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Original Research

Unicortical Versus Bicortical Proximal Locking Screw for Prevention of Peri-Implant Fracture: A Biomechanical Analysis of an Osteoporotic Distal Radius Model

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A R T I C L E I N F O

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Purpose: Osteoporotic patients are at risk of peri-implant fractures after distal radius fixation. A unicortical screw in the proximal hole of the plate can theoretically decrease stress riser formation by eliminating the hole in the far bone cortex. This construct has been proposed in orthopedic literature to prevent peri-implant fractures but has not been tested in an osteoporotic distal radius model.
Methods: Eleven paired cadaver radii were harvested and plated with four-hole titanium volar distal radius plates. No osteotomies were created. The fixation constructs were identical except that group A used a bicortical proximal locking screw and group B used a unicortical proximal locking screw. Bone mineral density was estimated using radiographic measurements. The samples were potted and tested for four-point bending stiffness, torsion stiffness, and load to failure.
Results: Between the bicortical and unicortical screw groups, there was no significant difference in four-point bending stiffness (110.8 vs 106.2 N/mm, apex volar bending; 105.4 vs 107.1 N/mm, apex dorsal bending) or torsional stiffness (430.6 vs 427.6 N-mm/degree, internal rotation; 430.8 vs 429.7 N-mm/degree, external rotation). There was also no significant difference in load to failure with apex dorsal four-point bending (795.3 vs 770.0 N).
Conclusions: This study shows that a healed osteoporotic distal radius volar plate construct with a proximal unicortical locking screw is not statistically different from a bicortical screw in stiffness or load to failure in apex dorsal bending. Although a unicortical locking screw has been proposed as a mechanism to prevent stress risers at the proximal aspect of the distal radius plate, this study suggests no significant difference when compared with a bicortical locking screw.
Clinical relevance: There is no significant biomechanical advantage to unicortical over bicortical locking screws in the proximal hole of a distal radius plate to prevent diaphyseal peri-implant fractures in osteoporotic patients.

Distal radius fractures (DRFs) are common in older patients and are associated with osteoporosis.[1] Peri-implant fractures after distal radius volar plating, that is, fractures of the diaphyseal radius at the proximal aspect of the plate, were previously reported as a rare occurrence.[2–7] However, with increasing preference for surgical DRF treatment, the aging United States population, and the low incidence of plate removal, the occurrence of distal radius peri-implant fractures is becoming more common and is now a topic in orthopedic review articles and textbooks.[7–12]

Diaphyseal peri-implant fractures can occur at stress risers even after the fracture has healed. Fractures can occur at the proximal plate-bone interface, where fractures typically traverse the proximal bicortical screw hole.[4,13,14] Diaphyseal peri-implant fractures occur after the initial peri-articular fracture has healed, likely because patients have returned to normal

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Specimen	Laterality	BCT (mm)	GT1
1	L	4.7	0.330
	R	4.9	0.329
2	L	3.3	0.248
	R	3.3	0.248
3	L	5.0	0.334
	R	4.3	0.287
4	L	5.4	0.336
	R	5.5	0.299
5	L	5.4	0.334
	R	4.7	0.294
6	L	5.5	0.357
	R	4.6	0.373
7	L	4.9	0.339
	R	3.0	0.246
8	L	4.2	0.316
	R	4.5	0.313
9	L	4.3	0.269
	R	4.7	0.296
10	L	3.5	0.193
	R	2.9	0.146
11	L	4.9	0.325
	R	4.7	0.292

Figure 1. (Left) The wrist radiograph shows the measurements used to calculate the average bicortical thickness (BCT) and gauge cortical thickness at 50 mm (GT_1) on wrist radiographs of each specimen, as described in detail by Webber et al.[18] (Right) The BCT and GT1 measurements calculated for each specimen. BCT is calculated with the formula ([M1−M2] + [M3−M4]/2). GT_1 is calculated with the formula (BCT/M1). Receiver operating characteristic curve analysis performed by Webber et al[18] indicated optimal osteoporosis cutoffs for BCT and GT_1 were values less than or equal to 5.5 mm and 0.375, respectively.

weight-bearing activities. Peri-implant fractures may occur due to bone loss from stress shielding, osteoporosis, and increased strain at the plate-bone interface resulting from mismatched elastic moduli. Technical aspects of volar distal radius fixation can decrease the risk of peri-implant fracture, such as using a plate with a modulus of elasticity similar to bone and avoiding errant drill holes. The use of a unicortical screw in the proximal hole has been proposed as a technique that can decrease stress riser formation by eliminating the hole in the far bone cortex.[15,16]

We sought to investigate if there is a biomechanical advantage to a unicortical locking screw in the proximal hole of a volar distal radius plate in an osteoporotic model. This clinical question is relevant to avoiding a diaphyseal peri-implant fracture after operatively treated peri-articular radius fractures have healed. Our hypothesis was that in an osteoporotic distal radius model, a unicortical proximal locking screw will provide a biomechanical advantage over a bicortical proximal locking screw in bending load to failure.

Materials and Methods

Eleven paired fresh-frozen cadaveric radii were used. This sample size was chosen based on an a priori power analysis of results from a similar study by Roberts et al,[17] indicating that a minimum of four paired samples would be necessary to reach statistical significance for bending stiffness ($\alpha = 0.05$; power $=$ 0.8; effect size 58.3 N/mm; SD, 20.0). The Roberts et al[17] study was preferable for a priori power analysis because they used a similar hardware construct, despite using synthetic bone rather than a cadaver. Bone mineral density was estimated using radiographs and measurements of distal radius bicortical thickness as previously described in detail by Webber et al,[18] with the receiver operator characteristic curve indicating bicortical thickness and gauge cortical thickness cutoffs for osteoporotic bone. Using the radius bicortical thickness, we determined that all of our specimens were below the suggested cutoff values for likely underlying osteoporosis (Fig. 1).[18] Titanium four-hole volar distal radius locking plates were used (Skeletal Dynamics) that have three locking holes and one oblong nonlocking hole in the shaft, as well as standard peri-articular locking screw holes. A four-hole plate was chosen, rather than a standard three-hole plate, to create a transition zone of elasticity between the plate and

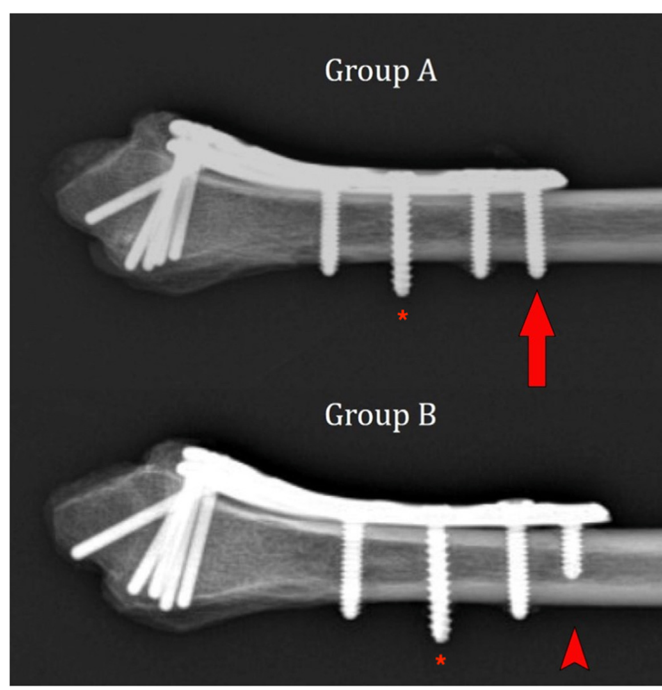

Figure 2. The radiographs show the constructs in groups A and B. In group A, the proximal screw (arrow) is bicortical. In group B, the proximal screw (arrowhead) is unicortical. The asterisk marks the nonlocking screw in both groups.

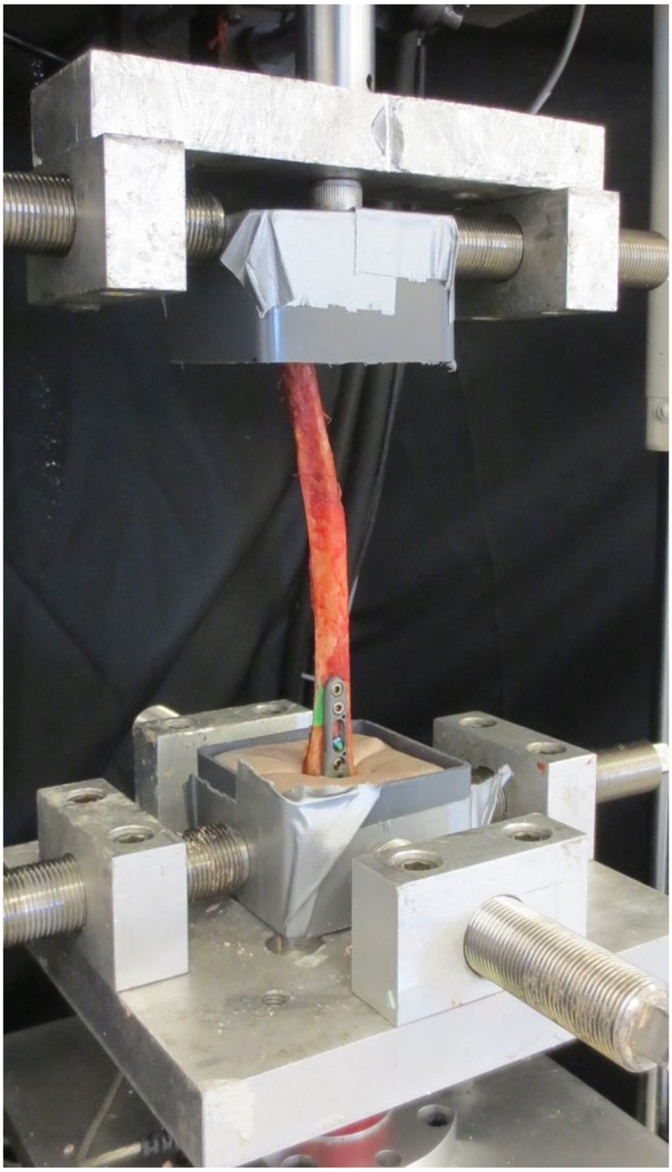

Figure 3. The image shows the torsional testing apparatus used in our study.

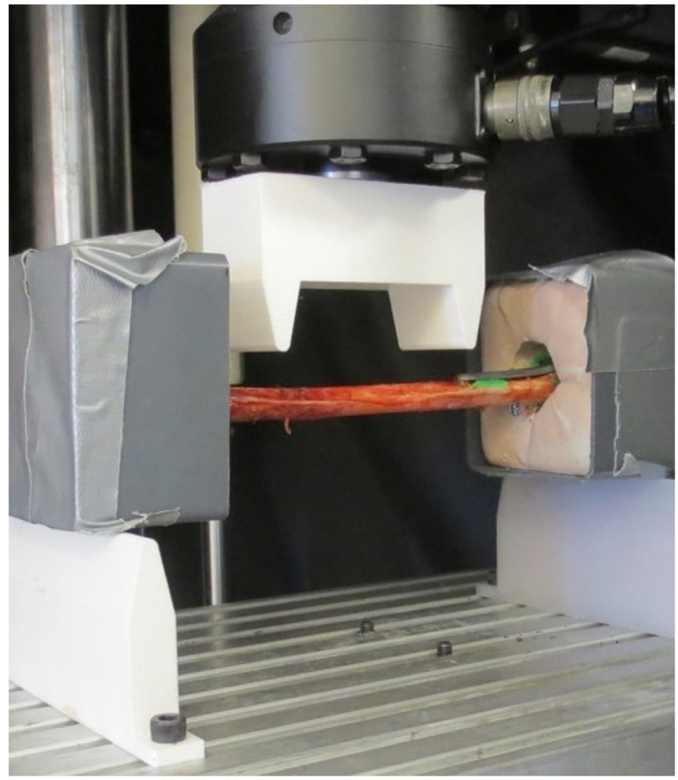

Figure 4. The image shows the four-point bending testing apparatus used in our study (configured for apex dorsal testing).

bone interface, without compromising the strength of the construct during healing.[11,12]

The cadaveric radii were carefully stripped of all soft tissues. No osteotomies were performed, as we were simulating a healed fracture. The plates were fixed to the radii and split into two paired groups: group A used two bicortical locking screws, one bicortical nonlocking screw, and one proximal bicortical locking screw; group B used two bicortical locking screws, one bicortical nonlocking screw, and one proximal unicortical locking screw. All unicortical screws abutted the far-cortex. Locking bicortical peg screws were used for the distal fixation. Radiographs of representative constructs can be seen in Figure 2.

Each construct was potted at the distal and proximal ends of the radius, using a soft molding putty to prevent potting material from directly contacting the distal radius hardware. Potting was performed to allow rotational testing and, although not necessary for four-point bending, was performed to simplify the testing process and has been performed in prior studies for four-point bending.[19,20] Each specimen was tested for four-point bending stiffness, torsional stiffness, and four-point bending load to failure. Load to failure was performed in apex dorsal because prior studies have shown that there is minimal difference in strength between the use of unicortical and bicortical screws in all other testing configurations, but a significant benefit is present in some studies during apex dorsal bending.[13,15,21] Stiffness testing was performed within the elastic region of the cadaver bone, and there was no plastic deformity measured during the stiffness testing process. We believe this prevented any notable weakening of the bone during this phase of testing. Material testing was performed with an 858 MiniBionix MTS (MTS System Corporation). The load cell for axial loading was a 2,500 N capacity MTS model 661.18E-02 (MTS System Corporation). The torque cell for torsional testing was a 100 in-lb capacity Futek model TFF425 (Futek). The assembled testing apparatus for torsion and four-point apex dorsal bending can be seen in Figures 3 and 4, respectively.

Bending stiffness was performed apex volar and apex dorsal, at a rate of 1 mm/s for 20 cycles with a maximum force of 75 N. The volar radius was in compression during the apex dorsal bending, and the volar radius was in tension during the apex volar bending. Four-point bending was performed to create a uniform bending moment and prevent a high-stress region at the point of contact as has been performed similarly in multiple prior studies.[13,17,19,21] Due to practical constraints, the region of interest, that is, the plate-bone interface, could not be centered within the inner span loading noses but was placed at an identical distance on each paired sample ensuring that the bending moment and any resultant shear stress were identical for each paired sample.

Torsional stiffness was performed in internal and external rotation, at a rate of 5°/s for 20 cycles with a maximum torque

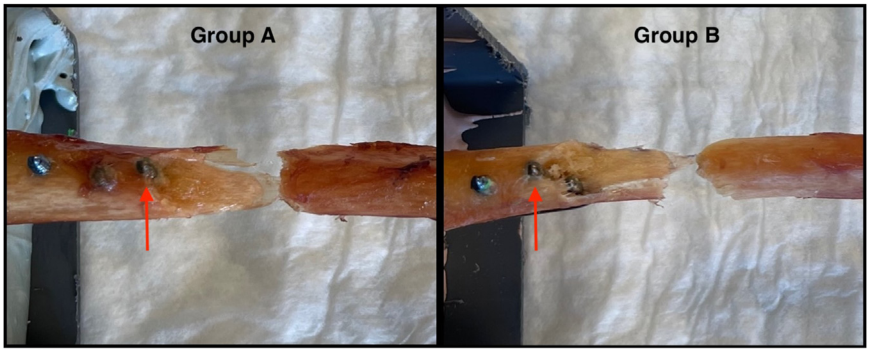

Figure 5. The images show the fracture patterns in groups A (left) and B (right) after failure. All fractures occurred through the most proximal bicortical screw hole. The arrows point to the most proximal bicortical screws in both constructs. Notice that the fracture on the right bypasses the most proximal screw, which is unicortical.

of 2 N-m. Failure testing was performed at a rate of 0.7 mm/s and only in apex dorsal four-point bending since this configuration placed maximal tensile stress on the dorsal cortex with varying hole configurations, that is, the region of interest. During failure testing, force was applied beginning at 0 N, but displacement measurement started at 1 N to ensure that the loader was in contact with the bone. Load and displacement were continuously recorded at 100 Hz until failure occurred. Specimens were inspected after failure, and the fracture pattern was recorded.

Since groups A and B are paired samples with continuous measures, a paired sample *t* test was used to determine whether the averages in each of the groups significantly differed. Normality of the data was assessed.

Results

The mean age of cadaver specimens was 75.3 years (SD, 7.5 years). Six cadavers were female and five were male. All 11 radii pairs were osteoporotic. Stiffness in apex volar bending (110.8 vs 106.2 N/mm, $P = .70$), apex dorsal bending (105.4 vs 107.1 N/mm, $P = .79$), internal rotation torsion (430.6 vs 427.6 N-mm/degree, $P = .93$), and external rotation torsion (430.8 vs 429.7 N-mm/degree, $P = .98$) were also not statistically different from one another. There was no significant difference in load to failure in apex dorsal bending between groups A and B (795.3 vs 770.0 N, $P = .47$). All fractures occurred through the most proximal bicortical hole, which was the most proximal screw in group A and the second most proximal screw in group B (Fig. 5).

Discussion

Peri-implant diaphyseal fractures that occur in osteoporotic patients after healed DRF fixation, although uncommon, can be challenging injuries. The use of a unicortical screw at the peripheral hole of a plate has been proposed previously to avoid peri-implant fractures.[20,22]

Unicortical screws have been previously tested in various fixation constructs, with biomechanical studies showing mixed results.[13–15,17] It has been demonstrated that the use of a unicortical nonlocking screw is inferior to a bicortical nonlocking screw.[13] Locking plates have demonstrated superior mechanical properties in terms of ultimate strength and fatigue in biomechanical models, particularly in those using osteoporotic models.[23,24] Currently available data regarding the use of unicortical fixation, particularly in the setting of osteoporotic bone and in the prevention of peri-implant fractures, are less clear.

Bockmann et al[14] compared a proximal bicortical locking versus a nonlocking screw in an osteoporotic cadaveric distal radius model, but the model was osteotomized, and testing was only performed in axial compression. There was no significant difference in stiffness or load to failure between the locking and nonlocking proximal screw constructs, and failure modes were most commonly due to distal screw pullout and longitudinal radius fracture. We can infer from this study that the proximal bicortical locking screw is likely of no benefit with axial load during the initial healing process.

Overtuf et al[21] have shown that the length of the unicortical locking screw may be important. When comparing bicortical locking screws with unicortical far-cortex abutting locking screws in comminuted radial shaft fractures, both constructs were equivalent in bending, axial, and torsional stiffness and bending load to failure strength. In our study, all unicortical screws abutted the far-cortex, and it is possible that not using this technique would have compromised the strength of the construct.

Beaupre et al[13] demonstrated a significant difference between unicortical and bicortical nonlocking screws using an osteotomized synthetic bone analog. The authors found that the unicortical model was 40% stronger with apex dorsal bending, but 12% weaker with apex volar bending, and 18% weaker with torsion. Although this study was performed with nonlocking screws, synthetic bone, an osteotomy, and stainless steel plates, it indicates a possible benefit to unicortical screws at the end of the plate in apex dorsal bending.

Davenport et al[15] performed a biomechanical study on a dog cadaver femur and showed that a unicortical nonlocking screw at the edges of the plate did not have any effect on torsional stiffness or failure strength but did prevent longer oblique fractures and prevented more significant comminution. The fracture morphology is an interesting finding but was not observed in our study, which may be due to the changes in mechanical properties seen with osteoporotic and/or human bone. However, it does suggest that the unicortical screws have little effect on failure strength in torsion.

The hypothesis in our study was that a proximal unicortical locking screw in a volar plate would provide a biomechanical advantage over a bicortical locking screw to prevent a peri-implant fracture at the plate-bone interface in a healed osteoporotic distal radius model. Our results show that these two constructs are biomechanically similar, thus supporting the null hypothesis. The proximal unicortical screw may be advantageous in an implant that is dissimilar to bone, for example, stainless steel, or has much greater stiffness, for example, a thicker plate, which would be more likely to lead to peri-implant fracture. However, this technique should be used with caution since further testing is needed to validate the construct in these scenarios.

Our study had several limitations. As this was a cadaveric biomechanical study, morphology and bone quality varied between the samples. We attempted to account for this by using matched radii pairs. Although we simulated force transmission through four-point bending and torsion, forces experienced in vivo, especially during the uncontrolled setting of a traumatic injury, may be different. However, because all samples were subject to the same forces during testing, we believe they accurately represent differences in relative construct strength. Deviation from the use of far-cortex abutting unicortical screws, a four-hole plate, and a titanium plate could alter the outcome of this study. Surgeons must rely on their clinical judgment when using this technique in a clinical setting.

This biomechanical study shows that a healed DRF with a proximal unicortical locking screw is not statistically different from a bicortical locking screw in stiffness or load to failure in apex dorsal bending. The unicortical screw construct may be useful in special situations and in conjunction with other techniques to avoid diaphyseal peri-implant fractures in the osteoporotic patient population, but this should be performed with caution as further testing is necessary.

Conflicts of Interest

No benefits in any form have been received or will be received related directly to this article.

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