Abstract

Objective: Determine contributions of plate length and locked fixation in an ulna fracture. Methods: two groups of six pairs of ulnae were plated with a small-fragment LCP around a 1 cm ostectomy. Control specimens: eight-hole plate, three consecutive unlocked screws on each side. Experimental specimens: 10-hole plate, two screws (Group 1, Unlocked; Group 2, Locked) in near-far configuration on either side. Outcomes: Stiffness in torsion and 4-point bending stiffness and load at yield. Results: Unlocked: mean torsional stiffness (Ncm/deg) for the experimental and control specimens, 7.57 and 7.73, respectively (p > 0.05); mean bending stiffness (kN/m), 88.50 and 90.76, respectively (p > 0.05); and mean yield strength (kN), 1.06 and 0.89, respectively (p < 0.05). Locked: mean torsional stiffness for the experimental and control specimens, 7.10 and 8.27, respectively (p > 0.05); mean bending stiffness, 72.96 and 79.20, respectively (p > 0.05); and mean yield strength, 1.23 and 1.03, respectively (p > 0.05). Mean differences between the experimental and control specimens in torsion: Unlocked, 0.17; Locked, 1.17 (p > 0.05). Mean differences in bending stiffness: Unlocked, 2.25; Locked, 6.24 (p > 0.05). Mean differences in yield strength: Unlocked, 0.17; Locked, 0.21 (p > 0.05). Conclusions: Locked plating provided no mechanical advantage over unlocked plating. The use of a longer plate with unlocked screws increased yield strength.

Plate fixation of diaphyseal forearm fractures in adults has become accepted as standard of care.1 The AO Foundation empirically recommended five cortices of screw fixation on either side of a fracture.2 Technical data has since demonstrated that the use of longer plates with fewer, more widely spaced screws is biomechanically stronger in bending than the use of shorter plates with more screws.3-5 Lindvall and Sagi6 reported a 97.1% rate of forearm fracture union and no hardware failure using only two screws on either side of the fracture in near-far configuration.

The use of locking screws has become widely popular in treating fractures, not only of the forearm but of other long bones as well. Locked plating provides the advantage of a fixed angle device, allowing the use biologic plating techniques. Other relative indications for the use of locked plating include periarticular fractures, osteoporotic bone, and bridge plating of segmental comminution. Despite its theoretical advantages, in a prospective randomized trial comparing locked and unlocked plating of diaphyseal forearm fractures, the two methods of fixation had equal rates of union, infection, and refracture.7 Two recently published biomechanical studies have demonstrated a biomechanical advantage to locked plating in the forearm, in both bending and torsion.8,9 However, in both of these studies, three consecutive screws on either side of the fracture were used. Neither study addressed the use of longer plates with wider spaced screw placement. We hypothesized that plate length and screw spacing would be a more important biomechanical factor than the use of locking screws. The purpose of the current study was to test this hypothesis by comparing locked versus unlocked screws in two different plate lengths in a human cadaveric comminuted ulna shaft fracture model.


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Materials and Methods

Twelve matched pairs (left and right) of formalin-fixed cadaveric ulnas were stripped of all soft tissue and periosteum and divided into two groups of six pairs each (12 ulnae per group). One ulna of each pair was randomly assigned to be the control specimen and the other the experimental specimen for each group. The control construct was the same for all groups, while the experimental model varied. Specimens were preserved at -20º C and thawed for 24 hours prior to testing. Each specimen pair underwent radiographs to rule out bone lesions and to ensure that the approximate density in each pair was equal. A standardized aluminum step-wedge was used for density standardization.

Small-fragment 3.5 mm locking compression plates (LCP) (Synthes; Paoli, Pennsylvania) were applied on the dorsal surface of each specimen. A 1 cm gap ostectomy at the midpoint of each ulna was created to simulate a comminuted fracture. The screws were then retightened. Each experimental specimen received a 10-hole plate, while the control specimens all received an eight-hole plate. The control specimen was an eight-hole plate with three bicortical unlocked screws in consecutive holes on each side of the fracture. All the experimental groups had two bicortical screws inserted in near-far configuration on each side of the fracture (Fig. 1). Group 1 (Unlocked) consisted of unlocked screws in a 10-hole plate. Group 2 (Locked) consisted of locked screws in a 10-hole plate. The two holes over the ostectomy were left open. The proximal and distal aspect of each specimen was then potted in methylmethacrylate. A constant working length of 20 cm between the potted ends was maintained.

All the specimens were first tested pre-yield in torsion at a constant displacement rate of 5° for 1 second using a servo-hydraulic MTS machine (model 810; Minneapolis, Minnesota). This was determined to be below the failure threshold, based on preliminary testing. Specimens were then tested with the MTS machine in 4-point bending to failure, with the plate on the tension side of the bending, using displacement control mode and a custom jig (Fig. 1).

Torsional stiffness (Ncm/deg) was measured as the slope of the force-displacement curve, with a maximum of 5° of displacement. Bending stiffness (kN/m) was measured as the slope of the force/displacement curve during 4-point bending. Yield strength (kN) was the point on the force/displacement curve where plastic deformation occurred. For each set of measurements, paired t-tests were performed between the experimental and control specimens within each group. The difference in measurements between the experimental and control specimens within each group was also calculated. An unpaired t-test was used to compare the differences between each group.

Results

For the Unlocked group, the mean torsional stiffness (Ncm/deg) of the 10-hole unlocked constructs was 7.57 (SD, 2.10) and the control group was 7.73 (SD, 3.44; p 0.85). The mean

<table>
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<th>Table 1</th>
<th>Unlocked Group Data (10-Hole Plate Unlocked vs. Eight-Hole Plate Unlocked)</th>
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<tbody>
<tr>
<td>Group 1</td>
<td>Torsional Bending Yield</td>
</tr>
<tr>
<td>Mean</td>
<td>Stiffness Stiffness Strength</td>
</tr>
<tr>
<td>(Std Dev)</td>
<td>(lbs/sec) (lbs/sec) (lbs)</td>
</tr>
<tr>
<td>Experimental</td>
<td>3.35 (0.93) 505.40 (53.05) 238.28 (7.64)*</td>
</tr>
<tr>
<td>Control</td>
<td>3.42 (1.52) 518.26 (43.39) 199.90 (67.51)</td>
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*p < 0.05

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<th>Table 2</th>
<th>Locked Group Data (10-Hole Plate Locked vs. Eight-Hole Plate Unlocked)</th>
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<tr>
<td>Group 2</td>
<td>Torsional Bending Yield</td>
</tr>
<tr>
<td>Mean</td>
<td>Stiffness Stiffness Strength</td>
</tr>
<tr>
<td>(Std Dev)</td>
<td>(lbs/sec) (lbs/sec) (lbs)</td>
</tr>
<tr>
<td>Experimental</td>
<td>3.14 (0.85) 416.63 (44.32) 277.34 (88.51)</td>
</tr>
<tr>
<td>Control</td>
<td>3.66 (1.93) 452.26 (30.92) 231.12 (104.59)</td>
</tr>
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bending stiffness (kN/m) of the 10-hole unlocked constructs was 88.50 (SD, 9.29) and the control group was 90.76 (SD, 7.60) (p 0.21). The mean yield strength (kN) of the 10-hole unlocked constructs was 1.06 (SD, 0.26) and the control group was 0.89 (SD, 0.30) (p 0.03).

For the Locked group, the mean torsional stiffness of the 10-hole locked constructs was 7.10 (SD, 1.93) and the control group was 8.27 (SD, 4.36) (p 0.33). The mean bending stiffness of the 10-hole locked constructs was 72.96 (SD, 7.76) and the control group was 79.20 (SD, 5.41) (p 0.09). The mean yield strength of the 10-hole locked constructs was 1.23 (SD, 0.39) and the control group was 1.03 (SD, 0.47) (p 0.12).

The mean differences between the experimental and control specimens for torsional stiffness of the Unlocked group was 0.17 and for the Locked group, 1.17 (p 0.49). The mean differences between the experimental and control specimens for bending stiffness of the Unlocked group was 2.25 and for the Locked group, 6.24 (p 0.30). The mean differences between the experimental and control specimens for yield strength of the Unlocked group was 0.17 and for the Locked group, 0.21 (p 0.79).

Of note, data from one pair in the Unlocked group was unable to be used because of a technical error; therefore, data from five pairs were analyzed in this group.

Discussion

Our study found that a longer 10-hole plate with two unlocked screws, in near-far configuration, on either side of a comminuted fracture, had a higher yield strength than an eight-hole plate with three consecutive unlocked screws on either side. However, bending and torsional stiffness were similar for both constructs. We found that the 10-hole plate with two locked screws, in near-far configuration, were similar to the eight-hole plate with three consecutive unlocked screws in torsional and bending stiffness. Both constructs also had a similar yield strength. When the 10-hole unlocked plates with two unlocked screws, on either side of the fracture were compared with the 10-hole plates with two locked screws, no difference was found for torsional stiffness, bending stiffness, and yield strength.

Tornkvist and colleagues used large-fragment (4.5 mm) dynamic compression (DC) plates tested with polyurethane foam and concluded that plate length was more important than the number of screws. However, for 4-point bending with the plate on the tension side, there had to be a screw in a hole nearest to the fracture and one screw five holes away to be stronger than three consecutive screws. In torsion, they found that using two screws in near-far configuration on one side of a fracture was weaker than three consecutive screws.

Sanders and coworkers also plated formalin-fixed ulnae with small-fragment (3.5 mm) DC plates in 4-point bending, with the plate on the tension side as well as orthogonal to the applied force. They also concluded that plate length and filling the end holes were more important than the number of screws. However, they used an osteotomy without a gap that was plated in compression. They found that the 10-hole plates with four screws in near-far configuration had higher peak loads and ultimate moments, but similar stiffness when compared to a six-hole plate with three consecutive screws on either side. The eight-hole plates with four screws in near-far configuration had similar peak loads, ultimate moments, and stiffness. They did not compare the 10-hole plates to the eight-hole plates.

Gardner and associates plated radii with small-fragment eight-hole LCP using three screws, either all locked or all unlocked, in consecutive holes on either side of a 5 mm fracture gap. The locked constructs were stronger in torsion, but not in either bending with the plate on the tension side or orthogonal to the applied force. Data from fracture site motion and energy absorption suggested that the unlocked plates may have slipped. However, the investigators themselves concluded that, overall, the differences between the two constructs were subtle and they questioned their clinical significance.

Fulkerson and colleagues recently concluded that bicalcical locked plating is stronger than unlocked plating in osteoporotic bone. They used eight-hole LCP plates on Sawbone, or polyurethane, ulnae (Pacific Research Laboratories, Vashon, Washington) with a 1 cm gap and three consecutive screws on either side, either all locked or all unlocked. The unlocked constructs sustained more displacement with cyclic axial load and lasted fewer cycles with subsequent cantilever bending to failure. However, the unlocked constructs still survived a mean of over 15,000 cycles before failing.

Our model simulated a comminuted forearm fracture, which is traditionally plated with a small-fragment plate that must span the comminution. Therefore, the working length...
of the construct must be longer, and an eight- or 10-hole plate is most often the appropriate size. Longer plates can be used, but the amount of soft-tissue dissection is greater and probably unnecessary. The 10-hole plates with unlocked screws were stronger than the eight-hole plates, but had similar stiffness. This may represent an advantage to using a longer plate. However, we found no biomechanical advantage for using the locked screws in this diaphyseal bone model. It is possible that locking screws might be an improvement in osteoporotic bone; however, this has not been studied in a similar model.

Limitations of our study included the small number of specimens tested in each group. Also, we are unable to directly correlate our results with clinical data. Our study does not take into account biologic factors involved in fracture healing. All soft tissues were dissected off the specimens. Furthermore, there may be differences, based on fracture motion, in the healing of comminuted diaphyseal fractures between unlocked and locked plates, even when both are used as bridge plates.

Statement Disclosures

Each author certifies that he or she has no commercial associations, including consultancies, stock ownership, equity interest, patent and licensing arrangements, that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

References