Do Locking Screws Work in Plates Bent at Holes?
Christina L. Boulton, MD,* Hyunchul Kim, MS,† Swapnil B. Shah, MD,‡ Scott P. Ryan, MD,* Thomas A. Metzger,† Adam H. Hsieh, PhD,† and Robert V. O’Toole, MD*

Objective: To assess whether plate bending at a hole significantly changes the biomechanical properties of a locked screw.

Methods: Coronal plane bends of 5-, 15-, or 45-degree angles were placed in 3.5-mm locking compression plates with the apex at a locking hole. An additional 45-degree angle test group was created in which a threaded screw head insert was placed before bending. Ten plates were tested in each group and compared with nonbent controls in a stepwise cyclic loading protocol.

Results: Statistically significant differences in protocol survival were shown between the control group and the 15-degree angle (P = 0.006) and 45-degree angle (P = 0.0007) groups. An apparent decrease in protocol survival in the 5-degree angle group did not reach statistical significance (P = 0.17). The average number of cycles survived was significantly different between the control group and the 15-degree angle (P = 0.027) and 45-degree angle (P = 0.0002) groups. The mean cycles to failure for the 5-degree angle group was 16% lower than for controls but did not reach statistical significance (P = 0.37). The test group bent to an angle of 45 degrees after placement of a threaded screw head insert showed no difference in protocol survival or in mean number of cycles survived compared with the regular 45-degree angle group.

Conclusion: Bending of a 3.5-mm locking compression plate by more than 5 degrees at a locking hole results in a statistically significant decrease in survival of the corresponding locked screw. This effect cannot be prevented by the placement of a threaded screw head insert before bending.

Key Words: locking plates, plate bending, hybrid plating, locked screw function

(J Orthop Trauma 2014;28:189–194)

INTRODUCTION
Locking plates are used frequently and at multiple anatomic locations. They often require bending to aid in fracture reduction or to contour the plates to bony anatomy. However, little is known about the effects of bending on subsequent locked screw function. Multiple studies have been published investigating other factors that affect the biomechanical properties of locked plate constructs.1–5 Placement of a nonlocking screw at the end of a locking construct has been shown to increase bending strength by 40% in osteoporotic bone.1 The filling of an open central hole has been shown to significantly increase the stiffness and fatigue life of locking one-third tubular plates.2 Biplanar (staggered) locking screw placement has been found to increase the torsional strength of bridging constructs in osteoporotic and normal bone.3 Early studies of new far cortical locking technology have shown decreased construct stiffness and increased callus formation with minimal changes in axial, torsional, and bending strength.3,5

Despite these reports, no publications in the literature focus on the effects of plate bending on locked screw function. Manufacturer recommendations regarding the contouring of plates can be vague and challenging to implement. For the Synthes (Synthes, Inc., West Chester, PA) 3.5-mm limited contact dynamic compression plate, the technique guide states, “plate holes have been designed to accept some degree of deformation” and “significant distortion of the locking holes will reduce locking effectiveness.” However, no objective guidelines are available regarding how much bend is too much. In addition, it is recommended that the surgeon “place the bending irons [to] ensure that the threaded holes will not be distorted.” However, accompanying illustrations of contoured locking plates clearly show bends through the threaded holes.6 In clinical practice, bending and distortion of screw holes can be difficult to avoid when contouring a plate to fit a patient’s specific bony anatomy (Fig. 1). Therefore, more information is needed regarding the effects of plate bending on locking screw function.

The traditional use of locked plates as internal–external fixators to bridge comminuted fractures rarely involves a need for plate contouring. This could explain why published data on bent plates are lacking. However, the use of hybrid plating techniques with both locking and nonlocking screws is
becoming increasingly more common and often requires plate bending.

Hybrid plating is especially useful for periarticular fractures in osteoporotic bone for which the use of fixed-angle locking screws can be helpful to bridge areas of metaphyseal comminution, supplement standard fixation in poor quality bone, or provide adequate unicortical fixation into limited bone stock.\(^7,8\) Hybrid plating has been shown to provide greater torsional strength and similar bending strength when compared with all-locked bridge plating in comminuted fractures of the humerus (Fig. 1).\(^7\) Precontoured locking plates are available for use in many anatomic locations and typically are manufactured such that the locking holes and threads are cut into the plate after contouring has occurred, thereby preventing warping and damage to the locking function (Synthes). However, their invention has not precluded the need for in situ plate bending in clinical practice and their cost is not comparable. For the distal humerus, standard locking compression plates (LCP) are 3–5 times less expensive than their precontoured alternatives (Synthes).

Our objective was to determine whether plate bending significantly changes the biomechanical properties of a locked screw–hole unit when the bending is performed through a locking hole. Our null hypothesis was that locked screws placed into plates that have been bent at the holes show no significant survival difference compared with those placed into nonbent control plates in a clinically modeled cyclic loading protocol.

**MATERIALS AND METHODS**

Small fragment 3.5-mm LCP were used, and a single coronal plane bend was placed in each test plate using a standardized technique that placed the bend apex at a locking hole. Handheld bending irons were used for all bending. A standard small fragment locking screw was placed into each sample at the bent locking hole and was hand tightened using a standard surgical technique. Torque limiters were not used because they would not be used in our clinical practice for this implant.

Sample test plates were created with bends at angles of 5 (n = 10), 15 (n = 10), and 45 (n = 10) degrees and were compared with nonbent controls (n = 10). An additional 45-degree angle test group was created in which a threaded screw head insert (Synthes) (Fig. 2) was placed before bending. Bending was performed in the same manner as described above, and the insert was then removed and replaced with a locking screw. Plates were potted with 2-part Bosworth Fastray self-hardening epoxy-based filling material (The Bosworth Company, Skokie, IL) and were placed into custom aluminum boxes. Bent test plates were potted obliquely such that the screw shaft was perpendicular to the loading device (Fig. 3). Horizontal screw alignment was confirmed with a level before loading. Both ends of the plate were fixed in pots to best mimic a clinical scenario in which the plate is anchored to the bone both proximally and distally, allowing minimal plate motion with loading of the screw (Fig. 3). Each screw was loaded orthogonal to its long axis at a distance of 15 mm from the undersurface of the plate. Locked screw failure was defined...
as a change in screw angulation of 10 degrees from the starting orientation, which corresponded to a vertical displacement of 2.7 mm at the point of loading. A tilting of 10-degree angle was chosen because it consistently represented a point at which the locking mechanism failed, allowing free toggling of the locking screw within the hole.

Loading and failure testing were performed with a mechanical testing and simulation (MTS) system (MTS 858 Mini Bionix II load frame; MTS Systems Corporation, Eden Prairie, MN). Values for load and displacement were recorded directly from the MTS transducer and stored on a dedicated data acquisition computer. All testing was conducted under load control. A stepwise cyclic loading protocol was performed for a total of 10,000 cycles or until failure. The loading protocol was performed at 2 Hz with increasing force every 2500 cycles starting at approximately 5% of body weight (35 N) and finishing at approximately 20% of body weight (140 N). The complete protocol was as follows: 5% of body weight (35 N) for 2500 cycles, then 10% of body weight (70 N) for 2500 cycles, then 15% of body weight (105 N) for 2500 cycles, and 20% of body weight (140 N) for 2500 cycles.

The loading protocol was designed to model early postoperative forces across a single locking screw in the humerus. Although multiple experimental loading protocols have been previously published for testing fixation constructs in the humerus,8,9 no such protocols have been reported for testing of a single locking screw–hole unit. Pre-experiment testing revealed that single locked screws could sustain continuous (noncyclic) loads in the range of 350–450 N before failure occurred by deformation of the screw shaft while the integrity of the locking mechanism remained intact. This method of loading was therefore judged neither to adequately test the locking screw–plate interface nor to accurately represent clinical failures in which bony fixation is lost before screw deformation. For this reason, the cyclic loading protocol was designed with a maximum force well below 350 N to allow loading through the screw–plate interface but prevent screw deformation. A stepwise increase in loading was used to simulate the gradual increase in forces across the screw with increased weight bearing and range of motion. All experimental samples were examined after either completion of the cyclic loading protocol or failure.

All failures were identical in mechanism and involved disengagement of the screw threads, allowing the locking screw to be freely toggled within the hole, similar to a nonlocking screw. No difference in failure mechanism was observed within or between groups, and no screws had undergone plastic deformation in any group.

**Statistical Analyses**

Outcome variables included screw failure and number of cycles survived before failure. The Fisher exact test was used to compare frequency of screw failure among groups, and 2-tailed \( P \) values were obtained. Analysis of variance was used to compare number of cycles survived among groups. Paired group-to-group comparisons of cycles to failure were conducted with the

**TABLE 1. Protocol Survival Data**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>5-Degree Bend</th>
<th>15-Degree Bend</th>
<th>45-Degree Bend</th>
<th>45-Degree Bend + Insert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survived</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Failed</td>
<td>2</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Survival rate</td>
<td>80</td>
<td>40</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>( P ) *</td>
<td>—</td>
<td>0.17</td>
<td>0.006*</td>
<td>0.007*</td>
<td>0.006*</td>
</tr>
</tbody>
</table>

*Statistically significant.
Tukey Honestly Significant Difference Test when analysis of variance produced statistically significant results. Statistical significance was set at $P = 0.05$ for all analyses.

**RESULTS**

None of the plates in the 45-degree angle group survived the full cyclic loading protocol. One, 4, and 8 of 10 plates survived the full protocol in the 15-degree angle, 5-degree angle, and control groups, respectively. Of the 10 test plates bent to a 45-degree angle, 1 was unable to be tested because the threads of the contoured hole would not engage a locking screw despite multiple attempts. This plate was excluded from analyses; therefore, only 9 samples were tested in the 45-degree angle group ($n = 9$).

Comparison of protocol survival between the control group and each of the bent plate groups showed a statistically significant difference between the control group and both the 15-degree angle ($P = 0.006$) and 45-degree angle ($P = 0.0007$) groups. The 5-degree angle group showed apparent poorer survival than the control group, but the difference did not reach statistical significance ($P = 0.17$) (Table 1 and Fig. 4).

The average cyclic load (number of cycles) survived was also poorer for all bent plate groups. The difference between the control group (mean: 9004.5 cycles) and the 15-degree angle (mean: 5691.4 cycles; $P = 0.027$) and 45-degree angle (mean: 3827.6 cycles; $P = 0.0002$) groups was again statistically significant. The mean cycles to failure in the 5-degree angle group was 16% lower than in the control group (mean: 7537.5 vs. 9004.5 cycles); however, the difference did not reach statistical significance ($P = 0.37$). Analysis

**TABLE 2. Data Summary: Number of Cycles Survived**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Control</th>
<th>5-Degree Bend</th>
<th>15-Degree Bend</th>
<th>45-Degree Bend</th>
<th>45-Degree Bend + Insert</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>5043</td>
<td>2502</td>
<td>4199</td>
<td>17</td>
<td>5001</td>
</tr>
<tr>
<td>S2</td>
<td>10,000</td>
<td>5010</td>
<td>2502</td>
<td>2373</td>
<td>733</td>
</tr>
<tr>
<td>S3</td>
<td>10,000</td>
<td>10,000</td>
<td>7682</td>
<td>5001</td>
<td>2504</td>
</tr>
<tr>
<td>S4</td>
<td>10,000</td>
<td>9440</td>
<td>7501</td>
<td>5001</td>
<td>2501</td>
</tr>
<tr>
<td>S5</td>
<td>10,000</td>
<td>10,000</td>
<td>5006</td>
<td>2502</td>
<td>7508</td>
</tr>
<tr>
<td>S6</td>
<td>10,000</td>
<td>5001</td>
<td>2501</td>
<td>5001</td>
<td>2500</td>
</tr>
<tr>
<td>S7</td>
<td>10,000</td>
<td>5250</td>
<td>7500</td>
<td>6042</td>
<td>5001</td>
</tr>
<tr>
<td>S8</td>
<td>10,000</td>
<td>8172</td>
<td>10,000</td>
<td>5003</td>
<td>5000</td>
</tr>
<tr>
<td>S9</td>
<td>5002</td>
<td>10,000</td>
<td>5011</td>
<td>3508</td>
<td>10,000</td>
</tr>
<tr>
<td>S10</td>
<td>10,000</td>
<td>10,000</td>
<td>5012</td>
<td>NA†</td>
<td>2500</td>
</tr>
<tr>
<td>Mean</td>
<td>9005</td>
<td>7538</td>
<td>5691</td>
<td>3828</td>
<td>4325</td>
</tr>
<tr>
<td>SD</td>
<td>2099</td>
<td>2822</td>
<td>2428</td>
<td>2028</td>
<td>2787</td>
</tr>
</tbody>
</table>

$P$* = 0.37, $P$ = 0.027§, $P$ = 0.0002§, $P$ < 0.01§

*Analysis of variance, $P = 0.0002$.
†NA, not applicable.
‡Computed by comparison of control group with test groups using Tukey honestly significant difference test.
§Statistically significant.

FIGURE 4. Bar graph illustrates cyclic loading protocol survival. Asterisks indicate groups that were statistically significantly different from the control group.
of variance among all groups combined showed a statistically significant effect ($P = 0.0002$) (Table 2 and Fig. 5).

In the 45-degree angle test group of plates that were bent with a threaded screw head insert in place, 1 of 10 plates survived the full cyclic loading protocol; however, no statistically significant difference was shown in the protocol survival ($P = 1.00$) or in the mean number of cycles survived (mean: 3827.6 vs. 4324.8 cycles; $P < 0.01$) when this group was compared with the original 45-degree angle group. As with the original 45-degree angle group, when compared with the control group, the 45-degree angle group with inserts showed a statistically significant difference in both protocol survival ($P = 0.006$) and mean cycles survived ($P < 0.01$) (Tables 1, 2 and Figs. 4, 5).

**DISCUSSION**

Our results indicate that plate bending of more than 5 degrees at a locking hole can significantly compromise the function of a locking screw. The severity of this effect increases with magnitude such that plate bends of 45 degrees result in severe compromise of locking function. This is evidenced in that none of the plates in the 45-degree angle group survived the loading protocol and 1 of the 45-degree angle plates needed to be excluded from analysis because no screw could be threaded into the locking hole after plate bending. Less severe but significant compromise was observed with 15-degree angle bends, and no statistically significant difference was observed with 5-degree angle bends, suggesting a threshold effect.

Considering these findings, we sought to determine whether the deleterious effect of bending on the locking hole was preventable with the placement of a threaded screw head insert before bending. These inserts are also known as 3.5-mm threaded plugs and are commercially available from Synthes (Fig. 2). Use of the inserts to fill empty holes has previously been shown by Bellapianta et al. to improve the mechanical properties of locking one-third tubular plate constructs. Our theory was that the threaded insert may prevent warping and deformation of the hole during bending and therefore decrease the subsequent loss in locking function. However, our results indicated no benefit.

Our findings are important because as hybrid fixation becomes more popular, an increasing body of evidence is emerging to guide surgeons in the application of the technique to maximize fracture fixation. In locations such as the distal humerus, bends in excess of 5 degrees are commonly required to adequately contour the plate to the bony anatomy. Our data suggest that if this bending occurs through a locking hole, the surgeon cannot rely on preservation of normal locking function at that site.

In cases of limited bone stock, achieving screw fixation in distal humeral fragments can be very challenging. The use of locking screws for this application has been well supported in the literature. Hak et al. showed that 2 locked screws per segment confer mechanical stability equivalent to that of 3 in the osteoporotic humerus. Mehling et al. showed superior resistance to bending loads when more than 1 locking screw is used in the ulnar fragment of T-type distal humeral fractures. However, studies to date have not taken into account the changes to locking function when plate contouring is performed.

As with all biomechanical modeling, several important limitations need to be considered. Our study focused on the function of a single locking screw–hole unit after plate bending. However, multiple variables likely affect locking screw function when a plate is bent in clinical practice. Examples of other potential variables include plate-related factors, such as...
length, thickness, material, spacing between holes, and number of locking threads per hole, and technique-related factors, such as type of plate benders used, length of area involved in bend, location of locking hole with respect to bend apex, contouring in multiple planes, and number of attempts made before acceptable contour is achieved. Our isolation of plate bend to a single plane and a single locking hole within the plate allowed our analysis to detect differences between test groups that might otherwise have been masked by compounding factors. However, the simplicity of our design also limits the extent to which our results can be extrapolated to more complex clinical situations.

Another limitation is that the biomechanical loading protocol might not reflect the true magnitude or direction of forces across a single locking screw in vivo. In addition, our investigation focused on the Synthes LCP because it was in widespread use and available in most clinical settings. However, several other 3.5-mm locking plates that can be contoured are available from Synthes and from other implant manufacturers. Because the locking holes in the LCP are within oval combi-holes, the locking threads do not come in contact with the entire circumference of a locking screw compared with the threads in the round locking holes of alternative implants. It is not clear whether our results can be generalized to other implants.

We analyzed outcomes of screw failure and number of cycles survived before failure. Our findings regarding the differences between groups and the apparent threshold effect for bends greater than 5 degrees were the same for both outcomes. However, it should be noted that these 2 outcomes are by no means independent of each other. Groups with lower protocol survival rates will subsequently have lower mean number of cycles to failure.

Although our analysis largely focused on the bent test plates, interestingly, 2 of the 10 control plates did not survive the cyclic loading protocol, suggesting that other factors also influence the function of a locked screw–hole interface. Post-testing inspection revealed that 1 of the 2 plates had inadvertent cross-threading of the locked screw. Further study is needed to determine whether cross-threading has a significant impact on locked screw survival.

We conclude that plate bending at a locking hole results in a statistically significant decrease in cyclic loading cycles to failure of the corresponding locked screw. For the 3.5-mm Synthes LCP, this effect reaches statistical significance for bends in excess of 5 degrees. Placement of a locking screw–hole insert before bending does not protect locking hole function. Caution should be taken to avoid contouring plates such that the bend apex falls at a locking hole that will later be used for screw placement. In cases in which screw placement through bent locking holes cannot reasonably be avoided, the surgeon should be cognizant that bending can compromise locking screw function and should adjust adjacent fixation accordingly.

ACKNOWLEDGMENTS

The authors thank Dori Kelly, MA, Senior Editor and Writer, for assistance with the article preparation and Dr. W. Andrew Eglseder for providing the radiographs shown in Figure 1.

REFERENCES


