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Intramedullary Screw Fixation of Proximal Fifth Metatarsal Fractures: A Biomechanical Study

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ABSTRACT

Intramedullary screw fixation is a popular technique for treatment of proximal fifth metatarsal fractures. The purpose of this study was to compare the fixation rigidity of a 5.5 mm partially threaded cannulated titanium screw, with presumed superior endosteal purchase, to a similar 4.5 mm screw. Acute fifth metatarsal fractures were simulated in cadavers, stabilized with intramedullary screws, and loaded to failure in three-point bending. The initial failure loads for the metatarsals fixed with 4.5 mm and 5.5 mm screws were not significantly different (332.4 N vs. 335.2 N, respectively), nor were the ultimate failure loads (849.8 N vs. 702.2 N, respectively). Based upon our results, maximizing screw diameter does not appear to be critical for fixation rigidity and may increase the risk of intraoperative or postoperative fracture.

Key Words: Biomechanics; Bone Screw; Bending Strength; Fracture Fixation

INTRODUCTION

The treatment of proximal fifth metatarsal fractures has been a debate in the literature since Dr. Robert Jones's first clinical series in 1902.[10] Confusion regarding eponymic description and classification clouded most of the early series, making it difficult to determine optimum management. Currently, it is clear that many acute, nondisplaced fractures can be treated conservatively with nonweightbearing.[1,5,12,22,24,25] However, fractures with either clinical or radiographic evidence of chronic injury have well documented problems with prolonged disability, delayed union, and nonunion with conservative treatment.[2,3,5,13,14,20-22,24] This has led to operative techniques of bone grafting and intramedullary fixation.[3,6,9,11,13,14,19,21,23,24] Intramedullary fixation with a cancellous lag screw has the advantage of decreased healing time, accelerated mobilization, and percutaneous procedure.[15,16] This, along with possible expanding indications in the athlete, has made intramedullary screw fixation an increasingly popular technique.[6,13,15,16] Few studies, however, have looked at optimal surgical technique and instrumentation.

In his original technique, DeLee et al. described Kirschner wire placement followed by drilling and placement of a 4.5 mm malleolar screw.[6] Quill used a 7.0 mm partially threaded cancellous screw in most cases, and a 4.5 mm partially threaded cancellous screw in smaller bones.[18] Dameron used a 4.5 mm screw in average-sized persons.[4] In the only clinical series of failures, Glasgow et al. described 6 failures of intramedullary screw fixation.[8] Two 4.0 mm screws led to refracture and refracture with screw deformation, respectively. Two 4.5 mm screws led to refracture and delayed union with screw deformation, respectively. One 6.5 mm screw led to distal cortex penetration and delayed union. One cannulated titanium screw led to extension of the fracture with early screw removal and eventual delayed union. All refractures occurred along the original fracture line. The only biomechanical study of note compared 4.5 mm cannulated and noncannulated screws, which were found to be equivalent.[17] The purpose of this study was to determine if use of a 5.5 mm partially threaded cannulated titanium screw, with presumed superior endosteal purchase, would improve fixation when compared to a similar 4.5 mm screw.

MATERIALS AND METHODS

Nine matched pairs of fresh-frozen cadaver fifth metatarsals were procured, radiographed in anteroposterior and lateral planes, and templated for screw size and length. Each screw was templated to the longest length fitting into the distal canal as described by

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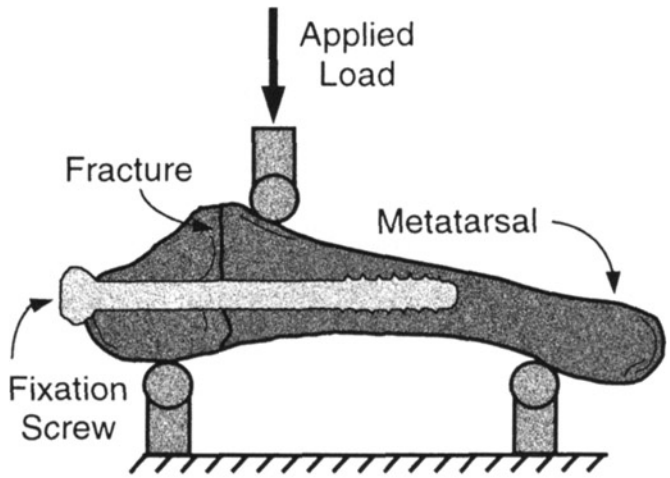

Fig. 1: Experimental set-up. Line drawing depicting a fixed fifth metatarsal during three-point bending. The superior roller was positioned dorsally 2 mm distal to the fracture site. The proximal inferior roller was positioned at the plantar junction of the fourth-fifth metatarsal articular facet and the fifth metatarsocuboid articular facet. The distal inferior roller was positioned at the plantar junction of the most proximal aspect of the distal inferior condyles and the diaphysis of the metatarsal.

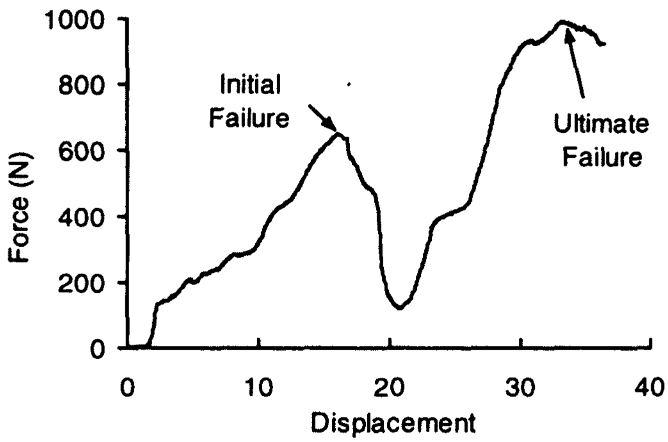

Fig. 2: Representative force-displacement curve for one specimen.

DeLee et al.[6] One surgeon created a transverse osteotomy at the metaphyseal/diaphyseal junction of each specimen using an oscillating saw. A modified intramedullary fixation technique described by DeLee et al.[6] was performed using 4.5 mm partially threaded cannulated titanium screws (Synthes, Paoli, PA) in all left metatarsals and 5.5 mm partially threaded cannulated titanium screws (Smith and Nephew, Andover, MA) in all right metatarsals as templated. Postfixation radiographs were taken for analysis of canal fill.

Each metatarsal was then placed into a materials testing machine (MTS Systems Corp, Eden Prairie, MN) and loaded in 3-point bending in a dorsal to plantar direction at a rate of 36 mm/minute. The superior roller was attached to the actuator of the MTS machine and positioned dorsally 2 mm distal to the fracture site. The proximal inferior roller was positioned at the plantar junction of the fourth-fifth metatarsal articular facet and the fifth metatarsocuboid articular facet. The distal inferior roller was positioned at the plantar junction of the most proximal aspect of the distal inferior condyles and the diaphysis of the metatarsal. Initial and ultimate failure was noted on the force-displacement curves as described by Pietropaoli et al. (Figs. 1 and 2).[17] Failure values were compared for each matched pair of metatarsals for the two types of screws tested. Statistical analysis was performed using a paired, two tailed t-test with a level of significance of 0.05.

Two methods were used to quantitatively assess intramedullary canal fill. In the first method, the screw diameter was divided by the canal diameter at its narrowest point. In the second method, three diameter values for that part of the canal surrounding the screw threads were measured to compute an average canal width. The length of the canal that surrounded the screw threads was used in conjunction with the average diameter to determine an estimated canal area. This value was divided into the screw area (threaded portion of the screw) to determine percent canal fill. Pearson product-moment correlation coefficients (r) were determined in an attempt to correlate percent canal fill with fixation strength.

RESULTS

All screw threads were found to extend completely beyond the osteotomy level. No metatarsal was fractured with screw insertion. Initial failure occurred as refracture along the original osteotomy line in all metatarsals tested. Ultimate failure occurred via penetration of the screw threads through the superior cortex of the distal metatarsal segment.

Templating demonstrated that screw length and diameter was limited by the medial wall in all cases, not by either tapering anatomy or diameter of the canal. The mean lengths of the 4.5 mm and 5.5 mm screws were not significantly different: 48.9 mm (range, 38 mm to 62 mm) and 45.3 mm (range, 38 to 60 mm), respectively. The mean force to cause initial failure of the construct was 332.4 N (SD 175.7 N) for the 4.5 mm screws and 335.2 N (SD 146.6 N) for the 5.5 mm screws. The mean ultimate load for the metatarsals fixed with 4.5 mm screws was 849.8 N (SD 428.8 N) and 702.2 N (SD 340.8 N) for those fixed

TABLE 1
Initial and Ultimate Failure Loads of Fifth Metatarsals with Intramedullary Fixation

	5.5 mm screws		4.5 mm screws	
Fifth metatarsal pair number	Force to reach initial failure (N)	Force to reach ultimate failure (N)	Force to reach initial failure (N)	Force to reach ultimate failure (N)
1	355.7	825.5	648.7	988.7
2	510.0	510.0	512.0	1199.2
3	110.7	666.0	225.6	1062.2
4	447.2	1044.9	463.1	1271.0
5	335.9	1356.1	376.5	1287.4
6	459.4	572.5	182.6	190.9
7	178.6	179.8	144.6	174.2
8	173.9	661.4	239.6	734.8
9	445.1	503.2	198.8	739.5
Mean	335.2	702.2	332.4	849.8
SD	146.6	340.8	175.7	428.8

with 5.5 mm screws (Table 1). There was no statistical difference for any of the above comparisons.

The mean percent canal fill as determined by dividing screw diameter by canal diameter at its narrowest point was 93% (SD 20%) for the 4.5 mm screws and 116% (SD 26%) for the 5.5 mm screws ($P < 0.01$). The mean percent canal fill as determined by dividing screw area by estimated canal area averaged 81% (SD 14%) for the 4.5 mm screws and 105% (SD 20%) for the 5.5 mm screws ($p < 0.01$). Values greater than 100% indicate that the screw threads penetrated into the endosteal cortex. Correlation analysis showed no significant correlation between canal fill and fixation strength ($p > 0.05$).

DISCUSSION

Intramedullary fixation of proximal fifth metatarsal fractures is becoming more popular due to an increased understanding of the physiology of such fractures as well as the possible expanded indication in athletes. Using this technique, Mologne et al. demonstrated return to sporting activities at 7.8 weeks in 12 of 13 patients as compared to 16.4 weeks with nonoperative treatment in the athlete.[16] Other reports have confirmed rapid, predictable healing in the athlete.[6,15]

Other than DeLee's original description,[6] few studies have addressed surgical issues such as instrumentation choice. Pietropaoli et al. conducted a biomechanical study demonstrating no biomechanical difference between a 4.5 mm malleolar screw and a 4.5 mm partially threaded, cancellous, cannulated screw.[17] However, no biomechanical studies have been performed to determine an optimal screw diameter for use in intramedullary fixation of metaphyseal/diaphyseal fractures of the proximal fifth metatarsal.

Our data show no statistically significant difference between the three-point loads necessary to cause initial or ultimate failure of simulated metaphyseal/diaphyseal fractures with 4.5 mm partially threaded cannulated titanium screws and similar 5.5 mm screws. Although 5.5 mm screws demonstrated a statistically significant greater canal fill than 4.5 mm screws by both methods used, fixation strength was not significantly different.

The present study used hydrated, fresh-frozen paired human metatarsals; in addition, all procedures were performed by one surgeon. Inherent weaknesses remain, however, as three-point bending is not an exact simulation of physiologic loading; moreover, *in vivo* conditions cannot be completely modeled in a specimen devoid of ligamentous, tendinous, and soft-tissue attachments. Osteotomies of bone do not exactly reproduce the geometry or inherent stability of true fractures; however, producing fractures in specimens instead of osteotomies would probably cause unacceptable differences between matched specimens.

The present study evaluated only the issue of screw size in attempting to determine the ideal method of fixation of proximal fifth metatarsal fractures. Comparison of cannulated to non-cannulated and titanium to stainless steel screws was not performed; these parameters are equally important and should be considered in future studies.

In addition to structural stiffness as evaluated in this study, other important variables that affect the outcome of intramedullary fixation include torsional stability, fatigue behavior, and micromotion. Loading regimens to study such parameters would be useful in fully evaluating this surgical technique. Future studies should consider the use of a dynamic gait simulator as described by Donahue and Sharkey.[7] In this type of study, the fixed construct would remain in the foot to be loaded to simulate normal walking as well as walking with fatigue of the auxiliary plantar flexors, more accurately estimating the postoperative condition.

In our study, lateral bowing of the fifth metatarsal intramedullary canal was the consistent limitation to intramedullary fixation. This anatomical parameter makes the medial wall vulnerable to disruption, hence limiting the screw length that may be used. Indeed, although 4.5 mm screws should theoretically be able to pass further than 5.5 mm screws into a canal that narrows distally, templating showed no difference in achievable screw length. Therefore, smaller screws with increased length cannot be inserted to increase endosteal purchase distal to the fracture site; this can only be accomplished by increasing screw width. However, our data show that increasing screw width from 4.5 mm to 5.5 mm does not increase fixation rigidity. Consequently, maximizing screw diameter may not be of critical importance and should not be done if it risks fracture.

In conclusion, in our study, the length of screw used in intramedullary fixation of proximal fifth metatarsal fractures is limited by lateral bowing of the canal and subsequent medial wall vulnerability. In addition, use of a screw with increased diameter does not increase ultimate failure stiffness of fixed constructs. In instrumentation choice, therefore, maximizing screw diameter does not appear to be critical for fixation rigidity and theoretically risks intraoperative or postoperative fracture. Further studies may need to include more accurate assessment of *in vivo* conditions.

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