THE EFFECT OF DIVERGENT SCREW PLACEMENT ON THE INITIAL STRENGTH OF PLATE-TO-BONE FIXATION

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Introduction

Recent approaches to open reduction and internal fixation have led to the use of techniques that are less invasive and destructive to the soft tissues. Bridge plating and even percutaneous techniques are now commonplace. These techniques frequently do not impart absolute stability to the repair and thus load transfer to the plate becomes more important. Recommendations are made for the use of longer plates, without necessarily implementing screws into all of the holes. Another area in which the strength of plate to bone fixation becomes more important is in the situation of osteoporotic or pathologic bone. Not only is the fixation often compromised, but also fractures through poor quality bone are often comminuted and interfragmentary stability may be impossible or unwise to achieve.

Newer implants have been developed which allow screws to be placed into bone at varying angles, most commonly for lag fixation or to grab additional fracture fragments. This study was developed to determine if placing screws at different angles into the same piece of bone would increase the overall strength of the fixation. This is a biomechanical study in two parts: The first investigates the resistance of individual screws inserted at varying angles to the axis of pullout. The second portion compares the initial strength of a plate-bone construct with the end screws placed at varying divergent angles along the axis of the plate to the strength of a traditional parallel screw arrangement.

Methods

Polyurethane foam with a density of 0.32 g/cm3 (Pacific Research Labs, Vashon, WA) was cut into 40mm x 74mm strips for use in testing. An MTS 858 Biokinetics testing system was used. All screws were inserted with custom fixed-angle drill guides and hand tightened by a single investigator (KR). Results were analyzed through one-way ANOVA, with post-hoc Student-Newman-Keuls tests, all at a 5% significance level.

Screw Pullout Testing: In order to model clinical implementation, a standard narrow large-fragment LC-DC plate (Synthes, Paoli, PA) was mounted into a pullout jig that allowed for angulation of the screw in the plate up to 40 degrees in either direction along its axis. The construct was assembled by drilling a 3.2mm hole in the foam at the test angle with a drill guide. The pullout jig was then placed over the hole and the appropriate length 4.5 mm cortical screw (Synthes, Paoli, PA) was inserted through the plate and tightened. The assembly was then placed into the test machine with the foam block clamped to a platform on the load cell and the plate bolted to a jig on the actuator. The test was run by lowering the actuator at 0.5 mm/sec to failure of the construct. The resultant torque at failure was measured by the torsional load cell.

Plate Fixation Testing: To investigate the strength of plate fixation, a single plate to bone construct was tested. This correlates clinically with testing one end of bridge plate fixation where no interfragmentary stability is assumed. The last three holes of a large-fragment broad LC-DC plate were used to fix the plate to the test material with 4.5 mm cortical screws in 3.2 mm drill holes. The center screw was placed perpendicular to the plate in each test. The two outer screws were placed at the angle to be tested diverging from the center screw at 10, 20, and 30 degrees along the axis of the plate. The center hole was fitted with a 30 mm screw and the length of the end screws was varied with the angle of insertion to maintain a consistent overall insertion depth. For control the construct was tested with all of the screws in a traditional parallel configuration (0 degrees.) To ensure comparable tests the plate was placed in a consistent position for each mode of testing allowing for the space needed for the most divergent screw. Each angle of divergence (0, 10, 20 and 30 degrees) was assembled and tested five times in each of three loading modes: gap-open bending, axial compression and torsion.

Results

The bending strength of the construct was tested with the use of a four-point bending frame. The actuator and upper support was then lowered at a rate of 0.5 mm/sec to the failure of the construct. The resultant force at failure was measured and the moment was calculated using beam theory.

The strength of the construct in axial compression was tested by assembling the plate to the foam model as described above. The construct was then mounted vertically in the MTS machine with the foam block clamped to a platform on the load cell and the plate bolted to a jig on the actuator. The test was run by lowering the actuator at 0.5 mm/sec to failure of the fixation. The resultant force at failure was noted.

**Macropore, Inc, San Diego, CA.

Discussion

These tests reveal that although screw pullout strength may be diminished by inserting the screws at an angle, the strength of the construct may increase in compression and gap open bending. However, no effect was shown in torsional strength. This technique is readily applicable, and should not alter the duration or difficulty of standard plate-to-bone fixation. This method should be particularly pertinent to bridge plating and as well as minimally invasive procedures. Additionally the technique may be even more advantageous for minimally invasive and percutaneous plating in that diverging the outer screws can allow several screws to be inserted through a single incision over the middle screw.

This study has several limitations: Although shown to be generally similar in its properties to human metaphyseal bone, the fracture mechanics of the foam may be dissimilar to the failure mode in human bone. Also only the parameter of failure load was evaluated, whereas long-term failure modes such as fatigue are clinically relevant.

Despite these limitations, these results suggest that screws inserted at an angle may improve bone-to-plate fixation. Certainly, these results should allay hesitation to angle screws for fear of weakening bone to plate fixation.

Table 1

<table>
<thead>
<tr>
<th>Screw Angle (Degrees)</th>
<th>Pullout Resistance (N)*</th>
<th>Gap Open Bending (Nm)*</th>
<th>Torsion (Nm)</th>
<th>Axial Compress (N)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1688 ± 103</td>
<td>33.57 ± 2.2</td>
<td>18.69 ± 1.7</td>
<td>1345 ± 115</td>
</tr>
<tr>
<td>10</td>
<td>1502 ± 120</td>
<td>33.27 ± 1.8</td>
<td>18.76 ± 1.2</td>
<td>1454 ± 93</td>
</tr>
<tr>
<td>20</td>
<td>1066 ± 88</td>
<td>38.54 ± 2.5</td>
<td>18.97 ± 1.4</td>
<td>1740 ± 119</td>
</tr>
<tr>
<td>30</td>
<td>1102 ± 74</td>
<td>38.76 ± 3.9</td>
<td>19.56 ± 1.7</td>
<td>1870 ± 84</td>
</tr>
</tbody>
</table>

*Resistance at 20° bending and axial compression (indicated by asterisks on the table). No effect of angle was found in torsion. The post-hoc tests revealed that pullout resistance at 20° and 30° was lower than at 0°. In contrast, gap open bending and axial compression failure loads were higher for 20° and 30° than for 0° and 10°. No significant differences were found in torsion. Table 1 shows in bold those values that were significantly different from the values at 0°.