Biomechanical comparison of interfragmentary compression in transverse fractures of the olecranon

Compression and absolute stability are important in the management of intra-articular fractures. We compared tension band wiring with plate fixation for the treatment of fractures of the olecranon by measuring compression within the fracture. Identical transverse fractures were created in models of the ulna. Tension band wires were applied to ten fractures and ten were fixed with Acumed plates. Compression was measured using a Tekscan force transducer within the fracture gap. Dynamic testing was carried out by reproducing cyclical contraction of the triceps of 20 N and of the brachialis of 10 N. Both methods were tested on each sample. Paired t-tests compared overall compression and compression at the articular side of the fracture.

The mean compression for plating was 819 N (SD 602, 95% confidence interval (CI)) and for tension band wiring was 77 N (SD 19, 95% CI) (p = 0.039). The mean compression on the articular side of the fracture for plating was 343 N (SD 276, 95% CI) and for tension band wiring was 1 N (SD 2, 95% CI) (p = 0.038).

During simulated movements, the mean compression was reduced in both groups, with tension band wiring at -14 N (SD 7) and for plating -173 N (SD 32). No increase in compression on the articular side was detected in the tension band wiring group.

Pre-contoured plates provide significantly greater compression than tension bands in the treatment of transverse fractures of the olecranon, both over the whole fracture and specifically at the articular side of the fracture. In tension band wiring the overall compression was reduced and articular compression remained negligible during simulated contraction of the triceps, challenging the tension band principle.

Transverse fractures of the olecranon are common. Union with displacement or the formation of excessive callus can lead to post-traumatic osteoarthritis of the elbow. Anatomical reduction and absolute stability is recommended for the treatment of articular fractures, and in the United Kingdom most patients with displaced, transverse fractures of the olecranon are treated with tension band wiring. Numerous other methods of fixation have been described, including interfragmentary screws, intramedullary screws and Rush pins, with or without figure-of-eight wires, fixation with a plate and excision of the proximal fragment with advancement of triceps. When applied to fractures of the olecranon, the tension band principle predicts that flexion of the elbow joint compresses the site of the fracture. However, no data have been provided to support this theory. Previous biomechanical studies of techniques of fixation of these fractures have concentrated on load to failure and have measured displacement. We aimed to identify the most effective method of compressing a transverse fracture of the olecranon, and to characterise the variation in compression of the fracture during simulated movements of the elbow.

Pre-contoured plate fixation was investigated as this is a satisfactory way of compressing other fractures, and there is evidence that it may have advantages over other methods. It was compared to tension band wiring, as this is the most commonly used method in clinical practice. Materials and Methods The experiments were performed on model ulna bones and both methods of fixation were used on each specimen. This cross-over method was used to reduce variability between the samples. A disadvantage of this design is the effect on each model of the previous fixation, which could alter the effectiveness of the second technique. In order to mitigate systematic bias that could arise from this, sealed
envelopes were used to randomly allocate exactly half the sample to tension band wiring first and the other half to plate fixation first. Synthetic material was chosen rather than cadaveric tissue, in order to reduce the variability encountered when human tissue is used. Even subtle variations in the dimensions of the materials subject to the experiment would necessitate a much larger sample size to counteract the problems caused by inexact matching.

The model ulnas (Sawbones, Vashon, Washington) were manufactured to exactly match the proportions and anatomical dimensions of the human ulna. They were also produced from two densities of resin in order to match the structure of bone.

A film pressure sensor (Tekscan, Boston, Massachusetts) that allowed force measurements at 27 individual points per cm² was selected for this project. The film could also be pierced to allow the passage of the implants used to fix the fracture. The sensor had a pressure range from 0 kPa to 13 789 kPa. Prior to each procedure, the sensor was calibrated using the technique recommended by the supplier. The dynamic testing jig was specifically designed and produced in collaboration with the Durham University Engineering Department. It was arranged in the horizontal plane to neutralise the effects of gravity. The force of the triceps pull, generated by the pneumatic piston, was set at 20 N. This was calibrated using a spring force gauge. This value was chosen to replicate the forces used in biomechanical analysis of movement of the elbow by previous authors. This force caused the model ulna to rotate about the pivot, through an arc of between 75° and 125° of flexion. The resistance cord, simulating the reciprocal pull of the brachialis, was set at 10 N at its maximum excursion. Again, this was verified using a spring force gauge and was fixed at half the value of the triceps force. Once the piston relaxed the triceps pull, the 10 N force of the simulated brachialis returned the model ulna to the starting position (Fig. 1).

The two primary outcome measures were the compression force across the whole surface of the fracture and the compression force adjacent to the articular surface. The secondary outcome measure was the change in compression of the fracture adjacent to the articular joint surface during simulated contraction of the triceps.

A transverse fracture was created in each model ulna through the mid-point of the sigmoid notch. Figure 1 shows the site of the fracture and the sensor film can be seen in the gap. A cutting jig and a 0.5 mm straight saw blade were used to standardise the position of the fracture. The pressure sensor was then placed between the fragments, which were then reduced and fixed using tension band wiring or plate fixation. In order to eliminate potential performance bias, all fixations were performed by one surgeon (JW). On completion of fixation the sensor was connected to the monitoring equipment and the model ulna placed in the testing jig.

Compression of the fracture was measured during cycles of simulated elbow movement.

**Statistical analysis.** Data from the experiment were recorded on a Microsoft Excel database and statistical analysis was performed using SPSS v.16 (SPSS Inc., Chicago, Illinois).

A power calculation was carried out using Sample Power 2.0. A pilot study revealed that compression by tension band wiring produced a mean compressive force of 78 N over the whole surface of the fracture. The validity of this value was corroborated by a previous study by Parent et al., who found compression to be 60 N (SD 13). The pilot data had an SD of 31 N. A clinically significant difference in compression was considered to be 40 N. This value was chosen as it is half of the average compressive force measured and larger than the SD. No previous publications have quantified this value. Both methods of fixation were carried out on each specimen, and therefore a paired-samples t-test was used to compare the mean values. With α set at 0.05, only seven model ulnas would be required for a power of 81%. However, to improve the precision of the results and to align this study with the sample sizes of previous similar biomechanical experiments, this value was exceeded and a sample size of 10 was selected. This gave a power to detect a significant effect of 95%.

The mean values of the outcome measures were calculated and the precision of these values indicated by 95% confidence intervals (CI). The normality of the data was verified using the Kolmogorov-Smirnov test. Mean values were compared using a paired-samples two-tailed t-test.

**Results**

In total, ten model ulnas were used, with tension band wiring and plate fixation carried out on each specimen in a randomly allocated order. Using data from the sensor, three-dimensional pressure contour diagrams were generated to illustrate the concentration of the forces. An example of this for tension band wiring is shown in Figure 2 and the equivalent diagram for plate fixation, using the same scale, is in Figure 3. These diagrams show the parts of the sensor that are detecting compression. The height and colour of the peaks represent the magnitude of the force at
each location. Blank areas indicate no compression. This visual comparison shows that tension band wiring only produces compression at the posterior aspect of the fracture, away from the articular surface. The technique of plate fixation produces increased compression over the whole surface of the fracture.

For statistical comparison, the force through the whole area of the fracture was calculated for each experiment. The software was also capable of measuring the compressive force through specific areas of the sensor (Fig. 4). This allowed measurement of compression at the articular (anterior) aspect of the fracture. The individual measurements were then combined, and the mean values following all 20 experiments are shown in Table I. These figures indicate that plate fixation provides a larger force of compression over the whole surface of the fracture than does tension band wiring. Based on these values, the former can produce more than ten times the compressive force of the latter. The CIs of the means are shown in Table II.

At the articular side of the fracture, tension band wiring produces a small compressive force compared to plate fixation, with only one of the tension band wiring experiments producing a compressive force above zero. Figure 5 shows a box-plot which indicates the spread of the measurements.

Before parametric tests were performed, the data were analysed for normality. The Kolmogorov-Smirnov test was carried out on the differences between the total

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Table I. Comparison of the mean compression force produced by the two methods of fixation over the whole surface of the fracture and at the articular side

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<th>TBW†</th>
<th>PF‡</th>
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<tr>
<td>Mean total compression (N)</td>
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<td>819 (217 to 1421)</td>
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<tr>
<td>Mean articular compression (N)</td>
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<td>* TBW, tension band wiring</td>
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Table II. Mean compressive force produced over the whole fracture surface and at the articular side of the fracture by the two methods of fixation

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<tr>
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<th>TBW† (95% CI)</th>
<th>PF‡ (95% CI)</th>
<th>p-value of paired t-test</th>
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compression produced by the two methods of fixation (p = 0.096), and the same test was repeated for the differences in compression at the anterior part of the fracture (p = 0.141). Both of these p-values indicate that the distribution of these measurements were not significantly different from normal, and hence parametric tests could be applied.

A paired t-test was used to compare the mean compressive force over the whole surface of the fracture. The 95% CIs of the mean values were also calculated. The same statistical analysis was applied to the mean value for the compression in the anterior half of the fracture. These results are shown in Table II. There was a statistically significant difference between the total compressive forces produced by the tension band wiring fixation and that produced by plate fixation, as the p-value is < 0.05 and the CIs do not overlap. The result of the t-test relating to the anterior part of the fracture shows that there is also a statistically significant difference between the two methods of fixation.

With the sensor positioned within the fracture, it was possible to measure the changes in compression that occurred during simulated movements of the elbow. The compression throughout the whole fracture and within its anterior part were recorded separately. Figure 6 shows an example of these measurements for plate fixation. The model ulna was subjected to several cycles of simulated triceps contraction, which produced a temporary reduction in the force of compression at the fracture site. The reduction in compression occurred over the whole surface of the fracture and at the fracture surface adjacent to the joint. The downward waves of the tracing seen in Figure 6 correspond to each time the sample underwent a cycle of elbow movement. Figure 7 uses a small section of Figure 6 to illustrate how the tracing relates to the different parts of the cycle of simulated movement of the elbow.

Figure 8 shows an example of the same measurements for tension band wiring. Again, there is a reduction in compression of the fracture during the simulation of triceps contraction. It is important to note no anterior compression was detected while the ulna was at rest, and no increase in compression was found when contraction of the triceps was simulated. This is contrary to the tension band theory.

The peak or trough measurements were recorded to combine and summarise these data. During simulated movements, overall compression was reduced in both groups. For tension band wiring the overall compression was reduced by a mean of 14 N (7 to 21, 95% CI) and for plate fixation by a mean of 173 N (141 to 205, 95% CI).

**Discussion**

This study has shown that plate fixation provides significantly greater compression of transverse fractures of the olecranon than does tension band wiring, both over the whole surface of the fracture and of the anterior half adja-
cent to the articular surface. The CIs of the mean compression over the whole surface of the fracture area do not overlap, but are quite broad. Plate fixation can produce approximately two to 24 times more compression over the whole surface of the fracture than tension band wiring.

The locking olecranon plates (Acumed, Weyhill, United Kingdom) used in this study can achieve compression of the fracture at two points of the fixation. There are two slotted holes in the plates. Once the fracture is held reduced with a clamp, the plate is applied to the ulna and provisionally held with a 2 mm Kirschner (K)-wire through the screw-in K-wire guide and a non-locking screw in the first slotted hole in the plate. A second non-locking screw can be inserted in dynamic compression mode into the distal hole in the plate. Further compression can be achieved when inserting the most proximal screw in the plate. This hole accommodates a screw that traverses the fracture. A non-locking screw can be selected which can act as a lag screw.14

This study has shown that tension band wiring produces negligible compression of the fracture at the articular side, where primary cortical healing is especially desirable. In contrast, plate fixation did produce compression over the anterior part of the fracture, with a mean force of 343 N.

Fyfe et al12 showed that in transverse fractures of the olecranon, tension band wiring provided more stable fixation than intramedullary or plate fixation. Stability was defined as resistance to displacement of the fracture fragments when a fixed force was applied to the fixation construct, but this is not equivalent to measuring the compression between the fragments. The metal plate used was a one-third-tubular plate, which is less rigid than pre-contoured plates.15

A retrospective, non-randomised, single-centre study by Rommens et al1 followed 58 patients who had surgical treatment for fractures of the olecranon. There was a mixture of fracture patterns, only 20 of which were transverse. The majority had a tension band wiring fixation, and only five had plate fixation. A further procedure was necessary in 15% of cases. No difference between the fixation techniques could be concluded owing to the small number in the plate fixation group.

Hume and Wiss9 carried out a prospective randomised clinical trial to compare the clinical and radiological outcomes of tension band wiring and plate fixation. Details of the randomisation process were not described and blinding was not attempted. There were 41 adults with displaced olecranon fractures, and the average follow-up was for only six months. Of the 41 patients, 11 had sustained transverse fractures, which were divided equally between the two methods of fixation. Overall, plate fixation had a lower complication rate, better clinical outcomes and less displacement of the fracture fragments. The range of movement of the elbow was equivalent in the two groups.

Plate fixation achieves greater compression. In clinical use it might be expected that the increased bulk of the plate would cause more complications because of its prominence or through irritation of the skin. However, eight of the 22 patients with tension band wiring complained of problems with the metalware, whereas only one of 19 patients had a similar problem following plate fixation.

The measurements taken during simulated movements of the elbow show that the compressive forces across the fracture alter during contraction of the triceps. However, compression of the fracture reduces with both fixation techniques, and compression at the anterior part remains negligible with tension band wiring. These findings are contrary to the tension band theory, which states that due to contraction of the triceps, flexion of the elbow compresses the fracture site.7 With plate fixation, compression does reduce during simulated elbow movements but never diminishes to zero, and remains several times greater than with tension band wiring.

The application of the tension band theory to fracture of the olecranon has been questioned by previous authors. Rowland and Burkhart16 presented mathematical calculations, arguing that the standard configuration of tension band wiring led to the fracture gap opening up on the articular side of the fracture. They proposed a modification to the technique but provided no empirical data. Hutchinson et al18 found that in simulated contraction of the triceps, the fragments were distracted at both the anterior and the posterior sides of the ulna. These observations agree with ours.

These findings indicate that in clinical practice plate fixation should be performed in order to effectively compress a transverse fracture of the olecranon. Previous clinical studies have not had sufficient power or follow-up to investigate the incidence of post-traumatic osteoarthritis. However, the results of this study indicate that plate fixation compresses transverse fractures more effectively than tension band wiring, reducing excess bone formation and suggesting a reduced risk of osteoarthritis.

During dynamic testing, this investigation revealed that fracture compression is reduced during contraction of the triceps. The rehabilitation programme following an olecranon fracture aims to avoid stiffness of the elbow by encouraging movement exercises. Clearly, this should involve passive movements rather than active.

The potential limitations of this study relate largely to the use of an elbow simulation. The ulna models were specifically designed so that the external dimensions matched human anatomy and the internal structure corresponded to normal bone. The testing jig reproduced contraction of the triceps and the reciprocal pull of brachialis, with the magnitudes of forces based on published values.11 However, the effects of blood flow, the healing response of bone and of the surrounding tissue and skin cannot be easily estimated or modelled, but may be very important.6
Nevertheless, this study has provided information about the compressive forces within the fracture gap that could not be obtained from a study on living human subjects.

Steps were taken in the design of the investigation to ensure internal validity. The samples were exactly matched, the order of the procedures on each specimen was randomised, a cutting jig was used to produce identical fractures in each model, and each procedure was carried out according to the published technique guide. However, blinding of the operator was not possible and the validity of the findings is therefore reliant on the operator performing all procedures with the same level of technical skill.

It is difficult to standardise tightening of the figure-of-eight wire during tension band wiring. A torque-limited or torque measuring tool could make this step of the procedure more reproducible. However, the same individual performed all of the tension band wirings, aiming for the highest tension achievable without breaking the wires. The mean compression achieved with tension band wiring was 77 N (95% CI, 58 to 96). This is greater than the value of 60 N (95% CI, 47 to 73) found by Parent et al., indicating than an effective tensioning technique was used.

This study has addressed a specific question regarding compression in transverse fractures of the olecranon. However, many other fracture configurations and combinations of injuries occur clinically, and these results may not be applicable in such circumstances. Hence, the external validity of these findings for fractures of the olecranon in general may be weakened. However, the implications of these results are that, in order to compress a transverse fracture of the olecranon effectively, plate fixation should be performed. If tension band wiring is undertaken, contraction of the triceps risks the fracture opening up at the joint surface. Contraction of the triceps should be avoided and during rehabilitation passive elbow exercises used.

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No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References