Observational Study

Medicine® OPEN

Comparison of the fixation ability of headless compression screws and locking plate for metacarpal shaft transverse fracture

Yung-Cheng Chiu, MD, PhD[a,b], Cheng-En Hsu, MD, PhD[c,d], Tsung-Yu Ho, MD[b], Yen-Nien Ting, MS[e], Bor-Han Wei, MD[f], Ming-Tzu Tsai, PhD[g], Jui-Ting Hsu, PhD[h,i,*]

Abstract

Metacarpal shaft fractures are common hand fractures. Although bone plates possess strong fixation ability, they have several limitations. The use of headless compression screws for fracture repair has been reported, but their fixation ability has not been understood clearly.

This study aimed to compare the fixation ability of locked plate with that of headless compression screw for metacarpal fracture repair.

A total of 14 artificial metacarpal bones (Sawbones, Vashon, WA, USA) were subjected to transverse metacarpal shaft fractures and divided into 2 groups. The first group of bones was fixed using locked plates (LP group), whereas the second group was fixed using headless compression screws (HC group). A material testing machine was used to perform cantilever bending tests, whereby maximum fracture force and stiffness were measured. The fixation methods were compared by conducting a Mann–Whitney *U* test.

The maximum fracture force of the HC group (285.6 ± 57.3 N, median + interquartile range) was significantly higher than that of the LP group (227.8 ± 37.5 N; $P < .05$). The median of the HC group was 25.4% greater. However, no significant difference in stiffness ($P > .05$) was observed between the HC (65.2 ± 24.6 N/mm) and LP (61.7 ± 19.7 N/mm) groups.

Headless compression screws exhibited greater fixability than did locked plates, particularly in its resistance to maximum fracture force.

Abbreviations: HC = headless compression screws, IQR = interquartile range, K-wires = Kirschner wires, LP = locked plates.

Keywords: headless compression screw, locked plate, metacarpal shaft fracture

1. Introduction

Metacarpal fractures constitute 36% to 42% of all hand injuries.[1] Among metacarpal bone fractures, the incident rate of metacarpal shaft fractures is second only to that of metacarpal neck fractures. The ratio of metacarpal shaft fractures to metacarpal neck fractures is 1:2.[1–3] Metacarpal shaft fractures with a stable fracture pattern can be immobilized using conservative treatment with casting immobilization.[4] By contrast, transverse metacarpal bone fractures require surgical interventions.[5] Because the contact area of the fractured site in this fracture pattern is limited, complete displacement is highly likely when the fractured bone end is subjected to the traction force generated by the intrinsic muscle of the hand. Therefore, surgical fixation is necessary for bone healing. Patients with

Editor: Mehmet Sonmez.

This research was partially supported by China Medical University in Taiwan (Grant Number: CMU109-MF-117) and the Taiwan Ministry of Science and Technology (Grant Number: MOST 109-2221-E-039-005).

This study does not require the ethical approval because the artificial foam bone specimens are used in this study.

The authors have no conflicts of interests to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

[a] School of Medicine, China Medical University, Taichung, Taiwan, [b] Department of Orthopedic Surgery, China Medical University Hospital, Taichung, Taiwan, [c] Department of Orthopedics, Taichung Veterans General Hospital, Taichung, Taiwan, [d] Sports Recreation and Health Management Continuing Studies-Bachelor's Degree Completion Program, Tunghai University, Taichung, Taiwan, [e] 3D Printing Medical Research Center, China Medical University Hospital, Taichung, Taiwan, [f] Orthopedic Department, China Medical University Beigang Hospital, Yunlin County, Taiwan, [g] Department of Biomedical Engineering, Hungkuang University, Taichung, Taiwan, ROC, [h] School of Dentistry, College of Dentistry, China Medical University, Taichung, Taiwan, [i] Department of Bioinformatics and Medical Engineering, Asia University, Taichung, Taiwan.

[*] Correspondence: Jui-Ting Hsu, School of Dentistry, College of Dentistry, China Medical University, 91 Hsueh-Shih Road, Taichung 40402, Taiwan (e-mail: jthsu@mail.cmu.edu.tw, richard@ms32.url.com.tw).

How to cite this article: Chiu YC, Hsu CE, Ho TY, Ting YN, Wei BH, Tsai MT, Hsu JT. Comparison of the fixation ability of headless compression screws and locking plate for metacarpal shaft transverse fracture. Medicine 2021;100:39(e27375).

Received: 8 June 2021 / Received in final form: 10 September 2021 / Accepted: 11 September 2021

http://dx.doi.org/10.1097/MD.0000000000027375

improper anatomic reduction of the fractured metacarpal shaft are prone to scissor finger deformity, causing squeal with abnormal hand prehension function.[6]

According to the literature and the clinical experience of surgeons, consensus on the use of the optical surgical fixation technique for metacarpal shaft fractures has not been reached.[2,7,8] Kirschner wires (K-wires) fixation has a relatively long history. Although K-wire fixation is minimally invasive, the fixation strength of the technique has been questioned.[9,10] Alternatively, bone plate fixation has been widely recognized as a therapeutic approach to metacarpal fractures. Over the past 2 decades, locked plates have demonstrated significantly stronger biomechanical fixability than K-wires, enabling patients to perform active motions immediately after surgery and to attend rehabilitation programs sooner.[6] However, a wound must be created for bone plate insertion. This nonminimally invasive procedure has several disadvantages, such as extensor tendon adhesion, stiffness of metacarpal phalangeal joint due to surgical scar contracture, avascular necrosis of the metacarpal head, c, a much higher cost than other fixation approaches, and reoperation for plate removal.[11–15]

Using a locked plate to fix a fractured metacarpal shaft results in excellent fixation strength. However, locked plate fixation is not minimally invasive; consequently, postsurgical complications including tendon adhesion, iatrogenic injury of the superficial sensory nerve, and surgical scar contracture are almost inevitable. Physicians have begun conducting minimally invasive surgery using headless compression screws to treat metacarpal shaft fractures.[16] A few studies have reported successful outcomes for this fixation technique, but in vitro biomechanical studies are rare. To the best of our knowledge, extremely few in vitro biomechanical studies have compared the fixation strength of headless compression screws with that of locked plate in the treatment of transverse metacarpal bone fractures.

Because metacarpal shaft fractures are a crucial topic and sufficient numbers of fresh cadaver metacarpal bones cannot be obtained, this study used artificial metacarpal bones with simulated material properties of the cortical and cancellous bones to conduct experiments. The objective was to compare the fixation ability of locked plate with that of headless compression screws. The results were expected to demonstrate that the use of headless compression screws in transverse metacarpal bone fracture surgery is less invasive in soft tissue stripping with greater fixation strength.

2. Materials and methods

2.1. Artificial metacarpal bone specimen preparation

In all, 14 artificial fourth generation third metacarpal bones (Sawbones, Vashon, WA, USA) were used. A metacarpal shaft fracture was created in all specimens using a saw blade. The transverse metacarpal shaft fracture was 30 mm from the distal articular surface. The proximal end of each specimen was held in a custom fixture using molded epoxy clamps.

2.2. Fixation by headless compression screw and locked plate

All specimens were assigned to one of 2 fixation techniques performed by a single senior hand surgeon (Yung-Cheng Chiu).

- Group 1. Headless compression screw group: 7 specimens were stabilized with 1 Dart-Fire Headless Compression Screw (Wright Medical Technology, Memphis TN) 4.3 mm in diameter and 40 mm in length. First, a pilot 1.6 mm K wire was inserted at the center of the metacarpal head, penetrate through the fracture site, and punctured out from the metacarpal base. Then, a 3.0 mm annulated drill bit was advanced along the path of the K wire. The screw was then inserted to fix the metacarpal shaft fracture. Fracture reduction was maintained using manual axial compression throughout the procedure (Fig. 1A).
- Group 2. Locked plate group: 7 specimens were fixed using 5-hole straight locked plate with 4×2.3 mm diameter locking screws (Stryker, Freiburg, Germany). First, the plate was applied at the dorsum of the metacarpal shaft, with the plate centered on the fracture site. Then, 2 bicortical locked screws were fixed distally to the fracture site. Then, 2 bicortical locked screws were fixed proximally to the site. Fracture reduction was maintained using manual axial compression throughout the surgery (Fig. 1b).

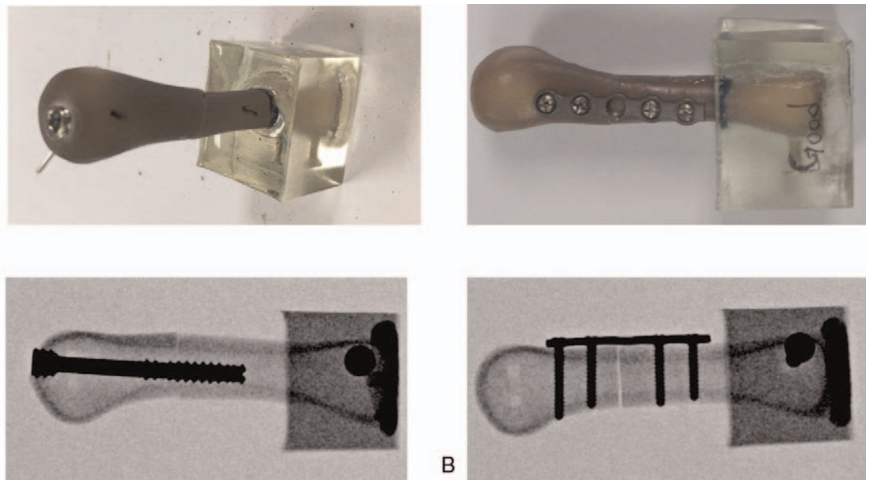
A
B

Figure 1. Artificial metacarpal bones and 2 types of fixation of metacarpal shaft fracture: (A) headless compression screw; (B) locked plate. (Top) experiments; (bottom) radiographs.

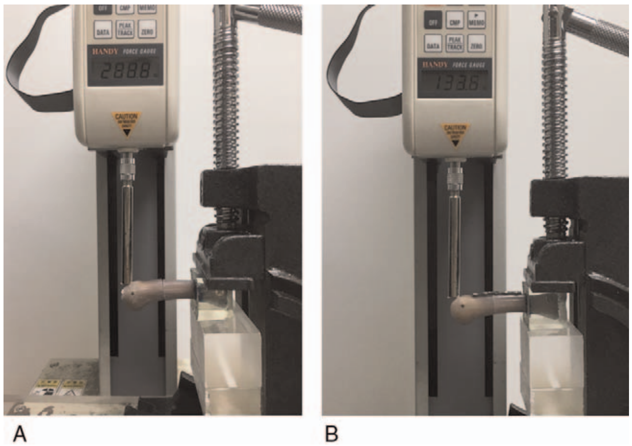

Figure 2. Cantilever bending test used in the experiment to evaluate the fixation ability of metacarpal shaft transverse fracture. (A) headless compression screw;(B) locked plate.

2.3. Biomechanical test

Cantilever bending tests were conducted to evaluate the fixation ability of the 2 groups. The tests were performed using a material testing machine (JSV-H1000, Japan Instrumentation System, Nara, Japan) (Fig. 2). A perpendicular load was applied to the dorsal side of the artificial metacarpal bone at a distance of 50 mm from the fixture until bone fracture. The strain rate of the cantilever bending test was set as 10 mm/min. The maximum fracture force and stiffness of each specimen was determined according to the force-displacement curve.

2.4. Statistical analysis

Due to the small sample sizes of the groups, the maximum fracture force and stiffness for the 2 fixation types are summarized as median ± interquartile range (IQR). The Mann–Whitney *U* test was used to compare the groups. SPSS software (IBM Corporation, Armonk, NY) was used to analyze performance; values of $P < .05$ were considered statistically significant.

3. Results

Table 1 presents the experimental results for maximum fracture force and stiffness. The maximum fracture force of the headless compression screws (HC) group (285.6 ± 57.3 N, median + IQR) was significantly greater than that of the locked plates (LP) group (227.8 ± 37.5N; $P < .05$; Fig. 3A). The median value of the HC group was 25.4% larger than that of the LP group. However, no significant difference between the 2 groups ($P > .05$) was observed (HC group = 65.2 ± 24.6N/mm, median ± interquartile range (IQR); LP group = 61.7 ± 19.7 N/mm; Fig. 3B) for stiffness.

Table 1

Maximum fracture force (N) and stiffness (N/mm) of the 2 fixation types for metacarpal shaft fracture.

	Headless compression screw		Locked plate	
	Max fracture force	Stiffness	Max fracture force	Stiffness
Median	285.6	65.2	227.8	61.7
IQR	57.3	24.6	37.5	19.7
Unit	N	N/mm	N	N/mm

CH = headless compression screw group, IQR = interquartile range, LP = Locked plate group.

4. Discussion

Metacarpal shaft fractures are common hand fractures. K-wire fixation has long been used to treat such fractures. Despite its minimally invasive nature, K-wire fixation has prompted concerns due to questionable fixation strength.[9,10] Although locked plate fixation for metacarpal shaft fractures has proved to provide excellent fixation strength, this open fixation is not a minimally invasive operation. Consequently, complications including tendon adhesion, iatrogenic injury of the superficial sensory nerve, and postoperative scar contracture are nearly inevitable.[11–15,17] To address this problem, physicians have begun conducting minimally invasive surgery using headless compression screws to treat metacarpal shaft fractures, aiming to provide a treatment that is less invasive in soft tissue stripping and has greater fixation strength. Several successful cases in clinical practice have been reported, but in vitro biomechanical studies are rare. Therefore, we conducted a biomechanical experiment with the hope of demonstrating that headless compression screws, which do not require soft tissue stripping or dissection, outperform locked plates in the treatment of transverse metacarpal shaft fractures in fixation strength.

Metacarpal fractures account for 13% of all hand fracture incidents and 23% of all forearm fractures, with an incidence rate lower than only that of distal radius fractures and phalangeal

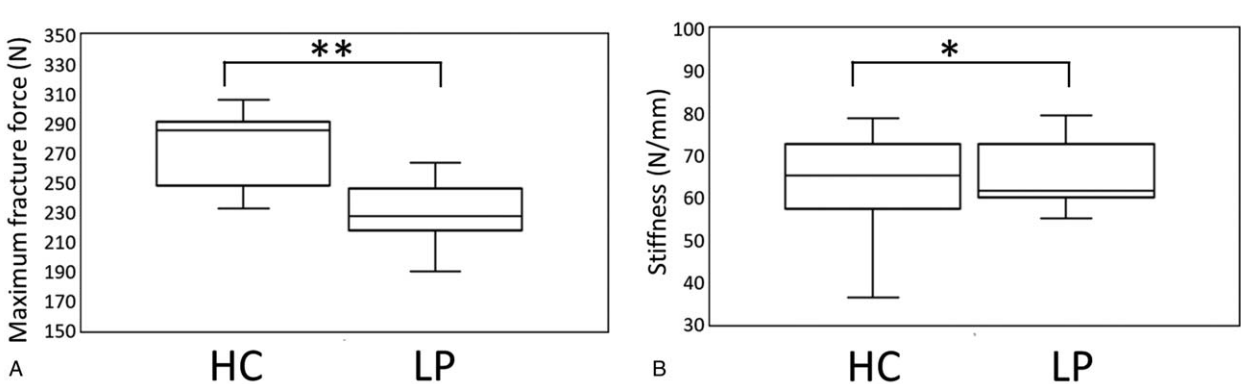

Figure 3. Box plots of maximum fracture force (A) and stiffness (B) of each fixation type (** $P < .05$; * $P > .05$). HC = headless compression screw, LP = locked plate.

fractures.[15,18,19] Among metacarpal fractures, only metacarpal neck fractures are more common than metacarpal shaft fractures. The ratio of metacarpal shaft to metacarpal neck fractures is 1:2.[2,3] Because the transition force generated by the intrinsic muscles leads to an unstable fracture end and angulation deformity, fracture site malunion or nonunion is likely if not properly treated. Metacarpal shaft fractures are most common among individuals aged 20 to 50 years. If their injury is not well treated, they are prone to the loss of hand functions; the costs of and time required for subsequent treatments can be enormous.[20–22] Although most isolated metacarpal fractures can be treated with nonoperative interventions,[4] studies have reported that every 2 mm of fracture shortening can cause 7 degrees of extensor lag.[23,24] Malrotation is the most unbearable fracture deformity; any rotational deformity of more than 10 degrees where the injured finger crosses over the neighboring finger during grasping must be corrected using corrective derotation osteotomy.[25] With surgical advances over the past decade, the effectiveness of operative treatments for metacarpal fractures has been recognized.[26] Identifying a treatment that is less invasive in soft tissue violation with desirable fixation strength is the ultimate goal of surgeons. This study analyzed the biomechanical strength and stiffness of 2 common fixation materials for metacarpal fractures, namely the headless compression screw and the locked plate, the results of which substantially contribute to surgical strategy development and rehabilitation program planning.

K-wire fixation is conventionally used for metacarpal fractures, but the fixation strength of the technique is unsatisfactory.[9,10] By contrast, studies have confirmed that locked plate fixation has excellent fixation strength. However, several drawbacks of the method were identified.[11] K-wire fixation entails weaknesses and complications such as wire breakage, loss reduction, and pin tract infection. Moreover, surgeons are subject to radiation exposure during K-wire surgery.[9,10] To avoid fixation failure, the hand must be immobilized for 6 to 8 weeks after surgery, and rehabilitation cannot begin until the K-is wire removed. Long-term immobilization leads to knuckle stiffness and longer physical therapy to return normal hand function.[27] The invention of locked plates revolutionized strategies for fracture management because they facilitate strong bony fixation, enabling early motion and initiation of rehabilitation. Patients can shorten sick leaves and achieve desirable recovery of range of motion.[6] However, because the dorsal skin of metacarpal bones is thin and the extensor digitorum tendon is closely adhered to the bones, applying plates on the dorsal side can readily cause stiffness in the metacarpophalangeal joint as well as extensor tendon adhesion, consequently creating discomfort at the fracture site. To mitigate the discomfort, patients must undergo surgery for implant removal after the bone heals.[11,13]

Alternatively, intramedullary screw fixation has become a popular surgical treatment for metacarpal shaft fractures. The surgery is performed by retrogradely inserting a headless compression screw through the metacarpal joint to fix the fractured site after fracture reduction. Because the fixation does not require contact with the extensor tendon, this method avoids extensor tendon adhesion caused by plate fixation. Nevertheless, the long-term effects of screw-fixation–caused joint cartilage damage on range of motion requires further investigation. In clinical orthopedic treatment of fractures, headless compression screws have long been used in treating scaphoid fractures.[28] The design of headless compression screws differs from that of general cortical screws in the following respects:

1. The screw can be fully buried in the bone following fracture fixation; therefore, the screw does not generate irritation in the surrounding soft tissue.
2. The proximal screw head and distal screw tip of a headless compression screw have different screw pitches; therefore, its insertion can create compression between the proximal and distal fracture sites, resulting in a higher bone union rate.

Clinically, a study proved that headless compression screws are effective in treating radial head fractures.[29] Del Piñal was the first to use headless compression screws to treat metacarpal fractures, achieving favorable results.[16] However, few studies have demonstrated that the fixation strength of headless compression screws is comparable to that of locked plates.

Because fresh cadaver metacarpal bones with similar bone strength are difficult to obtain, this study adopted artificial metacarpal bones for experiments by referring to a previous study[30] and a report published by the American Society for Testing and Materials. On the basis of previous experimental procedures,[31–33] we conducted cantilever bending tests to verify fixation effectiveness in which maximum fracture force and stiffness, 2 common indicators of fixation ability,[14,33–35] were measured.

During metacarpal fracture fixation, a locked plate is placed at the dorsal site (i.e., tension site) of the fractured bone; this method creates an effect similar to that of tension banding wire fixation.[6] During hand prehension, the locked plate helps convert the tension force at the dorsal site into compression force, thereby facilitating bone union.[31,36] However, open fixation is required for plate placement, which can require soft tissue dissection. Unlike locked plate fixation, fixation using a headless compression screw facilitates bone union by utilizing the pitch difference between the screw head and tip. Specifically, inserting the screw during fracture fixation can generate compression force between the proximal and distal fracture sites, thereby increasing the bone union rate.[37] However, studies have not proved that the bending resistance of a headless compression screw is comparable to that of a bone plate. In this study, in vitro biomechanical experiments revealed that despite the absence of a significant difference in maximum stiffness, the maximum fracture force of the HC group was significantly greater than that of the LP group, demonstrating that headless compression screws have greater fixation ability than do locked plates. Unlike locked plate fixation, the use of such screws in surgery does not cause squeal such as tendon adhesion, iatrogenic injury of the superficial sensory nerve, or surgical scar contracture. Moreover, the cost of the screws is lower than that of the plate. In addition, screw fixation does not require a reoperation for implant removal. Therefore, we recommend using headless compression screws to fix metacarpal shaft transverse fractures.

This study has several limitations. First, like most related studies,[30,31,33] we did not use fresh cadaver metacarpal bones but instead used artificial ones. Additionally, cantilever bending tests were conducted by referring to several studies.[31–33] However, the tests could not fully simulate actual phalanx motions and forces on the phalanges. Although these limitations did not affect the results, additional experiments are required.

5. Conclusion

An experiment using artificial metacarpal bones confirmed that the maximum fracture force of fixation headless compression screws was 25.4% greater than that of locked plate.

Author contributions

Conceptualization: Yung-Cheng Chiu, Jui-Ting Hsu.
Funding acquisition: Jui-Ting Hsu.
Methodology: Yung-Cheng Chiu, Cheng-En Hsu, Tsung-Yu Ho, Yen-Nien Ting, Bor-Han Wei, Ming-Tzu Tsai, Jui-Ting Hsu.
Writing – original draft: Yung-Cheng Chiu, Cheng-En Hsu, Jui-Ting Hsu.
Writing – review & editing: Yung-Cheng Chiu, Jui-Ting Hsu.

References

[1] Jones CM, Padegimas EM, Weikert N, Greulich S, Ilyas AM, Siegler S. Headless screw fixation of metacarpal neck fractures: a mechanical comparative analysis. Hand 2019;14:187–92.
[2] Aykut S, Öztürk K, Özcan Ç, Demiroğlu M, Gürün AU, Özden E. Results of surgical treatment in metacarpal shaft fractures using low profile mini plates. Ulus Travma Acil Cerrahi Derg 2015;21:279–84.
[3] Nakashian MN, Pointer L, Owens BD, Wolf JM. Incidence of metacarpal fractures in the US population. Hand 2012;7:426–30.
[4] Pratt DR. Exposing fractures of the proximal phalanx of the finger longitudinally through the dorsal extensor apparatus. Clin Orthop 1959;15:22–6.
[5] Soong M, Got C, Katarincic J. Ring and little finger metacarpal fractures: mechanisms, locations, and radiographic parameters. J Hand Surg Am 2010;35:1256–9.
[6] Wong KP, Hay RAS, Tay SC. Surgical outcomes of fifth metacarpal neck fractures—a comparative analysis of dorsal plating versus tension band wiring. Hand Surgery 2015;20:99–105.
[7] Greeven A, Bezstarosti S, Krijnen P, Schipper I. 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;42:169–75.
[8] Kozin SH, Thoder JJ, Lieberman G. Operative treatment of metacarpal and phalangeal shaft fractures. J Am Acad Orthop Surg 2000;8:111–21.
[9] Wong KY, Mole R, Gillespie P. Kirschner wire breakage during removal requiring retrieval. Case Rep Surg 2016;2016: Article ID 7515760, 3 pages.
[10] Sharma H, Taylor G, Clarke N. A review of K-wire related complications in the emergency management of paediatric upper extremity trauma. Ann R Coll Surg Engl 2007;89:252–8.
[11] Padegimas EM, Warrender WJ, Jones CM, Ilyas AM. Metacarpal neck fractures: a review of surgical indications and techniques. Arch Trauma Res 2016;5:e32933.
[12] Malasitt P, Owen JR, Tremblay M-A, Wayne JS, Isaacs JE. Fixation for metacarpal neck fracture: a biomechanical study. Hand 2015;10:438–43.
[13] Kollitz KM, Hammert WC, Vedder NB, Huang JI. Metacarpal fractures: treatment and complications. Hand 2014;9:16–23.
[14] Ochman S, Vordemvenne T, Paletta J, Raschke M, Meffert R, Doht S. Experimental fracture model versus osteotomy model in metacarpal bone plate fixation. ScientificWorldJournal 2011;11:1692–8.
[15] Facca S, Ramdhian R, Pelissier A, Diaconu M, Liverneaux P. Fifth metacarpal neck fracture fixation: locking plate versus K-wire? Orthop Traumatol Surg Res 2010;96:506–12.
[16] del Piñal F, Moraleda E, Rúas JS, de Piero GH, Cerezal L. Minimally invasive fixation of fractures of the phalanges and metacarpals with intramedullary annulated headless compression screws. J Hand Surg Am 2015;40:692–700.
[17] Bozic KJ, Perez LE, Wilson DR, Fitzgibbons PG, Jupiter JB. Mechanical testing of bioresorbable implants for use in metacarpal fracture fixation. J Hand Surg Am 2001;26:755–61.
[18] Boussakri H, Elidrissi M, Azarkane M, et al. Fractures of the neck of the fifth metacarpal bone, treated by percutaneous intramedullary nailing: surgical technique, radiological and clinical results study (28 cases). Pan Afr Med J 2014;18:187.
[19] Potenza V, Caterini R, De Maio F, Bisicchia S, Farsetti P. Fractures of the neck of the fifth metacarpal bone. Medium-term results in 28 cases treated by percutaneous transverse pinning. Injury 2012;43:242–5.
[20] Karl JW, Olson PR, Rosenwasser MP. The epidemiology of upper extremity fractures in the United States, 2009. J Orthop Trauma 2015;29:e242–4.
[21] Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg Am 2001;26:908–15.
[22] Emmett JE, Breck LW. A review and analysis of 11,000 fractures seen in a private practice of orthopaedic surgery 1937-1956. JBJS 1958;40:1169–75.
[23] Metcalfe D, Aquilina A, Hedley H. Prophylactic antibiotics in open distal phalanx fractures: systematic review and meta-analysis. J Hand Surg Eur Vol 2016;41:423–30.
[24] Stern PJ, Roman RJ, Kiefhaber TR, McDonough JJ. Pilon fractures of the proximal interphalangeal joint. J Hand Surg Am 1991;16:844–50.
[25] van der Lei B, de Jonge J, Robinson PH, Klasen HJ. Correction osteotomies of phalanges and metacarpals for rotational and angular malunion: a long-term follow-up and a review of the literature. J Trauma 1993;35:902–8.
[26] Hooper RC, Chen J-S, Kuo C-F, Chung KC. Closed metacarpal neck fractures: a review of resource use in operative and nonoperative management. Plast Reconstr Surg 2020;146:572–9.
[27] Hsu LP, Schwartz EG, Kalainov DM, Chen F, Makowiec RL. Complications of K-wire fixation in procedures involving the hand and wrist. J Hand Surg Am 2011;36:610–6.
[28] Gutow AP. Percutaneous fixation of scaphoid fractures. J Am Acad Orthop Surg 2007;15:474–85.
[29] Wu PH, Dixit A, Kiat Tan DM, Shen L, Chee YH. Prospective study of surgical fixation of radial head fractures using cannulated headless compression screws for simple and complex radial head fractures. J Orthop Surg (Hong Kong) 2017;25:2309499017716278.
[30] Elfar J, Stanbury S, Menorca RMG, Reed JD. Composite bone models in orthopaedic surgery research and education. J Am Acad Orthop Surg 2014;22:111–20.
[31] Chiu Y-C, Tsai M-T, Hsu C-E, Hsu H-C, Huang H-L, Hsu J-T. New fixation approach for transverse metacarpal neck fracture: a biomechanical study. J Orthop Surg Res 2018;13:183.
[32] Watt AJ, Ching RP, Huang JI. Biomechanical evaluation of metacarpal fracture fixation: application of a 90 internal fixation model. Hand 2015;10:94–9.
[33] Barr C, Behn AW, Yao J. Plating of metacarpal fractures with locked or nonlocked screws, a biomechanical study: how many cortices are really necessary? Hand 2013;8:454–9.
[34] Curtis BD, Fajolu O, Ruff ME, Litsky AS. Fixation of metacarpal shaft fractures: biomechanical comparison of intramedullary nail crossed K-Wires and plate-screw constructs. Orthop Surg 2015;7:256–60.
[35] Doht S, Meffert RH, Raschke MJ, Blunk T, Ochman S. Biomechanical analysis of the efficacy of locking plates during cyclic loading in metacarpal fractures. ScientificWorldJournal 2014;2014: Article ID 648787, 5 pages.
[36] Ali M, Kuiper J, John J. Biomechanical analysis of tension band wiring (TBW) of transverse fractures of patella. Chin J Traumatol 2016;19:255–8.
[37] Ahmed U, Malik S, David M, Simpson C, Tan S, Power D. The headless compression screw–technical challenges in scaphoid fracture fixation. J Orthop 2015;12:S211–6.