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A biomechanical study comparing the compressive forces generated by a conventional 4.5 AO/ASIF cortical lag screw with a differentially pitched cortical compression screw

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The aim of this study was to compare the interfragmentary compression generated across a simulated femoral fracture model by a conventional 4.5 mm AO/ASIF cortical lag screw with a differentially pitched cortical compression screw.

A 45-degree osteotomy was made in a whole bone composite femoral shaft, this was internally fixed with either a conventional 4.5 mm AO/ASIF cortical lag screw or the differentially pitched cortical screw and the compressive force generated at the fracture site measured on an Instron 8874 Axial/Torsion Servohydraulic Testing System.

The mean interfragmentary compression generated by the differentially pitched screw was 81.4% of that generated by the 4.5 mm AO/ASIF cortical lag screw. The 4.5 mm AO/ASIF cortical screw produces a steep rise in compression per turn of the screw. The screw based on the differential pitch design creates a more gradual increase to peak compression. The resistance to torque was greater for the AO screw than for the differential pitch screw. Maximal interfragmentary compression is achieved within 4 180° turns after the head engages the near cortex for the 4.5 mm AO/ASIF screw but required 5 180° turns for the differentially pitched screw.

Interfragmentary compression is achievable in cortical bone using differential pitch technology. A differentially pitched screw offers obvious advantages over a conventional screw allowing independent placement of lag screw and neutralisation plate, without needing additional exposure of the fracture site, limiting the insult to local fracture biology. It is proposed as an adjunct to osteosynthesis in long bone fractures.

Key words: *femoral fracture, compressive forces, osteosynthesis, 4.5 OA/ASIF cortical lag screw, differentially pitched cortical compression screw*

1. Introduction

A screw is a simple device that changes rotational motion into translational motion while providing a mechanical advantage [1]. The Herbert scaphoid screw has an established place in the management of scaphoid and osteochondral fractures [2]. The difference in pitch between the leading and trailing threaded portions has the effect of drawing the two bone fragments together generating interfragmentary compression. The absence of a conventional screw head allows the implant to be buried below the articular surface of the bone, thus eliminating problems associated with hardware exposure. Although biomechanical tests have shown that the Herbert scaphoid screw produces less compression than a headed 4.0 mm AO/ASIF cancellous screw, there is sufficient compression to maintain stable fixation of a scaphoid fracture [3].

In diaphyseal fractures, exposure to the fracture site is limited by the surgical incision. The bone surface available is often inadequate to allow independent insertion of a correctly placed lag screw and neutralisation plate or the fracture configuration does not facilitate placement of the lag screw through the plate. In these cases either placement of the lag screw is

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compromised or the plate is applied in a suboptimal biomechanical position, thus increasing the risk of hardware failure and fracture malunion or non-union.

The aim of this study was to compare the interfragmentary compression generated by a headless designed differentially pitched cortical lag screw which overcomes the fore-mentioned problems with a conventional 4.5 mm AO/ASIF cortical lag screw.

2. Materials and methods

To evaluate the peak compressive force generated at the fracture site whole bone composite femur models (Pacific Research Labs, Malmo Sweden) were used. The screws investigated were a 50 mm 4.5 mm AO/ASIF cortex screw and a novel headless differential pitch cortical compression screw (figure 1).

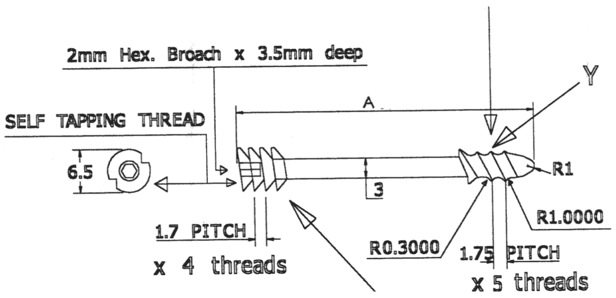

Fig. 1. Schematic representation of differential pitch screw

To ensure repeatability, all test blocks were placed in a bench vice and sectioned into 137 mm shaft segments starting form a point 93 mm from the tip of the greater trochanter using a 1 mm saw blade. Specimen blocks were then placed into a custom cutting block jig and a 45/135 degree cut made using a 1 mm saw-blade.

Specimens were then placed into a set of parallel vices mounted on the workbench. To obtain optimum compression the drill was introduced with its axis perpendicular to the axis of the plane of the fracture. This was guaranteed by using a 135 degree drill guide. The proximal and distal ends of the specimens were cemented into aluminium cylinders of the dimensions 38 mm × 20 mm ($w \times d$). The cement used was Suprastone Dental Cement (sds Kerr), which has a compressive strength of 1100 kg/cm^2 when dry. Standard cementing techniques were employed as per manufactures instructions, using 1:5 water to power ratio, at 18 degrees and 60% humidity. The cement was allowed to dry for 7 days prior to being mounted in the Instron 8874 Axial/Torsion Servohydraulic Testing System (Instron, Canton, MA, U.S.A.) using custom designed V-block grips.

A layer of pressure sensitive film was interposed between the fracture ends to all topographical characterisation of the force distribution in all cases.

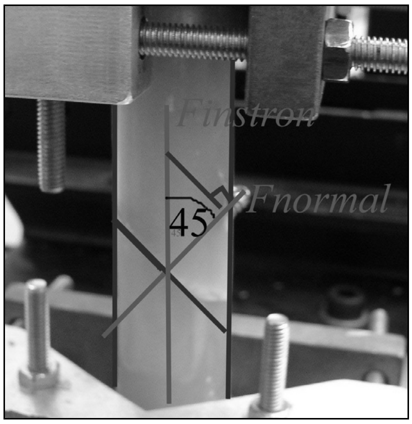

Fig. 2. Calculation of compressive force generated at fracture site

Testing consisted of advancing each screw in 180 degree increments, waiting 10 seconds for a stable load cell reading. The screw was inserted until a torque of 2.5 Nm was reached, this was the predetermined end-point. The data was logged by a P.C. attached to the Instron System and the data analyzed using Instron DAX V.7.0 for Windows (Instron, Canton, MA, U.S.A.). These results represent the force recorded by the Instron load cell, i.e. the force in the long axis of the specimen. The compressive force generated across the fracture site $F_{\text{normal}} = \cos\alpha\, F_{\text{instron}}$, where F_{instron} is equal to load cell readings, F_{normal} is the force acting along the axis of the screw & $\cos\alpha = \cos 45°$ (figure 2). The sample size used was 25 in each group.

3. Results

The mean maximal compressive force generated by a 4.5 mm AO/ASIF Cortical Lag Screw inserted using the above materials and methodology is 0.17441 kN or 174.41 N (figure 3).

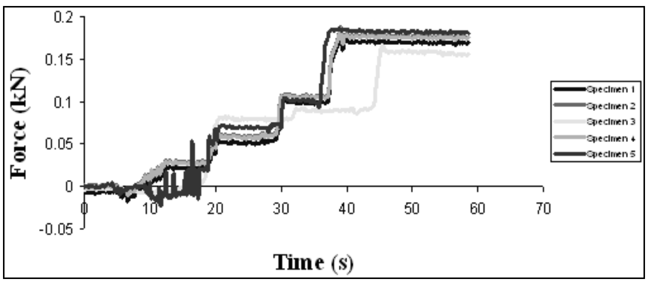

Fig. 3. Compressive force acting across fracture on insertion of 4.5 mm AO/ASIF cortical lag screw

The mean maximal compressive force generated by the low profile differential pitch cortical screw inserted using the above materials and methodology is 0.147727 kN or 147.727 N (figure 4). This represents 81.4% of the mean force generated by the 4.5 mm AO/ASIF cortex screw.

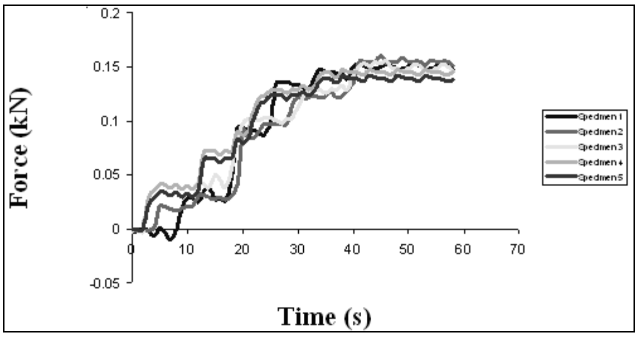

Fig. 4. Compressive force acting across fracture on insertion of differential pitch screw

Topographical distribution of force across the fracture site was similar for both screw types (figure 5).

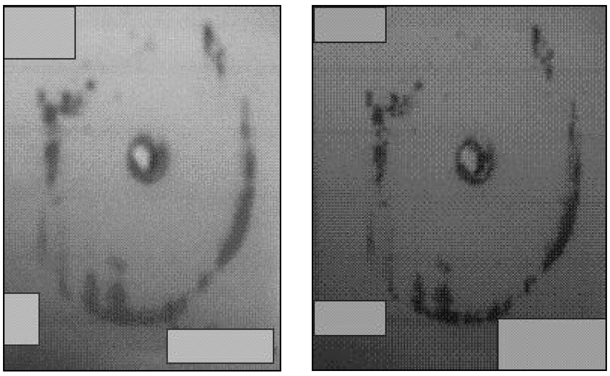

Fig. 5. Topographical characterisation of force distribution for both screw types

4. Discussion

One traditional method for fixation of long bone fractures is the use of a 4.5 mm cortical lag screw in conjunction with a neutralisation plate.

The exposed head of the lag screw may predispose to difficulties with plate orientation. The lag screw insertion technique is based on over-drilling the proximal fragment to prevent screw threads from engaging in this fragment with full screw purchase in the distal fragment. The head of the screw is drawn tightly to the surface of the proximal fragment, thereby producing interfragmentary compression. In our studies, the point at which maximal interfragmentary compression is achieved occurs within 4 180° turns or 720° after the head engages the near cortex. This study has shown that a 4.5 mm AO/ASIF cortical lag screw can generate a mean compressive force of 174.41 N when tightened to a torque of 2.5 Nm.

The differential pitch screw was developed to produce interfragmentary compression while eliminating the exposed head. It is designed to have coarser screw threads at the distal tip (1.75 mm pitch) than at the proximal aspect (1.70 mm pitch). The proximal and distal regions are separated by an unthreaded smaller diameter shaft passing through the fracture. The distal coarser threads advance more rapidly than do the proximal fine threads producing interfragmentary compression. The point at which maximal interfragmentary compression is achieved occurs within 5 180° turns or 900° after the engagement of the proximal threads in the near cortex.

The differential pitch screw when tested under the same conditions generated a mean compressive force of 147.72 N. This represents 81.4% of the mean force generated by the 4.5 mm AO/ASIF cortex screw with a p value of 0.018 using a paired Student's two-tailed t-test (Microsoft Excel 2000 for Windows).

The curves characterizing the development of interfragmentary compression as a function of screw turn clearly differentiate between the designs of compression screws. The 4.5 mm AO/ASIF cortical screw produces a steep rise in compression per turn of the screw. The screw based on the differential pitch design creates a more gradual increase to peak compression.

The resistance to torque was greater for the AO screw than the differential pitch screw. The preset torque limit of 2.5 Nm was never reached when testing the differential pitch screw generating compression at a lower torque value.

Pressure sensitive film (Fugi Film™) results confirmed that both screw types generated the same topographical force distributions (figure 3).

A recognized difficulty in biomechanical testing of this type is the use of bone substitutes. Prior to the advent of the Pacific Research Labs composite prototype, there was little agreement in the literature as to whether these models were reliable substitutes for cadaveric specimens. BIANCO et al. [4] reported that dimensions taken from several composite femur models were similar to those reported in the literature for human femurs. To evaluate the peak compressive force generated at the fracture site whole bone composite femur models (Pacific Research Labs, Malmo, Sweden) were used. These models offer many advantages over cadaveric models. In all the validation testing performed by CRISTOFOLINI et al. [5], the composite femurs were shown to fall well within the range for cadaveric specimens, with no significant differences being detected between cadaveric and composite femora. Moreover, the interfemur variability for the composite femurs is 20–200 times lower than that of cadaveric specimens, thus allowing smaller differences to be characterized as significant using smaller sample size and giving much better reproducibility.

The compression exerted by a lag screw is very efficient because it is very large. BERNNWALD et al. [6] determined that the force applied by expert surgeons using a plate screw amounts to 200–400 N. The results obtained in testing of the 4.5 mm AO/ASIF cortical lag screw fall below the range described, however torque limitation of 2.5 Nm was employed. It is noteworthy that the direction along which the compression acts must coincide fairly well with that perpendicular to the fracture surface. As JOHNER et al. have shown [7], sliding occurs if the compression applied to a smooth osteotomy is inclined only 20° in relation to an axis perpendicular to the fracture. To guarantee perpendicular placement of the lag screw a 135° drill guide was used, thus preventing any compromise of lag screw position.

Differential pitch screws are used in modern orthopaedic practice in the treatment of small bone fractures, e.g. scaphoid fractures. The Herbert compression screw (Zimmer, Warsaw, IN) was introduced in the early 1980's as an alternative to the AO lag screw. Its design is not dissimilar to that of the differential pitch screw investigated in this work; however, it is designed with fixation in cancellous bone and not suitably threaded for use in cortical bone. Indications include fractures of the carpal scaphoid, capitellar fractures, radial head fractures, small joint arthrodesis, osteochondral fractures and osteochondritis disecans [8]–[10].

The Acutrak screw (Acumed, Inc, Beaverton, OR) was introduced in the late 1990's as another option for fragment compression and fracture fixation. The Acutrak screw has a headless, tapered, fully threaded variable pitch design and like the Herbert screw is fabricated from titanium. WHEELER and McLOUGHLIN [3] investigated the compressive force generated by the Herbert, Acutrak and 4.0 mm AO/ASIF cancellous bone screws. In a series of mechanical tests on anatomic specimen cancellous bone and cancellous bone-like foam, the Acutrak and AO screws produced similar fragment compression in foam and bone. Acutrak and AO compression was significantly greater than that of the Herbert screw.

The Acutrak was able to maintain compression after cyclic loading significantly better compared with the AO and Herbert screws. A mean peak load of 85.4 N was obtained by the AO screw, 55.8 N by the Acutrak and only 33.0 N (38.6%) by the Herbert screw.

The differential pitch screw investigated in this work generates approximately 82% of the compression generated by its AO/ASIF counterpart. Since a single lag screw is insufficient to achieve stable fixation of diaphyseal fractures, the lag screw must be protected with a plate or plate equivalent [1], [11], [12]. As the use of a neutralisation device is therefore mandatory to control bending, translation and torsional forces, only interfragmentary compression is required from the lag screw [12].

The differential pitch compression screw has the advantage of allowing placement of the plate in the same plane over the screw, thus avoiding the need to incorporate it into the plate or compromise plate orientation.

5. Conclusion

Compression in diaphyseal fractures is achievable using a differential pitch screw. Sufficient compression is generated to allow osteosynthesis using a plate to be preformed independently of the lag screw positioning. It is thus advantageous over the traditional compromise that arises when exposure to the fracture site is limited, of either incorporating the lag screw into the plate of choosing a non-optimal plate or screw position.

The differential pitch screw investigated in this study generates 82% of the compression generated by a conventional 4.5 mm AO/ASIF cortical screw.

It is proposed as an adjunct to the internal fixation of long bone fractures and not a single fixation device.

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