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Asymmetrical fracture fixation: stability of oblique fractures is influenced by orientation

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Abstract

Background. Although clear differences in fracture site displacement have previously been demonstrated between transverse and oblique fracture models stabilised by an asymmetrical method, the direction of the obliquity has not been examined biomechanically.

Methods. Eight Sawbones tibiae were cut to represent oblique fractures: four ran from antero-inferior to postero-superior and four from antero-superior to postero-inferior. These were fixed with a Sheffield Ring Fixator and cyclically loaded in axial and off-axis compression. Direct measurements were taken of inter-fragmentary displacement.

Results. Significant differences were detected between the fracture directions ($P < 0.01$) and inter-fragmentary displacements were generally reduced in antero-superior to postero-inferior fractures compared with antero-inferio to postero-superior fractures.

Interpretation. Fixation asymmetries need to be tailored to specific fracture orientation to improve fracture site mechanics.

Keywords: Tibial fractures; Oblique fractures; External fixation; Shear

1. Introduction

Tibial fractures are common and complications such as delayed union or non-union may lead to considerable long-term pain and disability (Court-Brown and McBirnie, 1995; Lerner et al., 1993; Singer et al., 1998).

It is well accepted that the pattern of motion around a fracture site can have important influences on fracture healing. Limited compressive motion is considered to stimulate union, whereas shear motion is thought to be detrimental to healing, although it remains unclear as to the amount of shear motion required to disrupt the healing process (Kenwright et al., 1986; Loboa et al., 2001; Park et al., 1998; Wolf et al., 1998; Yamagishi and Yoshimura, 1955).

The motion which occurs around a fracture in vivo is a function of the forces applied to the bone, the mechanical properties of any implant or device used to stabilise the fracture, the fracture pattern and the influence of the surrounding soft tissues. In the majority of clinical cases it seems likely that many of these factors would be asymmetrical, such as the muscular forces applied to the tibia or the pattern of the fracture, which is only occasionally transverse (Brand et al., 1986; Court-Brown and McBirnie, 1995).

Studies of fracture fixation devices often utilise transverse gap models to assess their biomechanical properties (Bronson et al., 1998; Khalily et al., 1998; Pugh et al., 1999; Yang et al., 2003). Studies of fracture site motion in these models have demonstrated off-axis motion occurring in devices that utilise methods of fixation

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with asymmetrical mechanical properties with respect to a transverse plane through the fracture (i.e. superior and inferior fragments behave differently), such as hybrid external fixators (Bronson et al., 1998; Khalily et al., 1998; Yang et al., 2003). In a transverse fracture the bone would share the load with the fixation system and these asymmetries are likely to be less important (Koehnlien et al., 1999). However, as only a proportion of fractures are transverse, we also need to consider the interaction between the mechanical attributes of the method of fixation and other commonly occurring fracture types, such as spiral or oblique fractures (Court-Brown and McBirnie, 1995). High levels of shear motion are particularly seen around the fracture site of oblique fractures, and excessive shear has been implicated as a cause of delayed and non-union in oblique fractures (Gardner et al., 2000; Loboa et al., 2001).

Although clear differences in fracture site motion have previously been demonstrated between transverse and oblique fracture models (Koehnlien et al., 1999; Shelbrooke et al., 2001), the direction of the obliquity has not been examined biomechanically. We hypothesised that under the asymmetrical fixation conditions provided by a hybrid external fixator, different patterns of fracture site motion would be observed when the direction of an otherwise identical oblique fracture was reversed.

2. Methods

Eight testing models were constructed using synthetic tibiae (Type 1104, Sawbones Europe AB, Malmö, Sweden). A jig was developed that contains cutting and drilling guides to ensure that the models were constructed consistently in terms of the angle of obliquity, the plane of the fracture, and the build of the fixation devices. The tibiae were fixed in the jig and then oblique fractures in the sagittal plane were created using a handsaw and holes were pre-drilled for wires and screws. Four of the oblique fractures ran from antero-superior to postero-inferior (AS–PI) and four ran from antero-inferior to postero-superior (AI–PS). The fractures were made around the distal metaphyseo-diaphyseal junction with their centre 10 cm from the tibial pilon. The two surfaces of the osteotomy were sanded using grit-80 sandpaper to remove any roughness and achieve relatively consistent friction.

Antero-posterior and lateral radiographs were collected of the first 36 patients (37 fractures) with oblique tibial fractures that were treated with the Sheffield Ring Fixator in our unit. These were the first 36 patients in a study of oblique fracture fixation which has previously been described (Metcalfe et al., 2003). The obliquity of the fractures was measured using the pre-operative films, with 0° considered to be perpendicular to the long axis of the tibia (a true transverse fracture would be 0° obliquity). A histogram of the results can be found in Fig. 1. A bimodal distribution of angles was seen, with peaks at 50° and 70°. The 70° peak represented a greater number of cases overall, and these fractures have previously been shown to demonstrate the greatest instability, so therefore the models were constructed with an obliquity of 70° (Shelbrooke et al., 2001).

The fractures were then stabilised using the Sheffield Ring Fixator (Orthofix SRL, Verona, Italy) (Farrar et al., 2001; Saleh et al., 1999; Yang et al., 2003). Four metaphyseal wires with a 70° crossing angle were placed on one distal ring and tensioned to 1400 N using the same tensioner. Two diaphyseal 6 mm Orthofix screws were placed in the Sheffield Clamp and a further screw was placed antero-laterally at 67.5° (corresponding to the spacing of the holes in the ring) to the other two screws. The fixator is therefore considered to be asymmetrical with respect to the transverse plane through the fracture centre. The fracture was fully reduced with no gap. The condyles were removed and a plate was fitted to the proximal tibia for controlled transmission of force between the testing machine and the model. A completed model is shown in Fig. 2.

The bone was fitted with an inter-fragmentary motion device (IMD) that had been developed in house to measure linear inter-fragmentary displacements (IFD) in three dimensions (Fig. 3). The IMD consisted of two parts, one (the metal casing) with three mutually perpendicular displacement sensors and other a square metal block. The sensors were in the form of thin strip cantilevers with strain gauges bonded at the fixed end and connected to strain gauge amplifiers that in turn were connected to a PC data acquisition system. The sensors were individually calibrated to a resolution of

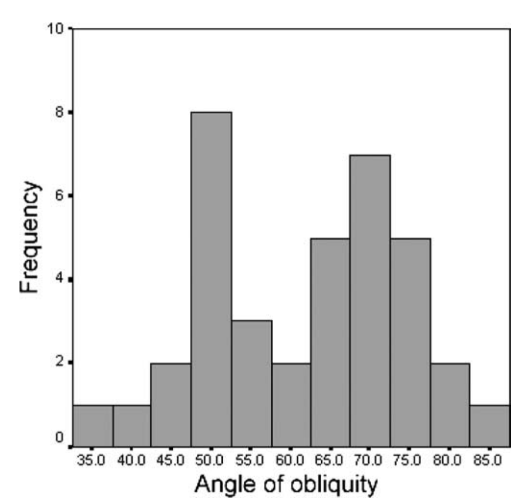

Fig. 1. Histogram demonstrating the angle of obliquity measured in pre-operative radiographs of the first 36 oblique fractures treated in our unit with the Sheffield Ring Fixator.