Original Study

Biomechanical Stability of a Volar Locking-Screw Plate Versus Fragment-Specific Fixation in a Distal Radius Fracture Model

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Abstract

Eight matched pairs of cadaveric radii were osteotomized by removing a 4-mm dorsal wedge of bone at the level of the sigmoid notch designed to simulate dorsal comminution. They were then fixed with either a volar locking-screw plate or fragment-specific fixation. All constructs underwent biomechanical testing in a custom-designed, custom-fabricated 4-point bending device. No statistically significant difference in stiffness was noted between the groups. Linear displacement and angulation at the osteotomy site were significantly less in the group with fragment-specific fixation at loads expected to be encountered during postoperative rehabilitation. Angulation at the osteotomy site was significantly less in the locking-screw plate group at higher loads.

Distal radius fractures are relatively common injuries that vary widely in presentation, and there is no consensus regarding management. Treatment goals should ideally include stable, anatomic restoration of the articular surface to facilitate motion at the wrist joint as soon as possible. Indications for open reduction and internal fixation to meet these goals are expanding with the advent of more sophisticated fixation systems. Traditional plate and screw devices are a proven method for obtaining union[1-15] but can cause soft-tissue complications when placed dorsally on the distal radius.[14] When placed volarly in typical fractures with dorsal comminution, they may be inadequate in buttressing the articular surface.

These problems are theoretically overcome by fragment-specific fixation. The TriMed wrist fixation system (TriMed, Valencia, Calif) incorporates a low-profile pin plate and wire form design to protect the dorsal soft tissues. The design provides for orthogonal placement of radial and ulnar pin plates. Peine and colleagues[16] showed superior biomechanical strength of orthogonally placed 2.0 titanium plates on the dorsum of the distal radius when compared with an AO (Arbeitsgemeinschaft für Osteosynthesefragen) 3.5-mm T plate and an AO pie plate. This orthogonal fixation approach can be compared with internal fixation of distal humerus fractures with medial and posterolateral plates.[17,18] The TriMed system has been shown to be stabler than a wrist-spanning external fixator with Kirschner-wire (K-wire) augmentation,[19] and excellent short-term clinical results have been reported with its use.[20] However, it is technically demanding to apply and requires additional training before routine use.

Locking-screw plate systems are an additional option for avoiding dorsal soft-tissue complications in distal radius fractures. The locking screws allow the formation of a fixed-angle device that can be used to buttress the articular surface when placed volarly. Excellent clinical results have been reported for a variety of fracture types,[10] and it has been shown to be the stablest of multiple dorsal and volar plate and screw designs.[21] However, it may not be appropriate for use in comminuted, intra-articular fractures with multiple small fragments. No biomechanical studies have yet compared fragment-specific fixation with a locking-plate design for treatment of distal radius fractures.

Our study compared the biomechanical stability of the TriMed wrist internal fixation system with the Synthes volar 5-hole locking-screw T plate (Synthes, Paoli, Pa) in a cadaveric extra-articular distal radius fracture model designed to simulate dorsal comminution. We investigated the performance of both systems under torsional extension loads expected to be encountered during rehabilitation and at loads high enough to cause implant failure.

Methods

For each of 8 matched pairs of cadaveric specimens, 1 radius was assigned to the fragment-specific group, and the contralateral radius was assigned to the locking-plate group. Right and left radii were distributed in equal numbers to each group. Plain films were taken of all specimens to rule out previous fracture and any pathologic condition. A standardized dorsal wedge of bone 4 mm in width was removed from all specimens just proximal to the sigmoid notch of the radius to simulate dorsal comminution. The first group was fixed with a volar Synthes locking plate

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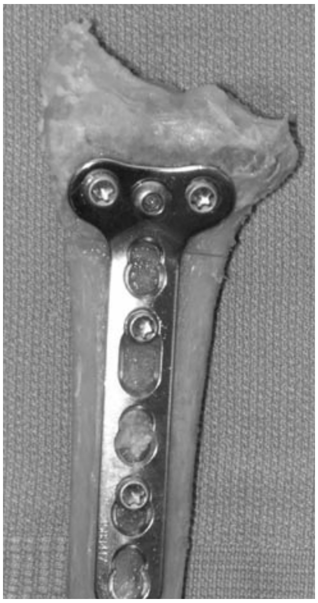

Figure 1. Volar locking plate (Synthes, Paoli, Pa).

Figure 3. Wrist internal fixation system (TriMed, Valencia, Calif).

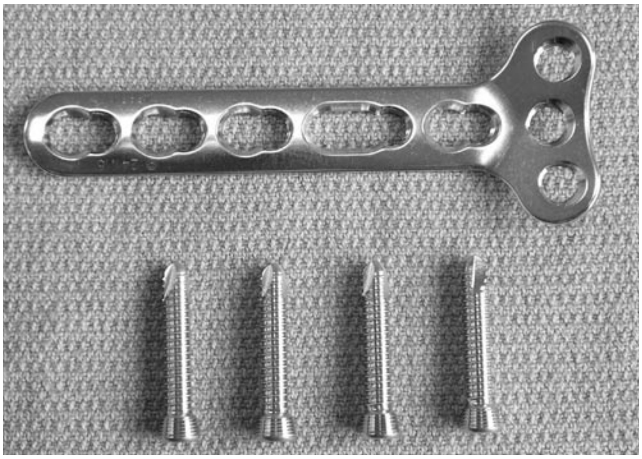

Figure 2. Equipment used from the locking-plate system (Synthes, Paoli, Pa).

(Figure 1). Two 3.5-mm locking screws were placed in the shaft fragment, and two 3.5-mm locking screws were placed in the distal fragment (Figure 2). The second group was fixed with a radial and ulnar pin plate from the TriMed wrist internal fixation system (Figure 3). Each pin plate was fixed with two 0.045-in pins and two 2.7-mm screws from the TriMed system (Figure 4). In all specimens, both fragments were then embedded in polyester resin within polyvinyl chloride pipe segments 2 inches in diameter to facilitate biomechanical testing (Figure 5). Two additional 0.062-in crossed K-wires were introduced into all distal fragments in an orthogonal orientation to improve fixation in the potting medium. All fixed radii were then subjected to biomechanical testing with a custom-designed, custom-fabricated 4-point bending device (Figure 6). This loading device applies a constant bending moment to the specimens between the inner support points. A moment arm was

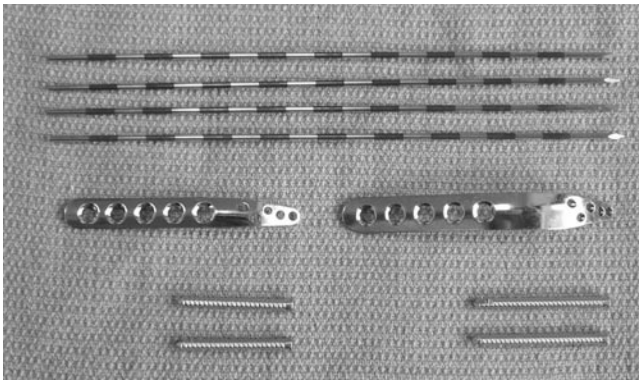

Figure 4. Equipment used from the wrist internal fixation system (TriMed, Valencia, Calif).

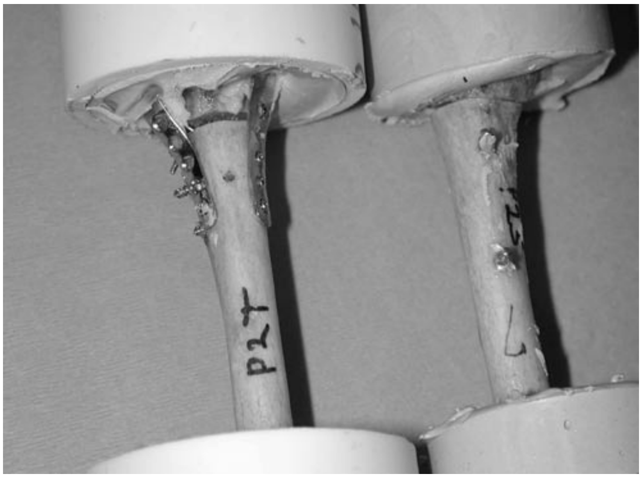

Figure 5. Proximal and distal fragments fixed in cylindrical potting medium.

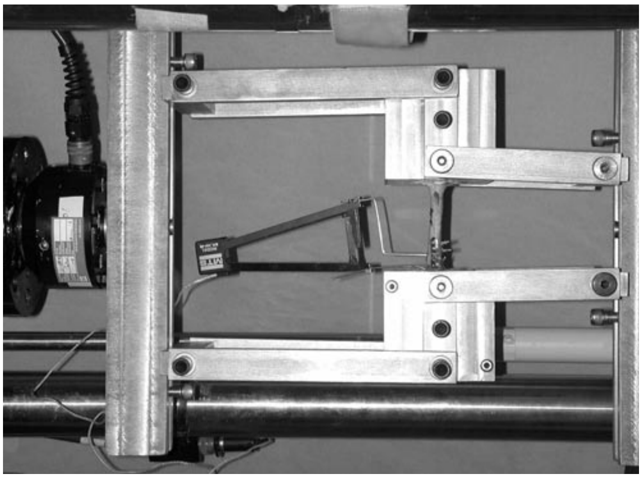

Figure 6. Custom-designed, custom-fabricated 4-point bending apparatus.

applied in a displacement control at a rate of 1 mm/s. An extensometer directly measured displacement (closing) at the osteotomy site dorsally in millimeters.

Data collected or calculated for all specimens included stiffness of the construct (N/mm), force (N) required to

Figure 7. Wrist internal fixation system (TriMed, Valencia, Calif) loaded to failure. Note widening of osteotomy site volarly and dorsal translation of distal fragment.

close the osteotomy site 2, 3, and 4 mm, and angulation (degrees) at the osteotomy site when the dorsal gap was closed 2, 3, and 4 mm. Previous studies have quantified the maximum torsional force a distal radius fracture undergoes with postoperative rehabilitation.[22-24] In our biomechanical testing apparatus, this corresponded to a torsional force of 46.3 N. Displacement and angulation at the osteotomy site were measured or calculated at this force level.

Data from the 2 groups were compared, and the Student *t* test was used for statistical evaluation. Level of significance was set at *P*<.05.

Results

Mean stiffness calculations from the load deformation curves were 66.79 N/mm (range, 23.8-94.5 N/mm) for the locking-plate group and 69.74 N/mm (range, 27.0-163.2 N/mm) for the fragment-specific fixation system group. The difference of 2.95 N/mm was not statistically significant (*P* = .87). Compared with the locking-screw plate group, the fragment-specific fixation system group showed significantly less mean linear displacement (closing) of the osteotomy site (*P* = .008) and significantly less mean angulation at the osteotomy site (*P* = .008) (Table I). More mean force was required to close the osteotomy site 2 mm in the fragment-specific fixation group versus the locking-screw plate group, and more mean force was required to close the osteotomy site 3 and 4 mm in the locking-screw plate group versus the fragment-specific fixation system group (Table II). These differences were not statistically significant (*P*s = .25–.84). Mean angulation was significantly higher in the fragment-specific fixation group versus the locking-screw plate group at all levels of osteotomy site closure (*P*s = .004–.050) (Table III).

Discussion

Fragment-specific fixation and volar locking-screw plates are 2 relatively new options for treating distal radius fractures that avoid dorsal soft-tissue complications. Excellent clinical results have been reported with both systems,[10,20] and both have been shown to be biomechanically stable in comparison with existing fixation options.[19,21] To date, the biomechanical stability of fragment-specific fixation and that of a volar locking-screw plate system have not been directly compared.

Table I. Displacement and Angulation at Osteotomy Site With Application of Rehabilitation Torsional Load of 46.3 N

Criterion	Fracture-Specific Fixation	Locking-Plate System	Difference	*P*
Mean displacement (closure) at osteotomy site (range)	0.52 mm (0.10-0.69 mm)	1.14 mm (0.55-1.87 mm)	0.62 mm	.008
Mean angulation at osteotomy site (range)	0.47° (0.09°-0.62°)	1.03° (0.50°-1.69°)	0.56°	.008

Table II. Mean Force (N) to Close Osteotomy Site 2, 3, and 4 mm

Amount of Displacement (mm)	Fracture-Specific Fixation (N)	Locking-Plate System (N)	Difference (N)	*P*
2	161.94	154.11	7.83	.84
3	188.37	221.01	32.64	.56
4	227.27	294.20	66.93	.25

Table III. Angulation (Degrees) at Osteotomy Site With Osteotomy Site Displaced (Closed) 2, 3, 4 mm

Displacement at Osteotomy Site (mm)	Fracture-Specific Fixation	Locking-Plate System	Difference	*P*
2	6.99°	4.88°	2.11°	.05
3	9.34°	6.39°	2.95°	.004
4	14.17°	8.14°	6.03°	.004

Our data indicate that the fragment-specific fixation system is significantly stabler than the volar locking plate at load magnitudes expected during postoperative rehabilitation based on linear displacement (closure) and osteotomy site angulation measurements. When larger loads were applied, the locking-screw plate held a statistically significant biomechanical advantage based on osteotomy site angulation measurements. This discrepancy in performance at low versus high loading may be attributed to our fracture model design. Loading with an extension moment in a 4-point bending device exerts a tension force on the volar cortex and a compression force on the dorsal cortex. These forces promote closure of the osteotomy site dorsally and opening of the osteotomy site volarly.

At lower load rehabilitative magnitudes, the dorsal pin plate in the fragment-specific system acts as a buttress against closure of the osteotomy site dorsally. The volar locking plate provides no dorsal buttress effect and relies solely on the fixed-angle construct to prevent closure of the osteotomy site dorsally. The fragment-specific system has a biomechanical advantage in this rehabilitative loading scenario. At higher load magnitudes, the osteotomy site eventually closes dorsally in both groups. At this point, the dorsal cortical contact prevents further closure. Continued application of torsional extension forces causes opening of the osteotomy site on the volar side. Opening on the volar side is effectively resisted in the locking-plate group because the construct spans the osteotomy site volarly. The fragment-specific fixation group in our protocol had no hardware on the volar side to resist tensile forces. In specimens fixed with this system at higher loads, the osteotomy site opened volarly, and the distal fragment translated dorsally (Figure 7). The locking-plate system has a biomechanical advantage in this load-to-failure scenario.

Our study was limited by the cadaveric fracture model, which does not represent the in vivo conditions of a true distal radius fracture, so definitive conclusions about the clinical utility of the 2 systems cannot be drawn from our data. However, at rehabilitative loads, each system allowed clinically acceptable amounts of linear displacement at the osteotomy site and angulation at the osteotomy site. These findings imply that both systems are adequately stable for use in fixation of extra-articular distal radius fractures followed by immediate postoperative wrist motion.

Another limitation of our study is its extra-articular model. Biomechanical testing in an intra-articular model would likely provide useful additional information. In such a scenario, the fragment-specific fixation system may prove stabler because of its ability to fix specific articular fracture fragments.

Proponents of the fragment-specific fixation system would argue that we did not use all the components of the system in our study—specifically, the volar plate. We chose not to include it because it is used clinically in only the least stable distal radius fractures. The majority of cases require only pin plate and wire form fixation. Inclusion of the plate in our study protocol would have provided resistance to tensile forces at the volar osteotomy site in specimens fixed with the fragment-specific system. This would likely have increased the load to failure in these specimens to a level comparable to, if not greater than, that in the locking-plate specimens.

Conclusions

Fragment-specific fixation is biomechanically stabler than a locking-screw plate in a cadaveric, extra-articular, distal radius fracture model with simulated dorsal comminution when forces expected during postoperative rehabilitation are applied. As the model is loaded to failure, the locking-screw plate becomes stabler. Both systems appear to provide clinically acceptable stability to proceed with immediate wrist motion postoperative therapy protocols.

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