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

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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
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, 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 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).
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 ± 37.5 N; $P < .05$; 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 ± 24.6 N/mm, median ± interquartile range (IQR); LP group = 61.7 ± 19.7 N/mm; Fig. 3B) for stiffness.

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 fractures.
fractures. 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. 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. Although most isolated metacarpal fractures can be treated with nonoperative interventions, studies have reported that every 2 mm of fracture shortening can cause 7 degrees of extensor lag. 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. With surgical advances over the past decade, the effectiveness of operative treatments for metacarpal fractures has been recognized. 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. By contrast, studies have confirmed that locked plate fixation has excellent fixation strength. However, several drawbacks of the method were identified. 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. To avoid fixation failure, the hand must be immobilized for 6 to 8 weeks after surgery, and rehabilitation cannot begin until the K-wire is removed. Long-term immobilization leads to knuckle stiffness and longer physical therapy to return normal hand function. 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. 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.

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. 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. Del Piñal was the first to use headless compression screws to treat metacarpal fractures, achieving favorable results. 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 and a report published by the American Society for Testing and Materials. On the basis of previous experimental procedures, we conducted cantilever bending tests to verify fixation effectiveness in which maximum fracture force and stiffness, 2 common indicators of fixation ability, 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. During hand prehension, the locked plate helps convert the tension force at the dorsal site into compression force, thereby facilitating bone union. However, open fixation is required for plate placement, which can cause 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. 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, we did not use fresh cadaver metacarpal bones but instead used artificial ones. Additionally, cantilever bending tests were conducted by referring to several studies. 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.

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Author contributions
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