Metacarpals and phalanges malunion: a narrative review

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Malunions are fractures that have healed with a deformity. Multiple abnormalities can coexist, but only one usually takes the lead causing symptoms, such as bone shortening, finger scissoring, etc. It is mainly caused by insufficient reduction. Malunions of the metacarpals are usually apex dorsal, while malunions of the phalanx tend to angulate volarly. Each patient with malunion should be assessed individually and treated conservatively if there is little to no functional impairment. Surgeries can be used to treat individuals with angular and rotational deformity.

Keywords:
malunion, metacarpals, osteotomy, phalanges

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Introduction

Fractures of phalanges and metacarpals are very common and being associated with complications renders their high prevalence more dangerous [1]. Complications can arise whether the treatment is conservative or surgical, and taking care of these issues is integrated in the routine management of these fractures [2]. One of these complications is malunion, and this term is used to describe fractures that have healed with a deformity [3]. Although being clinically stable, their functional impact on the metacarpals and the phalanges varies depending on many factors like the type, location and severity of the deformity, the presence or absence of joint or tendon adhesions and the time elapsed since the operation [4]. Malunion's symptoms can range from being asyptomatic, needing only rehabilitation, to potentially disturbing hand function requiring thus a treatment like an osteotomy [3].

This review article will shed light on available evidence regarding this pathology, to make its management clearer for orthopedic surgeons.

Etiologies

Metacarpal and phalangeal fractures make up 40% of all upper extremity fractures with frequent complications such as stiffness, malunion, nonunion, infection, tendon ruptures and adhesions [1]. The distal phalanx has the highest rate of fracture in the hand [5]. Young men and old women are the most susceptible usually. Fracture in young men is mostly due to sports injuries, while middle aged men are more susceptible to work injuries, and fractures in the elderly are mostly seen after a fall or road accident [5].

The problem can be an angular deviation in the coronal and/or sagittal plane, a rotational deformity or shortening [2], with the latter being usually due to angulation [3]. It can also be a combination of all three deformities, however one always predominates over the others [6]. Malunion usually occurs after a closed treatment of an unstable fracture, but it can also be due to a failed open reduction and internal fixation [2].

Risk factors

Despite the high frequency of metacarpal and phalangeal fractures, the literature does not provide clear guidance on how to best treat these injuries in order to prevent complications such as malunion. High level evidence is difficult to obtain since the fractures can be simple or comminuted with a very wide range of presentations, preventing randomized controlled trials, while studies published have a low number of patients [7,8]. Furthermore, it has been shown that there is no significant difference in the occurrence of metacarpal and phalanx malunion between percutaneous fixation in the procedure room versus the operating room [9]. In addition to conventional risk factors, misdiagnosis can prevent accurate and timely treatment of hand injuries, thus increasing the chance of complications including malunion [8].

Phalanx malunion influencing factors

Before 2008, there had been a single attempt at a prospective randomized controlled trial of spiral isolated and long oblique fracture of the proximal phalanx comparing lag screws and percutaneous pinning. Lag screws showed a high (8/15) frequency of malunions

compared to the possibility of good fixation and reduction [10]. Most simple short oblique and transverse fractures of the proximal phalanx should preferably be stabilized by two longitudinally placed Krischner wires through a fully flexed MCP joint. Often, using a single wire increases the risk of rotational deviations [7].

Conservative treatment has shown good results for the treatment of proximal phalangeal fractures in some studies; Held *et al.* showed a 5% rate of malunions (3/62 patients) [11]. Ahmad *et al.* reported one malunion in 15 patients treated conservatively [12]. Both Rajesh *et al.* and Özçelik *et al.* found no malunion in 32 patients (each) treated conservatively [13,14]. In addition, another study by Singh *et al.* included 84 fractures in 68 patients. Forty-seven were treated with closed reduction and immobilization, and had showed 4 malunions, and of the 37 treated surgically with various techniques, one malunion was noted [15].

Metacarpal malunion influencing factors

Spiral metacarpal fractures have shown equally good results with non-operative treatment versus surgical treatment in many studies [16]. A study following 25/30 patients after conservative treatment of spiral metacarpal fractures showed only one malrotation of 5° [17].

Simple head fractures should be treated by lag screws with deep countersinking of the screwhead [7]. However, neck fractures usually do not need open treatment and present no complication, functional or radiographic difference between intramedullary K-wire fixation and transverse pins [18].

Comminuted metacarpal fractures are typically treated with lateral plate fixation in order to stabilize it. The metacarpal bone has a true lateral surface distally which twists into a dorsolateral plane near the shaft, so when the plate is not carefully contoured early on, there can be an iatrogenic rotational malunion [7].

Clinical presentation and complications

Generally, a symptomatic metacarpal or phalangeal malunion is of rare occurrence [19], but when it does, its functional impact depends on its location, severity, type, involvement of joint, time elapsed since the injury and the co-presence of joint or tendon adhesion [4]. The deformities can range from mild, cosmetic, to severe with functional impairment [20]. A sagittal deformity is usually accepted especially in metacarpals, whereas a rotational deformity could cause fingers scissoring [21–23], and an intra-articular malunion, could results in arthritis [20].

To examine these deformities, plain radiographs are the standard imagings [19], but this method might not be in correlation with the clinical appearance and functional disabling, therefore the doctor must examine the deformity along with its functional impairment [3]. Three-dimensional computed tomography (3D CT) can provide a precise evaluation of the bony malformation, which is impossible using a 2-dimensional CT scan and conventional radiographs [24].

Phalangeal malunion

Many of the phalangeal malunions can be acceptable without the requirement of a surgical intervention, but when it's a severe angular or a combined angular and rotational deformity, it can cause cosmetic problems with an impairment of daily life activities, because of the resulting complications like fingers scissoring and deviation during finger flexion [25]. Other deformities can also lead to extensor lag, grip strength reduction, and an intra-articular malunion can result in capsular loosening, finger stiffness and osteoarthritis [26]. At the distal interphalangeal (DIP) joint, intra-articular malunion can cause extensor lag at the DIP joint which leads to proximal interphalangeal (PIP) joint hyperextension, causing a Swan-neck deformity [20].

Malunions of the proximal phalanx (which are often multidirectional) can be classified into 4 groups: shortening, rotation, lateral angulation and volar angulation [2]. The proximal phalanx neck fractures tend to angulate dorsally [27], alongside all of the distal condylar phalangeal ones [28]. This angulation will result in a subcondylar fossa obliteration with new bone formation, thus leading into a mechanical block of flexion [27]. When it comes to proximal phalanx fractures, the most common angulation is volar/palmar [2]. When this angulation exceeds 15°, it will cause an extensor lag because of bone length shortening and consequential increase in the length of the extensor tendon [29,30]. Whereas when it exceeds 25°, both extension and flexion are affected [31]. This extensor lag at the PIP joint can cause a fixed flexion contracture [20], which in turn will result in a pseudo-claw deformity [2]. The risk of an increase in flexor tendon adhesion may occur due to an increase in fractured bone ends exposure, and a decrease in tendon excursion due to residual angulation [30]. The most functional impairment resulting from a proximal phalanx malunion is due to digit malrotation, specifically on making a fist [32].

When compared to malunion of proximal phalanx and metacarpal bones, malunion at the middle phalanx shaft causes less functional problems [33]. In middle phalangeal malunions, the angulation is either apex dorsal when the fracture is proximal to the insertion of the flexor digitorum (FDS), or apex volar when the

fracture is distal to the insertion of the FDS [20]. In the latter, an alteration of the flexor tendon dynamics and correlative DIP and PIP joint deformities may appear [3].

Lateral angulation can appear due to bone loss in the fractured area, which can result in scissoring of the digits that can be absent during fist formation, because of the trapping effect of the neighboring digits [2].

Metacarpal malunion

When it comes to angular malunion, metacarpal shaft fractures usually have apex dorsal deformities with sagittal plane angulation [2]. Safe ranges of angulation vary from one finger to another, being up to 10° in the index/middle fingers, 20° in the ring fingers and 30° in the small finger [2]. This range difference shows the capacity of functional disability compensation of carpometacarpal (CMC) joints of the ring and small finger. Due to this angulation, metacarpal shortening occurs, which may cause extensor lag and loss of grip strength [34,35], and the latter can become measurable after 30° of dorsal angulation [34,36,37], but shortening greater than 3–4 mm is usually prevented by the deep intermetacarpal ligaments [38]. Other complications can occur like pseudo-claw deformity, knuckle contour loss, muscle fatigue and cramping, prominence of the metacarpal head in the palm of the hand and visible and/or palpable angular metacarpal deformity on the back of the hand [3]. Angulations in the coronal plane are tolerated as long as there is no digit impingement [39]. These angulations' toleration also vary between fingers, as they are more supported in the lateral metacarpals than in the medial ones [3]. In the evaluation of lateral metacarpal angulation, impingement is better examined while fingers flex and converge, whereas clinical deformity is more apparent when the fingers are extended [3]. In the little finger, metacarpal neck and shaft fractures result in a palmar angulation, which may cause its shortening and thus lead into its weakness [40]. But as long as this angulation is less than 30°–40° degrees in the shaft fractures, functional capacity of the injured hand will not be reduced [41]. In shaft fractures, aesthetic deformity is usually due to palmar angulation, whereas it is due to finger shortening in neck fractures [42].

To clinically measure the malunion in the neck and shaft fractures of the little finger [42], a straight metacarpophalangeal (MCP) measurement must be obtained while placing both hands flat on a table, and that is in order to assess the difference between the length of the ring and little finger, and compare it with the uninjured hand, thus examining the little finger metacarpal shortening [41]. A 90-MCP measurement is also clinically relevant to examine the little finger's metacarpal angulation or palmar displacement (in this case the injured 5th finger will be longer, thus a reduced difference with the ring finger) and to do so, both hands must be placed on a table with the MCP joint flexed to 90°, with the fingers flat on the surface and perpendicular to the table edge, and the same comparison as the straight MCP measurement must take place [41]. The absence of correlation between this clinical measurement, the fracture on the X-ray and the palmar angulation may question the validity of these methods in malunion evaluation, but ultimately they both seem to assess some of the malunion's aspects [42].

When it comes to malrotation, it is mostly present in the ring and small fingers [3]. This rotational malunion transmits and magnifies the rotation distally to affect the whole digit [2,3] which may cause symptomatic finger scissoring or impingement [3], and thus will not be tolerated [2]. During clinical evaluation, the patient must make a fist in order to detect digits' overlap and deviance of the convergence toward the scaphoid tubercle [2]. The contralateral hand can be used for comparison purposes when examining scaphoid convergence and digit rotation but it is not as reliable when it comes to digital overlap [43]. Physicians must also be vigilant in radiographs examination, because even a small degree of rotational malunion can cause a significant amount of functional impairment [2].

Treatment

Non-operative treatment

Even though the frequency of complications in malunion surgery is low, surgery is not always the best course of action. Sometimes accepting a mild deformity is better than operative correction and each case should be individually assessed to decide on the appropriate course of action [3]. Indications for surgical management of metacarpal malunions have appeared in the literature mainly following cadaver studies. As mentioned previously, shortening of less than 2 mm, dorsal angulation of less than 25° (ring finger), 30° (5th metacarpal) or 10° (middle fingers and index) can be accepted depending on each patient's wishes and cosmetic goals. Coronal deviation is accepted as long as fingers do not impinge.

In children with distal condylar phalangeal fractures in the sagittal plane, bone remodeling has been shown as an alternative to surgical treatment. In 2012, Pucket *et al.* reported significant remodeling in the sagittal plane (mean of 57.5% to 0.0%) accompanied with improved range of motion (97.5% flexion improvement with insignificant extension asymmetry). Prior to this study, remodeling was only thought to

occur in children younger than 7 years of age but of the 8 cases mentioned, 2 patients were 12 years old and another pair was 14. This study showed no significant remodeling in the coronal plane [33].

In 2019, Al Qattan *et al.* published a retrospective study of 8 patients who had a laterally deviated malunion of the small finger and were treated non-operatively. 7 showed normalization of the diaphysal axis-metacarpal head angle at final follow-up (between 9–18 month), the remaining one had an improvement from 162.9° (4–6 weeks after injury) to 175.7° (at 2 years) [44].

Operative treatment

Surgery to correct metacarpal and phalangeal malunions has multiple benefits that include functional and cosmetic improvement. It is best performed during the first 10 weeks after injury, since the callus is still immature (easily removable) and the fracture can be recreated (with dental picks or small osteotomes) and adjusted. If not performed within this time frame, it becomes best to wait until maximum functional recovery (at least 3 months) before undergoing the procedure. If there is contracture of the joint or tendon adhesions, they can be tackled concomitant to the surgery [3,4,45].

Angular deformity

For angular deformity, an opening or closing wedge osteotomy can be used to realign the malunited bone [31,46–51]. Closing wedge osteotomies (CWO) consist in the extraction of a bone fragment (a 'wedge'), and then align and stabilize the remaining two fragments without the need for a bone graft. This procedure is more likely to cause bone shortening [3,4,49]. CWO is simpler than opening wedge osteotomy, and is less likely to induce stiffness and muscle contracture [3,46,48,50]. When osteotomy is done at the site of malunion, if a rotational component is present concomitantly to the angular deformation, it can be approached at the same time.

Opening wedge osteotomy (OWO) implies the use of a bone graft (usually cancellous bone) in order to precisely fix the deformity. Osteotomy can be performed at the malunion site or elsewhere. The decision of where to operate can be influenced by many factors. If multiple components of deformity are present, it is preferable to operate on the injury site in order to treat both the rotational and angular deformity simultaneously. It should also be noted that diaphyseal bone heals slower than metaphyseal-diaphyseal junctions [3,4,52,53], so especially if malrotation predominates on the injury site, it is preferable to operate at the junction. In rotational deformity of the phalanx, surgery on the metacarpal bone (transverse osteotomy of the base) can correct 20° in the index, ring and middle fingers, and 30° in the fifth finger [3,54], and can avoid complications related to phalangeal surgery which can compromise the extensor apparatus. However, metacarpal surgery to treat a phalangeal fracture can lead to a zig-zag deformity.

Intercondylar wedge resection can produce a larger condylar fragment when associated with a sliding osteotomy of the injury site with its proximal supporting cortex, thus making manipulation and repair easier [55].

In 2007, yong *et al.* [56] presented a novel osteotomy technique for the correction of angular deformity, where instead of removing the segment of bone completely, it is rotated and placed back as a graft. 4/4 metacarpal and ½ phalangeal angulations were completely corrected using this technique, and the other phalangeal angulation was 75% corrected. Grip strength and pain also improved, and bone union occurred uneventfully though late in 2 cases. This technique avoids bone shortening and graft collection from distal sites. Another technique which prevents morbidity due to the collection of a distant bone graft was presented in a case report by Capo *et al.* in which the author harvested a graft locally from the metacarpal head to use on a proximal extra-articular phalangeal fracture [57].

Between 2010 and 2011, Zhang *et al.* treated 21 patients who had fifth metacarpal malunions with an opening wedge osteotomy. The results showed healing at an average of 2 months. 5 patients did not have any extensor lag at final follow-up, 13 had between 1 and 10 degrees of extensor lag and 3 had between 11 and 20 degrees of extensor lag with a mean follow-up of 14 months. Pinch strength and grip strength were comparable with the non-injured hand and 19 patients were esthetically satisfied, while 2 were sometimes concerned about the appearance [58].

Proximal phalanx neck fractures are difficult to treat since the bone is small and difficult to stabilize. Kang *et al.* described an approach from the mid-lateral ulnar side of the fifth proximal phalanx, in order to avoid the posterior extensor apparatus. After exposure of the proximal interphalangeal joint, the surgeon burred down the P1 volar cortex and reconstructed the subcondylar fossa. This technique is only suitable for angular malformation, and care should be given to spare the neurovascular bundles of the finger [27].

A retrospective study of 14 metacarpal fractures treated with a closing wedge osteotomy showed

that stabilization with temporary intramedullary Kirschner wires and plate fixation may provide more stability. All patients returned to their usual work and sports activity at final follow-up. 11 patients had concomitant rotational deformity which disappeared in 10 patients, showing that rotational deformities can be concomitantly treated when the osteotomy is at the malunion site [59].

Haider *et al.* [60] tried to approach 11 cases of phalangeal and metacarpal malunions using a multiple drill hole osteotomy instead of the usual oscillating saw. Of these, one case of broken drillbit was observed, but no other postoperative or intraoperative complication was observed. Hirsiger *et al.* [19] used CT scans for pre-operative planning as well as for post-op evaluation, accompanied by the creation of guides adapted to each patient using a 3D printer. Average rotational deformity improved from 10° to 2.3°, and translational malposition went from 1.4 mm to 0.4 mm. In 2 cases, soft tissue irritation happened, and the implants had to be removed. Grip strength improved in 5 out of 6 patients. Eleven patients with malunited proximal phalanx accompanied by flexor tendon adhesion were examined retrospectively [61]. They underwent antegrade intramedullary pinning accompanied by stepwise tenolysis. The results were good pain improvement and good to excellent range of motion recovery. No complications were noted.

In simple intra-articular fractures of the first metacarpal base, Van Royen *et al.* introduced a new technique which aims to restore trapeziometcarpal anatomy after aberrant healing of the fracture site. It consists of an anterolateral approach followed by closing wedge osteotomy and fixation with 3 interfragmentary screws. Passive mobilization of the trapeziometacarpal joint starts after 2 weeks of immobilization. Short-term improvement of pain and grip strength was seen, but whether this technique prevents osteoarthritis in the long term requires prolonged follow-up [62].

Izmalkov *et al*. treated 4 patients with fifth metacarpal malunion and 1 patient with fourth metacarpal malunion. The procedure was a V-shaped open wedge osteotomy at the top of the malformation. Grip strength, angulation and ROM improved. Stiffness was noted in one case [63].

Rotational deformity

Transverse extra-articular osteotomy at the base of the metacarpal, as introduced by Weckesser, has been used to treat rotational malunion of the metacarpals and phalanges [3,4,64]. We did not encounter any recent application of the technique in our search.

Step-cut osteotomies are also an alternative in correcting diaphyseal rotational deformities in the phalanx and metacarpals. It was first introduced by Manktelow and Mahoney with 10 patients, who had successful recovery and functional improvement after metacarpal step-cut osteotomy. Then Pichora *et al.* [65] operated 16 phalanx and 7 metacarpal rotational malunions with step-cut osteotomies. All the patients healed, but some patients had residual stiffness. In 2009, Jawa *et al.* introduced a modified step-cut osteotomy technique, and 12 patients were treated using this technique. The results were improvement of total motion from an average of 214° to 251°, and no perioperative complications. One patient kept 5° of rotational malalignment, and a patient required a secondary tenolysis [66]. In 2017, Fujioka *et al.* [25] applied the step-cut osteotomy technique to successfully treat a rotary deformity of the middle phalanx in the ring finger.

Seo *et al*. introduced a new technique as a minimally invasive alternative for the correction of proximal phalangeal malunion, with the aim of preventing tendon adhesions and extensor apparatus injury. It consists in a lateral approach using 2 Kirschner wires of small diameter on the malunion site, and then widening the aperture by progressively inserting kirschner wires of bigger diameters, in order to finally be able to insert an osteotome, which will easily permit osteotomy. It is done under local anesthesia, so the surgeon can then correct bone placement while the patient moves his hand until optimal positioning. Then 2 kirschner wires were used to stabilize the fracture site. 2-year follow-up showed no functional deficit, barely discernable scar and no deformity [67,68].

Conclusion

Malunions are fractures that healed with deformity which can manifest as a malrotation or an angular deformity. Multiple deformities can coexist but usually only one predominates and causes symptoms, which include bone shortening, finger scissoring, loss of grip strength as well as tendon adhesions, reduced ROM and extensor lag. Many factors contribute to the likelihood of malunion, the main one being inadequate reduction. Metacarpal malunions are usually apex dorsal, and phalanx malunions tend to angulate volarly. Each patient with malunion should be evaluated individually and may be treated conservatively, especially if there's little to no functional deficit. For patients with angular deformity, they can be treated with opening or closing wedge osteotomies. If rotational deformity is also present, the surgery should be done on the fracture site in order to correct both anomalies. If rotational deformity is predominant, transverse osteotomy of the

metacarpal base and especially step-cut osteotomies have shown good results in the literature.

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Conflicts of interest
There are no conflicts of interest

References

1 Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg Am 2001; 26:908–915.

2 Balaram AK, Bednar MS. Complications after the fractures of metacarpal and phalanges. Hand Clin 2010; 26:169–177. Available from: http://dx.doi.org/10.1016/j.hcl.2010.01.005

3 Freeland AE, Lindley SG. Malunions of the Finger Metacarpals and Phalanges. Hand Clin 2006; 22:341–355.

4 Ring D. Malunion and nonunion of the metacarpals and phalanges. Instr Course Lect 2006; 55:121–128. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16958445

5 Meals C, Meals R. Hand fractures: A review of current treatment strategies. J Hand Surg Am 2013; 38:1021–1031.

6 Diaz-Garcia R, Waljee JF. Current management of metacarpal fractures. Hand Clin 2013; 29:507–518.

7 Henry MH. Fractures of the Proximal Phalanx and Metacarpals in the Hand: Preferred Methods of Stabilization. 2008;

8 Fuller JB, Piscoya AS, Clark DRM, Markose K, Dunn JC. Surgical management of ulnar metacarpal base fracture-dislocations: a systematic review. Hand 2022;17:405-411. Epub 2020 Aug 8.

9 Garon MT, Massey P, Chen A, Carroll T, Nelson BG, Hollister AM. Cost and Complications of Percutaneous Fixation of Hand Fractures in a Procedure Room Versus the Operating Room. Hand 2018; 13:428–434.

10 Horton TC, Hatton M, Davis TRC. A prospective randomized controlled study of fixation of long oblique and spiral shaft fractures of the proximal phalanx: closed reduction and percutaneous Kirschner wiring versus open reduction and lag screw fixation. J Hand Surg Br 2003; 28:5–9.

11 Held M, Jordaan P, Laubscher M, Singer M. Conservative treatment of fractures of the proximal phalanx: an option even for unstable fracture patterns. Hand Surgery 2013; 18:229–234.

12 Ahmad M, Hussain SS, Rafiq Z, Tariq F, Khan MI, Malik SA. Management of phalangeal fractures of hand. J Ayub Med Coll Abbottabad 2006; 18:38–41.

13 Rajesh G, Ip WY, Chow SP, Fung BK. Dynamic treatment for proximal phalangeal fracture of the hand. J Orthop Surg 2007; 15:211–215.

14 Özçelik D, Toplu G, Ünveren T, Kaçağan F, Şenyuva CTG. Long-term objective results of proximal phalanx fracture treatment. Ulus Travma ve Acil Cerrahi Derg 2011; 17:253–260.

15 Singh J, Jain K, Mruthyunjaya, Ravishankar R. Outcome of closed proximal phalangeal fractures of the hand. Indian J Orthop 2011; 45:432–438.

16 Giddins GEB. JHS (E) of hand fractures. 2015;

17 Khan A, Giddins G. The outcome of conservative treatment of spiral metacarpal fractures and the role of the deep transverse metacarpal ligaments in stabilizing these injuries. J Hand Surg Eur Vol 2015; 40:59–62.

18 Wong TC, Ip FK, Yeung SH. Comparison between percutaneous transverse fixation and intramedullary K-wires in treating closed fractures of the metacarpal neck of the little finger. J Hand Surg Br 2006; 31:61–65.

19 Hirsiger S, Schweizer A, Miyake J, Nagy L, Fürnstahl P. Corrective osteotomies of phalangeal and metacarpal malunions using patient-specific guides: CT-based evaluation of the reduction accuracy. Hand 2018; 13:627–636.

20 Gajendran VK, Gajendran VK, Malone KJ. Management of complications with hand fractures. Hand Clin 2015; 31:165–177. Available from: http://dx.doi.org/10.1016/j.hcl.2014.12.001

21 Jupiter JB, Goldfarb CA, Nagy L, Boyer MI. Posttraumatic reconstruction in the hand. Instr Course Lect 2007; 56:91–99. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17472296

22 Bindra RR, Burke FD. Metacarpal osteotomy for correction of acquired phalangeal rotational deformity. J Hand Surg Am 2009; 34:1895–1899. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19969197

23 Royle SG. Rotational deformity following metacarpal fracture. J Hand Surg Br 1990; 15:124–125. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2307874

24 Nakamura R, Horii E, Tanaka Y, Imaeda T, Hayakawa N. Three-dimensional CT imaging for wrist disorders. J Hand Surg Br. 1989; 14:53–58. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2926224

25 Fujioka H, Takagi Y, Tanaka J, Yoshiya S. Corrective step-cut osteotomy at the affected bone for correction of rotational deformity due to fracture of the middle phalanx. J hand Surg Asian-Pacific Vol 2017; 22:240–243.

26 Potenza V, De Luna V, Maglione P, Garro L, Farsetti P, Roberto C. Post-traumatic malunion of the proximal phalanx of the finger. medium-term results in 24 cases treated by 'in situ' osteotomy. Open Orthop J 2012; 6:468–472.

27 Kang YC, Tan PL. Simple surgery to improve flexion deficit resulting from mal-union of fracture neck of the proximal phalanx - a case report. Hand Surg 2014; 19:123–125.

28 Al-Qattan MM. Phalangeal neck fractures in children: classification and outcome in 66 cases. J Hand Surg Br 2001; 26:112–121. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11281661

29 Vahey JW, Wegner DA, Hastings H. Effect of proximal phalangeal fracture deformity on extensor tendon function. J Hand Surg Am 1998; 23:673–681. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9708382

30 Agee J. Treatment principles for proximal and middle phalangeal fractures. Orthop Clin North Am 1992; 23:35–40. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1729667

31 Coonrad RW, Pohlman MH. Impacted fractures in the proximal portion of the proximal phalanx of the finger. J Bone Joint Surg Am 1969; 51:1291–1296. Available from: http://www.ncbi.nlm.nih.gov/pubmed/4898578

32 Roebke AJ, Goyal KS. Surgical correction of finger malrotation secondary to proximal phalanx malunions. J Orthop Trauma 2020; 34:S17–S18.

33 Puckett BN, Gaston RG, Peljovich AE, Lourie GM, Floyd WE. Remodeling potential of phalangeal distal condylar malunions in children. J Hand Surg Am 2012; 37:34–41. Available from: http://dx.doi.org/10.1016/j.jhsa.2011.09.017

34 Low CK, Wong HC, Low YP, Wong HP. A Cadaver study of the effects of dorsal angulation and shortening of the metacarpal shaft on the extension and flexion force ratios of the index and little fingers. J Hand Surg Am 1995; 20:609–613. Available from: http://journals.sagepub.com/doi/10.1016/S0266-7681%2805%2980120-2

35 Strauch RJ, Rosenwasser MP, Lunt JG. Metacarpal shaft fractures: The effect of shortening on the extensor tendon mechanism. J Hand Surg Am 1998; 23:519–523. Available from: https://linkinghub.elsevier.com/retrieve/pii/S036350230580471X

36 Ali A, Hamman J, Mass DP. The biomechanical effects of angulated boxer's fractures. J Hand Surg Am 1999; 24:835–844. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10447177

37 Birndorf MS, Daley R, Greenwald DP. Metacarpal fracture angulation decreases flexor mechanical efficiency in human hands. Plast Reconstr Surg 1997; 99:1079–1083. Available from: http://journals.lww.com/00006534-199704000-00024

38 Eglseder WA Fractures of the fourth metacarpal. J Orthop Trauma 1997; 11:441-5.

39 Seitz WH, Froimson AI. Management of malunited fractures of the metacarpal and phalangeal shafts. Hand Clin 1988; 4:529-36.

40 Horton TC, Sauerland S, Davis TRC. The effect of flexor digitorum profundus quadriga on grip strength. J Hand Surg Am 2007; 32:130-4.

41 Westbrook AP, Davis TRC, Armstrong D, Burke FD. The clinical significance of malunion of fractures of the neck and shaft of the little finger metacarpal. J Hand Surg Eur Vol 2008; 33:732–739.

42 Westbrook AP, Davis TRC. An evaluation of a clinical method to assess malunion of little finger metacarpal fractures. J Hand Surg Eur Vol 2007; 32:641–646.

43 Tan V, Kinchelow T, Beredjiklian PK. Variation in digital rotation and alignment in normal subjects. J Hand Surg Am 2008; 33:873–8.

44 Al-Qattan MM. Fractures of the base of the proximal phalanx in children: Remodeling of malunion in the radioulnar plane with a diaphyseal axis-metacarpal head angle of 156° to 163°. Ann Plast Surg 2019; 82:399–402.

45 Lester B, Mallik A. Impending malunions of the hand: Treatment of subacute, malaligned fractures. Clin Orthop Relat Res 1996; 327:55–62.

46 Froimson AI. Osteotomy for digital deformity. J Hand Surg Am 1981; 6:585–589.

47 Lucas GL, Pfeiffer CM. Ost6otomies Correctrices de M6tacarpiens et des Phalanges Stabilis6es avec Plaques et Vis (AO) Osteotomy of the

metacarpals and phalanges stabilized by AO plates and screws. Annales de chirurgie de la main 1989; 6.

48 Trumble T, Gilbert M. In situ osteotomy for extra-articular malunion of the proximal phalanx. J Hand Surg Am 1998; 23:821–826.

49 Büchler U, Gupta A, Ruf S. Corrective osteotomy for post-traumatic malunion of the phalanges in the hand. J Hand Surg Br 1996; 21:33–42.

50 Harness NG, Chen A, Jupiter JB. Extra-articular osteotomy for malunited unicondylar fractures of the proximal phalanx. J Hand Surg Am 2005; 30:566–572.

51 vanderlei1993.pdf.

52 Fusetti C, Della Santa DR. Influence of fracture pattern on consolidation after metacarpal plate fixation. Chir Main 2004; 23:32–36.

53 Claes L, Heitemeyer U, Krischak G, Braun H, Hierholzer G. Fixation technique influences osteogenesis of comminuted fractures. Clin Orthop Relat Res; 1999: 221–229.

54 Gross MS, Gelberman RH. Metacarpal rotational osteotomy. J Hand Surg Am 1985; 10:105–108.

55 Teoh LC, Yong FC, Chong KC. Condylar advancement osteotomy for correcting condylar malunion of the finger. J Hand Surg Am 2002; 27 B:31–35.

56 Yong FC, Tan SH, Tow BPB, Teoh LC. Trapezoid rotational bone graft osteotomy for metacarpal and phalangeal fracture malunion. J Hand Surg 2007; 32:282–288.

57 Capo JT, Shamian B, Lim PK. Corrective osteotomy and local bone grafting for extra-articular malunion of the proximal phalanx. Hand Surg 2012; 17:399–403.

58 Zhang X, Liu Z, Shao X, Wang L, Huang X, Zhu H. Palmar opening wedge osteotomy for malunion of fifth metacarpal neck fractures. J Hand Surg Am 2013; 38:2461–2465.

59 Karthik K, Tahmassebi R, Khakha RS, Compson J. Corrective osteotomy for malunited metacarpal fractures: Long-term results of a novel technique. J Hand Surg Eur Vol 2015; 40:840–845.

60 Haider T, Geisler D, Thalhammer G, Erhart J. Multiple drill-hole osteotomy in hand surgery-description of a novel application and proof of feasibility. BMC Musculoskelet Disord 2017; 18:1–7.

61 Yin CY, Huang HK, Wang JP. Antegrade intramedullary pinning and stepwise tenolysis for malunion of the proximal phalanx with flexor tendon adhesion. J Hand Surg Eur Vol 2019; 44:1091–1092.

62 Van Royen K, Vanmierlo B, Bonte F, Goorens CK, Berghs B, Goubau J. Intra-articular osteotomy for symptomatic bennett fracture malunion. Tech Hand Up Extrem Surg 2019; 23:138–142.

63 Izmalkov SN, Semenkin OM, Bratiichuk AN, Litvinov SA. Opening-wedge V-shaped corrective osteotomy for malunited fractures of metacarpal bones. J Orthop 2020; 19:208–211.

64 Botelheiro JC. Overlapping of fingers due to malunion of a phalanx corrected by a metacarpal rotational osteotomy-Report of two cases. J Hand Surg Am 1985; 10:389–390.

65 Pichora R. Step-cut osteotomy for treatment of metacarpal and phalangeal malunion. J Trauma 1991. (June 1988).

66 Jawa A, Zucchini M, Lauri G, Jupiter J. Modified step-cut osteotomy for metacarpal and phalangeal rotational deformity. J Hand Surg Am 2009; 34:335–340.

67 Seo BF, Kim DJ, Lee JY, Kwon H, Jung SN. Minimally invasive correction of phalangeal malunion under local anaesthesia. Acta Orthop Belg 2013; 79:592–595.

68 https://www.pennmedicine.org/for-patients-and-visitors/find-a-program-or-service/penn-orthoplastic-limb-salvage-center/complex-fracture-care/malunion-and-nonunion-fractures.