The effects of wire diameter and an additional lateral wire on pin and tension-band fixation subjected to cyclic loads

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Introduction

Pin and tension-band wire (PTBW) is the most commonly used fixation technique for simple olecranon fractures and osteotomies despite frequent complications, including nonunion, soft-tissue irritation, and implant failure (1–5). Researchers have evaluated pin and tension-band modifications (double wire twists, transcortical pins, and long intramedullary pins) and alternatives (bone plate, interlocking nail, interfragmentary screw, circular external fixator) with the goal of reducing the incidence of complications (7–19).

We recently subjected Delrin® olecranon osteotomy models to linearly-increasing loads to investigate several fundamental pin and tension-band factors, including pin and wire configuration (figure-of-eight versus lateral), and osteotomy angle. Wire diameter was found to be the key determinant of fixation strength with 1.25-mm wire demonstrating advantage over 1.0-mm wire at fracture gaps as small as 0.03 mm. We also found that a laterally-placed wire, previously suggested to replace or augment a figure-of-eight wire, provides weaker fixation alone, but strengthens fixation when combined with a figure-of-eight wire (6, 20–22).

The present study employed a similar Delrin model to assess any advantage provided by 1.25-mm wire or an additional lateral wire over 1.0-mm wire for pin and tension-band fixation under cyclic loading. Cyclic fatigue is generally considered a more clinically representative testing method and has been used in previous olecranon non fixation studies (10, 17). In terms of cycles to failure, minimum displacement, maximum displacement, and displacement per cycle, it was our hypothesis that 1.25-mm wire would survive the most cycles and allow the smallest displacements, followed by combined figure-of-eight/lateral wires, and finally 1.0-mm wire.

Materials and methods

The olecranon osteotomy model

Pin and tension-band wire fixation was applied to bars of Delrin, an acetyl resin that has effectively served as a bone model in previous mechanical studies (6, 23, 24). This model was designed to mimic a canine olecranon osteotomy. An osteotomy was created on one end of the Delrin bar, repaired by PTBW, and tested with a cyclic tensile force applied at 135° to the long axis of the bar to simulate the triceps tendon. All Delrin bars (13 mm x 24 mm x 148 mm) were from a single lot (McMaster-Carr Supply Company, Cleveland, Ohio) to maintain uniform size and density. In order to simplify description of the model, anatomical terms were assigned to its various aspects. Two 5-mm holes were drilled transversely through each bar 15 and 45 mm from the distal end to provide fixation points during testing and a 4-mm hole was drilled transversely 3 mm from the cranial and proximal surfaces to later accommodate a steel rod with clamps (Fig. 1).

Summary

Despite reports of frequent complications, pin and tension-band wire remains the most common repair of simple olecranon fractures and osteotomies (1–5). A recent mechanical study found wire diameter to be the key determinant of pin and tension-band construct strength; models with 1.25-mm wire were much stronger than those with standard 1.0-mm wire exposed to single loads to failure (6). Additionally, fixation strength was also increased when a lateral wire was used in combination with a standard figure-of-eight wire. The purpose of the present study was to assess any advantages provided by 1.25-mm wire or an additional lateral wire over 1.0-mm wire for pin and tension-band fixation subjected to cyclic loading. Pin and tension-band fixation was applied to plastic olecranon osteotomy models with three wire configurations: 1.0-mm figure-of-eight, 1.25-mm figure-of-eight, and combined 1.0-mm figure-of-eight and lateral. Cyclic load was applied while caudal osteotomy displacement was measured with an extensometer. The three groups were compared in terms of cycles to failure, mean minimum displacement, mean maximum displacement, and mean displacement per cycle. Models with an additional lateral wire survived significantly more cycles than those with a solitary 1.0-mm figure-of-eight wire, although caudal osteotomy displacements were not significantly different. Conversely, models with 1.25-mm wire allowed significantly smaller minimum and maximum displacements than those with 1.0-mm wire, but did not survive significantly more cycles. It therefore appears that clinical use of 1.25-mm wire may improve stability, while use of an additional lateral wire may improve durability.

Keywords

Pin and tension-band wire, olecranon fixation, olecranon osteotomy, cyclic testing, Delrin®
Three tension-band wire configurations

Three PTBW configurations were defined with eight models included in each group. The 1.0-mm-Wire Group was defined as having an oblique osteotomy fixed with a 1.0-mm figure-of-eight wire passed around two 1.6-mm pins according to AO technique (25). The alternative configurations were identical to the 1.0-mm-Wire Group other than the substitution of 1.25-mm wire for the 1.25-mm-Wire Group and the addition of a 1.0-mm lateral wire for the Combined-Wires Group (Fig. 2).

Pin and tension-band wire model construction

Osteotomy simulation was performed with an electric table saw with a kerf of 1 mm. The Delrin bars were cut at an angle of 75° from the longitudinal axis starting 20 mm from the proximal surface cranially and ending 26 mm from the proximal surface caudally (Fig. 1).

The pins and wire, also obtained from single lots (Securos Incorporated, Charlton, Massachusetts), were placed using a custom-designed Plexiglas® (Atoglas, Philadelphia, Pennsylvania) jig. 1.6-mm pins were inserted into 1.6-mm holes drilled 5 mm apart, 4 mm from the caudal edge, and equal in diameter to the selected pin. Pins were marked with ink 55 mm from their tips and then inserted at an angle of 15° from the longitudinal-axis until the mark met the proximal surface (Fig. 1).

Tension-band wires fashioned from 1.0-mm wire were passed through 1.1-mm drill holes. The 1.25-mm wire was passed through 1.6-mm drill holes. The figure-of-eight wires were passed proximally around the pins and distally through a hole 52 mm from the proximal surface and 5 mm from the caudal surface. In addition to a 1.0-mm figure-of-eight wire, models of the Combined-Wires Group contained a 1.0-mm lateral wire which was passed through two holes: 12 mm from the caudal surface and 7 mm and 52 mm from the proximal surface (Fig. 2).

Utilizing a torque-controlled screwdriver (Snap-on Tools, Crystal Lake, Illinois) with a custom-designed wire-twisting attachment, the failure threshold for 1.0 and 1.25-mm wire was determined to be 40 and 70 N-cm, respectively. Consequently, maximum torques of 39, and 69 N-cm for the two wire sizes were used to produce consistent twist tension and prevent wire breakage during twisting. Each tension-band wire was tightened with twist knots on both sides of the figure-of-eight. Knots were cut leaving four to five twists and not bent over.

Once all pins and wires were applied, 4-mm-diameter, 5-cm-long stainless steel rods were placed through the aforementioned cranio-proximal transverse drill holes. Braided-steel cable (7x7 strands) (McMaster-Carr Supply Company; Cleveland, Ohio) of 3-mm diameter was cut into 28-cm segments and threaded through medium Kirschner-Ehmer external fixator clamps. The cable ends were fastened with 7-mm-long round compression sleeves to prevent slippage through the clamps (McMaster-Carr Supply Company; Cleveland, Ohio) (Fig. 3).
Pin and tension-band fixation subjected to cyclic loads

Mechanical testing

Mechanical testing was performed with a Bionix 858 servo-hydraulic materials test system (MTS Systems Corporation; Eden Prairie, Minnesota) and a custom-designed aluminum test fixture. Each of the twenty-four models was randomly selected and rigidly fixed at a 45° angle within the fixture by passing two 5-mm pins through the transversely-drilled holes. An extensometer (MTS model 632.31F-24 (travel 6 mm, nonlinearity .06%), MTS Systems Corporation; Eden Prairie, Minnesota) was placed caudally with its arms equally spaced from the osteotomy to record displacement. The extensometer straddled the crossing point of each figure-of-eight wire with no contact occurring between the two during testing (Fig. 3). Tensile load was applied to each construct via the steel-cable loop at a constant angle of 135°. Cycles from 45 to 450 N were applied at a rate of 5 Hz until failure, defined as 2-mm fracture-site displacement, was obtained. Minimum and maximum displacements were defined as the gaps caused by the minimum (45 N) and maximum (450 N) load applied during each cycle. To obtain a manageable amount of data, the minimum and maximum displacements over ten cycles were recorded every one thousand cycles. The mode of failure was also observed and recorded.

Statistical analysis

The mean, median, and standard deviation of number of cycles to failure, mean minimum displacement, mean maximum displacement, and mean displacement per cycle (maximum displacement– minimum displacement) over the first 15,000 cycles were determined for the three groups. All three groups were compared. Based on the results of Bartlett’s test for group variance homogeneity, comparisons between groups were made with the Kruskal-Wallis test followed by Dunn’s multiple comparison test. Pearson’s correlation coefficient was used to explore the relationship between cycles to failure and displacement per cycle for each of the three groups. Significance was defined as p values less than 0.05. All statistical analysis was performed with GraphPad Prism version 4.02 for Windows (GraphPad Software, San Diego California USA, www.graphpad.com).

Results

Failure of all models occurred by wire breakage at the base of one of the twists, breakage of the figure-of-eight wire was at the base of a wire twist. Lateral wire breakage was not necessary to achieve failure as it did not occur in any Combined-Wires model; once the figure-of-eight wire broke, a 2-mm displacement was immediately obtained with the lateral wire remaining intact. Some degree of proximal pin back out was observed in most models; however, fixation was never lost due to pins exiting the distal fragment prior to wire breakage.

A typical plot of the minimum and maximum displacement values for a Combined-Wires Group model is presented in Fig. 4. This plot is similar to those of the other 23 models in that displacement values remained relatively constant until just prior to the point of failure. Failure (2-mm gap) coincided with breakage of the figure-of-eight wire in all models, including the Combined-Wires Group models whose lateral wires invariably remained intact.

Descriptive statistics and dot plots are provided in Table 1 and Fig. 5, respectively. Group variances were not homogenous for cycles to failure (p < 0.0001), minimum displacement (p < 0.0001), maximum displacement (p < 0.0005), and displacement per cycle (p < 0.0005).

Statistical group comparison results are provided in Table 2. The Combined-Wires Group survived significantly more cycles than the 1.0-mm-Wire Group (p < 0.05). The other cycles to failure group comparisons revealed no significant differences (p > 0.05). The 1.25-mm-Wire Group maintained significantly smaller minimum (p < 0.05) and maximum (p < 0.05) displacements than the 1.0-Wire Group, while other
displacement comparisons revealed no significant differences (p > 0.05). No significant differences were found in terms of displacement per cycle (p > 0.05).

Plots of displacement per cycle versus cycles to failure are provided in Fig. 6. Correlation between these two measures was found to be significant for both the 1.0-mm-Wire (p = 0.0179) and 1.25-mm-Wire Groups (p = 0.0029), but not the Combined-Wires Group (p = 0.492).

Discussion

In our previous study using a Delrin olecranon osteotomy model, it was demonstrated that pin and tension-band fixation with 1.25-mm wire or an additional lateral wire was stronger than that with solitary 1.0-mm wire when subjected to a single load to failure (6). Logistically, single-load testing was well-suited to that study to allow testing of a number of variables, including pin diameter, wire diameter, wire-hole position, wire configuration, and osteotomy angle in a single study. The 1.0-mm wire diameter was selected as our control based on its popularity in previous biomechanical studies of olecranon fixation by pin and tension-band wire (7–10, 12, 15–17). Wire diameters of 0.8 and 1.25 mm have also been used, and overall past selection of wire diameter seems to have been largely arbitrary (11, 14, 18, 19).

The present study was designed to determine what advantages, if any, 1.25-mm wire or an additional lateral wire offered over 1.0-mm wire when pin and tension-band fixation was subjected to cyclic loads. Cyclic testing is a better representation of the loads faced by orthopaedic implants clinically and has been used in two previous biomechanical olecranon studies (10, 17).

The magnitude of tensile force placed upon the olecranon by the triceps tendon is unknown. In our previous study, 1.0-mm wire models were displaced 2 mm by a load of approximately 900 N (6). Since the 1.0-mm-Wire Group was expected to be the weakest in the present study, the maximum load of each cycle was set at 50% of the 2-mm failure load of that group (450 N) (6). An arbitrary minimum cyclic load of 45 N was selected to eliminate slack in the system at low loads.

Table 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Statistic</th>
<th>Cycles to failure</th>
<th>Minimum displacement (mm)</th>
<th>Maximum displacement (mm)</th>
<th>Displacement/cycle (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0-mm-Wire</td>
<td>Mean</td>
<td>30,875</td>
<td>0.363</td>
<td>0.917</td>
<td>0.554</td>
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<tr>
<td></td>
<td>S. D.</td>
<td>17,618</td>
<td>0.369</td>
<td>0.412</td>
<td>0.063</td>
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<tr>
<td></td>
<td>Median</td>
<td>24,500</td>
<td>0.209</td>
<td>0.762</td>
<td>0.565</td>
</tr>
<tr>
<td>1.25-mm-Wire</td>
<td>Mean</td>
<td>107,500</td>
<td>0.022</td>
<td>0.470</td>
<td>0.448</td>
</tr>
<tr>
<td></td>
<td>S. D.</td>
<td>121,838</td>
<td>0.058</td>
<td>0.197</td>
<td>0.158</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>54,000</td>
<td>0.005</td>
<td>0.474</td>
<td>0.470</td>
</tr>
<tr>
<td>Combined-Wires</td>
<td>Mean</td>
<td>62,625</td>
<td>0.120</td>
<td>0.611</td>
<td>0.490</td>
</tr>
<tr>
<td></td>
<td>S. D.</td>
<td>13,949</td>
<td>0.072</td>
<td>0.106</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>60,500</td>
<td>0.110</td>
<td>0.622</td>
<td>0.209</td>
</tr>
</tbody>
</table>
Comparison of mean displacement values over the first 15,000 cycles was performed based on preliminary data which suggested that all models survived at least that many cycles. Moreover, all models behaved similarly, invariably maintaining consistent minimum and maximum displacements until just prior to failure of the figure-of-eight wire (Fig. 4).

Part of the rationale for this study was to better define any advantage held by large wire (1.25 mm) over more typically used 1.0-mm wire and thereby to provide a stronger basis for wire selection in future studies and clinically. This did appear to be the case when comparing mean cycles to failure of the 1.25-mm wire (107,500 cycles) to the 1.0-mm wire (30,875 cycles). However, this difference was not statistically significant due to the large variation of the former. Three 1.25-mm-Wire models survived much longer (118,000, 178,000, and 378,000 cycles) than the other five, which averaged 37,200 cycles. Consequently, even though the overall mean of the 1.25-mm-Wire Group was over three times greater than that of the 1.0-mm-Wire Group, a significant difference was not detected. The use of non-parametric statistical analysis may have influenced this, but group variances were unequal even after logarithmic transformations were performed, so parametric analysis was inappropriate. It is also possible that this lack of significant difference was due to a type II error.

The Combined-Wires Group, on the other hand, survived significantly more cycles than the 1.0-mm-Wire Group (p < 0.05). Even though the mean of the Combined-Wires Group (62,625 cycles) was less than that of the 1.25-mm-Wire Group (107,500 cycles), models of the former group were more consistent with none failing prior to 41,000 cycles. Three of the 1.25-mm-Wire models failed prior to 30,000 cycles, below the 1.0-mm-Wire Group mean.

Although the 1.25-mm-Wire Group did not survive significantly more cycles than the 1.0-mm-Wire Group (p > 0.05), it did maintain significantly smaller minimum (p < 0.05) and maximum (p < 0.05) displacements over the first 15,000 cycles. Less disruption of healing tissues might therefore be expected in the clinical situation, resulting in quicker healing with the use of the larger wire. On the other hand, minimum and maximum displacements of the Combined-Wires Group were not significantly smaller than those of the 1.0-mm-Wire Group. The wide range of cycles to failure within the 1.25-mm-Wire Group paralleled a similarly wide range in mean displacement per cycle (Figs. 5, 6). The fact that a significant correlation (p = 0.0029) was found between these two measures is not surprising; the further a material is repeatedly displaced, the more rapidly it will fatigue. The most likely reason for these wide variations within the 1.25-mm-Wire Group is that the wire was better contoured to some models than to others. Due to the stiffness of the 1.25-mm wire it was more difficult to perfectly bend it around each model. If any unperceived slack remained in the wire after twisting, more motion would be allowed, resulting in earlier failure. Thus the decreased ease of workability of the large wire may explain why some 1.25-mm-Wire models were vastly more durable than the 1.0-mm-Wire models, while others were roughly equivalent. This may parallel the clinical situation where despite the potential advantages of using larger wire, there is greater technical difficulty in applying the wire securely.

A correlation between cycles to failure and mean displacement per cycle also existed for the 1.0-mm-Wire Group (p = 0.0179), but not for the Combined-Wires Group (p = 0.492) (Fig. 6). In other words, solitary figure-of-eight models of either 1.0 or 1.25-mm wire diameter that allowed greater displacements per cycle failed in fewer cycles than other models in their respective groups. It seems that the figure-of-eight wire of Combined-Wires models that allowed greater displacements per cycle were provided some protection by the lateral wire which likely absorbed a portion of the applied energy as displacements increased. Consequently, Combined-Wires models survived a similar number of cycles regardless of displacement per cycle. This may have

### Table 2
Dunn’s multiple comparison test p values.

<table>
<thead>
<tr>
<th>Groups compared</th>
<th>Cycles to failure</th>
<th>Minimum gap</th>
<th>Maximum gap</th>
<th>Displacement/ cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0-mm-Wire vs. 1.25-mm-Wire</td>
<td>&gt; 0.05</td>
<td>&lt; 0.001</td>
<td>&lt; 0.01</td>
<td></td>
</tr>
<tr>
<td>1.0-mm-Wire vs. Combined-Wires</td>
<td>&lt; 0.05</td>
<td>&gt; 0.05</td>
<td>&gt; 0.05</td>
<td></td>
</tr>
<tr>
<td>1.25-mm-Wire vs. Combined-Wires</td>
<td>&gt; 0.05</td>
<td>&gt; 0.05</td>
<td>&gt; 0.05</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 6: Plots of displacement per cycle versus cycles to failure for the 1.0-mm-Wire, 1.25-mm-Wire, and Combined-Wires Groups (A-C). Best fit lines and 95% confidence intervals are displayed. Models of the 1.0-mm-Wire and 1.25-mm-Wire Groups that allowed greater displacements per cycle failed earlier (p = 0.0179 and 0.0029, respectively). Significant correlation did not exist between these measures for the Combined-Wires Group (p = 0.492). Note that models in the latter group failed after a similar number of cycles regardless of displacement per cycle.
some clinical applicability in that a supplemental lateral wire could provide more consistently durable fixation.

The primary limitation of this study is that it was performed using a plastic model that may not perfectly predict the in vivo performance of pin and tension-band wire. The decision to use a Delrin olecranon osteotomy model was based on its availability, machinability, and the lack of the heterogeneity and variability of cadaveric bone. A solid-plastic model does not perfectly replicate a bone-implant interface; however, the coefficient of friction of Delrin against steel (0.35) is similar to that of bone against titanium (0.34) and it was believed that it would interact with implants in a clinically representative fashion (26, 27). Furthermore, the nature and direction of the forces placed upon the implants would be expected to be similar regardless of the material of the olecranon model. An additional limitation is the size of our model, which was similar to the ulna of a medium dog. Implants may have performed differently in a model of size similar to a large breed dog.

In conclusion, our hypothesis was partially correct. Benefits of both 1.25-mm wire and an additional lateral wire were observed when applied in pin and tension-band fixation subjected to cyclic testing as compared to 1.0-mm wire. 1.25-mm wire provided smaller minimum and maximum osteotomy-site displacements, but did not provide predictably more durable fixation than 1.0-mm wire. On the other hand, the addition of a lateral wire to a figure-of-eight wire provided consistently more durable fixation than a figure-of-eight wire alone, but did not provide smaller fracture-site gaps. When pin and tension-band fixation is applied clinically, the use of a 1.25-mm wire or an additional lateral wire may be considered because it appears the former improves fixation stability, while the latter improves fixation durability. The effect of combining these two modifications remains unknown.

References