SCIENTIFIC ARTICLE

A Biomechanical Comparison of Volar Locked Plating of Intra-Articular Distal Radius Fractures: Use of 4 Versus 7 Screws for Distal Fixation

David P. Moss, MD, Kenneth R. Means Jr, MD, Brent G. Parks, MSc, Christopher L. Forthman, MD

Purpose To determine whether the number of distal locking screws significantly affects stability of a cadaveric simulated distal radius fracture fixed with a volar locking plate.

Methods We created AO/ASIF type C2 fractures in 10 matched pairs of human fresh-frozen cadaveric wrists and then fixed them using volar locking plates. The number of distal locking screws used was 4 screws or 7 screws in each wrist of the matched pair. We loaded the stabilized fractures cyclically to simulate 6 weeks of postoperative stressing during a therapy protocol and then loaded them to failure. Failure was defined as 2 mm or more of displacement of any fracture fragment as recorded by differential variable reluctance transducers.

Results No wrists failed during the cyclic loading portion for either the 4- or 7-screw construct. The average initial stiffness of the 7-screw construct was 69 N/mm (±38) versus 48 N/mm (±14) for the 4-screw construct. The average failure load for the 7-screw construct was 139 N (±78) versus 108 N (±18) for the 4-screw construct. Neither of these differences was statistically significant.

Conclusions Although there was a trend toward increased initial stiffness and higher failure load in fractures fixed distally with 7 locking screws, the results were not statistically significant compared with fractures fixed with only 4 screws. Both constructs can withstand forces likely encountered in early therapy protocols.

Clinical relevance The use of extra distal locking screws when fixing distal radius fractures increases expense and may increase the risk of complications, such as extensor tendon irritation or rupture. *(J Hand Surg 2011;36A:1907–1911. Copyright © 2011 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Biomechanical, distal radius fracture, locking screws, volar locked plate.

From the Curtis National Hand Center, Union Memorial Hospital, Baltimore, MD.

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Corresponding author: Kenneth R. Means Jr, MD, c/o Anne Mattson, The Curtis National Hand Center, Union Memorial Hospital, 3333 N. Calvert Street, #200, Baltimore, MD 21218; anne.mattson@medstar.net.

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Operative repair of unstable distal radius fractures has changed considerably in recent years. Most notably, there has been a dramatic increase in the use of volar locked plates (VLPs). In theory, VLPs provide stable fracture fixation that permits early wrist range of motion (ROM). A biomechanical comparison showed that fractures fixed with volar fixation plates were more rigid than those fixed with dorsal plates.[1] A clinical study found superior functional outcomes and fewer complications with volar plating of distal radius fractures compared with dorsally plated fractures.[2] Early ROM is thought to enhance cartilage healing[3] and hasten overall functional recovery.[4–6]

The increased popularity of VLPs led us to question how many distal locking screws are necessary to achieve acceptable fracture stability. Besides the obvious associated cost increase with the use of more locking screws (approximately $60 to $100 per screw), the use of more locking screws increases the risk of extensor tendon irritation and subsequent rupture, intra-articular screw placement, intra-fracture screw placement, and iatrogenic comminution.[7,8] The number of distal locking screws needed to achieve distal radius fracture stability has been previously studied but not in an intra-articular fracture model.[9] In that study, using an extra-articular comminuted distal radius fracture model, the authors found that placing all 7 of the distal set of screws in the distal fracture fragment statistically significantly increased the average stiffness under axial load. The clinical significance of this finding was uncertain because some of the other screw configurations tested achieved stability that was likely sufficient to allow early ROM. The authors recommended placing at least 4 screws in the distal fracture fragment, with at least 2 of those screws placed in the distal-most row of screw holes.

We hypothesized that when fixing unstable intra-articular distal radius fractures, the use of more locking screws in the distal fragments would create a stiffer and stronger construct than using fewer locking screws.

MATERIALS AND METHODS

We obtained 10 matched pairs of fresh-frozen cadaver forearms from the state anatomy board (6 female, 4 male; age range, 45–82 y). We modeled testing after a previous study performed by Taylor et al,[10] with modifications to this model as described below.

We stripped all dorsal soft tissues except for the intrinsic and extrinsic ligaments of the wrist and the interosseous membrane from the specimens. All volar soft tissues superficial to the transverse carpal ligament were stripped from the specimens.

We then simulated AO/ASIF type C2 distal radius fractures in each specimen using an oscillating saw. The fracture pattern was reproduced by excising a 1-cm dorsally based wedge centered 2.5 cm proximal to the radiocarpal joint (simulating dorsal comminution), and then creating a sagittal split in the plane between the scaphoid and lunate fossae (Fig. 1).

We then fixed all specimens with standard titanium DVR Hand Innovations volar locking plates (DePuy, Warsaw, IN). Although there is an option to use variable-angle locking screws distally, this system is typically used with fixed-angle locking screws distally by drilling through a drill sleeve that is screwed into the distal locking screw holes. We used this fixed-angle distal locking screw mode for this study. This system has a total of 7 distal fragment locking screw hole options, with 4 of these holes in the distal-most row and 3 in a row slightly more proximal. We used three 3.5-mm bicortical non-locking screws to fix the plate to the radial diaphysis. The specimens within each pair were randomized to VLP fixation with either 4 (4-screw construct) or 7 (7-screw construct) 2.0-mm partially threaded distal locking screws. All distal locking screws were bicortical to guarantee uniform bone purchase among specimens. The plate was aligned on the distal fragments such that the most distal screws would be placed as distally as possible without penetrating the radius articular surface. Direct visualization confirmed no articular surface penetration during drilling or insertion of the distal-most screws. The 4-screw construct specimens received 2 screws in the distal row of the plate and 2 screws in the slightly more proximal row of the plate, with 2 screws being placed in each distal fracture fragment. All distal screw holes were filled in the 7-screw construct specimens, with 2 of the distal-most screws in each distal fracture fragment.

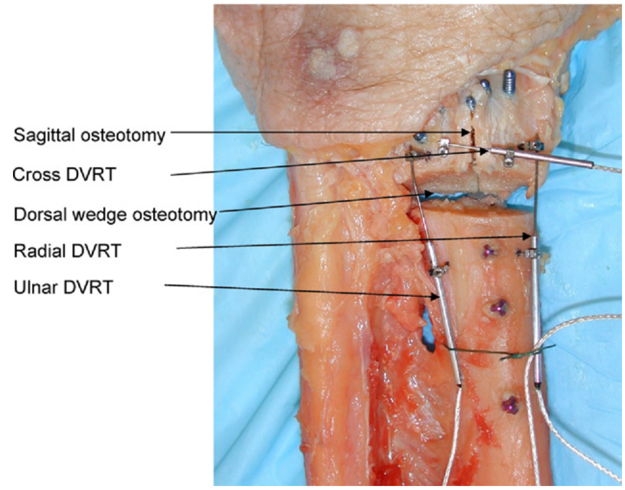

FIGURE 1: Simulated dorsal comminution model in a cadaver specimen. We applied 3 DVRTs to measure relative motion between the bone segments.

We applied 3 differential variable reluctance transducers (DVRTs) (MicroStrain, Williston, VT) to the dorsal surface of the radius and spanned the osteotomies. One DVRT, the cross-gauge, was applied between the lunate and scaphoid facet fragments of the distal radius. We also applied a DVRT between the scaphoid facet fragment and the radial shaft. The final DVRT spanned the lunate facet fragment and the radial

FIGURE 2: Test setup showing specimen with locking plate in place and the extension load applied.

shaft. We used the DVRTs to measure the relative motion between bone segments (Fig. 1).

We loaded the specimens onto the testing apparatus and applied a load onto the carpus with the wrist in extension using an MTS Elite electromechanical load frame (MTS Systems, Eden Prairie, MN). The force, applied to the carpus at the level of the transverse carpal ligament, applied a cantilever bending moment to the distal radius (Fig. 2). We cycled each wrist 1,000 times at a rate of 15 mm/s, from 0 N to a maximum of 50 N to simulate 6 weeks of postoperative stressing before expected fracture union. The load frame has a deceleration feature that helps prevent inadvertently exceeding the desired force level. Loads were within 5% of the 50 N load that was targeted. The 3 DVRTs recorded fracture fragment displacement during each testing cycle. We computed the radial- and ulnar-sided stiffness from the force and DVRT data for each specimen during each load cycle. Because overall DVRT displacement was relatively small at 1 to 3 mm, a data-sampling rate of 30 Hz allowed us to collect ample data points from the DVRT measurements. Overall construct stiffness was considered to be the lower of the radial- and ulnar-sided values. We then loaded the wrists to failure at a rate of 15 mm/s. Failure was identified as 2 mm or greater displacement of either fracture fragment in reference to the radial shaft as recorded by the DVRT gauges.

Statistical analysis

We used a paired *t*-test to analyze the data. A *P* value less than .05 was considered to represent a statistically significant difference between group averages.

RESULTS

No specimens failed during the cyclic loading portion of the study for either group. The initial stiffness (the value obtained at the beginning of testing) was lower than the final stiffness value after cyclic testing for all specimens, likely as a result of fracture settling and impacting as cycling occurred. For these reasons, we thought that initial stiffness was the best re-creation of immediate postoperative construct stiffness, and we used only these values for comparison. The average initial stiffness of the 4-screw construct was 48 N/mm (SD, 14 N/mm), compared with an average initial stiffness of 69 N/mm (SD, 38 N/mm) for the 7-screw construct. The average failure load after cyclic loading of the 4-screw construct was 108 N (SD, 18 N), compared with 139 N (SD, 78 N) for the 7-screw construct. We compared the initial radial stiffness of the 4- and 7-screw constructs as well as the initial ulnar stiffness of the 4- and 7-screw constructs. There were no statistically significant differences for radial or ulnar initial stiffness or failure loads between the 4- and 7-screw constructs ($P > .05$ for all). The cross-gauge DVRT between the scaphoid and lunate facet distal radius fracture fragments revealed no notable radial-to-ulnar widening of these fracture fragments during testing.

DISCUSSION

Although it may not be a requirement for a good outcome in the mid to long term, many surgeons and patients believe early ROM after fixation of distal radius fractures is beneficial in that it hastens the recovery process.[4,6,11,12] This is the standard of care for many, and therefore it is worthwhile to continue investigating the different factors that may be involved with early therapy protocols. There are some reports of loss of distal radius reduction after internal fixation, although we are aware of none that were correlated with the number of distal fragment screws inserted.[6,13] Martineau et al[14] studied AO C3 fractures in a synthetic bone model with a secondary goal of determining how distal bicortical locking screw and peg configurations affect fracture fixation stability. Their specimens were axially loaded to failure; as in our study, they used DVRTs to measure fracture fragment motion and construct failure. In their study, they concluded that locking screws provided more stability than locking pegs for the palmar and dorsal lunate facet fracture fragments. They did not find that the number of screws or pegs in the fracture fragments independently determined fracture stability. Another study compared the use of volar locked plating and fragment-specific fixation using the same AO C2 fracture model as in the current study with cyclical loading.[10] In that study, fragment-specific fixation provided more stability for the lunate facet fracture fragment with regard to initial and final stiffness but not failure load. Those authors thought that 2 points of fixation for the scaphoid and lunate facet fracture fragments were adequate for early rehabilitation whether using volar locked plating or fragment-specific fixation. Our study agrees with the general findings and recommendations of these prior studies with regard to fragment fixation stability.

Several authors have examined loads across the wrist during motion and gripping. Putnam et al[15] used force transducers across a distal radius osteotomy in cadavers and simulated power grip by loading the extrinsic flexor tendons. The results showed that when 10 N of grip is produced, 26 N of force is seen at the distal radius osteotomy site. Rikli et al[16] used an intra-articular pressure sensor to measure joint pressures in vivo. That study showed that force transmitted to the radius during active flexion is 54 N, and the force at the radius during active extension is 35 N. Although the loading mechanisms were different for each study, including ours, our study shows that failure loads of both 4-screw and 7-screw constructs for fixation of AO type C2 distal radius fractures exceed the greatest of these normal physiologic force values (54 N in flexion) by at least 2 times (Fig. 3). Furthermore, we believe that our cantilever bending moment applied at the distal radius fracture site would have stressed the fixation constructs even more than with pure axial load or physiologic wrist ROM. Also, none of the fixation constructs in our study failed during cyclical loading, which simulated 6 weeks of postoperative stressing. These findings support the concept that early postoperative motion protocols, including active wrist flexion and extension and light grip, are safe from a biomechanical standpoint for the distal radius fracture pattern fixed with 4-screw and 7-screw volar locking plate constructs.

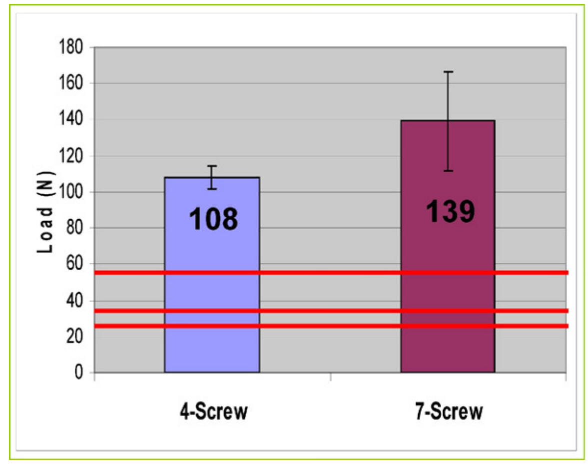

FIGURE 3: Cantilever bending failure loads of both the 4-screw and 7-screw constructs exceeded the distal radius forces experienced with 10 N grip strength when the wrist was in neutral (26 N),[15] extension (35 N),[16] and flexion (54 N).[16]

Several study limitations exist. It is possible that by testing more specimens, we would have found a statistically significant difference in initial stiffness or load to failure between the 4- and 7-screw constructs. Using the results from this study, a post-hoc power analysis reveals that testing 124 matched pairs, or 248 wrists, would have given 80% power to detect a statistically significant difference in load to failure with a P value set at .05. However, we think this would likely not be a clinically significant difference given that the failure loads for both constructs well exceeded expected requirements for an early postoperative rehabilitation protocol. Second, the force exerted at the level of the transverse carpal ligament by the Mini-MTS testing apparatus likely differed from the force at the distal radius osteotomy site. However, this still should have at least attained stresses likely to be created during a postoperative therapy protocol. Also, our cantilever bending moment applied to the distal radius fracture site is different from some of the other biomechanical studies that have tested distal radius fractures and physiologic loads across the wrist. This limits our ability to directly compare our study with some of the other studies. However, we still believe that this manner of applied force would be similar to that seen at the distal radius fracture site during postoperative wrist extension therapy and is therefore clinically relevant. Another limitation is that we did not measure bone density of the specimens as a possible independent variable with regard to fixation stability. Because we used matched pairs for our testing of the 4- and 7-screw constructs, this should have helped to eliminate difference in bone density as an independent variable with regard to construct stability. There is also evidence that hand dominance is unlikely to have a significant impact on bone density.[17]

In our clinical experience, we have not seen catastrophic failure of distal radius volar locking plates during early or late ROM but have seen loss of fixation of articular fragments as well as complications from screw placement such as intra-articular screw penetration and tendon irritation and rupture. Because of these reasons, continued study of these implants and fracture patterns is relevant.

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