Articular Involvement With Retrograde Headless Compression Screw Fixation of the Metacarpal

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Purpose Retrograde headless compression screw (RHCS) fixation for metacarpal fractures can lead to metacarpal head articular cartilage violation. This study aimed to quantify the articular surface loss after insertion of the RHCS and determine the functional range of motion (ROM) of the metacarpophalangeal (MCP) joint at the point of contact between the proximal phalangeal (P1) base and the articular defect.

Methods Ten fresh-frozen cadaveric hand specimens were analyzed for prefixation MCP joint ROM. After screw insertion, the ROM at which the dorsal portion of the P1 base begins to engage the screw tract defect, as well as the ROM at which the midsagittal portion of the P1 bisector engages the screw tract defect, was recorded. The distal axial articular surface of the metacarpal and the defects from screw insertion were measured using a digital image software program.

Results Nine men and one woman (mean age, 69 years) were examined. The prefixation mean extension-flexion arc for all MCP joints ranged from 1° to 85°. After screw insertion, the mean MCP ROM at which the dorsal P1 articular surface first engaged the screw tract was 31°. Only 7 digits had screw tract engagement with the midsagittal bisector of the P1 base at a mean flexion angle of −18° (18° hyperextension). Mean articular surface violation increased from the index finger moving ulnarly, with an average of 3.9% involvement.

Conclusions Articular surface loss of the metacarpal head following RHCS insertion is negligible in a cadaveric model, with minimal engagement between the corresponding defect and the P1 base during functional ROM.

Clinical relevance Retrograde headless compression screw fixation of metacarpals inevitably damages the cartilage. However, the actual defect is small in proportion to the articular surface area and not engaged during functional activity. These biomechanical features may mitigate the surgeon's concern about joint destruction, while ensuring the benefits of early rehabilitation and minimal invasiveness of this technique. *(J Hand Surg Am. 2024;49(1):62.e1-e6. Copyright © 2024 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Metacarpal fractures, headless compression screw, articular violation, cadaver.

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Metacarpal fractures account for nearly 20% of all hand fractures and cause a burden on the economy because of delayed return to work.[1–3] Operative fixation is the mainstay treatment for fractures with unacceptable deformity, malunion, or nonunion[4]; however, there exists no consensus on the ideal surgical intervention.[1,5,6] Traditionally, these fractures have been treated surgically with crossed Kirschner wire fixation, locking plate constructs, and, more recently, retrograde headless compression screw (RHCS) fixation.[1,5,7,8]

While biomechanical studies have shown similar fixation strength and load to failure between these fixation modalities,[9,10] RHCS fixation has avoided many of the associated complications seen with Kirschner wire and locking plate constructs, such as avascular necrosis, adhesions, stiffness, and pin site issues.[7,8,11–15] Early adopters of the RHCS technology have noted high union rates within 6 weeks,[3,7,16,17] with the added benefits of early functional rehabilitation and expedited return to work,[1,10,16,18] Concerns regarding this technique relate to the unavoidable articular disruption in the process of screw placement. Doarn et al[3] and Warrender et al[13] have shown during revision surgeries that these screw holes fill in with fibrocartilage, similar to what is seen with joint-preservation techniques like microfracture. Further, ten Berg et al[19] used a 3D-computed tomography (CT) model to demonstrate minimal functional metacarpophalangeal (MCP) articular violation following screw insertion; however, the risk of the development of osteoarthritis and associated functional consequences remains unclear.

While the consequences of antegrade HCS insertion for simulated metacarpal shaft fractures have already been evaluated in a cadaveric model,[20] a similar cadaveric study evaluating the extent of the articular surface disruption following retrograde HCS insertion and its impact on the functional range of motion (ROM) in the MCP joint has not been completed. Accordingly, we assessed articular violation after RHCS insertion and determined the ROM of the MCP joint before engagement with the articular defect. We hypothesize that insertion of an RHCS will result in minimal metacarpal head articular surface loss, and this defect will not engage with the proximal phalangeal (P1) base during functional ROM.

MATERIALS AND METHODS

Ten fresh-frozen cadaveric hands were studied after receiving an exemption from the University of Chicago institutional review board. While a formal sample size estimate was not completed, a similar study by Borbas et al[21] evaluating phalangeal base surface area violation used 6 cadavers; Hoang et al[20] also used 10 specimens in their assessment of antegrade screw insertion in metacarpals. Thumb metacarpals were not included, making 40 lesser digit metacarpals available for analysis. Before prefixation ROM analysis, index, long, ring, and small finger MCP joints were cycled in a flexion-extension arc 10 times to reduce any adhesions caused by the preservation process. Goniometric prefixation ROM was recorded for each digit with the wrist held in neutral (Fig. 1A). The ROM was measured 3 times by a single investigator, and the mean was recorded. The mean ROM for each digit across all specimens was also calculated.

No simulated fractures were created in the metacarpals because the focus of the study was the entry point of the screw, regardless of the fracture location or pattern. RHCS insertion was completed via a dorsal paratendinous approach to the MCP joint. The screw diameter was determined by the "best fit" of the metacarpal canal on fluoroscopy. Specifically, a screw was placed on the skin over the canal of the respective metacarpal. Under fluoroscopic examination, the screw size was selected for the tightest fit of the isthmus. If the fluoroscopic imaging demonstrated room for potential increased sizing, the next screw size was placed over the metacarpal canal until the "best fit" was identified.

After exposure of the MCP joint, a 0.9 mm guide wire (for 2.5 mm HCS) or 1.1 mm guide wire (for 3.0 mm HCS and greater) placement was centered on orthogonal fluoroscopic views of the metacarpal. The wire was placed in the dorsal third of the metacarpal head and centered on the radio-ulnar plane. The guide wire was advanced with serial fluoroscopic spot checks, ensuring a good trajectory. With confirmatory fluoroscopic imaging, the guide wire was further extended to the proximal end of the metacarpal. The articular surface and subchondral bone were predrilled with 1.8 mm, 2.1 mm, 2.4 mm, and 2.7 mm cannulated drill bits before insertion of 2.5 mm, 3.0 mm, 3.5 mm, and 4.0 mm HCS, respectively. Screws were inserted beneath the level of the articular cartilage. Fluoroscopy was again used to ensure satisfactory placement. The screw diameters with corresponding demographics for each specimen are provided in Table 1.

Following insertion of the RHCS, two separate ROM observations were made to identify the extent of P1 base engagement during simulated ROM. The

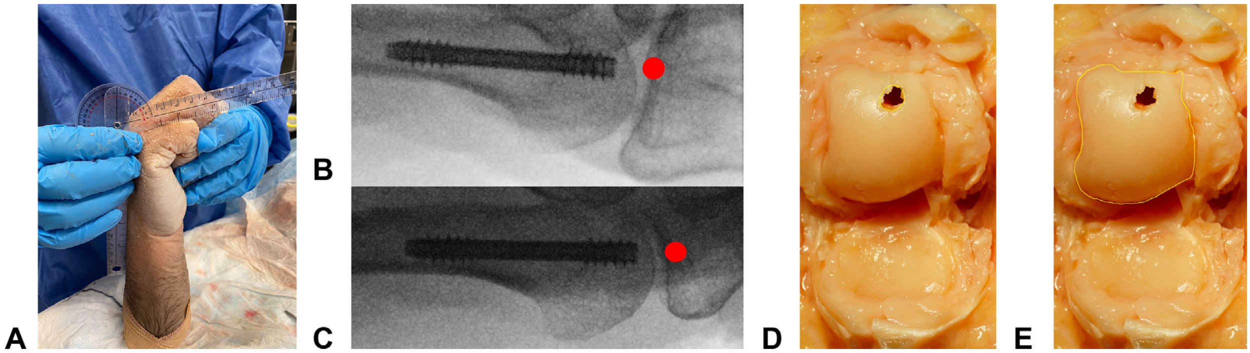

FIGURE 1: Prefixation MCP joint ROM was measured using a goniometer after manipulation. **A** After screw insertion, the ROM at which the dorsal P1 base first engages the screw head was measured, as well as the ROM at which the midsagittal P1 base engages the screw head (Red circles in photos **B** and **C**, respectively). ImageJ processing software was used to measure **D** the articular defect created from the insertion of RHCS and **E** the distal axial articular surface of the metacarpal head.

first measurement included the ROM at which the dorsal P1 base engaged the distal longitudinal bisector of the screw center (Figs. 1B and 2); the second measurement was obtained by recording the ROM at which the distal longitudinal bisector of the screw engaged the midsagittal bisector of the P1 base (Figs. 1C and 2). A single investigator recorded the average of 3 trials for each ROM. The mean of these ROM averages was then calculated across all specimens for each digit.

After ROM analysis, the MCP joints were dissected to fully expose the distal axial articular surface of the metacarpal heads and the defects from screw insertion. Standardized *en face* photographs perpendicular to the distal articular surface of the metacarpal heads were made.[21] These photos were analyzed using ImageJ image processing software (National Institute of Health) to quantify the articular defect, as was described prior by Borbas et al.[21] The articular defect and articular surface were measured in 3 independent trials by 2 investigators (Fig. 1D, E), and the means of these measurements were used to calculate the percent surface area violation from screw insertion ([surface area screw defect/surface area distal articular surface] × 100). The mean of these articular violation averages was calculated across all specimens for each digit and all digits combined.

RESULTS

Table 1 provides cadaver demographics for the 10 specimens, including 9 men and 1 woman with a mean age of 69 years (61 to 82 years). No samples had surgery on any of the lesser digits; a fifth metacarpal malunion was identified in one specimen (man, 61 years), but this was not considered relevant to the data collection. The average prefixation extension-flexion arc was 1° to 85° for all digits. Moving from radial to ulnar, the average arc of motion increased. Engagement of the articular defect with the dorsal aspect of the P1 base occurred at an average of 31° of flexion. Seven of the 40 digits showed articular defect engagement with the midsagittal P1 base bisector, occurring in the ring and small finger in 5 of 7 specimens. Of these digits, this occurred at an average of −18° of flexion (18° of hyperextension). The average violation was 3.9% for the articular surface analysis, with the average percentage violation increasing from a radial to ulnar direction. Eighty percent of the specimens had either a 3.5 mm or 4.0 mm screw placed. Detailed descriptions of the results concerning each digit and screw size are provided in Tables 2 and 3.

DISCUSSION

Metacarpal fractures are commonly seen with hand trauma, and operative fixation may be warranted in displaced fractures or those not healing adequately with nonsurgical treatment.[1,5,8] While traditional fixation modalities, such as Kirschner wire and locking plate fixation, are still used, RHCS fixation has increased in popularity because of its minimally invasive technique and potential for early functional rehabilitation.[9,10,16,18] The unavoidable violation of the metacarpal head articular surface is one consequence of RHCS insertion and has been a source of concern, even though prior CT studies have shown this to be minimal.[5,19] This cadaveric study adds to the preexisting image-based literature in evaluating screw tract engagement with the P1 base during simulated ROM and articular surface area disruption following RHCS insertion.

TABLE 1. Demographics of Specimens and Corresponding Screw Diameters

Demographics		Screw Diameter (mm)			
Age, y	Sex	Index	Long	Ring	Small
66	Male	4.0	4.0	3.5	4.0
65	Male	3.5	3.0	3.5	3.5
82	Male	3.5	3.5	3.0	3.5
57	Female	3.5	3.5	3.0	3.5
71	Male	4.0	4.0	4.0	4.0
77	Male	3.0	3.0	2.5	3.0
61	Male	3.5	3.5	3.0	4.0
64	Male	4.0	3.5	4.0	4.0
77	Male	4.0	4.0	3.5	4.0
74	Male	4.0	4.0	3.5	4.0

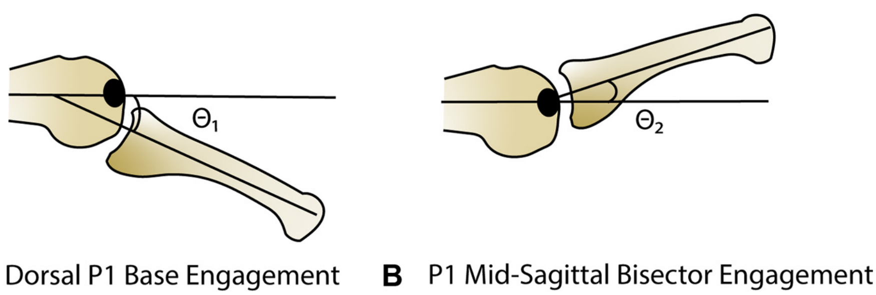

FIGURE 2: Diagram of screw tract engagement with the P1 base. Assessment of screw tract engagement was measured at 2 endpoints, including **A** the ROM (Θ1), at which the dorsal P1 base engages the screw tract, and **B** the ROM (Θ2), at which the midsagittal P1 base engages the screw tract.

The mean extension-flexion arc of our specimens, and trend toward increased ROM in the ulnarward direction, is consistent with prior literature.[22] We also assessed engagement of the metacarpal head articular defect with the midsagittal bisector of the P1 base fluoroscopically, with 18% of digits engaging at an average of 18° hyperextension, a ROM that was supraphysiologic for this cohort's simulated motion. This is corroborated by Murai et al,[23] who used electronic goniometers to measure the functional ROMs of MCP joints during simulated activities of daily living. This group identified functional ROM to be 10.6° to 67.8°, 4.0° to 79.9°, 3.0° to 83.9°, and 2.9° to 91.4° for the index, long, ring, and small finger, respectively.[23] Given these values, none of our cadaveric specimens would have engaged with the midsagittal P1 base bisector during simulated activities of daily living. The CT-based study by ten Berg et al[19] similarly noted these dorsal defects in the metacarpal head following RHCS insertion, which ultimately only engaged with the P1 base during hyperextension.

Our specimens showed an average metacarpal head surface area violation of 3.9%, lower than prior CT and computer modeling analyses.[5,19] Del Pinal et al[5] noted 13 to 18% violation with 2.5 mm screws and 19 to 25% for 3.0 mm screws; whereas, ten Berg et al[19] noted surface area violation from 4 to 13% through 3-dimensionally modeled 2.0 and 3.0 mm screws. The discrepancy in surface area violation between prior publications and the current study could be due to the manual inspection and analysis of the surface area defects rather than more precise methods using quantitative CT. Decreased implant profile used in newer screw designs and 20% of our cohort receiving undersized screws, via the senior author's *ad hoc* "best fit" sizing on fluoroscopy,[24] are other explanations for the decreased surface area violation observed in this study. Conversely, using more appropriate, larger screw diameters could increase the overall articular surface violation measurements.

TABLE 2. Average Prefixation MCP Joint ROM* , P1 Base Engagement ROM*, and Articular Violation Measurements

Digit	Prefixation Extension (Degrees)	Prefixation Flexion (Degrees)	Dorsal P1 Engagement (Degrees)	Midsagittal P1 Engagement (n, Degrees)	Articular Violation (%)
Index	2	84	34	1/10 at −12†	3.5
Long	1	84	27	1/10 at −5†	3.6
Ring	0	86	33	3/10 at −17†	3.8
Small	-1†	88	29	2/10 at −39†	4.7
Average	1	85	31	7/40 (18%) at −18†	3.9

*ROM measurements are recorded as flexion angles.
†A negative flexion angle value is consistent with hyperextension.

TABLE 3. Average Articular Violation and Number of Screws Placed by Screw Diameter

Screw Diameter (mm)	Screws Placed (%)	Articular Violation (%)
2.5	2.5 (1/40)	4.1
3.0	17.5 (7/40)	3.7
3.5	37.5 (15/30)	3.8
4.0	42.5 (17/40)	4.0

With analysis of surface area violation by screw diameter, we observed a mean increase in violation with increasing RHCS diameter from 3.0 to 4.0 mm (3.7%, 3.8%, and 4.0%, respectively). The single 2.5 mm RHCS proved an outlier with its articular violation of 4.1%. An explanation for this could be a technical error during drilling before screw insertion. The unintended increase in surface violation, coupled with the lack of other screws of this diameter being placed, resulted in this skewed data. Of note, 80% of our specimens had either a 3.5 mm or 4.0 mm RHCS placed by the principal investigator's technique of "best fit" of the metacarpal canal on fluoroscopy. Previous literature has demonstrated the morphologic differences between the metacarpals. It is suggested that the minimum diameters of screws necessary for interference are 3.5 mm for the ring finger and 4.0 for the remaining lesser digit metacarpals.[24,25] While 20% of the screws encompassing 2.5 mm and 3.0 mm diameters may have been undersized by recent computed tomographic parameters; most specimens being sized appropriately in this study may support this *ad hoc*, pragmatic approach to screw selection before insertion.

The strengths of this study include its use of 10 cadaveric specimens (40 digits) in evaluating the consequences of RHCS insertion into metacarpals. Analyses of the metacarpal head defects associated with RHCS insertion thus far have been limited to advanced imaging and computer modeling of the defects, with this study providing cadaveric evidence that corroborates the prior literature. The limitations of our study include the measurement of joint ROM and surface area violation utilizing a manual goniometer and image processing software. Given the user-dependent nature of the data acquisition, the study attempted to limit intraobserver error by taking the average of 3 trials for each sequential measurement. Additionally, the inserted screw sizes varied from 2.5 mm to 4.0 mm. While the nonuniform screw size limits generalizability, screws were selected following the "best fit" of each metacarpal canal using fluoroscopy. In theory, specimens with larger canals would also have larger metacarpal heads, resulting in proportional degrees of articular violation between specimens. Finally, it must also be acknowledged that 90% of our specimens were male. Ideally, even proportions of both sexes could have limited this inherent selection bias.

The authors also chose to measure the total metacarpal head surface area via imaging software following the capture of an *en face* photo of the metacarpal head. The authors acknowledge that while the distal axial articular surface measurement does not account for volar articular cartilage, the distal surface was more clinically relevant to any engagement or impingement of screw tracts with the P1 base. Finally, the study did not include the iatrogenic creation of fractures in the metacarpals; as such, the ease and reproducibility of precise screw placement in the dorsal aspect of the metacarpal head may be limited while concomitant maintenance of reduction is required.

This study adds to the growing body of literature supporting RHCS fixation for metacarpals. These data corroborate other CT-based modeling studies of metacarpal head articular surface violation following retrograde screw insertion, demonstrating a proportionally small surface area actually violated. Additionally, this study supports that using dorsal start positions during RHCS insertion results in limited P1 base engagement with screw tracts during functional ROM. While this suggests that the inevitable articular violation may not be as clinically relevant as once thought, the short arc contact between the dorsal P1 base and screw tract must not be minimized. This increased contact could potentially lead to eccentric wearing of the articular cartilage and future arthritis, though the functional consequences of such have yet to be elucidated.

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