Biomechanical Comparison of Fixed-Angle Volar Plate Versus Fixed-Angle Volar Plate Plus Fragment-Specific Fixation in a Cadaveric Distal Radius Fracture Model

Steven I. Grindel, MD, Mei Wang, PhD, Matthew Gerlach, MD, Linda M. McGrady, BS, Susan Brown, BA

From the Department of Orthopaedic Surgery, Medical College of Wisconsin, Milwaukee, WI.

Purpose: To test the hypothesis that combining orthogonal fragment-specific fixation with volar fixed-angle fixation provides markedly higher interfragment stability and construct strength compared with volar fixed-angle fixation alone.

Methods: Eight matched pairs of fresh cadaveric hand and forearm specimens were potted upright in cement. Flexor and extensor tendons were isolated at insertion sites and sutured into a looped bundle for loading in flexion and extension, respectively (up to 61 N). Osteotomies to simulate an AO type C2, 3-part fracture pattern were created with a saw. One randomized specimen from each pair received a locking volar plate and a radial pin plate (VP+PP), and the other received a locking volar plate only (VP). The relative angular displacements between the radial, ulnar, and proximal fragments were obtained with a motion analysis system. After stability tests, specimens were compressed to failure in a wrist-extended position on a material testing machine. Paired *t* tests were used to compare the interfragment displacement, construct stiffness, and strength between the 2 groups.

Results: Comparing fragment displacement in the VP+PP and VP groups showed that with flexion-extension and radial-ulnar deviation, distal fragment displacement was reduced to a statistically significant degree. The VP+PP group also showed higher failure strength and construct rigidity than the VP group.

Conclusions: In a simulated cadaveric model of the distal radius intra-articular fracture, the combined technique of fragment-specific plating with volar fixed-angle fixation alone provides superior biomechanical strength and stability over the volar fixed-angle fixation alone.
(J Hand Surg 2007;32A:194–199.

Key words: Distal radius fracture, fixed-angle volar plate, fragment-specific fixation.

Distal radius fractures are among the most common injuries managed by hand surgeons. Those fractures associated with high-energy trauma often have intra-articular extension and comminution at the fracture site. As with any periarticular fracture, anatomic reduction, stable fixation, and early rehabilitation of the hand and wrist are the primary goals for treating these complex fractures. Closed reduction and cast immobilization with or without pin fixation may be appropriate for simple fractures but frequently is associated with loss of reduction in more unstable fracture patterns. Gartland and Werley[1] described the adverse effect of dorsal metaphyseal comminution in 1951. In their study, simple cast immobilization was found to be inadequate to maintain radial length and volar tilt. As many as 60% of the fractures lost their reduction and collapsed back to the original deformity. Augmented external fixation using K-wires has become a mainstay of treatment for these fractures. Standard external fixation, however, does not permit wrist motion and can be associated with complications including infection, pin loosening, loss of reduction, and permanent stiffness.

Internal fixation of unstable distal radius fractures allows early resumption of motion.[2] Traditional dorsal plating techniques are associated with complications in up to 39% of cases.[3] Ruch and Papadonikolakis[4] found that 25% of their dorsally plated group went on to volar collapse. Outcomes of dorsal plating have not been shown to be superior to the results of external fixation.

Fragment-specific fixation and volar fixed-angle plate fixation are two recently introduced concepts for internal fixation of unstable distal radius fractures. Both techniques use either low-profile modular implants or a fixed-angle volar implant to stabilize fracture fragments through limited surgical approaches. These techniques have been designed with the aim of securing stable anatomic fixation, but avoiding the complications associated with current dorsally placed internal fixation techniques.[2,5–8] Fragment-specific fixation has the advantage of being able to stabilize small fracture fragments. The disadvantage of this technique is that although small, the dorsally placed fixation is associated with up to an 11% rate of painful dorsal hardware that requires removal.[7] Fragment-specific fixation also requires a volar and dorsal incision. Volar fixed-angle fixation has been shown to be a reliable option in treating displaced distal radius fractures. There are circumstances in which the degree of comminution is such that a volar plate alone will not address the fracture adequately. In this situation, combining fixed-angle volar plating with fragment-specific fixation of the radial styloid fragment through a volar approach seems to achieve our goal of stable fixation, which allows early mobilization of the injured extremity.

There have been several biomechanical studies that have compared fragment-specific fixation with other more traditional techniques.[9–13] Taylor et al[9] compared the cyclic behavior of the fragment-specific fixation with the fixed-angle volar plate in a C2-type distal radius fracture model and found the fragment-specific fixation systems to be significantly stiffer in stabilizing the ulnar segment than the volar plate in both precyclic ($p = .04$; 219 N/mm vs. 79 N/mm) and postcyclic ($p = .003$; 355 N/mm vs. 150 N/mm) states. When the model was compressed to failure with the wrist in an extended position, however, the strength between the 2 systems was comparable. Dodds et al[10] compared the interfragment motion of the fragment-specific fixation systems with an augmented external fixation in simulated C2-type and C3-type fractures, and found that the fragment-specific fixation systems provided similar construct stability in the C2 fracture but superior stability in the C3 fracture.

The first objective of this study was to create a fixation construct that combined the concepts of fragment-specific fixation and volar fixed-angle fixation. The second, primary objective of this study then was to compare the biomechanical stability of the combined fixation construct (volar fixed-angle fixation and fragment-specific fixation) versus volar fixed-angle fixation alone in a 3-part distal radius intra-articular fracture model. Our hypothesis was that combining orthogonal fragment-specific fixation with rigid volar fixed-angle fixation would show higher interfragment stability and higher construct strength when compared with volar fixed-angle fixation alone.

Materials and Methods

Specimen Preparation

Eight matched pairs of fresh human cadaveric hand and forearm specimens were procured for this study. The average age at the time of death for the cadavers was 79 years (range, 61–90 y). Before inclusion into the study, plain radiographs of each specimen were taken to rule out any underlying osseous pathology. The specimens were stored in a −29°C freezer until testing.

Specimens were thawed at room temperature on the day of testing. Skin and soft tissues were removed from the forearm. The wrist capsule and the interosseous membrane of the forearm were left intact. Major flexors (flexor carpi radialis, flexor carpi ulnaris) were isolated at their insertion sites (the base of the metacarpal bones) and sutured into a looped bundle for loading. Similarly, the extensor tendons of the wrist (extensor carpi ulnaris, extensor carpi radialis brevis, extensor carpi longus) were isolated and sutured into an extensor bundle.

Before any osteotomy was performed to simulate a distal radius fracture, further dissection was performed 10 cm proximal to the radial styloid to expose the bone. A single locking volar plate (TriMed, Inc., Valencia, CA) then was affixed to the volar cortex on all specimens. Next, a 1-cm wedge osteotomy was created with a microsagittal saw in the dorsal aspect of the radius and centered 2 cm from the articular margin. The volar cortex was broken at the apex of the wedge to create an isolated distal fragment. The distal fragment was split into 2 with a longitudinal cut between the 2 radial and 2 ulnar screws. The cut was made initially with the microsagittal saw, and then was completed with a small osteotome. After

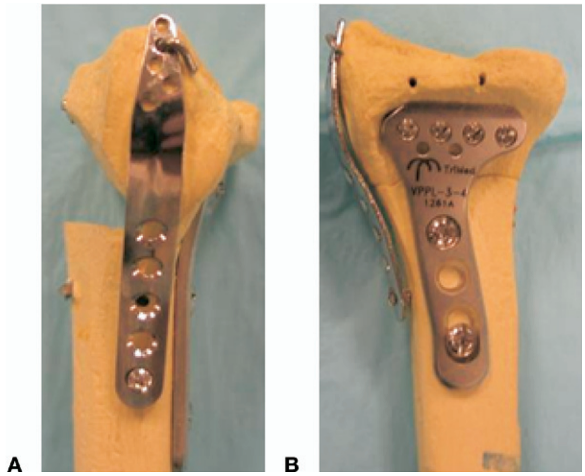

Figure 1. Saw bones model of fracture fixation: (A) radial pin plate, (B) fixed-angle volar plate.

osteotomies and volar plate application, half of the specimens were selected randomly to receive a radial column pin plate (TriMed, Inc.). The radial column plate was fixed dorsally to the first extensor compartment in line with the longitudinal axis of the radius. Two radial styloid pins were placed before the plate was secured with 2 proximal screws (Fig. 1). To ensure that the osteotomies and plate fixation were performed in a consistent and reproducible manner, the procedure was performed on all 8 pairs of specimen in 1 continuous session by the same 2 hand surgeons (S.I.G. and M.G.).

Experimental Design

After plate fixation, each specimen was potted upright in dental cement (Die Keen Green; Sullivan-Schein Dental, Inc., West Allis, WI). A series of nondestructive and destructive tests were conducted.

Nondestructive Tests

The potted specimen was mounted on a customized loading frame in which static step loads were applied to the distal radius through a cable system connected to the flexor and extensor tendons. A compressive preload of 19.6 N was applied evenly to the flexor and extensor tendons. Seven additional loading steps (at 9.8, 19.6, 27.4, 35.3, 41.3, 51.0, and 60.8 N) were applied to the flexors only to generate wrist flexion motion, and then to the extensors only to generate wrist extension. These values were selected based on an *in vitro* study of wrist tendon forces using a wrist joint motion simulator, and reflect the normal range of dynamic tension in these muscles.[14] A 6-axis load cell was mounted under the specimen to record the resultant compressive force and flexion/extension bending moment applied to the specimen. This loading set-up does not constrain the wrist motion, which better imitates the *in vivo* loading conditions.

To track rigid-body angular displacement between fracture fragments, a set of 3 reflective markers was mounted onto each of the 2 distal fragments (radial styloid and ulnar) and the proximal fragment via K-wires. The spatial locations of these markers were recorded at each loading step by using a motion analysis system (Vicon 370; Vicon Peak, Oxford, UK). The relative angular displacement between the radial fragment and the proximal fragment, the ulnar fragment and the proximal fragment, and between the radial and the ulnar fragment was derived based on a 3-dimensional rigid-body kinematics algorithm. The basic principles of using a 3-dimensional motion analysis system for investigating the relative movement between multiple segments have been well explained in the literature.[15,16]

Destructive Test

After the nondestructive test, the specimens were mounted onto a servohydraulic materials loading frame (Model 809; MTS Systems, Eden Prairie, MN) for destructive compression testing. Each specimen was placed in 90° of wrist extension by using a set of potting fixtures. A preload of 15 N was applied before the test. The specimen then was loaded to failure in axial compression at a constant rate of 1 mm/s. Load and displacement data were recorded and load-displacement behavior of the construct was plotted. From the load-displacement plot, failure load was obtained as the peak load before the first decrease in load. The rigidity of the construct also was obtained from the straight-line region of the load-displacement plot. Finally, the energy needed to produce the failure was calculated from the load-displacement behavior.

Data Analysis

For the nondestructive test, the angular displacement of the radial fragment with respect to the proximal fragment, the ulnar fragment with respect to the proximal fragment, and the radial fragment with respect to the ulnar fragment during wrist flexion-extension were compared between the 2 groups. The angular displacements between fragments included flexion-extension, radial-ulnar deviation, and pronation-supination. A 1-tailed paired Student *t* test was performed to compare the angular displacement between the volar plate group (VP) and the volar plate combined with a pin plate (VP+PP) group. For the load-to-failure test, a 1-tailed paired Student *t* test

Table 1. Angular Displacement Between 2 Distal Fragments With Respect to the Proximal Segment

	Radial Fragment to Proximal Fragment			Ulna Fragment to Proximal Fragment		
	VP	VP+PP	p Value	VP	VP+PP	p Value
Flexion-extension	0.71 ± 0.24	0.42 ± 0.28	**.01**	0.80 ± 0.32	0.56 ± 0.31	**.01**
Radial-ulnar deviation	0.38 ± 0.31	0.22 ± 0.17	.11	0.62 ± 0.39	0.30 ± 0.20	**.02**
Pronation-supination	0.27 ± 0.13	0.29 ± 0.17	.34	0.30 ± 0.14	0.23 ± 0.12	.16

All measurements are shown in degrees. Values shown in bold are statistically significant.

was applied to the comparison of failure load, construct stiffness, and energy to failure. Statistical significance was set at .05 for all analyses.

Results

Angular Displacement Between Fragments

The dominant movement of the 2 distal fracture fragments to the proximal fragment was flexion-extension, followed by radial-ulnar deviation (Table 1). With the fixation of the volar plate only, the maximum angular displacement in flexion-extension direction was 0.71 for the radial fragment and 0.80 for the ulnar fragment. With the addition of the radial pin-plate, the maximum flexion-extension displacement was reduced to 0.42° on the radial side (40% reduction, $p < .01$) and 0.56° on the ulnar side (30% reduction, $p < .01$). In the direction of radial-ulnar deviation, a reduction of 51% was found on the ulna side when comparing the combined volar plate and radial pin plate with the volar plate alone ($p < .02$) (Fig. 2).

The relative displacement of the 2 distal fragments showed no statistically significant differences between the 2 construct configurations (Table 2). The dominant direction of displacement was radial-ulnar deviation for the volar plate alone group and flexion-extension for the combined volar plate and radial pin plate group.

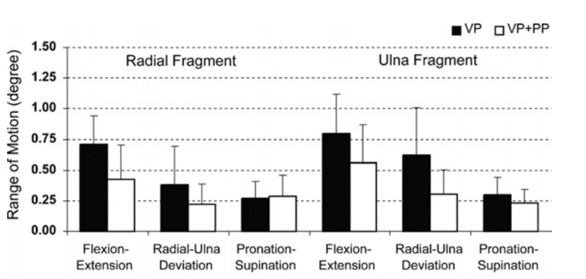

Figure 2. Angular displacement (means and SD) between the 2 distal fracture fragments with respect to the proximal fragment of volar plate only group (■, VP) and the volar plate with radial pin plate group (□, VP+PP).

Load-to-Failure Test

Several parameters were obtained from the load-displacement plots of the load-to-failure tests. The average failure load, construct stiffness, and energy absorbed by the construct until the failure point of the 2 groups are presented in Table 3. The VP+PP group showed failure at a 76% higher load than the VP group ($p < .01$). The average rigidity of the VP+PP construct was 50% higher than the VP only construct ($p < .02$). Finally, the energy needed to produce construct failure was 92% higher for the VP+PP group than the VP group ($p < .03$). In most cases, the constructs failed when one or more screws were pulled out from the volar plate or the radial pin plate.

Discussion

A number of basic science and clinical studies have highlighted the goals of successful intra-articular distal radius fracture treatment: to reconstruct anatomic alignment of the fracture fragments, to maintain stability until healing, and to allow early postoperative motion to prevent tendon adherence and arthrofibrosis.[17,18] There also have been a number of studies espousing the benefits of a number of different treatment options for complex distal radius fracture care. Fragment-specific fixation and volar fixed-angle plate fixation are 2 new internal fixation techniques that aim to maintain anatomic fixation, but avoid the complications associated with traditional internal fixation techniques.

Table 2. Angular Displacement Between the Radial Fragment to the Ulnar Fragment

	VP	VP+PP	p Value
Flexion-extension	0.52 ± 0.12	0.48 ± 0.28	.34
Radial-ulnar deviation	0.60 ± 0.49	0.47 ± 0.27	.24
Pronation-supination	0.24 ± 0.17	0.26 ± 0.15	.19

All measurements are shown in degrees.

Table 3. Results From Compression to Failure Tests

	VP	VP+PP	% Increase	p Value
Failure force, N	240.9 ± 130.5	424.3 ± 109.0	76%	**.01**
Stiffness, N/mm	30.8 ± 15.1	46.1 ± 17.8	50%	**.02**
Energy-to-failure, Nm	1.2 ± 0.8	2.3 ± 0.5	92%	**.03**

Values shown in bold are statistically significant.

Early clinical outcomes have shown promising results using either fragment-specific fixation or volar fixed-angle fixation techniques. Constantine et al,[19] Kamano et al,[20] and Orbay and Fernandez[21] have reported more than 80% to 90% good/excellent preliminary results using volar reduction and fixed-angle plate fixation for unstable, dorsally displaced distal radius fractures. Konrath and Bahler[5] reported 90% excellent preliminary results using a fragment-specific fixation technique. These studies were limited, however, by their short-term follow-up evaluation, small study sizes, and lack of prospective, randomized, controlled data.

Biomechanical studies have investigated both fragment-specific fixation and volar fixed-angle plate fixation in comparison with traditional internal and external fixation techniques. Peine et al[22] showed that a dorsal fragment-specific double-plating technique that stabilized the radial and ulnar metaphyseal columns in biplane fixation provided superior stability to standard dorsal plating techniques under axial load application. Dodds et al[10] compared fragment-specific fixation versus external fixation augmented with K-wires. They found that fragment-specific fixation was markedly more stable than the K-wire–augmented external fixation in a simulated 4-part fracture model. Leung et al[11] compared a volar locking T-plate with conventional volar and dorsal T-plates. Their results showed that, under 100-N axial load, the palmar locking compression T-plate restores stability comparable with that of the intact radius, and is superior to conventional palmar or dorsal T-plates. Osada et al[13] compared a fixed-angle volar plate with 3 conventional dorsal plates and 2 conventional volar plates. In a separate study, Osada et al[12] compared a different fixed-angle volar plate with 2 different conventional volar plates. In both studies they found the fixed-angle volar plates to be superior in stability and ultimate strength versus traditional plating techniques in testing to failure under axial compression. More recently, Taylor et al[9] compared fixed-angle volar plate fixation with fragment-specific fixation and showed similar biomechanical results for the 2 fixation systems.

In the present study, we evaluated the *in vitro* stability and strength of a combined fixation system using a volar fixed-angle plate and a radial column pin plate in a simulated cadaveric C2-type fracture model. The stability of the construct was measured by using a 3-dimensional motion analysis system to track the angular displacement of an individual fracture fragment. We found that the predominant motion for both the radial and ulnar fragments was in the direction of flexion-extension. This finding is agreeable with a previous study by Dodds et al[10] that used a similar set-up, but the magnitudes of the fragment motion were much smaller in our study. The different fixation systems used in the 2 studies likely contributed to the discrepancy. When comparing the combined fixation with the volar plate alone, the addition of the radial column pin plate reduced motion by 40% on the radial side, by 30% in the ulnar side, and provided 76% higher strength. We suspect that the orthogonal placement of the 2 systems in the combined fixation might be responsible for this substantial improvement in construct stability and strength.

Findings from this study provide important comparative information on the biomechanical performance of 2 commonly used fixation systems, which can be used as the basis for future clinical studies.

Received for publication June 9, 2006; accepted in revised form December 6, 2006.

Material assistance was provided by TriMed, Inc., Valencia, CA.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Corresponding author: Steven I. Grindel, MD, Department of Orthopaedic Surgery, Medical College of Wisconsin, 9200 W. Wisconsin Ave, PO Box 26099, Milwaukee, WI 53226-0099; e-mail: sgrindel@mcw.edu.

0363-5023/07/32A02-0009$32.00/0

doi:10.1016/j.jhsa.2006.12.003

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