The Effect of Distal Screw Orientation on the Intrinsic Stability of a Tibial Intramedullary Nail

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**Abstract**

To compare the intrinsic stability of two distal interlocking screw orientations for tibial nailing of distal third tibial diaphyseal fractures without isthmal support, six Depuy (Warsaw, Indiana) tibial intramedullary nails were implanted in simulated distal tibiae. The constructs received both two parallel (medial to lateral) and two perpendicular (one medial to lateral, one anterior to posterior) distal interlocking screws in a random order. Angular, translational, and torsional displacements of the nails were measured in response to 70 N proximal applications of anterior, posterior, medial, and lateral loads, and a 7.7 Newton-meter torsional load. There were no differences in medial or lateral angulations between the screw orientations (average: 2.5°, p > 0.8). Angulation in the sagittal plane (anterior and posterior) was slightly less for parallel screw fixation (1.6° versus 2.4°), but this was not statistically significant (p > 0.1). Rotational angulation was higher in the parallel (average: 9.9°) versus the perpendicular (average: 8.1°) screw orientation, but these results were not statistically significant (p > 0.1). Pure translation did not occur in either the parallel or perpendicular screw orientations. These results indicate that fixation stability of these tibial intramedullary nails is not significantly influenced by distal interlocking screw orientation in response to sagittal, coronal, or rotational forces.

The advantages of intramedullary nailing for treatment of tibial diaphyseal fractures include fracture stabilization with early weightbearing and relative preservation of the soft-tissue envelope.1-14 The addition of interlocking screws affords additional control of alignment, length, and rotation for unstable fracture patterns. Finally, dynamization by interlocking screw removal may allow for enhanced rates of fracture union.4,5 Recently, controversy has emerged surrounding the optimal number and configuration of interlocking screws for intramedullary nailing.15-21 Although risk to neurovascular structures in proximity to the posterior tibia remains concerning, it has been suggested that distal interlocking using a perpendicular (one medial to lateral, one anterior to posterior) screw orientation confers greater fixation stability than the standard, parallel (two medial to lateral) orientation, particularly for distal fracture patterns.8,9,15 However, to the authors’ knowledge, no study has specifically investigated this issue.

The present laboratory investigation evaluated the stability of tibial intramedullary fixation with either perpendicular or parallel distal interlocking screws in response to applied medial, lateral, anterior, posterior, and torsional loads in a simulated distal tibial shaft fracture model.

**Materials and Methods**

Solid titanium-alloy tibial intramedullary nails (11.0 mm diameter, 330 mm length; Depuy, Warsaw, IN) having three distal interlocking holes were inserted in antegrade fashion in six composite fiberglass pipes that simulated a distal tibia (outer diameter 25.0 mm, inner diameter 17.0 mm). This oversized canal was used as a worst-case scenario such that contact between the nail and the inner diameter of the simulated distal tibia did not limit deflection. The nails received both two parallel (medial to lateral) and two perpendicular (one medial to lateral,
one anterior to posterior) distal interlocking screws (4.5 mm diameter) in a random order (Fig. 1).

Each simulated distal tibia construct was secured in a vise with a straight-edged stylus and nail construct projecting horizontally. Care was taken to ensure that only the pipe was secured in the vise, and that the intramedullary nail did not impinge on any aspect of the testing apparatus (Fig. 2). A bubble-level was used to ensure initial parallel alignment between the nail and the stylus.

A 70 N load was applied to the most proximal hole of each nail. Calipers were used to measure the amount of deflection between a fixed proximal point on the nail and stylus in response to the applied load. Loading was performed with 90° rotations of the construct within the vise to simulate anteriorly, posteriorly, medially, and laterally directed forces.

For torsional loading, a rigid, stainless steel rod was inserted through the proximal hole with the stylus projecting perpendicular to the nail and parallel to the rod. A 70 N load was applied to the rod, 11.0 cm from the longitudinal axis of the tibial nail. A support was placed beneath the nail at the level of the stylus to negate any effects of angular displacements due to nail bending (Fig. 3).

As a control, the un-implanted tibial nails were secured in a vise with the stylus and tested in a similar fashion as described above in order to determine the contribution of bending or torsion due to the device itself.

Angular deflections were calculated using simple trigonometric principles. Students t-test was used for statistical analysis for comparison of the two screw positions. A p-value of 0.05 or less was considered statistically significant.

Results

Load application in the medial and lateral planes resulted in average angular deflections of 2.6° (range: 2.3° to 2.8°) and 2.5° (range: 2.4° to 2.7°), respectively, for the perpendicular distal screw orientation group, and 2.5° (range: 2.3° to 2.8°) and 2.5° (range: 2.4° to 2.6°), respectively, for the parallel distal screw orientation group. There was no statistically significant difference between the two groups (p > 0.80).

Load application in the anterior and posterior planes resulted in average angular deflections of 2.6° (range: 2.4° to 2.9°) and 2.2° (range: 1.9° to 2.3°), respectively, for the perpendicular distal screw orientation group, and 2.5° (range: 1.7° to 1.8°) and 1.5° (range: 1.3° to 1.6°), respectively, for the parallel distal screw orientation group. Although average angular deflection was less for the parallel group, this was not statistically significant (p > 0.50).

Torsional loading resulted in average angular deflections of 8.1° (range: 7.8° to 8.2°) for the perpendicular screw orientation group and 9.9° (range: 9.5° to 10.2°) for the
parallel screw orientation group. These results were not statistically significant (p > 0.3).

Loading of the un-implanted tibial nail revealed negligible (< 0.25°; range: 0.10° to 0.23°) angular deflections in sagittal or coronal planes. Pure translation without angular deflection of the nail within the distal tibial construct was not observed in either the parallel or perpendicular screw orientation groups. Torsional loading of the nail demonstrated an average angular deflection of 7.1° (range: 6.4° to 7.6°).

Discussion

This study demonstrated no statistical difference in nail stability between the two screw patterns in anterior, posterior, medial, or lateral directions, or torsional loading. The cause of the measured nail instability is the mismatch between the diameter of the locking screws and the distal screw holes. Figure 4 shows that there are two types of screw movement within the hole that can affect nail tilt depending on the initial screw position and diameter mismatch. It is possible to mathematically calculate the tilt and torsional movement for a worst-case scenario (using the measured dimensions of the nails and screw). For example, this was found to be 2.2°, which is similar to the 2.4° to 2.6° observed values for the medial-lateral tilt of the parallel screws.

The torque applied (7.7 Nm) in this investigation is approximately one-third of physiologic torques observed during normal activities.22 The observed increases in angular deflection with torsional loading as compared to values observed with sagittal and coronal plane loading can be explained by the torsional rigidity of the nail itself, which, upon torsional loading, resulted in an average angular deflection of 7.1° (range: 6.4° to 7.6°). If this deflection is taken into consideration, the magnitude of angular deflection values are similar to those observed in the other planes.

Our model assumed an unstable fracture pattern in a worst-case scenario of cortical bone loss or extensive comminution in which angular deflection would be limited only by distal interlocking screw configuration and position. Cortical apposition with fragment interdigitation would contribute to fracture stability and may limit angular deformity. Additionally, an interference fit between the nail and tibial cortex would limit translation of the nail within the medullary canal, thus providing additional fracture stability.

With perpendicular screw orientation, angular deflection is limited by the more eccentrically placed screw, as screw offset within the hole results in earlier impingement with angulation. However, with parallel screws, coronal plane offset must also be considered, as screw eccentricity in opposite directions (anterior and posterior or superior and inferior) may further limit angulation. Additionally, with parallel screws, the greater inter-hole distance results in greater limitation to angulation.

There are several limitations of this investigation. An inherent limitation is that the inter-hole distance varies depending on whether the parallel versus perpendicular interlocking configuration is used. By strict geometric considerations alone this favors the parallel consideration as the greater working length further restricts angulation; however, this design parameter is of practical importance and should be considered when deciding on distal interlocking screw orientation. We recreated a worst-case scenario of perfect, central screw placement (which would allow for greater angulation until screw impingement as compared with an eccentrically placed screw), a wide intramedullary canal with an undersized component, and no fragment apposition or proximal nail-cortical contact. Lastly, we did not investigate other possible interlocking screw orientations.20

Our study indicates that regardless of the configuration of distal interlocking screws, due to design limitations and technical considerations, such as provision of a beveled screw hole of sufficient diameter to allow ease of intraoperative placement, there exists a small degree of angular motion with distal interlocking. Geometrical considerations dictate that, as the distal interlocking screws represent the apex of angular deflection in response to load, the more proximal the fracture, the greater the linear displacement of the fracture allowed. Based on this, a 2° tilt may cause a one millimeter fracture gap in a distal third fracture of the tibia.

We conclude that despite recent enthusiasm for the use of biplanar distal interlocking screw fixation, there exist no clear advantages over parallel screws for this
nail design with regard to fixation stability after intramedullary nailing of the tibia. Due to concerns of hardware failure and risk to neurovascular structures in proximity to the tibia,\textsuperscript{9,10} we believe that the use of two, parallel, medial to lateral distal interlocking screws is advisable.

References