median (P_{25}-P_{75}) or as N (%).
$ Pearson Chi Square test
^ Fisher's exact test
# most frequently injured in dominant hand (p<0.05)
* most injured in non-dominant hand (p<0.05)

Fourth and Fifth Metacarpal Fractures



Fluorscopy during surgery



Radiological follow-up 9 weeks post-operatively

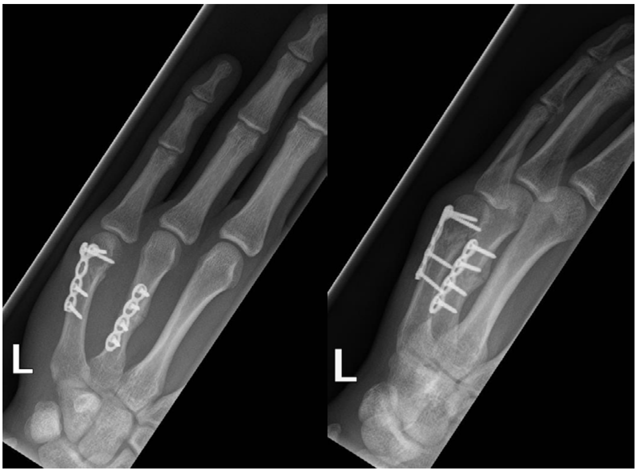


Figure 1. Example of ORIF in the treatment of Multiple Metacarpal Shaft Fractures

Treatment characteristics

All operations were performed by a Consultant Orthopaedic Surgery. Choice for type of treatment was based on personal preference. Surgery time was significantly shorter for percutaneous than for the open technique, *i.e.*, 21 (P_{25}-P_{75} 14-29) vs. 50 (P_{25}-P_{75} 34-69) minutes (**Table III**). Fixation type was most frequently plate fixation in the ORIF group and transverse K-wire fixation in the CRIF group (**Figure 1 and 2**).

Post-operative cast immobilization was found in 13% of the ORIF patients and in 95% CRIF patients (**Table III**). Of the ORIF patients 15 were immobilized post-operatively. Of these 15 patients, nine had a single fracture and six had multiple fractures. Cast immobilization after ORIF resulted in seven of these 15 patients to develop functional impairment post-operatively. All but one of the CRIF patients were given post-operative cast immobilization. All CRIF patients including made a full functional recovery.

Table III Treatment Characteristics

	All	ORIF	CRIF	p-value
	n=142	n=121	n=21	
Time to surgery (days)	7 (5-11)	7 (5-11)	6 (4-11)	0.462
Surgery time (minutes) *	44’’ (33-66)	50’’ (34-69)	21’’ (14-29)	<0.001
Single fracture		49’’	23’’	
Multiple fractures		84’’	62’’	
Fixation type				
Single fracture		33 x screws	3 x IM	
		57 x plates	12 x trans	
Multiple fractures		12 x screws	3 x IM	
		19 x plates	3 x trans	
Cast immobilization				
number of patients	36 (25.4%)	16 (13.2%)	20 (95.2%)	<0.001
duration of immobilization (weeks)	4.0 (2.8-8.0)	3.0 (2.0-4.0)	6.0 (4.5-11.0)	<0.001

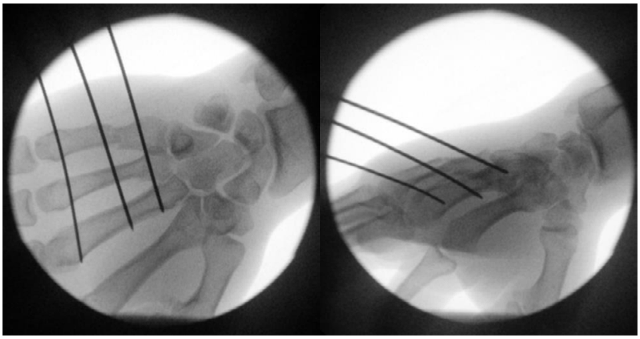
ORIF = Open Reduction and Internal Fixation
CRIF= Closed Reduction and Percutaneous Fixation
IM= Intra-Medullary K-wire fixation
trans = trans-metacarpal K-wire fixation
’’ = minutes
Data are shown as median (P_{25}-P_{75}) or as N (%)
* missing data in 2 percutaneous and 38 ORIF treated patients

Complications

Loss of reduction and rotational deformity was found in five ORIF patients (**Table IV**). This resulted in five re-operations in which new ORIF were applied. Loss of reduction and rotational deformity was not seen in the CRIF patients.

Fourth and Fifth Metacarpal Fractures

Fluoroscopy during CRIF



Radiological follow-up 10 weeks post-operatively

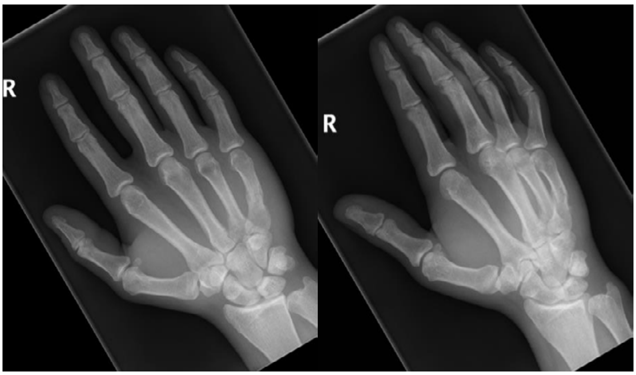


Figure 2. Closed Reduction and Percutaneous Fixation of Multiple Metacarpal Shaft Fracture

Table IV Complications Overall and Selected by Surgery Type

Complications	All (n=142)	ORIF (n=121)	CRIF (n=21)	p-value
Loss of reduction	3 (2.1%)	3 (2.5%)	0	NS
Rotational deformity	2 (1.4%)	2 (1.7%)	0	NS
Infection	2 (1.4%)	1 (0.1%)	1 (4.7%)	NS
Pain during exercise *	13 (9.2%)	10 (8.2%)	3 (17.6%)	0.395^
Functional impairment**	16 (11.2%)	16 (16.5%)	0	0.178$
Total	36 (28.1%)	32 (29.1%)	4 (22.8%)	0.778^

ORIF = Open Reduction and Internal Fixation
CRIF = Closed Reduction and Percutaneous Fixation
NS = not statistically significant
Data are shown as median (P_{25}-P_{75}) or as N (%).
* missing data for 3 patients in percutaneous and 12 in ORIF group
** missing data for 3 patients in percutaneous and 11 in ORIF group
^ Fisher exact test
$ Mann Whitney test

Post-operative infections were seen in two patients. One ORIF patient was treated with intravenous antibiotics and required a second operation for wound debridement. One CRIF patients developed a pin-tract infection as was treated with oral antibiotics and K-wire removal after fracture healing and made a full functional recovery.

Pain during exercise was seen in 13 patients. In total ten ORIF patients reported this pain. Two of these patients were re-operated for this reason. These operations consisted of adhesiolysis and removal of osteosynthesis material. All ten patients continued to experience pain during exercise at final follow-up. Three CRIF patients experienced pain during exercise at final follow-up. None required a re-operation.

Functional impairment was found in 16 (16.5%) ORIF patients. Of these, four patients required a second operation (**Table V**).

In total complications were found in 32 (29%) ORIF patients and 4 (22.8%) CRIF patients.

Re-operations

Of all 142 patients, 19 (15.7%) were re-operated. These were all ORIF patients (**Table V**). Pain, infection and loss of reduction was reason for a re-operation in six patients.

Seven patients experienced irritation from osteosynthesis material and required removal of the material. Four patients experienced functional impairment and were re-operated and required hardware removal and adhesiolysis. Two patients had a rotational deformity and were re-operated in which correction and re-osteosynthesis was performed.

Table V Indications for Re-operations Overall and Selected by Surgery Type

Indications	All (n=142)	ORIF (n=121)	CRIF (n=21)	p-value
Loss of reduction (Re-fixation)	3 (2.1%)	3 (2.5%)	0	NS
Rotational deformity (Re-fixation)	2 (1.4%)	2 (1.7%)	0	NS
Infection (removal + debridement)	1 (0.7%)	1 (0.8%)	0	NS
Pain (removal)	2 (1.4%)	2 (1.7%)	0	NS
Functional impairment (removal + adhesiolysis)	4 (2.8%)	4 (3.3%)	0	NS
Hardware irritation (removal)	7 (4.9%)	7 (5.8%)	0	NS
Total	19 (6.3%)	19 (15.7%)	0	0.052^

ORIF = Open Reduction and Internal Fixation
CRIF = Closed Reduction and Percutaneous Fixation
NS = not statistically significant
( ) = type of re-operation
Removal = Removal of osteosynthesis material
Data are shown as median (P_{25}-P_{75}) or as N (%).
^ Mann-Whitney test

Discussion

The most important new finding of this study is that multiple as well as single metacarpal shaft fractures can be safely treated by CRIF without loss of reduction, rotational deformity and re-operations.

No significant difference in complications is reported by patients after ORIF and CRIF surgery, 29.1% vs 22.8% respectively. However, the consequences of these complications were very different. For the ORIF patients 19 of the 32 patients with complications needed to be re-operated. None of the CRIF patients required a second operation.

The high percentage of re-operations found in the ORIF patients (16%) confirms the results from an earlier review which reported on pooled data from five smaller studies in which all re-operations also occurred in the ORIF treated patients (17%) [16]. Re-operations after ORIF might be explained as a result from the trade-off between the anatomical restoration of the injured metacarpal bone and the consequences of exposure of the fracture site, specifically soft tissue irritation and scar formation [95].

The current study substantiates these earlier review results in a larger patient group in a single Level I Trauma Centre. This retrospective comparative study therefore strengthens these earlier findings. Especially the percentage of complications and re-operations is of clinical significance and could be used during the shared decision-making process whilst informing the patient of benefits and risks related to the operation [101]

Cast immobilization after ORIF resulted in seven of these 15 patients to develop functional impairment post-operatively. An advantage of open surgery is direct functional mobilization in comparison with a percutaneous technique, thereby preventing scar formation to occur between moving anatomical layers otherwise resulting in a limitation of movement of the hand.

The clinical significance of this finding could be found in the importance of direct mobilization after ORIF. The aim of ORIF in hand surgery therefore should be stabilization enabling direct mobilization. When no such stability can be reached and post-operative cast immobilization seems necessary, an additional fixation technique should be considered.

An important limitation is the misbalance between the number of patients treated with ORIF and CRIF. This limits the statistical power of these findings. However, this study is the largest study reporting solely on second to fifth metacarpal shaft fractures without any patients lost to follow-up making these findings clinically important.

Another limitation is the choice for ORIF or CRIF was made by the surgeon based on personal preference. Selection bias therefore might be present. The patient however did not choose to be operated by a specific surgeon. The fact that a patient did not specifically choose a surgeon could also be interpreted as fate [102]. Therefore, randomizing each patient for a specific surgeon and subsequently a treatment type.

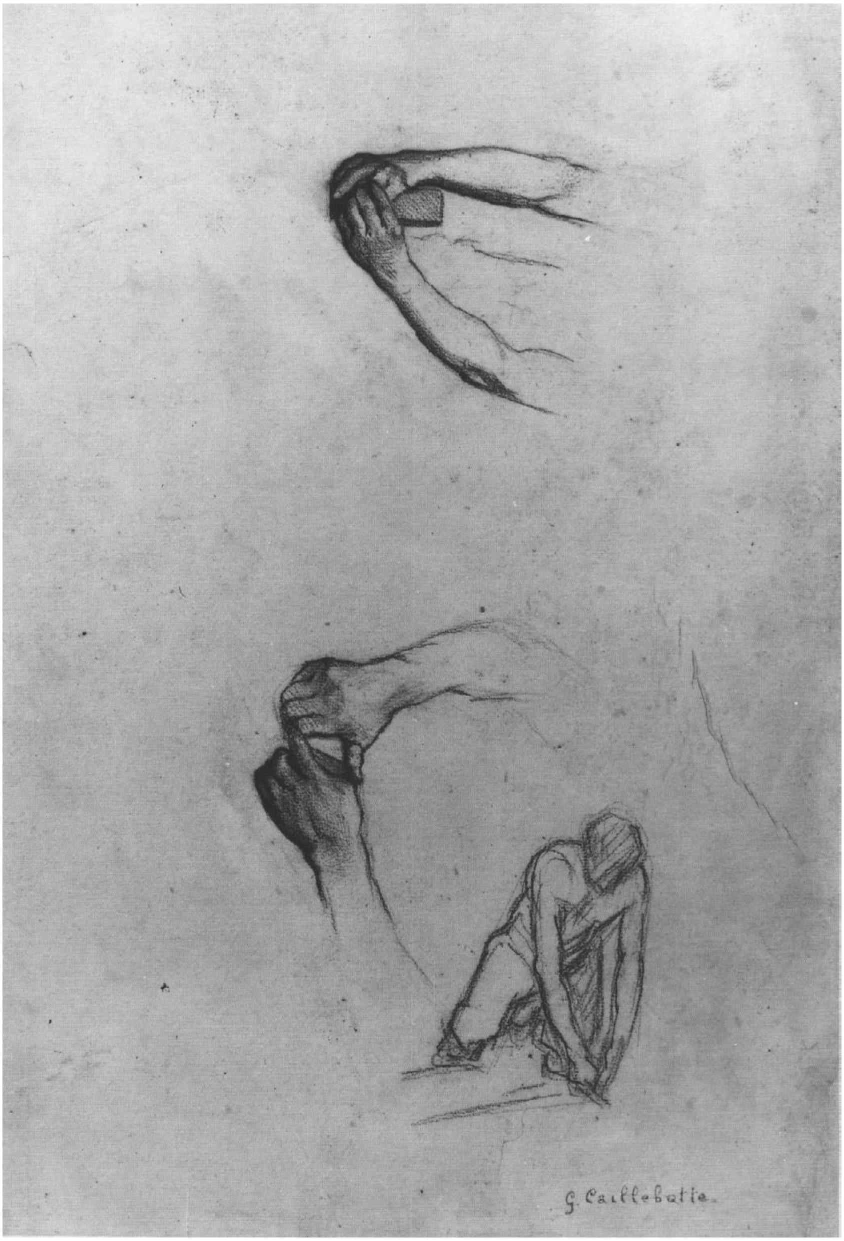
Fracture type could be a reason to choose for open or closed technique. Within the CRIF group mostly spiral, oblique and transverse fractures were seen. Comminuted fractures were treated with ORIF mostly. Therefore, spiral, oblique and transverse fractures can be treated with CRIF without the risks associated with ORIF.

The current study shows that spiral, oblique and transverse metacarpal shaft fractures can be safely treated by CRIF resulting in good outcome, shorter operation time, and less re-operations than ORIF [16, 18, 90].

Secondly, the results of CRIF for multiple metacarpal shaft fractures are as good as the ORIF treated patients with less risk of complications.

Étude pour les Raboteurs de parquet
Gustave Caillebotte (1848-1894)
Musée Pissarro, Pontoise
Date circa 1875
Source Kirk Vaebedoe: Gustave Caillebotte, 1987 Author
HYPERLINK "/wiki/Gustave_Caillebotte"Gustave Caillebotte

Part B



VII

Accuracy of Fluoroscopy in the Treatment of Intra-articular Metacarpal Fractures

J Hand Surg Eur Vol. 2013 Nov;38(9):979-83.

A.P.A. Greeven
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Abstract

The purpose of this study was to determine the accuracy of fluoroscopic imaging during closed reduction and percutaneous fixation of intra-articular thumb metacarpal fractures. Closed reduction and percutaneous fixation was assessed in eight simulated intra-articular thumb metacarpal fractures, using fluoroscopy and digital radiographs. Displacement and fracture step-off were measured during fluoroscopy, on plain radiographs, and by direct visualization after careful dissection. Displacement on fluoroscopy was 0.8 (SD 1.0) mm and 1.2 (SD 1.4) with radiographic imaging. Direct visualization showed displacement of 0.9 (SD 1.2) mm. Intra-articular step-off on fluoroscopy was 0.8 (SD 1.0) mm and 0.8 (SD 0.8) with radiographic imaging. Direct visualization showed an intra-articular step-off of 0.8 (SD 1.2) mm. Statistical analysis showed excellent compatibility between fluoroscopy and direct visualization. Fluoroscopic visualization during surgery provides an adequate assessment of articular step-off and displacement in comparison with radiographs and direct visualization.

Level of Evidence: **Anatomical / Technical study**

Introduction

An intra-articular fracture at the base of the thumb metacarpal (Bennett's fracture) is the most common fracture in the carpometacarpal joints [27, 103]. Post-traumatic deformity of the joint surface may result in osteoarthritis, causing a painful joint and decreased function in the hand [20, 27, 104, 105].

Surgical treatment aims to prevent these problems by anatomical reduction of the fracture fragments [24, 29, 49, 104, 106].

During closed reduction and percutaneous fixation, fluoroscopic imaging can be used to assess the reduction. However, limited data are available on the accuracy of fluoroscopy in hand surgery. Only one study describes the accuracy of fluoroscopy in the treatment of intra-articular fractures of the hand [32]. This study showed significant differences in the accuracy of fluoroscopy in comparison with radiography and direct visualization. The authors concluded that fluoroscopy is often in error in comparison with radiography and direct examination when gap, step-off, and displacement are assessed. This would mean that the use of fluoroscopy during hand surgery is unreliable.

The alternative to closed reduction and percutaneous fixation is open reposition and internal fixation. The advantages of open reposition and fixation are a more rigid fixation and the possibility of starting early mobilization. The disadvantages are the necessity for extra exposure, which is associated with extra tissue damage and risk of complications. Open reduction also causes the formation of scar tissue, resulting in loss of function (Fusetti et al., 2002). Unnecessary exposure could be avoided if closed reduction can be determined accurately by intra-operative fluoroscopy.

The purpose of this study was to compare the accuracy of fluoroscopic imaging with radiography and direct visualization during closed reduction and percutaneous fixation in the treatment of simulated Bennett fractures.

Materials and methods

The study was done on preserved specimens from persons who had voluntarily consented to have their bodies used for medical research and died at age of 75 years or older. During life none had experienced arthritis or previous trauma of the hand.

In eight preserved forearms, an intra-articular thumb metacarpal fracture was made with an osteotome. Intact arms were used. An incision was made on the dorso-medial side of the thumb metacarpal. All osteotomies were identically performed with an osteotome at an angle of 30° to the thumb metacarpal. In all eight hands, this resulted in an intra-articular fracture at the base of the thumb metacarpal with only one intra-articular fragment at the ulnar side. In all eight hands, this fragment consisted of at least 5 mm of the shaft and one-third of the joint surface, consistent with a Bennett fracture (**Figure 1**).

Figure 1 Simulated intra-articular thumb metacarpal fracture.
(Detail of fluoroscopic image of the hand)

All eight Bennett fractures were treated using closed reduction and percutaneous fixation with two parallel-positioned 1.6 mm Kirschner wires between the thumb and index metacarpal shaft [11, 31, 42, 53, 56]. Fluoroscopic images were taken in two directions (anteroposterior [59] and lateral) to determine the quality of the reduction (**Figure 2**). The quality of the fixation was assessed by moving the thumb, during which any movement of the fracture fragments was noted using constant fluoroscopic imaging. A stable fixation was defined as one in which no displacement of the fracture fragments occurred.

Figure 2 Fluoroscopy after closed reduction and percutaneous fixation
(Similar hand as Figure 1)

A digital image program (ImageJ; Scion Corp., Frederick, Maryland, USA) was used to measure intra-articular step-off and displacement on the fluoroscopic images. Measurements were calibrated on the thickness of the 1.6 mm K-wires. A step-off and displacement of up to 2.0 mm was accepted [47, 56]. When a Step-off or Displacement of > 2.0 mm was seen on fluoroscopy, the K-wires were removed and the closed reduction and percutaneous fixation was done again.

After closed reduction and fixation, plain AP and lateral radiographs were taken in all eight hands. The fluoroscopic images and radiographs were saved digitally. The digital measurements on fluoroscopy were done before the radiographs were taken. A different researcher measured step-off and displacement for each type of visualization. All measurements were made by either a surgical or radiology resident.

The dissection consisted of division of the abductor pollicis longus and extensor pollicis longus tendons together with the ligaments of the trapezio-metacarpal joint on the dorso-radial side. This enabled direct measurement of the fragment displacement and intra-articular step-off without applying additional force on the percutaneous fixation (**Figure 3**).

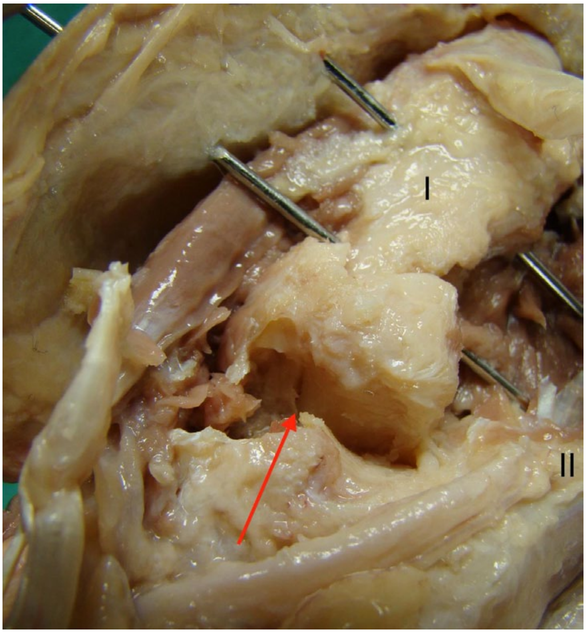

Figure 3 Open visualization of the fracture
(I = thumb metacarpal; II= index metacarpal; red arrow indicates intra- articular fracture)

Fracture displacement and step-off were measured with a precision of 0.1 mm for all three modalities (fluoroscopy, radiographs, and direct visualization). Step-off was defined as the largest intra-articular step perpendicular to the joint surface that could be measured. Displacement was defined as the largest distance between two fracture fragments that could be measured. The results of fluoroscopic imaging measurements were compared with the measurements on the plain radiographs and the results of measurements after dissection. In these comparisons, direct visualization was considered the gold standard.

Data are expressed as mean (standard deviation [SD]). Measurement results of the three visualization methods were compared using paired Student t-tests. A p value < 0.05 was considered to be statistically significant. Intraclass correlation coefficients (ICC's) were calculated to assess the agreement between the three visualization methods, using a two-way random model with measures of consistency.

Results

In all eight hands fracture reduction and percutaneous fixation was achieved. In three hands a second reduction and percutaneous fixation was necessary after measurement of displacement and step-off under fluoroscopy. After reduction and fixation, the intra-articular step-off was 0.8 (SD 0.8) mm with fluoroscopic imaging. Radiographs showed an intra- articular step-off of 0.8 (SD 1.2) mm. After dissection, direct visualization showed a step-off of 0.8 (SD 1.0) (**Table I**).

Table I Measurement of displacement and step-off

Specimen	Dislocation			Step-off		
	Fluoroscopy	Radiography	Open	Fluoroscopy	Radiography	Open
I	0,0	0,0	0,0	0,0	0,8	0,0
II	0,0	0,0	0,0	0,0	0,0	0,0
III	0,0	1,3	0,0	0,0	0,0	0,0
IV	2,0	4,0	2,0	2,0	1,3	2,0
V	0,0	1,0	0,0	0,0	1,5	0,0
VI	2,0	2,5	2,0	2,0	2,0	1,0
VII	2,0	0,8	3,0	2,0	0,5	3,0
VIII	0,0	0,0	0,0	0,0	0,0	0,0
Mean	0,8	1,2	0,9	0,8	0,8	0,8
SD	1,0	1,4	1,2	1,0	0,8	1,2

Fl = fluoroscopic imaging, Ra = Radiological imaging, Op = Open direct visualization

Displacements measured using fluoroscopy, radiographs, and direct visualization were 0.8 (SD 1.0) mm, 1.2 (SD 1.4) mm, and 0.9 (SD 1.2) mm, respectively. Comparison of these results with the Student's t-test showed no significant difference between the measurements of displacement and step-off between the three visualization methods.

The agreement between measurements from open visualization and fluoroscopy, calculated with the ICC's, were excellent for both displacement and step- off (ICC 0.95 and 0.90, respectively; **Table II**). There was less agreement between open visualization and radiographs, and between fluoroscopy and radio- graphs (ICC 0.56 and 0.69, respectively, for displacement, and 0.22 and 0.52, respectively, for step-off).

Table II Intra-class Correlation Coefficient (ICC) with 95% CI

Comparing Displacement and Step-off using Open visualization, Fluoroscopy and Radiography

	Displacement ICC (95% CI)	Step-off ICC (95% CI)
Open vs. Fluoroscopy	0.95 (0.78 to 0.99)	0.88 (0.52 to 0.98)
Open vs. Radiography	0.56 (–0.17 to 0.89)	0.22 (–0.52 to 0.77)
Fluoroscopy vs. Radiography	0.69 (0.04 to 0.93)	0.52 (–0.23 to 0.88)

Discussion

The amount of incongruity that can be accepted after surgical treatment of intra-articular thumb metacarpal fractures is still unknown [47]. Some have shown that osteoarthritis does not occur with a step-off of up to 3 mm, whereas others accept a maximum of 1 mm [21, 56, 107]. The current study showed that step-off was adequately assessed using fluoroscopy. Using fluoroscopy, a measurement error of > 1 mm incongruity occurred in only one case. With radiography, measurement errors of > 1 mm were seen in four cases. The dis- placement and step-off found with fluoroscopy was never larger than the displacement and step-off found with direct visualization. This means that displacement is not overestimated with fluoroscopy.

Only limited data are available on the accuracy of fluoroscopy in hand surgery [32]. The current data showed an agreement between measurements with open visualization and fluoroscopy to be excellent for both displacement and step-off (**Table II**). The 95% confidence interval showed a small range for displacement and step- off when comparing open measurements with fluoroscopy. A larger range was found for displacement and step-off when radiography was com- pared with open measurement or fluoroscopy. These results are in contrast with the study by Capo et al [32]. There are several explanations for these discrepancies. Of major importance is the difference in the precision of measurements in their study. Measurements on the fluoroscopic and radiographic images were made in millimetres with a metric ruler placed on the screen. After dissection, open measurements were made in 0.01 mm with a digital caliper. These differences in measurement could have resulted in unjustifiable significances and conclusions. A further explanation for the difference in results could lie in the fact that their study used hands, which were already fully dissected. This would make the fracture fixation more prone to displacement during the experiment, because of the absence of soft tissue and its ligamentotaxis effect. During the design of the current study, these limitations were taken into consideration and accounted for. The measurements in the current study were done with equal precision (0.1 mm) in all modalities, and the experiments were done on intact hands.

We conclude that intra-operative fluoroscopic imaging provides an accurate assessment of articular step-off and displacement in comparison with radiographs and direct visualization and, therefore, intra-operative fluoroscopic imaging is an adequate tool for use in the treatment of fractures of the hand.

VIII

Optimal Surgical Approach for First Metacarpal Base Fractures; A Surgical-Anatomical Study

J Hand Surg Eur Vol. 2020 Feb;45(2):136-139.

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G.J. Kleinrensink
M.H.J. Verhofstad

Abstract

The aim of this study was to define a possible safe zone for a (minimally invasive) surgical approach of first metacarpal fractures in relation to the superficial branch of the radial nerve (SBRN) and the Dorsal Branch of the Radial Artery (DBRA).

Twenty embalmed arms were dissected and the course of the SBRN and the DBRA in each individual arm was marked. With Computed Assisted Surgical Anatomy Mapping (CASAM) a large diversity in anatomical pattern for the SBRN and a consistent pattern for the DBRA was found. Combining these findings, a safe zone could be defined for future surgical fixation. Preferably, a percutaneous or minimally invasive trans-metacarpal fixation technique should be used treating first metacarpal fractures, with K-wire positioned on the radial border of the first metacarpal, in the distal 75% of the first and second metacarpal to prevent iatrogenic damage to SBRN and DBRA.

Level of Evidence: **Anatomical Study**

Introduction

Long-term complications after percutaneous and open surgery of the first metacarpal have recently been reported, describing pain and loss of sensation of the thumb [108-111]. The SBRN is known for its involvement in pain syndromes which are very difficult to treat [112]. Therefore, it is generally assumed that preventing iatrogenic damage to the SBRN is of clinical importance.

Injury to the superficial branch of the radial nerve (SBRN) has been reported after various types of operations, e.g. external fixation of distal radial fractures [113-116]. Suggestions have been made to adjust pin positioning, from the radial side to the dorsal side of the radius while applying an external fixator to prevent damage of the SBRN [111]. Similar iatrogenic injuries have been described for K-wire fixation according to Kapanji. Semi-open procedures; i.e. surgical approach, blunt dissection and the use of a tissue guard; have also been suggested with direct vision to approach the distal radius. Iatrogenic injury of the radial artery has also been reported in hand surgery [117, 118]. The dorsal branch of the radial artery (DBRA) can be damaged during inter-metacarpal Kirschner wire fixation [50, 119, 120].

The anatomical technique called Computer Assisted Surgical Anatomy Mapping (CASAM) has been successfully used to define anatomical variance in a diversity of anatomical studies [121-124]. Based on these anatomical studies clinically important suggestions have been made to optimize surgical approaches [123, 125].

The current anatomical study uses CASAM to focus on the branching pattern of the SBRN and the DBRA in relation to the first and second metacarpal. The hypothesis was that based on the anatomical position of the SBRN and the DBRA a possible safe zone could be described for minimally invasive or even percutaneous surgery to approach of first metacarpal fractures preventing iatrogenic damage to the SBRN and DBRA.

VIII

Materials and methods

Preparation of the specimen

Twenty arms were flushed with anubifix® (www.anubifix.com) to regain flexion after rigor mortis and embalmed with a 4.4% formalin solution. None of these arms showed macroscopic signs of disease or previous surgery. All dissections were performed by two researchers (AG and JvG, Level of experience Level IV and III respectively) [76].

Dissection

A standardized dissection technique was used. A semi-circular incision was made on the radial side of the forearm, approximately 10 cm distally from the elbow. On the volar side of the forearm a longitudinal incision was made towards the thenar muscle. Another incision was made on the dorsal side over Lister's tubercle towards the second Metacarpal Phalangeal joint (MCP II). The two longitudinal incisions were connected via a semi-circular incision over the dorsal side of the Interphalangeal joint (IP) and the MCP II joint. The skin flap was then dissected from cranial to distal after identifying the SBRN submerging between Brachioradialis muscle (BR) and Extensor Carpi Radialis Longus (ECRL).

In each arm the SBRN was located directly where it emerges between the BR and the ECRL. The course of the SBRN was then dissected distally to the Interphalangeal joint (IP) and Second Metacarpal Phalangeal joint (MCP II). At each location where the nerve branched a yellow pin was placed.

The Radial Artery was identified at the styloid process of the radius. The Dorsal Branch of the Radial Artery was marked with a red pin. The dorsal branch was identified within the anatomical snuff box and webspace I. Both locations were again marked with a red pin.

CASAM

Using CASAM enables comparison of anatomical routes or anatomical relationships between different anatomical specimen which are different in size and dimension [121, 123-125]. CASAM is based on the fact that bony landmarks (BL), such as Lister's tubercle, have a relatively constant position in each arm. From these "bony landmarks" so called "shape defining landmarks" (SDL) are calculated, to mark the outline of each arm, by equally dividing the space between two BL's. The BL's and SDL's were used to define the shape of each arm and the locations for these landmarks were computed. A digital program called Magic Morph (Publisher eTinysoft, version Nov 2007) was used to merge all twenty arms into one "average" arm. Each separate arm was then transformed into the shape of this "average" arm using the "average" arm as a model, a process called warping.

The result is that all twenty arms now have the dimensions of the "average" arm making it possible to compare the arms and the course of the SBRN and the DBRA in each arm individually.

Photoshop processing

Each arm was photographed using a Nikon 60D camera with a Sigma 50mm 1:2.8 DG MACRO lens. These photographs were made using a standardized set-up [124]. The camera was positioned perpendicular to the specimen at a fixed distance and the arms were placed in specially designed clamps to ensure standard alignment [125].

The photographs of each are is then used for CASAM. After morphing of the twenty arms on these photographs, each arm is given the dimensions of the "average arm". On each of these twenty photographs the course of the SBRN and DBRA are traced using Photoshop CS4.

The photoshop layers marking the twenty routes of the SBRN are then compiled into one picture for further analysis. The same is done for the twenty routes of the DBRA.

Safe zone identification

A low-density area of the SBRN is defined for the branching pattern of the SBRN. The same was done for the branching pattern of the DBRA. The photoshop layers marking the SBRN and the

DBRA were than combined. The overlap between the low-density squares for the SBRN and the DBRA define the possible Safe Zone. The safe-zone is then related to bony landmarks for clinical reference.

Results

In all twenty arms the SBRN and DBRA could be identified and the anatomical course defined. Standardized photographs of all twenty arms could be made. Using CASAM it was possible to process all twenty arms. The course of the SBRN and DBRA were traced in all twenty arms and marked with yellow and red lines using Photoshop CS4 (**Figure 1**).

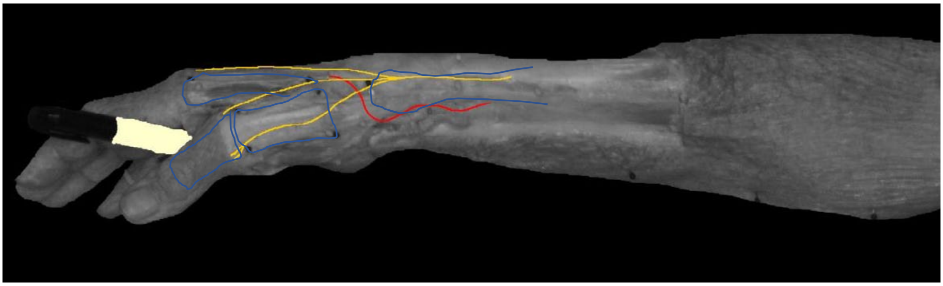

Figure 1. The marked course of the Superficial Branch of the Radial Nerve and the Dorsal Branch of the Radial Artery on one arm
(Yellow = Superficial Branch of the Radial Nerve, Red = Dorsal Branch of the Radial Artery, Dark Blue line: identifies Distal Radius, First and Second Metacarpal and Proximal Phalanx)

The marked courses of the SBRN of all twenty arms were than projected on one arm using photoshop (**Figure 2**). The course of the SBRN at the Carpo-Metacarpal joint and base of the first metacarpal was very diverse. A possible zone with low density of SBRN could be marked more distally from the CMC joint. The diversity pattern found of the SBRN considered a safe zone was marked with low density of the SBRN (**Figure 2; blue square**).

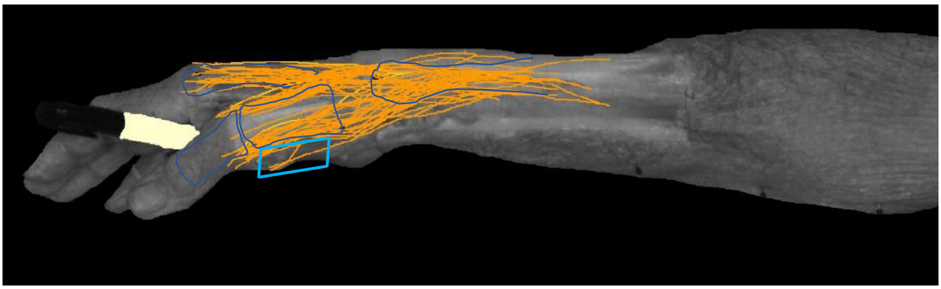

Figure 2. The twenty routes of the Superficial Branch of the Radial Nerve
Bleu-Square: low density zone
Dark Blue line: identifies Distal Radius, First and Second Metacarpal and Proximal Phalanx

The twenty courses of the DBRA were projected on one arm (**Figure 3**). The course of the DBRA was shown to be very similar in all twenty arms. A zone with low density of DBRA can be marked just distally from the base of the second metacarpal, this area corresponded with 25% of the total length of the second metacarpal (**Figure 3; green square**).

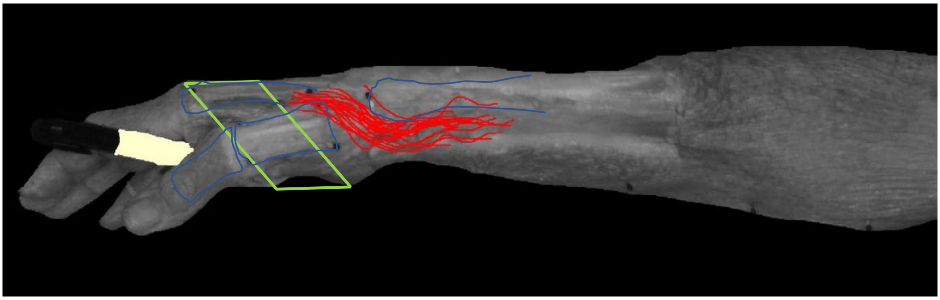

Figure 3. The twenty routes of the Dorsal Branch of the Radial Artery
Green Square: low density zone
Dark Blue line: identifies Distal Radius, First and Second Metacarpal and Proximal Phalanx

Combining the courses of the SBRN and DBRA shows overlap between the two squares resulted in a possible Safe Zone (**Figure 4**).

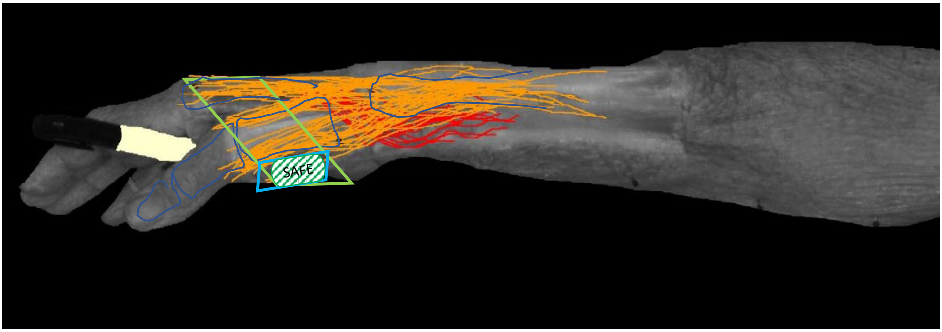

Figure 4. Combining the routes of the SBRN and the DBRA resulting in a possible Safe Zone
Combined Square: Safe Zone
Dark Blue line: identifies Distal Radius, First and Second Metacarpal and Proximal Phalanx

Assessment of the Safe Zone in relationship with bony structures showed that at the base of the first metacarpal a large diversity of branching pattern could be found of the SBRN. This area corresponded with 25% of the total length of the first metacarpal (**Figure 5 and 6**).

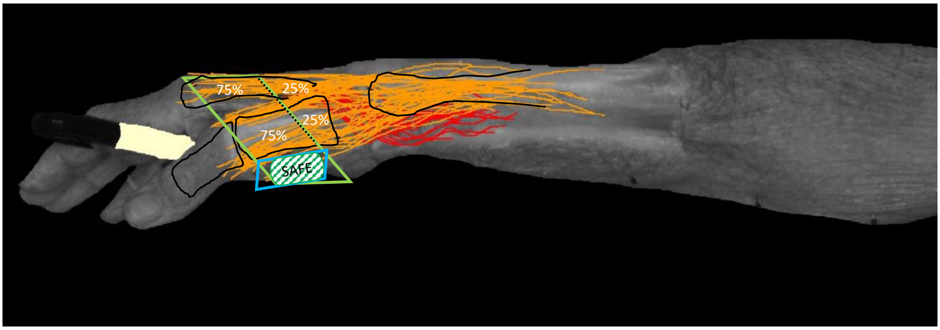

Figure 5. Safe Zone in relationship to bony structures
Black line: identifies Distal Radius, First and Second Metacarpal and Proximal Phalanx
% (in white): branches of SBRN mostly seen in base 25% of metacarpals

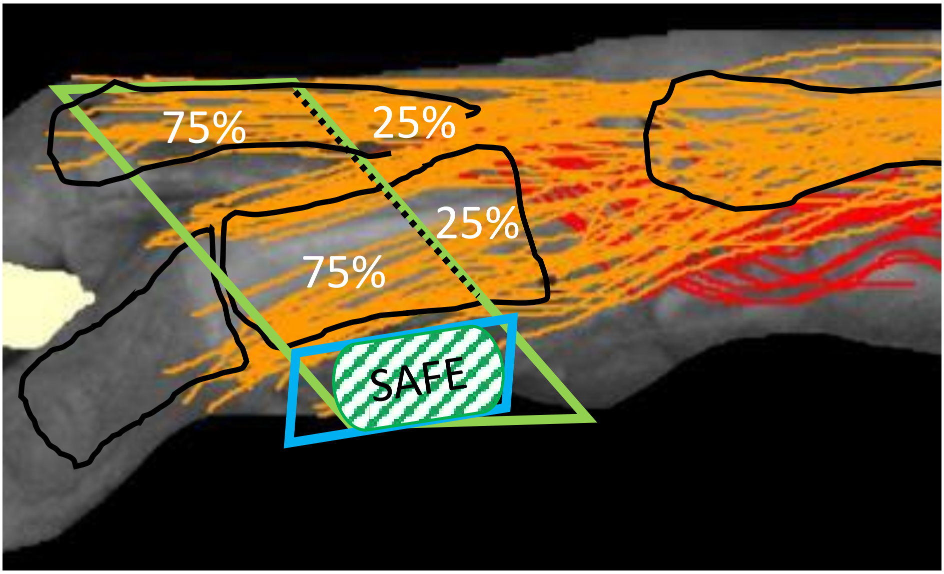

Figure 6. Detail of base of First Metacarpal with the Identiefied Safe zone.
Black line: identifies Distal Radius, First and Second Metacarpal and Proximal Phalanx
% (in white): branches of SBRN mostly seen in base 25% of metacarpals

VIII

Discussion

The most important finding of the current study is that a safe-zone for optimal surgical approach of first metacarpal fractures can be defined. This safe-zone for surgery of the first metacarpal is based on the diverse courses found for the SBRN and the very similar anatomical routes found for the DBRA.

The current study is the first in which CASAM was used to suggest a possible safe zone for first metacarpal surgery. The current study has shown that this new anatomical technique, in which modern digital processing techniques are used to compare anatomical findings in separate anatomical specimen, can be successfully used in hand surgical research as well.

The reported large diversity in anatomical course of the SBRN over the first and second metacarpal might be explanatory for the iatrogenic injury which sometimes occur during surgery resulting in post-operative pain and loss of sensation [109].

A similar anatomical route of the DBRA in all twenty arms was found. This might explain why iatrogenic arterial injury occurs less frequently in metacarpal surgery than in scaphoid fixation [126]. Nonetheless, according to the current study the dorsal branch of the radial artery can be at risk when using a percutaneous inter-metacarpal technique for first metacarpal fractures, in which the cranial Kirschner wire is placed at the base of the second metacarpal (**Figure 5**).

For ORIF of first metacarpal base fractures a dorsal or latero-dorsal approach is often recommended [127]. These incisions use anatomical landmarks such as the Extensor Pollicis Longus tendon, Extensor Pollicis Brevis tendon and Abductor Pollicis Longus and bony landmarks such as Radial Styloid Process, First Carpo-Metacarpal Joint (CMC-I) and Metacarpal Phalangeal Joint to define the surgical approach. With the large variance in anatomical branching pattern of the Superficial Branch of the Radial Nerve as found in this study an open approach for first metacarpal base fractures can be a challenging operation and the diversity in branching pattern makes it very hard to predict were sensory branches can be found. It therefore can be debated if a dorsal or latero-dorsal approach could better not be used.

The modified Wagner approach projects through skin overlapping the base of the first metacarpal. Based on the current anatomical study it can be confirmed that the SBRN is at risk during this approach. This explains the results reported in a recent long-term clinical study reporting on the comparison between outcome after ORIF and CRIF after 10-year follow-up. A change of sensation of the thumb was reported in 13 patients, of which 11 had been treated using ORIF. Secondly, patients with high pain scores (VAS) were only seen in ORIF patients [109].

Several K-wire positioning for CRIF are described [25, 61, 128, 129]. The findings of the current study suggest that with Wagner's and Iselin's technique, in which the cranial K-wire transfixes the first metacarpal to the base of the second metacarpal, the DBRA might be at risk [24, 25, 128]. To prevent possible injury to the DBRA the K-wire position should be placed in the area where the DBRA is absent. When compared with bony landmarks this corresponds with distal 75% of the second metacarpal (**Figure 3**). Clinical studies have shown that a parallel trans-metacarpal fixation technique can be safely used in the treatment of extra-articular fractures as well as intra-articular fractures at the base of the first metacarpal and result in good clinical and radiological outcome [11, 56].

Alternative K-wire placement is seen with pin fixation of the first metacarpal to the trapezium [129]. In order to prevent the SBRN from injury the skin overlying the base of the first metacarpal should be avoided. When compared with bony landmarks this corresponds with not placing K-wires in the proximal 25% of the first metacarpal (**Figure 5**). Therefore, this technique might be more difficult to perform when aiming to avoid the overlying skin of the proximal 25% of the first metacarpal.

Based on the current study an extra-focal pinning technique in which the K-wires are positioned more distally from trapezo-metacarpal joint and placed in the distal 75% of both the first and second metacarpal would be the safest option to prevent the DBRA and SBRN from injury.

Based on the current study the authors conclude that an open surgical approach of the base of the first metacarpal base might result in unintended damaging the sensory nerve of the radial nerve. A closed extra-focal pinning technique could prevent this complication from occurring, while using the defined safe-zone for K-wire positioning.

IX Discussion

The hypothesis of this thesis is that a minimal invasive surgical technique is preferable in the treatment of metacarpal fractures compared with open reduction and internal fixation.

Part A

CRIF applicable for first metacarpal fractures?

This thesis started with the assessment of 25 patients who had been treated for unstable fractures at the base of the first metacarpal with a closed reduction percutaneous fixation technique (CRIF) which had been widely used after its reported results in 1989 [11]. The aim of this first study was to see what the results of the CRIF would be when focussing solely on first metacarpal base fractures. The treated fractures consisted of Bennett's, Rolando's, comminuted, extra-articular and epiphyseal fractures. The reported results show that all 25 patients could be treated with CRIF and that no ORIF had been necessary.

After 24 months follow-up functional outcome, loss of reduction and post-traumatic arthrosis were assessed using visual analogue scale (VAS), Pinch and Grip-strength and radiographs to assess post-traumatic arthrosis. Comparison between Grip- and Pinch-strength between the injured and non-injured hand was done by defining a Minimal Clinically Important Difference (MCID) of 20% adjusted for hand dominance [35].

In the group of extra-articular fractures of 15 patients, only one patient had loss of Grip-strength greater than 20% in comparison with the contra-lateral side corrected for hand dominance. No clinically important difference was found for Pinch-strength. One patient experienced functional limitations and was unable to return to a previous hobby. In the patients' group with intra-articular fractures, seven patients had a Bennett's fracture and three a Rolando's fracture. One patient with a Bennett's fracture had a loss of Pinch strength greater than 20% corrected for hand dominance. One of the three patients with a Rolando's fracture had Grip loss greater than 20%. None of the patients with intra-articular fractures experienced any functional limitations.

In three patients, pin-tract infections occurred requiring treatment with oral antibiotics. In one of these patients, K-wire removal was delayed (50 days) compared to the average (32 days) of all 25 patients.

The described fixation procedure results in a stable fixation of the fracture fragments, and no secondary dislocation of the fracture occurred. All fractures consolidated within 32 (26–50) days and no new fractures were observed. **These results suggest that CRIF is a safe and easily applicable technique for the surgical treatment of first metacarpal base fractures.**

The reported patients in Chapter II were treated for different types of first metacarpal base fractures. To further assess the outcome after a closed surgical technique in comparison to ORIF in treating an intra-articular first metacarpal base fracture a systematic review was performed (**Chapter III**). The outcome after surgical treatment of solely Bennett's fractures was assessed

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comparing CRIF with ORIF. The literature search resulted in 10 studies being included, reporting on 215 patients. CRIF had been applied in 77 patients and ORIF in 138. ORIF consisted of screw, plate and tension-band wiring. The CRIF treatments applied were Iselin's technique, Van Niekerk's technique and Wagner's technique.

Failure of fixation was significantly more often seen in 8.2% of ORIF treated patients compared to 2.9% in CRIF treated patients (p= 0.048). Operation time was 71.9 min vs 30.2 min, ORIF vs CRIF respectively. Pain was seen in 32.9% of ORIF treated patient's vs 22.3 % in CRIF treated patients. As in the study of Chapter II, infections were more frequently seen in the CRIF group, i.e. 1.0% ORIF vs 7.0% CRIF. All infections were pin-tract infections that could be successfully treated with antibiotics and removal of K-wires after consolidation. These infections had no late consequences. No re-fractures were reported for ORIF nor for CRIF [108]. Planned removal of osteosynthesis material was 69% in the ORIF treated patients and 0% in the CRIF treated patients [108]. **These reported findings confirm that CRIF is easily performed and a safe alternative treatment in comparison to ORIF in the surgical treatment of Bennett's fracture.**

Prevention of developing post-traumatic arthrosis?

Based on the pooled data in the reported systematic review in **Chapter III** the choice for ORIF in the surgical treatment of Bennett fractures may not be made based on the claim that doing so reduces the chance of post-traumatic arthrosis. [20, 38, 40] Especially in the comparative studies with a follow-up period of 84 months (range 36-204) and 83 months (range 54-154) an advantage of ORIF over CRIF in preventing post-traumatic arthrosis was not found. [22, 42] However, there was a large variance in follow-up period in the included studies, ranging from 8 to 84 months (**Chapter III**).

To further assess the role of anatomical reduction via ORIF in the prevention of post-traumatic arthrosis in the surgical treatment of Bennett's fracture, a new study was designed with a 10-year follow-up. In **Chapter IV** the results are reported of the 50 patients with surgically treated Bennett's fracture after a 10-year follow-up period. Fifteen patients were treated with CRIF and 35 with ORIF. In line with previous publications with shorter follow up, this study confirms good clinical results for ORIF as well as for CRIF in the treatment of Bennett's fracture at 10-year follow up [22, 41, 56, 61, 62].

An anatomical reduction via ORIF did not prevent post-traumatic arthrosis from developing. More importantly, a significant correlation was found between a persistent step-off and gap larger than 2 mm and the development of post-traumatic arthrosis.

Previously, Cannon et al. reported on 22 patients treated non-operatively for a Bennett fracture. In 16 of these patients a persistent separation of the fracture fragment of 1 mm or more was seen after reduction. At follow-up (9.6 years) "little evidence was found that imperfect reduction leads to significant symptomatic arthritis" [21]. Timmenga et al. also found that ORIF did not prevent the development of post-traumatic arthrosis in 11 patients in comparison to 7 CRIF treated patients after 10-year follow-up [20]. Smaller studies also reported good results when step-off was smaller than 2mm [20, 38, 77]. These studies show that an anatomical reduction via ORIF does not prevent post-traumatic arthrosis. **Furthermore, it can therefore be confirmed that, based on the long-term follow-up study, a persistent step-off and gap of up to 2mm can be accepted in treating Bennett's fracture.**

Other intra-articular first metacarpal fractures?

The same persistence in step-off and gap might be considered for other intra-articular fractures at the base of the first metacarpal. In **Chapter II** 3 Rolando's fractures were treated with CRIF similar to the reported 7 Bennett's fractures. At follow-up after 24 months 2 patients with Rolando's fractures were assessed and no signs of post-traumatic arthrosis was seen. The short time follow-up (24 months) makes it difficult to predict if Rolando's fracture indeed allows persistent step-off and gap up to 2 mm or that an anatomical reduction via ORIF would be beneficial.

An important new finding of the long-term follow-up study was the difference in pain or loss of sensation on the radial side of the thumb after ORIF in comparison with CRIF. In both groups only one patient was re-operated with the same technique again, because of secondary dislocation. An important other finding in the same study is the high pain scores (VAS > 3) which were only seen in ORIF patients. A higher pain score was significantly correlated with a higher DASH and also with loss of strength. The reported pain was not correlated with post-traumatic arthrosis (Eaton-Littler score). Possibly dissection necessary for ORIF results in higher risk of iatrogenic injury to sensory nerves at the base of the first metacarpal. An anatomical study was designed to assess this possible explanation for difference in pain or loss of sensation after ORIF (**Chapter VIII**).

CRIF beneficial in all metacarpal fractures?
Single second to fifth metacarpal shaft fractures:

Would the reported beneficial effect of CRIF in the treatment of first metacarpal base fractures also exist in other metacarpal fractures? We hypothesized that if this would be the case, the beneficial effects would also be found comparing CRIF and ORIF in the treatment of second to fifth shaft fractures. These extra-articular fractures are not at risk for post-traumatic arthrosis. Treatment of these fractures aims to maintain length, axis and rotation by surgical fixation in case of instability. With a minimal invasive technique, the fractured metacarpal can be stabilized without the necessary tissue dissection necessary in ORIF, similar to first metacarpal fractures. To assess if a single metacarpal shaft fractures might benefit from CRIF a systematic review was performed combining available literature regarding this topic (**Chapter V**).

Based on the data from the included literature, reporting on a total of 101 patients operated for a single, closed unstable metacarpal shaft fracture, complication rates are more frequently found in the K-wire-treated patients in comparison to ORIF, 35% vs. 22 % respectively. However, the reported complications after ORIF are more frequently related to functional impairment and more often require reoperation (15%). In contrast, most complications after K-wire fixation again involved superficial infection, which could be treated conservatively. Furthermore, general functional outcome was reported to be equally good for both techniques. **Based on these results it can be confirmed that CRIF is a safe surgical treatment of single second to fifth metacarpal shaft fractures.**

Multiple metacarpal shaft fractures

Furthermore, multiple as well as single metacarpal shaft fractures might benefit from a minimal invasive surgical technique. The difficulty here lies in the fact that more unstable shaft fractures need stabilization. The fractured metacarpal cannot be stabilized to it intact neighbouring metacarpal. The percutaneous Kirschner wire fixation trans passes at least three metacarpals and makes the fixation less stable requiring post-operative mobilization. In addition, multiple metacarpal shaft fractures in the same hand are a result of larger impacted energy at time of the trauma resulting in more fractures but also in soft tissue injury. These soft tissue injuries might result in more adhesion formation. Post-operative immobilization might impair functional outcome where direct mobilization after open surgery might prevent impairment based on adhesion formation.

An additional, short-term study (**Chapter VI**) was performed to assess if CRIF would also be beneficial in treating multiple as well as single second to fifth metacarpal shaft fractures. A patient cohort of 142 patients, who had all been treated in a single Level I Trauma Centre, were retrospectively assessed. This retrospective comparative study confirmed the earlier findings of the systematic review in **Chapter V**. No significant difference in complications were found after ORIF and CRIF surgery, 29.1% vs 22.8% respectively. However, the consequences of these complications were very different. For the ORIF patients, 19 of the 32 patients with complications needed to be re-operated. None of the CRIF patients required a second operation.

Choice for ORIF includes an increased change of re-operations. This is explained by the consequences of exposure of the fracture site, specifically soft tissue dissection and subsequent scar formation [95].

Especially the percentage of reported complications and re-operations in treating metacarpal shaft fractures is of clinical significance and could be used during the shared decision-making process whilst informing the patient of benefits and risks related to the type of surgery [101]. Fracture type could be a reason to choose for open or closed technique. Within the CRIF group mostly spiral, oblique and transverse fractures were seen. Comminuted fractures were treated with ORIF mostly. Therefore, spiral, oblique and transverse fractures can be treated with CRIF without the risks associated with ORIF. Additionally, multiple shaft fractures of the fourth and fifth metacarpal could be treated safely with CRIF, similar to single metacarpal shaft fractures

This study shows that spiral, oblique and transverse metacarpal shaft fractures can be safely treated by CRIF resulting in good outcome, shorter operation time, and less re-operations than ORIF [16, 18, 90]. **The reported results of CRIF treated patients in multiple metacarpal IV and V shaft fractures are as good as the results after ORIF.**

Part B

Accuracy of fluoroscopy in hand surgery

Clinical studies have shown that a percutaneous technique is easily applied [56]. Without the need for dissection with this technique less iatrogenic injuries are reported in comparison with ORIF [34, 52, 108, 109]. The method is criticised because of the possible residual intra-articular unevenness of the joint surface resulting in post-traumatic arthrosis because persistent step-off and gap cannot reliably be assessed via fluoroscopy during a closed surgical technique [53].

Limited data is available on the topic of accuracy of fluoroscopy. However, Capo et al. found discrepancies in step-off and dislocation between fluoroscopy and open visualization and between radiography and direct visualization [32]. One explanation for this discrepancy may be the precision by which Capo measured step-off and dislocation between the visualization techniques. Another explanation may be that the statistical analysis in Capo's study was flawed, since the measurements should have been analysed as paired observations.

To assess the accuracy of fluoroscopy and radiography in determining the step-off and gap after fracture reduction, an anatomical study was performed (**Chapter VII**). This study was designed to address the issues stated above regarding the study by Capo et al. The three measurements were performed with equal precision (i.e., in one tenth of a millimetre), and were therefore comparable.

The major finding of this study is that per-operative fluoroscopic imaging provides an adequate assessment of articular step-off and gap in comparison with radiographs and direct visualization. The intraclass correlation coefficients showed agreement between the three visualization methods. These findings positively underline the adequacy of fluoroscopic as well as radiographic imaging. Also, of clinical importance is the finding that no significant over- or underestimation of results were found for fluoroscopy. When dislocation or step-off is not acceptable during surgery these results are not overestimated and the reduction should probably not be accepted.

Based on these data, persistent step-off and gap can be adequately assessed with fluoroscopic imaging during CRIF of intra-articular first metacarpal fractures and we therefore strongly advocate the use of fluoroscopy in hand surgery.

Anatomical safe zone for first metacarpal surgery

The reported results of pain and sensory loss at the radial side of the thumb after ORIF at long-term follow up (10 year) of surgically treated Bennett fractures, were the reason to design an anatomical study in which a possible safe zone for first metacarpal surgery could be defined (**Chapter IV**). A large diversity in the anatomical course of the superficial branch of the radial nerve (SBRN) over the first and second metacarpal was found (**Figure 2**, page 127). This variability could explain the iatrogenic damage that can occur during open surgery. Especially the density of branches found at the base of the first metacarpal correlates with the reported complications after open reduction and internal fixation of fractures at the base of the first metacarpal [108, 109].

The second important finding is this study is the similar anatomical route of the dorsal branch of the radial artery (DBRA) found in all twenty arms. This might explain why iatrogenic arterial injury occurs less frequently. Nonetheless, the DBRA is at risk when using a percutaneous inter-metacarpal technique for first metacarpal fractures, in which the cranial Kirschner wire is placed at the base of the second metacarpal, such as in Wagner's technique [50].

The most important finding of this study is that a safe-zone for optimal surgical approach of the first metacarpal can be defined. **A safe-zone for first metacarpal base fracture surgery exists.**

Safe zone positioning for closed reduction and percutaneous fixation

Several K-wire positioning for closed reduction and percutaneous fixation are described [26, 61, 128, 130]. The findings in **Chapter VII** suggest that with Wagner's and also with Iselin's technique, in which the cranial K-wire transfixes the first metacarpal to the base of the second metacarpal, the DBRA might be at risk [24, 130]. An extra-focal pinning technique in which the K-wires are positioned more distally prevents the DBRA from injury [11, 56, 73]. **A closed extra-focal pinning technique can prevent arterial injury, while using the defined safe-zone for K-wire positioning.**

Furthermore, without the dissection necessary for ORIF the patient is less at risk to develop complications such as found in the reported studies (**Chapter II, III and IV**). Pain was mostly seen in ORIF patients and patients whom had been re-operated because of functional impairment and complaints of osteosynthesis material. **The preferred surgical treatment of Bennett's fracture is via CRIF with K-wire positioning within the reported safe-zone.**

Future perspectives

Further research and development might focus on the following issues in hand surgery:

Percutaneous techniques without post-operative cast immobilization

In Chapter II the fracture stability after fixation was tested under fluoroscopy. When the fracture fragments were stable no additional cast was applied. This increases the change of secondary dislocation, but also enhances the mobility of the rest of the hand during surgical treatment. Possibly more stable percutaneous techniques will arise aiming to prevent unnecessary immobilization such as reported by Adi et al [73].

Timing of surgery?

Possibly an important factor for successful closed reduction is the timing of surgery. Closed reduction and percutaneous fixation is more easily performed when fracture hematoma, during the first week has not yet developed into a fibrinous cloth. Therefore, a possible window for closed reduction is a period of maximum 1 week after trauma, allowing easy reduction with step-off and gap not to exceed 2 mm after closed reduction.

What follow-up period should be used to detect post-traumatic arthrosis in hand surgery?

With the reported results after 10-year follow-up post-traumatic arthrosis could be assessed using the Eaton-Littler score in **Chapter IV**. Arthrosis was found in ORIF and CRIF patients independently of type Gedda fracture classification (Gedda I). In studies with shorter follow-up post-traumatic arthrosis was also found. For joints which are not weightbearing it can be debated that post-traumatic arthrosis formation takes more time to develop. Radiographic follow-up should therefore be at least 10 years to allow detection of all changes.

Cost effectiveness?

Further research is warranted to assess the economic effects of closed reduction and percutaneous fixation to be more cost effective than ORIF in the surgical treatment of metacarpal fracture.

X

Summary

Nederlandstalige samenvatting

The hypothesis of this thesis is that a minimal invasive surgical technique is preferable in the treatment of metacarpal fractures in comparison with open reduction and internal fixation.

Part A

The first half of this thesis focussed on the assessment of surgically treated patients with metacarpal fractures. To prevent biased outcome specific fractures were separately assessed. Outcome of surgical treatment of unstable first metacarpal fractures and second to fifth metacarpal fractures were evaluated. Surgical techniques applied can be classified as closed reduction and percutaneous fixation (CRIF) or open reduction and internal fixation (ORIF).

Chapter II reports the outcome of first metacarpal base fractures which all have been treated with CRIF. Functional assessment included Grip- and Pinch-strength during an outpatient assessment and radiological assessment of post-traumatic arthrosis using the Eaton-Littler score at 24-months follow-up. The described fixation procedure results in a stable fixation of the fracture fragments, and no secondary dislocation of the fracture occurred. All fractures consolidated within 32 (26–50) days and no new fractures were observed. These results suggest that CRIF is a safe and easily applicable technique for the surgical treatment of first metacarpal base fractures.

In **Chapter III** the combined results of multiple studies are assessed via systematic review into the surgical treatment of one specific type of first metacarpal base fracture, i.e. Bennett's fracture. The reported findings confirm that CRIF is easily performed and a safe alternative treatment in comparison to ORIF in the surgical treatment of Bennett's fracture.

Longer follow-up assessment of surgically treated Bennett's fractures was reported in **Chapter IV**. Differences in outcome between ORIF and CRIF and reported complications after surgery were discussed in relationship with these different surgical techniques. The study confirmed that, based on this long-term follow-up study, that a persistent step-off and gap of up to 2mm can be accepted in the surgical treatment of a Bennett's fracture.

To assess possible benefit for second to fifth metacarpal fractures from minimally invasive surgical treatment was compared with open surgical technique in **Chapter V.** Outcome, re-operations and complications were discussed after different surgical techniques based on the reported results of five studies combined in one systematic review. Based on the reported results it could be confirmed that CRIF is a safe surgical treatment for single second to fifth metacarpal shaft fractures.

To determine stability of fixation, chances of re-operation and complications after CRIF and ORIF in the treatment of single and multiple metacarpal second to fifth shaft fractures, the results of 142 surgically treated patients were evaluated in **Chapter VI**. The reported results of CRIF treated patients in multiple metacarpal IV and V shaft fractures are as good as the results after ORIF.

Part B

The second part of this thesis focused on technical aspects of metacarpal surgery. In **Chapter VII** the adequacy of fluoroscopy in the assessment of fracture reduction during closed reduction and percutaneous fixation was assessed. The persistent step-off and gap after closed reduction assessed with fluoroscopy was compared with radiography and direct visualization after dissection. Persistent step-off and gap could be adequately assessed with fluoroscopic imaging during CRIF of intra-articular first metacarpal fractures and we therefore strongly advocate the use of fluoroscopy in hand surgery.

Anatomical considerations were described in **Chapter VIII** regarding surgery on the first metacarpal. The anatomical route of the sensory branch of the radial nerve (SBRN) and the dorsal branch of the radial artery (DBRA) were assessed. Using computed assisted surgery anatomy mapping (CASAM) a safe-zone for first metacarpal fracture surgery is reported. Furthermore, without the dissection necessary for ORIF the patient is less at risk to develop complications such as found in the reported studies (**Chapter II, III and IV**). The preferred surgical treatment of Bennett's fracture is via CRIF with K-wire positioning within the reported safe-zone.

Finally, this thesis concluded with a general discussion and future perspectives based on the present findings were discussed.

Nederlandstalige samenvatting

De hypothese van dit proefschrift is dat minimaal invasieve chirurgie voor de behandeling van metacarpale fracturen te prefereren is boven open reductie met interne fixatie.

Deel A

In de eerste helft van dit proefschrift werd gekeken naar de uitkomsten van patienten na operatieve behandeling van metacarpale fracturen. Om selectie-bias te voorkomen werden verschillende type fracturen afzonderlijk onderzocht. De uitkomst na behandeling van instabiele metacarpale I basis fracturen en metacarpale II tot en met V schacht fracturen werden geanalyseerd.

De chirurgische techniek gesloten reductie en percutane fixatie (CRIF) werd vergeleken met open reductie met interne fixatie (ORIF).

Chapter II beschrijft de uitkomsten van behandeling van metacarpale I basis fracturen die allemaal behandeld zijn met gesloten repositie en percutane fixatie (CRIF). Uitkomst werd bepaald aan de hand van Grijp- en Knijp-kracht, als ook een radiologische beoordeling van het optreden van post-traumatische arthrose volgens de Eaton-Littler classificatie, tijdens een poliklinische controle 24 maanden na de initiële operatie. De beschreven percutane operatie techniek geeft een stabiele fixatie van de fractuur, er traden geen secundaire dislocaties op. Alle fracturen consolideerden binnen een gemiddelde periode van 32 dagen (26-50). Er traden geen nieuwe fracturen op. Deze resultaten geven de indruk dat CRIF een veilige en eenvoudig toepasbare technique is in de behandeling van metacarpale I basis fracturen.

Om nog selectiever naar de uitkomst van CRIF en ORIF te kijken in de Behandeling van één type fractuur werd een systematic review uitgevoerd. In **Chapter III** worden de resultaten beschreven van de gecombineerde uitkomsten van meerdere studies naar de operatieve behandeling van Bennett fracturen. De gecombineerde resultaten bevestigden dat CRIF een goed toepasbare techniek is en een veilig alternatief voor ORIF in de behandeling van Bennett fracturen.

Langere termijn resultaten naar de chirurgische behandeling van Bennett fracturen worden beschreven in **Chapter IV**. Verschil in uitkomst tussen CRIF en ORIF worden gerapporteerd. De studie bevestigd dat, op basis van deze lange termijn follow-up studie, een persisterende step-off en gap tot 2 mm geaccepteerd mag worden in de chirurgische behandeling van Bennett fracturen.

Om na te gaan of de gunstige effecten van een gesloten percutane behandeling ook voor andere metacarpale fracturen geldt, werd een systematic review verricht. Hierbij werd de gesloten repositie en percutane fixatie vergelekene met open reductie en interne fixatie voor de operatieve behandeling van enkelvoudige metacarpale II tot en met V schacht fractuur.

De gecombineerde resultaten van vijf studies konden worden gebruikt waarbij functionele uitkomst, re-operaties en complicaties werden beschreven en bediscussieerd. Gebaseerd op deze studie kan geconcludeerd worden dat CRIF een veilig toepasbare operatie techniek is voor enkelvoudige metacarpale II tot en met V schacht fracturen.

Om de stabiliteit van de fixatie te beoordelen, alsook de kans op re-operaties en complicaties werd een retrospectieve studie uitgevoerd waarin CRIF en ORIF in de behandeling van enkelvoudige en multipele metacarpale schacht fracturen werden vergeleken. In **Chapter VI** wordt de uitkomst van 142 geopereerde patienten beschreven waarbij de uitkomsten voor beide fixatie technieken goed zijn.

Deel B

Het tweede deel van dit proefschift beschrijft een aantal technische aspecten betreffende de chirurgie van de hand, maar in het bijzonder van metacarpale fracturen.

In **Chapter VII** wordt de betrouwbaarheid van per-operatieve doorlichting zoals toegepast tijdens gesloten repositie en percutane fixatie beoordeeld. Een persisterende step-off and gap na gesloten repositie en percutane fixatie werd vergeleken met Rontgenopname en het direct beoordelen van step-off en gap na dissectie en openen van het gewricht. De step-off and gap kon betrouwbaar worden bepaald middels doorlichting. Daarom bevelen wij het gebruik van doorlichting in de hand chirurgie van harte aan.

Anatomische overwegingen werden beschreven in **Chapter VIII** met betrekking tot de chirurgische behandeling van metacarpale I. De anatomische route van de sensibele tak van de nervus radialis (SBRN) en de dorsale tak van de arteria radialis (DBRA) werden geanalyseerd en middels een digital bewerkingsprogramma (CASAM) werd een safe-zone voor de chirurgische behandeling van metacarpale I fracturen beschreven.

Gebruikmakend van deze safe-zone is er minder dissectie nodig voor operatieve fixatie dan bij ORIF. Hierdoor is er een minder grote kans de patient bloot te stellen aan de risico's van chirurgische behandeling zoals beschreven in Chapter II, III en IV bij open redutie en interne fixatie.

Daarom is de geprefereerde chirurgische techniek in de behandeling van Bennett fracturen gesloten repositie en percutane fixatie waarbij de K-draden geplaatst worden binnen de safe-zone.

Met een discussie en suggesties voor toekomstig onderzoek wordt dit proefschrift afgesloten.

A

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List of Publications

PhD Portfolio

Acknowledgements

Curriculum Vitae

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Safe approach for fixation of first metacarpal fractures: an anatomical study.
Greeven APA, Van Groningen J, Poublon A, Van Lieshout EMM, Kleinrensink GJ, Verhofstad MHJ.
J Hand Surg Eur Vol. 2020 Feb;45(2):136-139.

Open reduction and internal fixation versus closed reduction and percutaneous fixation in the treatment of Bennett fractures: A systematic review.
Greeven APA, Van Groningen J, Schep NWL, Van Lieshout EMM, Verhofstad MHJ.
Injury. 2019 Aug;50(8):1470-1477

A painful ring finger following minimal trauma.
Ferrari BR, **Greeven APA**.
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Bennett's fracture: Comparative study between open and closed surgical techniques.
Kamphuis SJM, **Greeven APA**, Kleinveld S, Gosens T, Van Lieshout EMM, Verhofstad MHJ.
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King's Trauma Surgical Fellowship, Combining General Surgical and Orthopaedic Trauma in one specialty for the first time in the UK.
Greeven APA, Phillips M, Bew DP, Bentley RP.
The Royal College of Surgeons of England, Bulletin. Volume 97, Number 1, January 2015, pp. 34-35.

Open reduction and internal fixation versus percutaneous transverse Kirschner wire fixation for single, closed second to fifth metacarpal shaft fractures: a systematic review.
Greeven APA, Bezstarosti S, Krijnen P, Schipper IB.
Eur J Trauma Emerg Surg. 2016 Apr;42(2):169-75.

Accuracy of fluoroscopy in the treatment of intra-articular thumb metacarpal fractures.
Greeven APA, Hammer S, Deruiter MC, Schipper IB.
J Hand Surg Eur Vol. 2013 Nov;38(9):979-83.

Closed reduction intermetacarpal Kirschner wire fixation in the treatment of unstable fractures of the base of the first metacarpal.
Greeven APA, Alta TD, Scholtens RE, de Heer P, van der Linden FM.
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Outcome of patients with ruptured abdominal aortic aneurysm after cardiopulmonary resuscitation.
Greeven APA, Bouwman LH, Smeets HJ, van Baalen JM, Hamming JF.
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Long-term evaluation of instable metacarpal I fractures. Presenting a new, easier surgical treatment
Greeven APA, Alta TDW, Scholtens REM, de Heer P, Van der Linden FM.
British Journal of Surgery 2010; 94(S4): 1 –58

PhD Portfolio APA Greeven

1. PhD Training	**Year(s)**	**Hours /ECTS**
General academic skills		
Monthly research seminar	2009-2011	3
Presentation, poster		
ESTES, Amsterdam	2015	4
Chirurgendagen	2013	4
Traumadagen	2009, 2011, 2018	12
Presentations, oral		
Chirurgendagen	2006, 2007, 2011, 2019	16
Traumadagen	2011, 2018	8
ESTES	2013	4
ESSR	2010	4
Conferences		
Chirurgendagen	2006 – 2019	12
Traumadagen	2006 – 2018	8
ESTES, Lyon	2013	1
ESTES, Amsterdam	2015	1
Specific Courses		
- Good Clinical Practice	2015	1.5
2. Teaching		
Lecturing and Practical Skills Training		
- Stichting Beroeps Opleiding Huisarts Geneeskunde (SBOH) (Hoofd)docent, Bilthoven / Utrecht, the Netherlands	2009 - 2015	50
- Advances Trauma Life Support Instructor & Course Director		
o Riel / Tilburg, the Netherlands	2013 – 2018	50
o St. George Hospital, London, United Kingdom	2013 - 2015	40

A

Acknowledgement

Prof. Verhofstad, **beste Michiel,** veel dank voor je inspirerende gesprekken over traumachirurgie, handchirurgie en chirurgische praktijkvoering in bredere zin.

Prof. Schipper, beste Inger, veel dank voor de plezierige samenwerking, je snelle en inhoudelijk sterke feedback op de fraaie artikelen die wij samen hebben mogen schrijven.

Prof. Kleinrensink, beste Gert-Jan, ontelbaar veel kopjes koffie en enthousiasme voor anatomie en Den-Haag (!) hebben bijgedragen aan dit mooie proefschrift. Veel dank!

Dr. Van Lieshout, beste Ester, veel dank voor al je mee denken bij de opzet van de laatste onderzoeken en opbouwende kritiek en statistische bijdragen.

Mr. Bentley, dear Rob, Thanks for your contribution to my surgical training during my time in London (UK), you are an inspiration! Also, a great thanks for being part of the PhD Committee, I feel very privileged to count you among my friends.

Dr. Van der Linden, beste Frits, dankzij jouw enthousiasme voor de percutane behandeling van metacarpale fracturen konden wij samen de eerste groep patiënten analyseren hetgeen de start was van dit proefschrift. Veel dank!

Beste Jorg, hé baas, veel dank voor je kritische bijdragen bij de samen geschreven stukken en de goede gesprekken tijdens het prepareren van “onze armen” in het anatomisch laboratorium.

Beste Niels, hé ouwe, veel dank voor je wetenschappelijke bijdragen en voor de gezelligheid daarbuiten.

Beste Vakgroep Heelkunde HagaZiekenhuis, beste collegae, veel dank voor de ruimte die jullie (jonge) vakgroepleden geven te groeien binnen ons mooie vak!

Beste Arts-Assistenten Heelkunde HagaZiekenhuis, veel dank voor het aanhoren van mijn wetenschappelijke beslommeringen de afgelopen jaren. Samen met jullie positief-kritische houding leveren wij goede zorg in een geweldige opleidingskliniek!

Beste Ruud en Jan, dat dit proefschrift een mooi vertrekpunt mag zijn van gezamenlijk hand chirurgische wetenschappelijk onderzoek in ons Hand Pols Centrum.

A

Lieve vrienden, beste Bart en Ward, de laatste twee jaar hebben we elkaar zeker minder vaak gezien dan gewild door de vele uurtjes die zijn gaan zitten in dit proefschrift. Maar het zit erop! Heel veel dank voor jullie vriendschap.

Lieve Lisanne en John, ontzettend veel dank voor al die dagen oppassen zodat ik "aan de wetenschap" kon. Het resultaat is daar!

Lieve paranimfen, beste Diederik en Job, dank voor jullie hulp vandaag, maar vooral veel dank voor jullie vriendschap.

"Walk a little slower, (grand) daddy!" said a little child so small.
"I'm following in your footsteps and i don't want to fall.

Sometimes your steps are very fast, sometimes they're hard to see;
So walk a little slower (grand) daddy, for you are leading me.

Someday when I'm all grown up, you're what i want to be.
Then i will have a little child who'll want to follow me.

And i would want to lead just right, and know that i was true;
So, walk a little slower, (grand) daddy, for i must follow you!!"

\- *Unknown author* -

Lieve Ouders, lieve Carla en Martin, wat een bijzondere weg heb ik met jullie mogen afleggen de afgelopen 42 jaar. Een bijzondere leeftijd op een heel bijzonder moment in mijn leven. Heel veel dank voor jullie steun en liefde in al die jaren.

Lieve Marius en Miep, heel veel dank voor alle tosti's en pannenkoeken ;)

Lieve Barbara, lief zusje en lieve Bas en Daan, heel erg fijn zoveel steun ook van jullie te hebben gehad de laatste jaren. Met veel plezier kijk ik ernaar uit om samen onze kinderen groot te zien worden.

Lieve Beatrijs, *love of my life !* *Non si è fermato mai un momento*
Geweldig dat het gelukt is, 2 jaar na onze wandeling langs de Thames! Zonder jouw liefde en steun was dit zeker niet gelukt.

Lieve Sweder, Pippa en Bella, Wat een geweldig geschenk dat jullie onderdeel uitmaken van dit leven. Het is een groot voorrecht om de "*footsteps*" met jullie mee te mogen zetten!

Curriculum Vitae

Alexander Greeven was born on the 2nd of May 1978 in Doetinchem. After graduating from Maasland College in Oss in 1997 he studied law at Leiden University. The same year he was selected to start his medical studies at Erasmus University in Rotterdam. After completing his first year in Rotterdam (propedeuse) he continued his medical studies at Leiden University. During his internships he spent 3 months in Battor (Ghana) working under supervision of dr. K. Bijlsma, surgeon and previously the successor of his grandfather Dr. M.G.M. Bauer, surgeon in St. Anna Hospital, Oss. At the end of his medical studies his first scientific research focused on the surgical treatment of Proximal Humeral Fractures, under supervision of Dr. P.A. van Luijt (LUMC).

After finishing his medical studies in 2003 he started working as a Junior Clinical Fellow General Surgery in Leiden University Medical Centre (LUMC) under supervision of Dr. P.A. van Luijt. During this period research was performed under supervision of Prof.dr. J.J. Hamming focusing on the change of survival after cardio-pulmonary resuscitation during a ruptured abdominal aortic aneurysm. In 2004 an appointment followed as Junior Clinical Fellow at Bronovo-Nebo Hospital, the Hague (dr. H. Smeets).

In 2007 he started his surgical training in Groene Hart Hospital in Gouda (dr. R.T. Ottow). The first research into metacarpal surgery and the start of this thesis was conducted here together with Dr. F.M. van der Linden. Between 2009 and 2011 his surgical training continued LUMC (supervisor Prof.dr. J.F.P. Hamming) during which research into metacarpal surgery was performed under supervision of Prof.dr. I.B. Schipper. Further training into Trauma Surgery followed in 2011 in Haga Teaching Hospital, the Hague (dr. D. Meeuwis, drs. H. van der Meulen, drs. P.J. Van Huijstee, dr. J. Merkus and dr. J.J. Wever).

Following his surgical training he was appointed as a Senior Clinical Fellow at King's College Hospital, London (United Kingdom, Mr. R.P. Bentley). A special fellowship was created combining Acute General Surgery and Orthopedic Trauma Surgery for the first time in the United Kingdom. Successive fellows are still enjoying this fellowship, which now has been recognized by the Royal College of Surgeons (RCS). In 2014 a fellowship Trauma Surgery followed at Rijnstate Hospital, Arnhem for 6 months (drs. K. Kolkman & drs. E. Hekma). At the end of 2014 he returned to Haga Teaching Hospital, the Hague where he still works in a permanent position as Trauma Surgeon, with a special interest in hand surgery.

During all these years significant time was spend teaching and training medical students, junior doctors and colleagues. As Instructor and Course Director he has taught at the Stichting Beroeps Opleiding Huisartsgeneeskunde (SBOH) and also as ATLS Instructor and ATLS Course Director in Tilburg (NL) and London (UK). In his daily clinical activities at Haga Teaching Hospital these special interests in education and training are currently especially welcome as *acting* Surgical Training Program Director.

Alexander met the love of his life Beatrijs Wokke while working at Bronovo-Nebo Hospital in 2006. They married in 2013, before moving and working in London. They have been blessed with a son (Sweder) and two daughters (Pippa and Bella) and live in Leiden.