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Biomechanical Performance of Variable and Fixed Angle Locked Volar Plates for the Dorsally Comminuted Distal Radius

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BIOMECHANICAL PERFORMANCE OF VARIABLE AND FIXED ANGLE LOCKED VOLAR PLATES FOR THE DORSALLY COMMINUTED DISTAL RADIUS

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ABSTRACT

Background: The ideal treatment strategy for the dorsally comminuted distal radius fracture continues to evolve. Newer plate designs allow for variable axis screw placement while maintaining the advantages of locked technology. The purpose of this study is to compare the biomechanical properties of one variable axis plate with two traditional locked constructs.

Methods: Simulated fractures were created via a distal 1 cm dorsal wedge osteotomy in radius bone analogs. The analogs were of low stiffness and rigidity to create a worst-case strength condition for the subject radius plates. This fracture-gap model was fixated using one of three different locked volar distal radius plates: a variable axis plate (Stryker VariAx) or fixed axis (DePuy DVR, Smith & Nephew Peri-Loc) designs. The constructs were then tested at physiologic loading levels in axial compression and bending (dorsal and volar) modes. Construct stiffness was assessed by fracture gap motion during the different loading conditions. As a within-study control, intact bone analogs were similarly tested.

Results: All plated constructs were significantly less stiff than the intact control bone models in all loading modes ($p<0.040$). Amongst the plated constructs, the VariAx was stiffest axially ($p=0.032$) and the Peri-Loc was stiffest in bending ($p<0.024$).

Conclusion: In this analog bone fracture gap model, the variable axis locking technology was stiffer in axial compression than other plates, though less stiff in bending.

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INTRODUCTION

Fractures of the distal radius exhibit a bimodal distribution with high energy injuries in the younger population and fragility fractures associated with simple falls in older patients[1]. With the increase in average age of the population, it is not surprising that the incidence of distal radius fractures is increasing and this trend is projected to continue[2,3,4].

The treatment of distal radius fractures has evolved over the last several decades. Conservative and operative treatment modalities have been evaluated with evidence supporting surgical treatment for displaced fractures[5,6,7]. Successful outcome parameters have historically considered restoration of volar tilt to 11°, radial inclination of 23°, and/or radial shortening of less than 2 mm[8,9,10]. Other articles cite excessive intra-articular displacement as the chief factor for negative outcomes including arthritis[8,11,12]. Treatment guidance has been provided by the AAOS which has issued a 'moderate recommendation' for operative fixation instead of casting for fractures which exhibit: shortening >3 mm, dorsal tilt >10°, or intra-articular displacement >2 mm[7].

There is some debate as to the ideal surgical intervention. Successfully established techniques include closed reduction with percutaneous pinning, closed reduction and external fixation, external fixation and percutaneous pinning, open reduction and fixation with pins (ORIF), external fixators or internally fixed with either dorsal and/or volar plates[6,13,14,15,9,16]. Several recent studies have demonstrated that ORIF techniques yield better patient outcomes[17,18,19,20]. ORIF allows anatomic reduction and early stability which promotes the safe initiation of wrist and hand rehabilitation[21]. More specifically, the use of locked volar plating has the advantage of avoiding the complications associated with dorsal plating including extensor tendon irritation, attrition, or rupture.[9,16] In addition, biomechanical studies show that locked volar plates produce significantly greater stability than unlocked volar plates[22].

Despite the advantages of fixed angle locked volar fixation, there are potential disadvantages. For locked plates, it is not possible to truly lag a fracture fragment to the plate. Also, the fixed angle plate designs are dependent on conformance of the patient's distal radius anatomy and fracture pattern to the plate geometry. This problem can

TABLE 1. The cross section and axial and bending rigidity of each plate was assessed just proximal to the distal most shaft screw. This location coincided with the fulcrum for the three point bending test (see Figure 1).

	DVR	Peri-Loc	VariAx
Width (w, mm)	7.62	10.03	17.15
Thickness (t, mm)	2.54	2.54	2.03
E (GPa or 10^3 N/mm^2)*	Titanium= 110	Stainless steel= 190	Titanium= 110
Axial Rigidity (AE)* (10^6 N)	2.13	4.84	3.83
Bending Rigidity (IE)* (10^6 Nmm^2)	1.15	2.60	1.32

*E=elastic modulus, A=cross section area=w x t, I=area moment of inertia=wt^3/12, modulus values taken from [26].

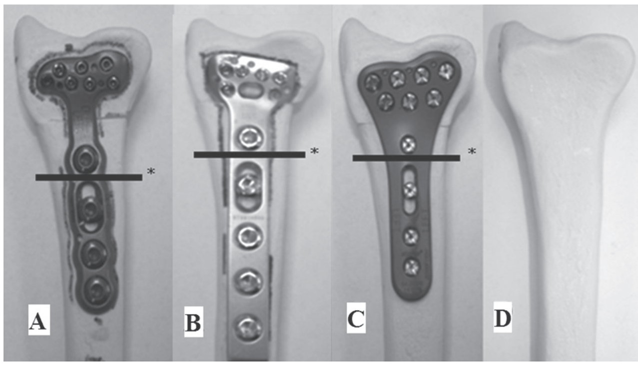

Figure 1: Radius Test Contructs. The radius test constructs (distal-volar view) were made up of fixed screw axis locked plates (A - DVR, B - Peri-Loc), a variable axis locking design (C - Variax), and uninstrumented controls (D). A representative measure of the plates' cross-sections was taken just proximal to the distal-most diaphysis screw. This location coincided with the three point bending fulcrum (see Figure 3).

often be adequately addressed via the availability of a variety of plate geometries. Regardless, some compromises may be necessary in either plate positioning or quality of subchondral support to facilitate fixed-angle fixation. Amongst different plate concepts, the so-called "variable axis" design provides the surgeon some flexibility on the trajectory of the 'locked' screws to facilitate fixation of variable fracture patterns and anatomy. The apparent design goal is to yield screw placement flexibility while providing equivocal fixation versus fixed angle screw designs. There is little data in the literature which compares the biomechanical stability of variable axis technology relative to traditional locked technology.

The purpose of this study is to compare the biomechanical properties of variable axis technology with traditional fixed angle locked technology. Several different plates were evaluated for fixation using an established model of a dorsally comminuted distal radius analog. Uninstrumented, intact control analogs were similarly tested assessed to provide a basis for comparison.

MATERIALS AND METHODS

Per Willis and coworkers, an analog radius model (model 1027, Pacific Research Laboratories, Vashon, Washington) was utilized for this study to limit specimen-to-specimen variability frequently observed in cadaveric models[22,23]. It is acknowledged that this bone model does not replicate the strength or stiffness of normal bone. However, this analog model has been used in the past to represent a consistent, suboptimal condition for the assessment of the stability and fixation for fracture plates[22]. Twenty-four radius analogs were divided into four groups; three groups were instrumented with one of three different plates as described below, and the fourth group served as intact controls. In the three plated groups, an extra-articular wedge shaped dorsally comminuted radius fracture was simulated via osteotomy with a 1 cm dorsal gap and positioned 2 cm proximal to the distal articular surface[22].

All plates were implanted volarly per the manufacturers' recommendations, leaving the volar cortices in contact. One plate featured the variable screw axis design (Titanium VariAx Distal Radius Locking Plate System, Stryker, Kalamazoo, Michigan) (Figure 1). The remaining two plates incorporated a fixed screw axis designs (Titanium DVR locking plate, Hand Innovations, Miami, Florida, and the Stainless steel Peri-Loc Volar Distal Radius Locking Plate, Smith & Nephew, Memphis, Tennessee). The distal locking screws were intentionally long to ensure bicortical purchase and consistency of fixation. The variable axis plate locking screws were positioned neutrally in their holes, which is within the company's specifications (i.e. within 15° from neutral). Regardless of the mode of fixation, all of the distal locking screws for all plates exited out the dorsal cortex of the distal radius and not through the fracture gap or into the articular surface.

Locked volar fixation is designed to permit early hand and wrist range of motion. Therefore, the biomechanical testing was designed to closely replicate the *in vivo* forces at the fracture site shortly following fixation and described in detail below. A servohydraulic testing machine (MTS Bionix, Eden Prairie, MN) delivered axial compression, and dorsal and volar three-point bending at sub-failure, physiologic magnitudes[15,22,24]. Radial and ulnar deviation forces were not tested for two reasons:

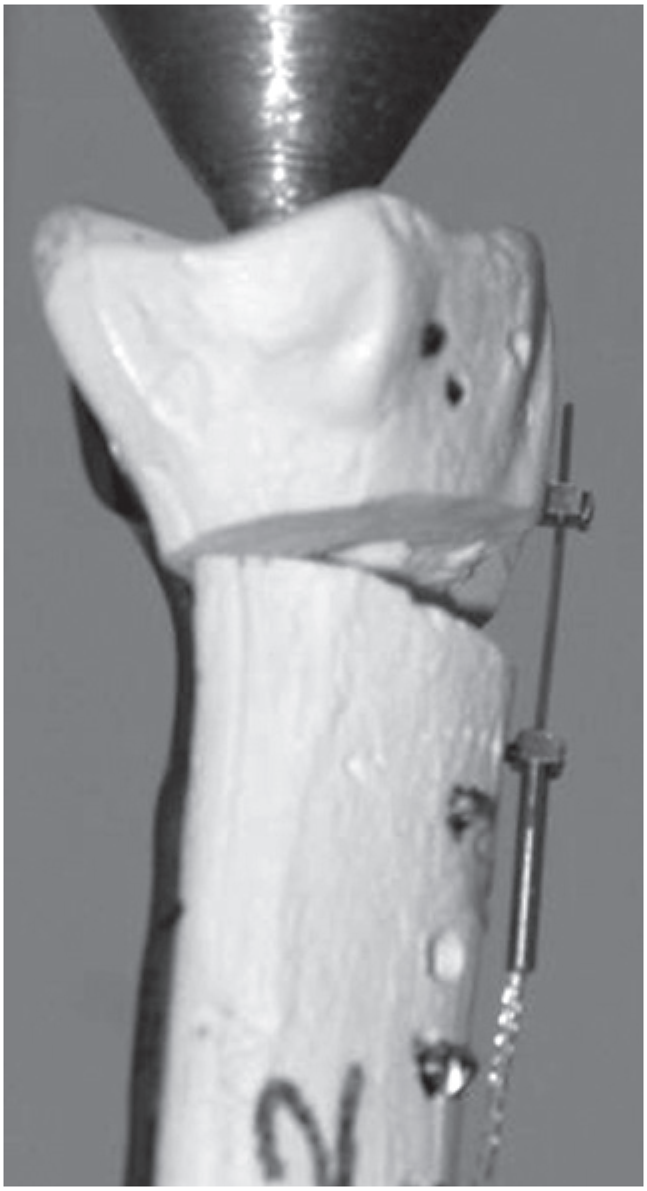

Figure 2: Axial Compression Test. Constructs were axially loaded to a physiologic sub failure load of 250 N using the protocol from [22]. This dorsal view shows the displacement transducer which spanned the fracture gap to record interfragmentary displacement.

firstly, it is not typically included in the postoperative therapy and secondly, the plates are approximately 25 times stiffer in this direction based on the Moments of Inertia for plane vs. edge loading (Table 1). Thus, the dorsal/volar bending tests were designed to investigate the anticipated loading during healing which also corresponds to the weaker loading axis of the plates. Axial compression was similarly assessed since it is anticipated during healing and the compressive force also subjects the plates' weak axis to bending moments. Such bending moments arise from the axial loads which were applied through the center of the radial lunate facet (Figure 2);

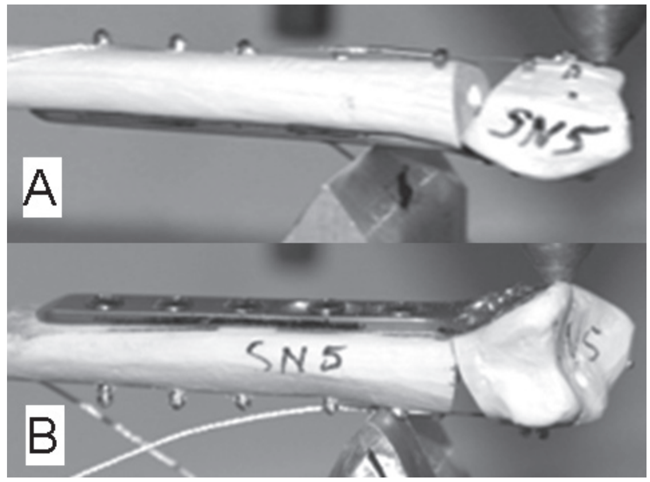

Figure 3: Dorsal and Volar Bending Tests. Three point bending was performed (A) dorsally and (B) volarly to a load of 50 N per [22]. The displacement transducer was again used to record interfragmentary motion.

this axial compression produced a combined loading condition of simultaneous plate compression and dorsal bending[22]. The proximal end of the radius was potted with room temperature curing epoxy. For axial compression, the potting cup was secured in the machine and the specimens were loaded under displacement control (0.5 mm/sec) to a force of 250 N. For three point bending, the construct was horizontally mounted in the test machine and the potted proximal end was secured (Figure 3). Dorsal bending placed the dorsal surface up such that the distal bending force was applied to the dorsal surface; for volar bending the construct was rotated 180 degrees about its long axis[22]. A 50 N force was applied to the distal central radius in displacement control at a rate of 0.5mm/s. Per Willis, the bending fulcrum was positioned immediately proximal to the first screw proximal to the fracture site. Pilot failure axial and bending tests were performed on instrumented and control constructs to ensure that the physiologic test forces were well within the linear elastic range of construct. These tests confirmed that all specimens were significantly below the load at which construct yield would occur.

A differential variable reluctance transducer (DVRT) (M-DVRT-6, MicroStrain; Williston, Vermont) was mounted dorsally across the osteotomy (Figures 2,3) to measure interfragmentary displacement[22]. For all tests, load data was recorded on a load cell attached to the test machine's base. The axial and bending stiffness were taken as the slope of the load vs. interfragmentary displacement curve for each construct. Each construct was tested three times with the construct stiffness taken as the average of the second and third tests (Figure 4)[22]. Positive stiffness values were arbitrarily assigned to indicate dorsal diastasis which was typical during

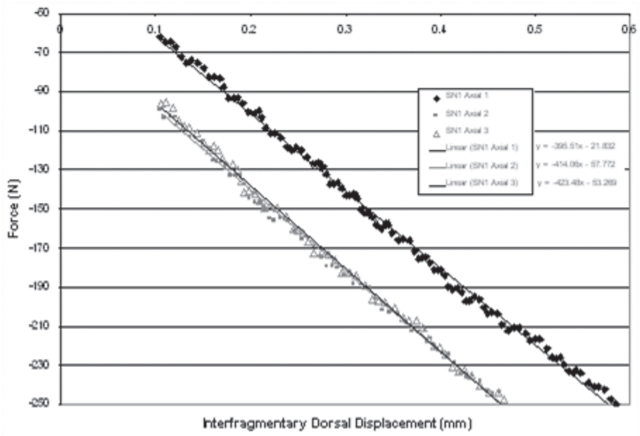

Figure 4: Stiffness Data Reduction. The stiffness was taken as the slope in the linear range and was averaged over the second and third subfailure tests for axial and dorsal and volar bending [22]. This figure shows the linear range for three axial compression trials for a Periloc plate; the R^2 values for all curve fits were 0.99 or greater.

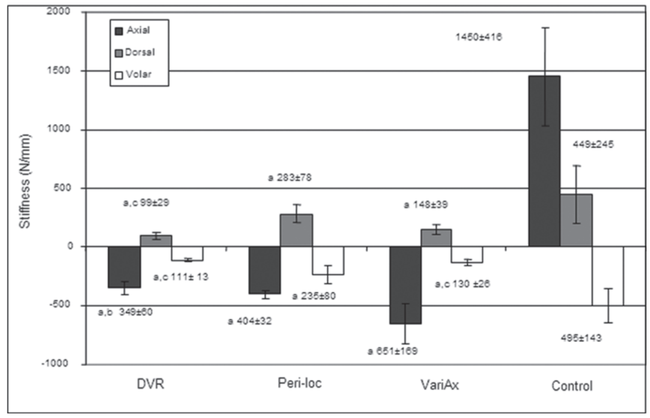

Figure 5: Comparison of Control and Test Stiffness Magnitudes. The axial and dorsal/volar three point bending stiffnesses were taken as the slope of the load vs. the dorsal interfragmentary displacement. Positive stiffness values indicate diastasis of the dorsal fracture gap; negative values indicate dorsal closure (see text for more details). (a Absolute value significantly different vs. control, b Significantly different vs. VariAx, c significantly different vs. Peri-loc)

volar bending. Negative stiffness values thus indicated fracture gap shortening as would occur during dorsal bending.

The uninstrumented control analog radius was tested under the same conditions as above with the only difference being a lack of an osteotomy or plate. The DVRT was placed in the same region as the three plate tests. The control data was intended to assess the consistency of the analog distal radius as well as to study any biomechanical differences between the control and treated radii. In all cases, normality was confirmed before performing statistical comparisons. For a given biomechanical test modality (axial or bending), the stiffness was compared for the four groups (3 plates, 1 control) with a one-way ANOVA (α=0.05) and Fishers LSD (Least Significance Difference) multiple pair-wise post-hoc comparisons.

RESULTS

The axial and bending stiffness magnitudes of the control specimens were significantly greater than all plated constructs (p=0.001 to 0.04) (Figure 5). The axial compressive stiffness of the control specimens was several times greater than the plates and was positive, indicating lengthening of the dorsal cortex. In contrast, all plated constructs exhibited negative stiffness values, which indicated compression at the fracture site. Visual inspection of the control specimens during loading revealed a first mode buckling shape such that the dorsal surface was in tension and the volar surface was in compression as was confirmed by the DVRT sensor. Similar evaluation of all plated constructs showed little observable deformation on the volar surface; rather the deformation appeared to be concentrated over the dorsal fracture gap. When comparing axial stiffness magnitudes between plates, the VariAx axial stiffness was significantly greater (651±169 N/mm) than the DVR (349±60 N/mm, p=0.032). The Peri-Loc (404±32 N/mm) was not significantly different vs. the Vari-ax (p=0.074) nor the DVR (p=0.679). With regard to volar and dorsal bending, the deformation was consistent between the control and all plated constructs: volar bending produced dorsal lengthening and dorsal bending caused dorsal shortening. The bending stiffness of the control analogs was several times greater than the plated constructs. Amongst the plated specimens, the Peri-Loc was stiffest in dorsal (283±78 N/mm) bending which was significantly greater than the DVR (99±29, p=0.024) but only tended to be greater than the Vari-ax (148±39 N/mm, p=0.089). In volar bending, the Peri-loc was again the stiffest plated construct (235±80 N/mm) which was significantly greater than both the DVR (111±13 N/mm, p=0.018) and Vari-ax (130±26 N/mm, p=0.041) specimens.

DISCUSSION

The current study sought to compare the biomechanics of different locked distal radius volar plate designs: a variable screw axis design and the traditional fixed screw angle plate. It was hypothesized that that the variable axis technology (VariAx) would show no significant biomechanical difference when compared to more traditional fixed angle locked plates.

The biomechanical data from the current study revealed that all plated constructs were significantly less stiff than control analog radius models in axial loading and volar/dorsal three point bending. Amongst the plated specimens, the VariAx plate was axially stiffer than the other plates with the comparison to the DVR being significant. In bending, the Peri-Loc was significantly stiffer than the DVR in both dorsal and volar bending;

the Peri-Loc was stiffer than the VariAx in both bending modes though only the comparison in volar bending was significant. The axial and bending comparisons reject the study hypothesis since there were significant plate-to-plate differences. The different plate stiffness magnitudes appear to be related to the plate rigidities. The bending rigidity magnitudes of each plate at the level of the bending fulcrum (Table 1) correlate with the bending stiffness values for the plated specimens. Rigidity takes into account the plate cross-sectional dimensions and the plate materials' modulus. A similar analysis of the axial rigidity at the level of the bending fulcrum (a consistently identifiable region) predicts that the Peri-Loc should have the greatest axial stiffness. However, the VariAx was actually stiffer. A comparison of the VariAx and Peri-Loc plate geometries shows that a gradual distal widening of the VariAx plate beyond the fulcrum may explain the higher resistance to axial loading of this plate.

A comparison of the stiffness values from the current study may be directly made to Willis, et al[22]. The methods from that study were adopted for the current study and both studies tested different versions of the DVR plate. The average DVR stiffness values from the current study are ~50% higher than Willis, et al., for all loading modes. One potential explanation for this difference is the increased number of distal screws for the DVR plate tested in the current study (seven in the current study versus four by Willis, et al.). Willis and coworkers note that of the volar locking and non-locking plates they tested, the DVR and AO locking plates provided similar stability that exceeded the non-locked plates. Combining the results of both studies would indicate that the Peri-Loc and VariAx plates would be stiffer than the AO volar locking plate. Comparisons with other studies highlight the influence of specimen type and test method. Other laboratories have tested the DVR plate but report widely varying axial stiffness values of 150 N/mm to 620 N/mm; in the current study the DVR stiffness averaged 349 N/mm[23,25]. These other studies used different types of specimens than the current study and/or utilized grip-to-grip displacement measurements (as opposed to the interfragmentary displacement method used in the current study which was adopted from Willis, et al.)[22].

The current study had several inherent limitations, first of which was the use of analog radius bone models. This model was adopted, however, to yield more consistent results which represented a suboptimal condition for stability and anatomic rigidity[22]. We adopted the model from Willis, et al.; this allowed our findings to be compared to their work and expand the database for distal radius plates using a consistent model[22]. That said, the findings from the current study should be interpreted with some caution since human tissues were not utilized as a test material. Relative comparisons between plates may be more relevant since the model was taken to be essentially constant between the current study and Willis, et al[22]. In an effort to quantify the behavior of un-altered bone models, intact control bones were also tested. These data revealed data dispersion which was similar to the plated constructs thus indicating a similar variability from the combination of the specimen, specimen preparation, and test methodology. As with all biomechanical laboratory tests, the results are limited to time zero and must rely on clinical studies to elucidate their long-term performance. Another limitation relates to the single point measurement of displacement along the dorsal comminution. This location was chosen to maximize the measureable displacement signal since it was on the opposite cortex as the plate. In addition, three independent loading modes were tested, whereas *in vivo* loading would be expected to be more complex. However, as noted in the Methods, the loads tested here were thought to represent either the plates' more vulnerable and/or common loading modes[15,22]. Finally, one element of the plate designs which has not been addressed here is the influence of the length of the plate proximally and the diameter and number of diaphysis screws. The specific DVR and VariAx plates selected for the current study were similar in length and had four shaft screws each, though the DVR screws were of a larger diameter. Alternatively, the Peri-Loc plate was longer such that it could accommodate an additional shaft screw. The plate and screw configurations used in the current study were selected to represent what was thought to be most reflective of current clinical practice.

Regardless of the locking screw design, plate shape or material, all instrumented radius models were significantly less stiff than control in axial compression and bending. Amongst the plates, there was a trend for the Vari-Ax locking screw design to be stiffer than the traditional fixed, locked plates. In bending, the PeriLoc fixed angle locked plate was significantly stiffer than the Vari-Ax or DVR plates. This finding was consistent with the bending rigidities of the different plates. Plate shape (i.e., cross-sectional geometry, length, etc.) and material selection appear to be the dominant variables influencing the plate stiffness magnitudes in this radius fracture model.

COMPETING INTERESTS

The authors have no competing interests.

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