The goal of this study was to determine whether there is any biomechanical difference in terms of construct strength with axial loading between volar fixed-angle locking plates with threaded locking vs smooth locking pegs. The control group comprised 7 cadaveric specimens with threaded locking pegs, and the test group comprised 7 cadaveric specimens from the same donor with smooth locking pegs. The DVR plate (Biomet, Warsaw, Indiana) was applied to the volar surface. A 15-mm dorsal wedge osteotomy was created near the level of Lister’s tubercle. The radii were potted in polymethylmethacrylate for biomechanical testing. The loading protocol consisted of 3 parts: ramp loading, cyclic loading, and failure loading. The outcome measures of stiffness and failure were used to test the plates fixed with threaded and smooth locking pegs. When comparing each cycle, the difference in mean stiffness between threaded and smooth locking pegs was as follows: 122 N/mm, -9.09 N/mm, -14.7 N/mm, 49.4 N/mm, 57.4 N/mm, 71.9 N/mm, 52.3 N/mm, 35.8 N/mm. The difference in mean failure load between the threaded and smooth locking pegs was -11.3 N. There was no difference in stiffness throughout all cycles. Failure analysis showed no significant difference between the smooth (962 N) and threaded (951 N) locking pegs. The difference in stiffness between the 2 constructs (smooth minus threaded locking pegs) in ramp loading ranged from -122 to 15 N/mm. The results of this study showed no significant differences in stiffness and failure load between constructs consisting of threaded locking pegs or smooth locking pegs in the distal rows of the DVR distal radius volar locking plate. Based on the results of this study, there may be no benefit to using threaded locking pegs vs smooth locking pegs when treating distal radius fractures with a volar locking plate.
Distal radius fractures are among the most common orthopedic injuries. Historically, treatment consisted of closed reduction, immobilization, and elevation. However, prolonged immobilization may lead to stiffness. The dorsal distal radius experiences more tensile forces, and the volar surface experiences more compression forces. The volar cortex is thick and strong for buttressing, and the dorsal cortex is thinner. With abnormal loading (e.g., a fall on an outstretched hand), the dorsal surface experiences compression forces and fractures. Sixty-eight percent of distal radius fractures are associated with soft tissue injuries, including the distal radio-ulnar joint, the triangular fibrocartilage complex, the scapholunate, or the lunotriquetral ligaments. Fractures of the ulnar-sided distal radius are especially associated with the distal radio-ulnar joint and triangular fibrocartilage complex injuries.

Volar fixed-angle fixation does not depend on screw purchase for construct stability. The construct is designed to buttress via the fixed-angle components. The Hand Innovations Distal Volar Radius (DVR) plate (Biomet, Warsaw, Indiana) supports the subchondral bone via 2 rows of fixed-angle pegs that create a multidirectional scaffold. Based on the manufacturer data, the proximal row directs the screws or pegs in a proximal-to-distal direction, which supports the dorsal articular surface. The distal row angles the screws or pegs proximally such that they cross the proximal screws or pegs. This row supports the central and volar subchondral bone. The DVR plate is rated to 200 lb (890 N) to support forces transmitted from the hand through the wrist. Biomechanical studies have shown that volar fixed-angle plates are stronger in cyclical loading than conventional dorsal plates due to a better implant-bone interface.

Because the volar locking fixed-angle plate construct acts as a scaffold that primarily relies on screw or peg trajectory and subchondral buttress for stability, the authors sought to discover whether there is a biomechanical difference in terms of construct strength with axial loading between the volar fixed-angle locking plates fixed with threaded locking vs smooth locking pegs. Theoretically, with locked fixed-angle constructs, the presence of threads on the pegs would not be necessary given the peg head-to-plate interaction providing the stability in these constructs. If the hypothesis that the peg head-to-plate interface is sufficient to provide stability in this study holds, the production of the threaded implants would no longer be necessary.

**Materials and Methods**

Fourteen frozen cadaveric radii, stripped of all soft tissue attachments, were used. All specimens were imaged with micro-computed tomography (CT) analysis for bone density. The control group (threaded locking pegs) comprised 7 right-sided radii specimens, and the test group (smooth locking pegs) comprised 7 matched left-sided radii specimens from the same donor (7 paired, total=14). All specimens were completely thawed prior to testing. The DVR plate was applied to the volar surface. The plate was placed as distal as possible to provide subchondral support, near the watershed line with all 7 distal locking holes as well as 3 proximal diaphyseal holes (Figure 1). The goal of screw and peg insertion length was to just breach the dorsal cortex, and this was verified by visual inspection of the dorsal cortex. A 15-mm dorsal wedge osteotomy was created near the level of Lister's tubercle (approximately 22.5 mm proximal to the articular margin). The plate was placed after the osteotomy. The volar cortex was left intact to ensure anatomic reduction.

The radii were potted in polymethylmethacrylate (PMMA) such that there was a 1-cm space between the proximal end of the plate and the PMMA. Polymethylmethacrylate was placed between the femoral head and distal radius articular surface to ensure even loading across the articular surface (Figure 2). There was a 1-cm space between the proximal end of the plate and the PMMA.

The loading protocol consisted of 3 parts: ramp loading, cyclic loading, and failure loading. There were 3 initial ramp loading cycles to 300 N of axial compression at 10 N/s (triangle wave loading pattern). Cyclic loading consisted of loading to 300 N at a frequency of 1 Hz (sine wave loading pattern) for 5000 total cycles. Five measurements were obtained after cycle 1000. Failure loading was performed under axial loading at a rate of 2 mm/min. The measurements were obtained at each one-thousandth cycle. The data were collected 5 times, once each at 1000-cycle increments.
The outcome measures of stiffness and failure were used to test the plates fixed with threaded and smooth locking pegs with a significance level of \( \alpha = 0.05 \). The stiffness was tested with the failure test from the cyclic data set at 1000-cycle intervals for up to 5000 cycles, yielding 5 data points. The failure load and failure stiffness is from the failure load data set. The triangle wave for 3 cycles is to prepare the construct for testing in the linear region. A paired \( t \) test analysis was used to detect a difference between the means of the 2 groups. A preexperiment power analysis was performed. The total sample size was 14 (7 paired groups), and \( \alpha = 0.05 \) with power equal to 0.80. With the standard deviation (sigma) equal to 1, the effect size (difference in mean) was 0.8101. This means that the study is powered to detect a large difference between the threaded and smooth locking pegs if one exists. Analysis was performed based on the fact that 7 pairs of specimen were available for testing. The traditional power analysis attempts to discover how many specimens are needed to obtain a power of 0.8. This could not be done for the current study because the total number of specimens in the study was not variable.

### Results

Based on micro-CT analysis, there was no difference in bone density in the paired specimens. When comparing each cycle, the difference in mean stiffness between threaded and smooth locking pegs was as follows: 122 N/mm, -9.09 N/mm, and -14.7 N/mm for the first 3 cycles; and 49.4 N/mm, 57.4 N/mm, 71.9 N/mm, 52.3 N/mm, and 5.8 N/mm, which reflects 0 stiffness for specimen 4377L for cycles 4 to 8, which failed during the loading phase. The difference in mean failure load between the threaded and smooth locking pegs was -11.3 N (Tables 1-2).

One specimen (4377L) with smooth locking pegs failed after 3 cycles of ramp loading, with a failure load of 297.9 N. In analyzing the data, 2 different calculations were performed for cycles 4 to 8. The first method of calculation assumed that the stiffness at cycle 3 would be similar to the stiffness at cycles 4 to 8. This trend was seen in all of the other 13 specimens. The other calculation assumed a stiffness value of 0 for cycles 4 to 8. Regardless of the method of calculation, there was no difference in stiffness throughout all 8 cycles. Failure analysis was also calculated. Calculations showed no significant difference between the smooth (962±769 N) and threaded (951±625 N) locking pegs (\( P = .929 \)). Even after removing the specimen that failed after 3 cycles of ramp loading, the overall results were not significantly different.

Average stiffness was 964±160 N/mm for the threaded locking pegs (cycles 1-8) and 971±213 N/mm for smooth locking pegs (carryover method cycles 4-8) (\( P = .74 \)) or 919±186 N/mm (0 stiffness cycles 4-8) (\( P = .022 \)) (Figures 3-4).

### Table 1

<table>
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<tr>
<th>Cycle</th>
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<th>Threaded</th>
<th>Difference</th>
<th>95% CI</th>
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</thead>
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<td>581</td>
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<td>-258 to 14</td>
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<tr>
<td>2</td>
<td>947</td>
<td>938</td>
<td>9</td>
<td>-118 to 136</td>
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<tr>
<td>3</td>
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<td>972</td>
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<td>-104 to 134</td>
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</tbody>
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*Abbreviation: CI, confidence interval.*

### Table 2–A

<table>
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<th>Difference</th>
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<td>8</td>
<td>1011</td>
<td>1047</td>
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</table>

*Abbreviation: CI, confidence interval.*
Removing the specimen that failed after 3 cycles did not significantly alter the results of the study.

**DISCUSSION**

The results of this study showed no significant differences in stiffness and failure load between constructs consisting of all threaded locking pegs or all smooth locking pegs in the distal rows of the DVR distal radius volar locking plate in this validated fracture model.⁶ Although Moss et al⁷ found no statistical significance in 7 vs 4 distal locking screws in their biomechanical study, they found an early trend toward higher stiffness and load-to-failure values with 7 screws. The current authors filled all 7 distal screw holes and all 3 proximal holes. Although the average stiffness was significantly different using the 0 stiffness calculation, the difference of 45 N/mm may not be clinically relevant. In addition, the difference in each cycle did not approach significance using the 0 stiffness calculation.

The forces through the wrist are transmitted axially through the scaphoid and lunate facets. The threaded peg purchase in the metaphyseal bone does not necessarily give additional stability when the force is perpendicular to the screw shaft (and parallel to the long axis of the radius). This study showed that there is no detectable difference between smooth and threaded locking pegs in the volar fixed-angle distal radius plate construct.

Previous biomechanical studies have shown comparable results between volar fixed-angle and dorsal nonlocking plates. Willis et al⁶ tested 5 distal radius plates in an extra-articular dorsally comminuted fracture model with axial compression along with volar and dorsal bending (simulating wrist flexion and extension). Although the dorsal pi-plate fared better than the volar plates in terms of fracture gap motion, the plate has not been widely used due to concerns regarding extensor tendon rupture. Weninger et al⁹ evaluated a Sawbones model of distal radius extra-articular fractures and noted no difference in axial loading between smooth and threaded pegs. However, they noted decreased torsional stiffness in constructs using only smooth locking pegs ($P=.017; 95\%$ confidence interval, $-0.0016$ to $0.0689$). The goal of the current study was to determine whether there is any difference in stiffness in axial load. However, the authors did not test torsion because it would have required another separate set of specimens, and differences were previously demonstrated in a Sawbones model.⁹ Still, the current study’s cadaver model primarily tested the extra-articular fracture pattern and cannot be extrapolated to clinical situations if intra-articular comminution is present. Orbay and Fernandez¹⁰,¹¹ recommend smooth locking pegs to avoid screw penetration into the radiocarpal joint and to avoid carpal articular damage in the case of articular collapse. They also noted that threaded pegs that penetrate the dorsal cortex have increased risk of extensor tendon irritation or rupture. Koh et al⁶ also found no difference in smooth vs threaded locking pegs. Martineau et al¹² used a Sawbones model to differentiate various configurations with threaded and smooth locking pegs (Volar 6-peg plate; TriMed Inc, Valencia, California) in an intra-articular distal radius fracture model. They concluded that
threaded locking pegs were mechanically superior in the lunate facet for AO C3 fractures with axial loading. However, that study used a different fracture model and longer locking pegs than would be used during clinical scenarios. The longer length of the locking pegs may alter the stiffness in axial loading.

CONCLUSION

This study showed no advantage of using threaded locking pegs compared with smooth locking pegs when used in fixed-angle volar distal radius fixation constructs in a well-established cadaver model of distal radius fractures in biomechanical simulations. The findings of this study may be used to extrapolate similar hypotheses for locking implants used in other fractures throughout the body. Further studies evaluating clinical performance of threaded vs smooth locking pegs in distal radius fixation constructs are required to make recommendations regarding the use of only smooth locking pegs because they have the potential advantage of being a safer option without compromising fixation strength.

REFERENCES