RESEARCH ARTICLE

Three-Dimensional Analysis of Metacarpal Head Articular Defects Created by Headless Screws

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Abstract

Objectives: Headless screw fixation used to treat metacarpal neck and metacarpal shaft fractures is gaining popularity. The aim of the study is to determine the proportion of the metacarpal head articular surface that is compromised during retrograde insertion of headless screws.

Methods: Metacarpal screw fixation through a metacarpal head starting point was performed using fluoroscopic guidance on 14 metacarpals. Headless compression screws, with a tail diameter of 3.6mm, were used. The specimens were subsequently skeletonized and digitized using a 3-dimensional surface scanner. The articular surface defects created by the screws were then determined using computer software. Screw position in the dorsal aspect of the metacarpal head was expressed as a percentage of the total volar-to-dorsal distance.

Results: The 14 metacarpals studied consisted of 2 index, 4 long, 4 ring and 4 small metacarpals, taken from 4 hands. The average total metacarpal head surface area was 284.6 mm^2 (range, 151.0-462.2 mm^2); the average screw footprint in the metacarpal head was 13.3 mm^2 (range, 10.3-17.4 mm^2), which compromised a mean of 5.0% (3.0-7.8%) of the total cartilaginous metacarpal head surface area. In the sagittal plane, screw placement was found to lie in the dorsal 37.4% of the metacarpal head (range, 20.7-58.6%).

Conclusion: The proportion of the articular surface area injured with retrograde insertion of headless compression screws into the metacarpal head is 5.0%. Screw placement is generally in the dorsal 37% of the metacarpal head.

Level of evidence: V

Keywords: Headless screw, Intramedullary screw fixation, Metacarpal head, Metacarpal fracture

Introduction

Numerous operative techniques have been used to treat unstable metacarpal neck and shaft fractures, including various configurations of Kirschner (K) wires and pins,[1, 2] plates and screws,[3-5] and intramedullary screws.[6-8] The use of headless compression screws to treat unstable metacarpal neck and distal metacarpal shaft fractures have become increasingly popular due to favorable short-term clinical results.[6-12] Intramedullary screw fixation has a number of advantages over K-wire fixation, including the absence of exposed hardware, more rigid fixation and earlier motion.[1, 6-8] In comparison to plate fixation, intra-medullary fixation is less invasive, minimizes soft tissue stripping, and generally takes less operative time. The disadvantages include increased implant costs relative to K-wires and less rotational control relative to plate fixation. Furthermore, a unique concern about this technique is iatrogenic injury to the articular surface of the metacarpal head and the risk of post-traumatic metacarpophalangeal joint (MPJ) arthritis; however, this technique is relatively modern, and long-term outcomes reporting the status of the joint are not yet available.

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In this study, the surface area of the metacarpal head that was iatrogenically damaged during retrograde insertion of headless compression screws was investigated. This knowledge may assist patients and surgeons in making a more informed decision about the application of this surgical option.

Materials and Methods

In this cadaveric study, four fresh frozen adult hands were used (3 right hands and 1 left hand). Thumb metacarpals (n=4) and arthritic metacarpal heads with large osteophytes (n=2) were excluded. The age and sex of the specimens were not available.

The Acumed Acutrak 2 *Mini* Cannulated screw system was used (Acumed, Hillsboro, Oregon). The *Mini* screws have a tip diameter of 3.5mm, and a tail diameter of 3.6mm. All screws used were 30mm in length. This screw size was selected and used for all specimens as it represented the most commonly used screw size in the authors' practice to treat these fractures. No metacarpal fracture was created. The screws were placed percutaneously in situ, under the guidance of fluoroscopy [Figures 1, 2]. No malunions from previous metacarpal shaft or neck fractures were detected in any of the specimens. The MPJ was flexed to 90º and a 0.045inch guide wire was placed percutaneously through the metacarpal head starting point in retrograde fashion. Once adequate placement along the shaft was confirmed with fluoroscopy, the K-wire was over-drilled with a 2.7mm diameter cannulated drill bit to drill the cartilage, subchondral bone and the intramedullary canal. The *Mini* screw was then placed and buried in subchondral bone [Figures 1, 2]. The metacarpals were then disarticulated and skeletonized, preserving the articular surfaces of the metacarpal heads. Digital photos of the dorsal, volar, distal, radial and ulnar surfaces of the metacarpal heads were then obtained for reference [Figure 3].

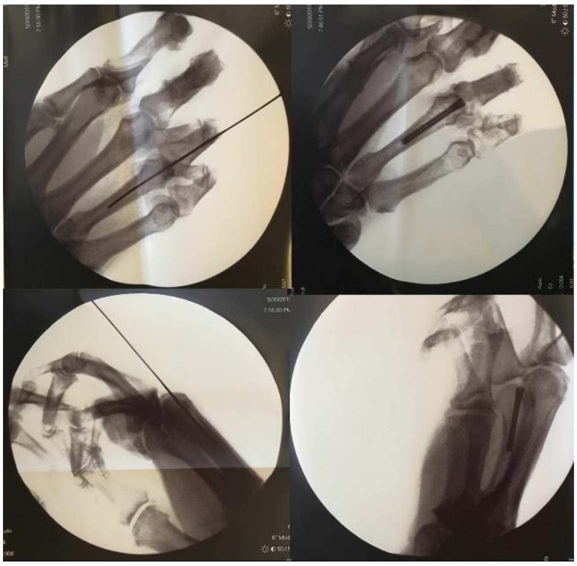

Figure 1. The headless compression screws were placed under fluoroscopic guidance. Initially, a 0.045" guide wire was placed through the metacarpal head in retrograde fashion. Once placement was confirmed to be within the intramedullary canal, the wire was overdrilled and a headless compression screw placed

Figure 2. All screws were placed percutaneously

Figure 3. Following fixation, specimens, were disarticulated, skeletonized, labeled and photographed

The metacarpal base was stabilized on a solid surface, allowing the head to protrude in its entirety to facilitate scanning. The *Artec Space Spider* 3-dimensional (3D) handheld scanner (Artec3D, Santa Clara, CA) was used to digitize each specimen by scanning it once circumferentially [Figures 4, 5]. The three-dimensional resolution of this scanner is up to 0.1 mm, and the three-dimensional point accuracy is up to 0.5 mm. This data was registered using *Artec Studio 13 Professional* computer software (Artec3D, Santa Clara, CA). The Rapidform XOR/XOS 3D Scan Data and CAD (XRL) files were then exported to *Geomagic Design X* reverse engineering software (3D Systems, Rock Hill, SC) and the 3D scan data was processed and analyzed.

The 3D articular surface of the metacarpal head area was manually selected based on the smooth outlines of the articular surface and based on reference photos obtained earlier in the study. The selected articular area with the screw hole subtracted was then obtained using the software. The screw hole was then filled using the software's "curvature fill holes" feature and the area was obtained again. The difference between the metacarpal head area with the hole filled and the metacarpal head area with the presence of the screw hole was the calculated area of the screw's footprint.

Figure 4. The Artec Space Spider 3D surface scanner was used to digitize the metacarpal head

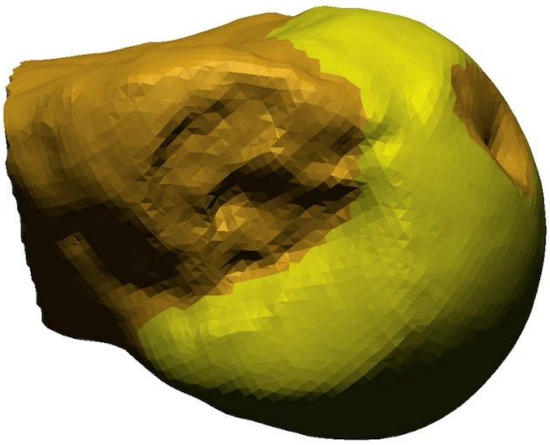

Figure 5. The scanned metacarpal head with the articular surface highlighted in yellow. The defect created by screw insertion in the metacarpal head is clearly visible

Next, an axial view of the 3D metacarpal head model was obtained and a plane of best fit was created in the sagittal plane centered over the center of the screw hole [Figure 6]. A 2-dimensional (2D) cross section of this plane was subsequently created using the "mesh sketch function" [Figure 7]. The volar to dorsal distance (X) of the metacarpal head was then obtained, and the distance between the most volar location of the screw hole and the dorsal metacarpal head (Y) was determined and expressed as a percentage of the entire volar to dorsal length of the metacarpal head (Y/X).

Institutional Review Board (IRB) approval was not required for this study. The surgical hardware, surface scanner and computer software were provided by Acumed, LLC. The study concept, study design, data acquisition and data analysis were performed by the authors exclusively.

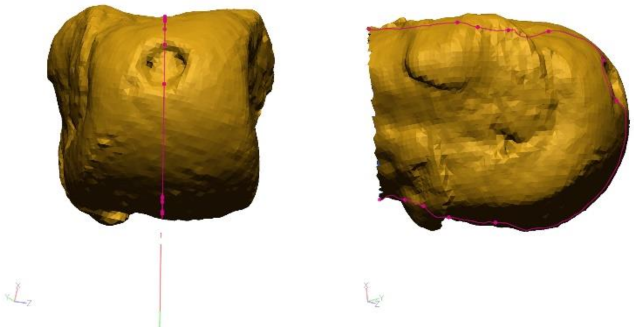

Figure 6. An axial view of the metacarpal head model was obtained and a plane of best fit was created in the sagittal plane centered over the center of the screw hole

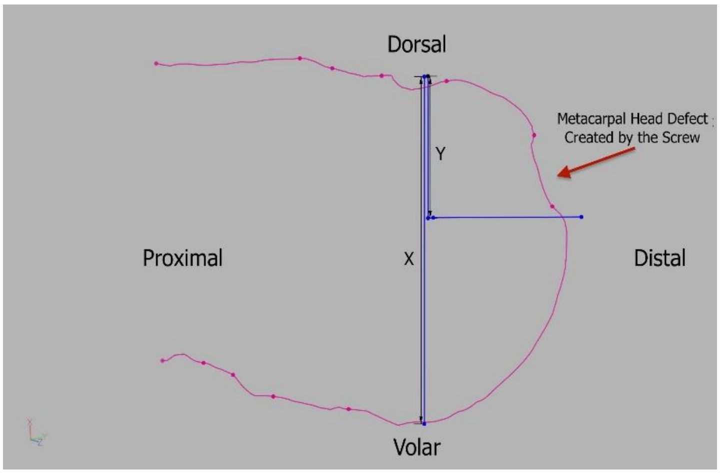

Figure 7. A 2-dimensional cross section of the metacarpal head, with the sulcus created by the screw clearly noticeable. The volar-to-dorsal distance of the metacarpal head cross section (X). The distance between the most volar location of the screw hole and the dorsal metacarpal head (Y). Screw placement within the dorsal aspect of the metacarpal head was expressed as a percentage (Y/X)

Results

A total of fourteen metacarpal heads were assessed; 2 index, 4 long, 4 ring and 4 small. Two index metacarpals were excluded due to arthritic changes. The mean surface area of the articular heads was 284.6mm^2 (range 151.0-462.2mm^2). The mean surface areas of the index, long, ring and small metacarpal heads were 281.6 mm^2 (range 247.7-315.5mm^2), 344.7 mm^2 (range 230.1-462.2mm^2), 272.2 mm^2 (range 202.9-377.8mm^2), 238.6 mm^2 (range 151.0-346.8mm^2) respectively [Figure 8]. The mean screw footprint was 13.3mm^2 (range, 10.3-17.4mm^2), which compromised a mean of 5.0% (range, 3.0-7.8%) of the articular surface of the metacarpal head. The defect area of the articular surface created by screw placement within each individual metacarpal head is presented in [Figure 9].

In the sagittal cross-sectional plane, screw placement was found to lie in the dorsal 37.4% of the metacarpal head (range, 20.7-58.6%).

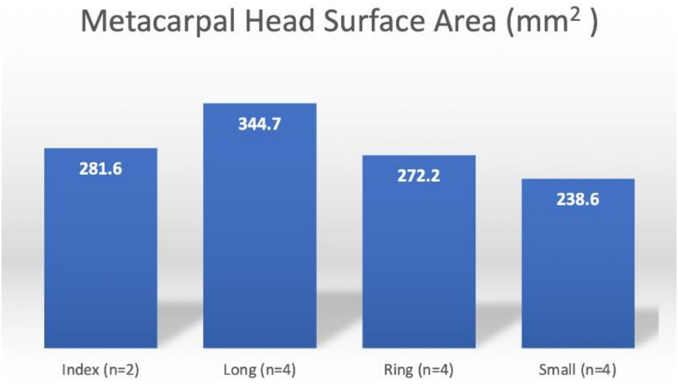

Figure 8. Metacarpal head articular cartilage surface area

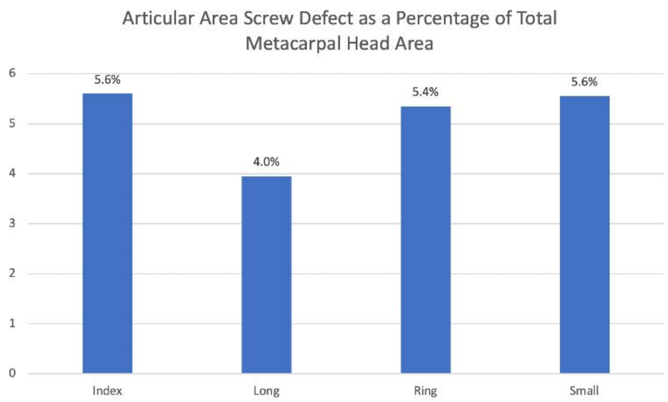

Figure 9. The defect in the articular cartilage as a percentage of total metacarpal head surface area

Discussion

Intramedullary headless compression and non-compression screws have been used to successfully treat metacarpal neck, as well as oblique, transverse and comminuted distal metacarpal shaft fractures.[6-12] Reported complications include extensor tendon lag secondary to adhesions, screw migration into the MPJ, painless clicking with MPJ motion, and MPJ stiffness.[12] No reports of post-traumatic arthritis or avascular necrosis secondary to this fixation technique have been reported however, as most case series report short to medium term outcomes.[6-12] In this study, it was determined that 5.0% of the articular surface area of the metacarpal head was compromised with the use of a 3.6mm Acumed *Mini* screw. Based on its inherent size, the proportion of the metacarpal head area affected the least was the long metacarpal head, followed by the index, ring and small metacarpal heads.

These results are similar to what has been described by ten Berg *et al*, who found that the countersunk trailing portion of 3.0mm headless compression screws occupied 5% of the metacarpal head subchondral volume.[13] In addition, ten Berg *et al* noted the absolute violations of the metacarpal head surface area by a 3.0mm screw averaged 12mm^2, while in the current study a 3.6mm screw occupied an average area of 13.3mm^2.[13] The contact area between the metacarpal head and the proximal phalanx becomes broader with MPJ flexion because of the unique shape of the volar region of the metacarpal head.[14] Using computer simulation to place a screw within the metacarpal, ten Berg *et al* found that the dorsal starting point was in line with the medullary canal and avoided engaging the center of the articular base of the phalanx through most of the sagittal plane arc.[13] In the current study, screw placement was found to lie in the dorsal 37.4% of the metacarpal head and ranged from 20.7% to 58.6%. These results represent a more volar starting point than previously described.[13] While the variability in screw position may be explained in part by investigator technique, the variability of the metacarpal shaft curvature in the sagittal plane, may have also influenced the starting point.[15] In order to obtain more central intramedullary placement in some instances, the guide wire starting point had to begin more volar than the dorsal third of the metacarpal head. It is not entirely clear from the presented data whether a more volar starting point has an impact on articular engagement with the proximal phalanx. Based on a prior study by Strazewski et al, [16] engagement of the articular defect of the metacarpal head with a dorsal third starting point and the dorsal aspect of the proximal phalanx base occurred at an average of 31º of flexion of the metacarpophanageal joint. We anticipate that a more volar starting point may expose the proximal phalanx base to an increased arc of contact with the articular defect in the metacarpal head, but it is unclear if that would be of clinical significance. In addition, it could also be speculated that a more dorsal starting point may increase the risk of extensor tendon engagement when the screw is driven into position, leading to soft tissue injury. Evaluation of specific metacarpals may also identify differences in the starting points due to differing metacarpal curvatures.[15] These proposed ideas could be considered future topics research.

The strength of this study lie in the methodology of data acquisition using a 3D scanner with high accuracy, capable of measuring a small, complex surface area, which is difficult to measure with conventional techniques. This method is also likely to be more accurate than conventional commuted tomography scanning for studying the thin cartilaginous surface covering the subchondral bone. Furthermore, screw placement was performed percutaneously under the guidance of fluoroscopy in order to simulate operative conditions, where screw placement may be affected by obstruction of the adjacent phalanges.

A number of limitations exist in this study. The percentage of the metacarpal head contact area with the base of the proximal phalanx could not be determined based on the study design. Not creating a fracture model is another limitation as the starting point might be more unpredictable due to instability when there is a fracture. All screws used were 3.6mm and 30mm in length. Larger screw diameters will compromise larger areas of the metacarpal head during insertion, while patients with smaller metacarpal heads will have a higher proportion of their articular surface affected by retrograde screw placement. The decision to use the *Mini* screw with a tail diameter of 3.6mm was based on what the authors believed to be reflective of their clinical practice. In addition, a systematic review of 9 studies that used headless compression screws noted that screws used had a diameter ranging from 2.2 to 4.0-mm, and screw length ranging from 26 to 50 mm.[12] it should be noted that there are currently numerous headless compression and noncompression screws available with various diameters and lengths applicable to this surgical technique. Other limitations include the small sample size and the lack of demographic data for the specimens.

Conclusion

The proportion of the articular surface area iatrogenically compromised with retrograde insertion of headless compression screws into the metacarpal head in the current study is 5.0%. Screw placement is generally in the dorsal 37% of the metacarpal head. Smaller diameter screws will affect less of the articular cartilage. When considered in the context of the risks and benefits, the small size of the articular defect created by screw insertion may alleviate some of the concerns about iatrogenic articular damage with the use of this technique.

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