Tension-band wiring of transverse fractures of patella. The effect of site of wire twists and orientation of stainless steel wire loop: a biomechanical investigation

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Abstract Tension-band wiring is commonly used to treat transverse patella fractures. The most common configuration has parallel Kirschner (K) wires and a stainless steel wire loop placed in a vertically oriented figure of eight. Early mobilisation is important but can cause detrimental displacement at the fracture site. A wooden model of a transversely fractured patella was used to compare different fixation constructs. The fracture was fixed using two K wires and a stainless steel wire loop. One or two wire twists were used, placed either arbitrarily or at corners of the loop. The loop was oriented either vertically or horizontally. Interfragmentary compression at the point of wire breakage and permanent displacement on cyclic loading was measured for each construct. Placement of the figure of eight in a horizontal orientation with two wire twists at the corner improved interfragmentary compression by 63% ($p<0.05$, Tukey post hoc test). On cyclic loading, all constructs with vertical figure of eight but none with a horizontal construct failed ($p=0.01$; Fisher's exact test). Permanent fracture displacement after cyclic loading was 67% lower with horizontal figure of eight constructs ($p<0.05$; t test). Placing wire twists at the corner and a horizontal placement of figure of eight improves stability of the construct.

Résumé Les cerclages métalliques sont utilisés de façon habituelle dans les fractures transversales de la rotule. La technique la plus courante est l'utilisation de deux broches et d'un cerclage en 8, placé de façon verticale. La

mobilisation précoce est importante mais peut entraîner un déplacement secondaire. Un modèle en bois de rotule avec fracture transversale a été utilisé pour comparer différents modes de reconstruction. La fracture a été fixée par deux broches et un fil métallique. Un ou deux laçages par fil ont été utilisés, le laçage se faisant soit horizontalement, soit verticalement. La compression inter fragmentaire a été examinée au niveau du foyer de fracture et les ruptures de matériel évaluées après mise en charge et mobilisation du modèle. L'utilisation, comme sur la figure 8 d'un laçage horizontal avec deux broches tendues au niveau de chaque coin améliore la compression inter fragmentaire de 63% ($p<0.05$, Tukey post hoc Test). En charge, avec mobilisation, tous les montages avec cerclage vertical ont montré une faillite alors que tous les montages avec cerclage horizontal ont été satisfaisants ($p=0.01$ test de Fischer). Le déplacement secondaire après mise en charge et mobilisation cyclique avec un montage horizontal est de 67% inférieur ($p<0.05$). Nous pouvons donc conclure que, mettre deux broches tordues à chaque coin rotulien avec un montage horizontal, comme indiqué dans la figure 8, améliore la stabilité de l'ostéosynthèse.

Introduction

The aim of any fixation of patellar fractures is to allow early mobilisation of the knee without detrimental displacement at the fracture site. A review of 49 patellar fractures found that 22% of fractures displaced more than 2 mm at the fracture site with early mobilisation after tension-band wiring using the technique popularised by the AO group [8]. Technical errors and failure by patients to comply with strict restrictions on postoperative mobilisation were reported to be the reasons for these failures. However, using a construct that produces the greatest interfragmen-

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tary compression and has the maximum stiffness to resist cyclic loads should decrease the problems that arise out of early mobilisation.

The tension-band technique popularised by the AO group involves the use of two Kirschner wires (1.6 mm) placed parallel to each other and an anterior tension band of stainless steel wire in a vertically oriented figure of eight pattern (Fig. 1a,b) [6]. Among various fixation constructs, this construction resulted in the smallest displacement at the fracture site [9]. Twisting the stainless steel wire at two sites is recommended to reduce losses due to friction and plastic deformation caused by the wire sliding around the K wire, allowing more uniform tensioning and greater interfragmentary compression [7].

On analysis of the AO tension band technique, we hypothesised that placing the two twists of wire at adjacent corners would decrease the effect of friction generated by the stainless steel wire having to slip around the ends of the K wires and would increase the interfragmentary compression developed at the fracture site. We also postulated that placing the wires in a horizontally oriented figure of eight would increase the number of wire lengths crossing the fracture site from two to four, which should increase the stability of the construct.

Materials and methods

A wooden model of a patella with a transverse fracture midway was made. Two-millimetre drill holes were made for placement of K wires. These holes were large enough to allow easy gliding of the K wires and ensured identical placement of the K wires for each experiment. A 25.4-mm diameter $\times$ 3.8-mm thick load transducer (ELW-D1, Entran Ltd, Watford, UK) was placed between the fragments in a slot to ensure its position would be identical at each experiment. Data from the load cell was read into a PC. Stainless steel wire (Aesculap, Tuttlingen, Germany) was used to compress the fracture site using one of four configurations (Fig. 1):

1. Vertical figure of eight with one twist of wire (Fig. 1a)
2. Vertical figure of eight with two twists of wire (Fig. 1b)
3. Vertical figure of eight with two twists of wire placed at adjacent corners (Fig. 1c)
4. Horizontal figure of eight with two twists of wire placed at adjacent corners (Fig. 1d)

Interfragmentary compression

For each of the four configurations, appropriate lengths of stainless steel wire were bent around the K wires and twisted while measuring interfragmentary compression.

Fig. 1 Configurations of stainless steel wire loops

When two twists were used, they were twisted in an alternating manner to ensure that each wire length was tensioned uniformly and equally. Measurements were stopped at wire failure. Five samples were tested for each configuration.

Cyclic loading

Configurations 3 and 4 (vertical figure of eight and transverse figure of eight, both with two twists placed at adjacent corners) were each subjected to a cyclic loading test. For this, four samples of each were prepared in the above manner. Wires were twisted until the interfragmentary compression force was half the average maximum interfragmentary compression force of the configuration. The samples were then placed in a materials testing machine (ESH Testing Ltd, Brierley Hill, UK) and loaded using a three-point bending test. Twenty-five cycles each were applied of 150, 300 and 450 N (corresponding to bending moments of 7.7, 15.4 and 23.1 Nm) while measuring applied force and resulting displacement using the testing machine's built-in transducers.

Fig. 2 Pattern of interfragmentary compression

Statistical analysis

For interfragmentary compression, forces were compared between the four configurations using one-way analysis of variance (ANOVA) followed by the Tukey post hoc test. For the cyclic loading tests, differences between the two groups in number of samples failed were compared using Fisher's exact test. Permanent displacement after 25 cycles at each load level was compared using Student's *t* test. In all cases, a *p* value of 0.05 was assumed to denote statistical significance. All statistical analyses were performed using SYSTAT vs. 11 (Systat Software Inc, Point Richmond, CA, USA).

Results

Interfragmentary compression

For each twist of the wire, interfragmentary compression peaked followed by a quick reduction to a lower sustained value after each twist (Fig. 2). At the point of wire breakage, the interfragmentary compression immediately dropped to zero. Because the sustained values after each twist are more representative of achievable values in clinical practice, these were used to compare the four groups.

Within the three vertical configurations (groups 1–3, Fig. 1a–c), using two twists increased compression by 12% compared with using one twist (Table 1). Placing the two twists in adjacent corners increased compression by a further 18% (Table 1). Comparing the two groups with two twists placed at adjacent corners, changing the configuration from vertical to horizontal, increased com-

pression by 63%. The latter configuration (Fig. 1d) was significantly stronger than all other configurations ($p < 0.05$, one-way ANOVA followed by Tukey post hoc test).

Cyclic loading

All four specimens fixed using the horizontal configuration (group 4) survived the full-loading protocol up to 23.1 Nm (Table 2). However, none of the specimens fixed using the vertical configuration (group 3) survived the two largest moments applied. Three samples failed during cyclic loading up to 15.4 Nm, and one sample failed during cyclic loading up to 7.7 Nm (Table 2). The differences between the two configurations in number of samples failing at the two largest load levels were significant ($p = 0.01$, Fisher's exact test). At a load of 7.7 Nm, average permanent fracture displacement of the surviving three samples fixed with the vertical configuration was 67% more than that of the samples fixed with the horizontal configuration—a significant difference ($p < 0.05$, *t* test).

Table 1 Sustained interfragmentary compression for each group tested

Groups	Compression	Standard Deviation
Vertical 1 twist	79.5	22.5
Vertical 2 twists	88.8	39.0
Vertical 2 twists corner	104.8	27.2
Horizontal 2 twists corner	171.1	33.3

Differences between groups were significant ($p = 0.005$, one-way ANOVA), with the horizontal configuration (group 4) producing greater compression than all other configurations ($p < 0.05$, Tukey post hoc test).

Table 2 Loading data of samples

Load level	Sample				Average	Standard deviation
Vertical configuration	1	2	3	4		
7.7	Failed	4.0	6.4	4.6	5.0	1.2
15.4		Failed	Failed	Failed		
Horizontal configuration	1	2	3	4	Avg	SD
7.7	3.9	2.1	2.7	3.2	3.0	0.8
15.4	6.1	2.2	4.4	5.0	4.4	1.6
23.1	16.7	12.2	6.8	15.9	12.9	4.5

Discussion

In this study, we demonstrated that the interfragmentary compression of vertical figures of eight showed an increasing trend changing from one twist of wire to two twists of wire arbitrarily placed along the loop, to two twists of wire placed at adjacent corners of the figure of eight. We also showed that changing the orientation of the figure of eight from vertical to horizontal significantly increased the interfragmentary compression and resistance to cyclic loading.

The forces that act at the fracture site after fixation are either a distraction force due to the action of the quadriceps in extension or three-point bending that occurs at knee flexion. The three-point bending is essential for the tension band principle to work. Greater interfragmentary compression not only helps bone healing but is also a measure of resistance to displacement at the fracture site secondary to distraction forces generated by the quadriceps in extension. The increase in interfragmentary compression achieved by placing two twists on the loop of stainless steel wire has been asserted [7] but not investigated. We found that compression improved by 12% when two twists of wire were used as opposed to one. We could increase the compression by a further 18% when the twists were placed at adjacent corners of the figure of eight. We believe that this further increase can be explained by a decrease in losses from friction and plastic deformation. By placing the twists at adjacent corners, bending and sliding of the stainless steel wire at the corners of the construct can be largely avoided. However, the increased compression achieved by these changes was relatively small. A much larger further increase of 63% in the interfragmentary compression was seen when the figure of eight loop was placed in a horizontal orientation with the twists placed at adjacent corners. This increase was statistically significant.

The horizontal placement of the figure of eight also significantly improved resistance to cyclic loads. All vertically oriented constructs failed following application of a bending moment of 15.4 Nm whereas none with horizontally oriented figure of eight failed, even at bending moments of 23.1 Nm.

In this study, we used stainless steel wire. Investigators have reported the use of synthetic, nonmetallic sutures for fixation of transverse fractures of the patella [3, 4]. Such materials have the obvious advantages of preventing metallic implant-related problems such as skin irritation that might necessitate implant removal. The increased interfragmentary compression and resistance to cyclic loading from a horizontally oriented figure of eight is likely to be achieved irrespective of the material used in the fixation construct. Compression and stability increased because in the horizontal figure of eight, four wire segments are in line with the interfragmentary forces as opposed to two segments of wire in a vertical figure of eight. In other words, a horizontal construct is more efficient, and this will not depend on the material used.

Although the horizontally oriented figure of eight has been used before with good clinical results [5], it has been used without K wires. However, other studies have shown that the displacement at the fracture site is least with range of motion only when K wires were used in the fixation construct [9]. We are not aware of any other biomechanical investigation, which has exposed the improvement in strength and stability of fixation construct achieved by horizontal placement of figure of eight with two twists at adjacent corners of the figure of eight.

The wooden model of a patella used in this investigation did not deform around the load transducer and allowed accurate measurement of the interfragmentary compression, both of which would not have been possible with cadaveric patellae, which have been used in earlier investigations. By using a wooden model, we were able to concentrate our investigation on the relative biomechanical merits of fixation constructs without the confounding influences that may arise from differences in properties of cadaveric patellae. Such confounding influences can be considerable and probably explain why previous investigations of patellar fixation on cadaveric patellae have reported wide variations to the extent of drawing opposite conclusions [1, 2].

We increased the sensitivity of our investigations by placing the K wires in predrilled holes and placing the transducer in the same slot to measure interfragmentary

compression at an identical test point. This reduced experimental variations.

Conclusion

Placing two twists of wire at adjacent corners of the figure of eight in a tension band construct (AO) increases interfragmentary compression. Compared with a vertically oriented figure of eight tension band construct, placing the figure of eight in a horizontal orientation increases interfragmentary compression and gives a more stable construct.

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