Intramedullary Tibial Nailing Reduces the Attachment Area and Ultimate Load of the Anterior Medial Meniscal Root

A Potential Explanation for Anterior Knee Pain in Female Patients and Smaller Patients

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Background: Intramedullary (IM) nailing is the treatment of choice among orthopaedic surgeons for tibial shaft fractures. However, because of the close proximity of the nail’s insertion site to the anterior medial (AM) meniscal root on the tibial plateau, there is increased risk of iatrogenic injury to the meniscal root during nailing.

Purpose: To quantify the area of the AM meniscal root footprint damaged by IM tibial reaming and determine its subsequent effects on the ultimate failure load in female versus male knees.

Study Design: Controlled laboratory study.

Methods: Twelve matched pairs (6 male and 6 female pairs; average age, 50.2 years) of human cadaveric knees were randomly assigned to native and reamed groups. In the reamed group, knees were reamed within the “safe zone” according to current guidelines for IM tibial nail insertion (3 mm lateral to the center of the tibial tubercle and adjacent to the anterior margin of the tibial plateau). The attachment areas and ultimate failure load were quantified and compared with paired knees in the native group.

Results: Intra-articular reaming within the “safe zone” for IM tibial nail insertion did not significantly decrease the AM root attachment area or ultimate failure load in male specimens, as only 2 of the 6 knees were damaged by reaming. In contrast, all 6 of the AM roots in the female knees were damaged by reaming, and on average, reaming decreased the female AM root attachment area by 19% and significantly decreased ultimate failure load by 37% (P = .028). There was a strong negative correlation (R² = 0.77) between reamed tunnel–AM root overlap area and medial-lateral width in female but not in male knees.

Conclusion: Standard reaming for an IM tibial nail induced significant damage to the AM meniscal root in smaller, female specimens, whereas larger, male specimens were not affected.

Clinical Relevance: These findings may suggest that improvements in current guidelines and surgical techniques are warranted to prevent iatrogenic injury to the AM meniscal root during intramedullary reaming for tibial shaft fractures in females and in smaller patients.

Keywords: medial meniscus; meniscal root; anterior medial meniscus; intramedullary tibial nailing; tibial shaft fracture

Intramedullary (IM) nailing is the treatment of choice among orthopaedic surgeons for tibial shaft fractures, the most common of long bone fractures.3,4,18,21,29 The use of IM nailing for tibial shaft fractures ensures minimal dissection of soft tissues, sparing of the extrascousinous blood supply, lower risk of malalignment, and faster bone union compared with nonsurgical treatment.5,18,31 Reamed nails typically have faster union times, fewer nonunions or malunions, and a lower likelihood of revision surgeries compared with unreamed nails.3,10,15

However, reamed IM tibial nailing is not without concerns due to the high prevalence of anterior knee pain, which has been reported to occur in up to 73% of patients.9 It is generally accepted that the cause of anterior knee pain after IM nailing is complex and not fully understood and that it most likely involves several factors. These may include reaming-induced intra-articular cartilage damage, retropatellar fat pad fibrosis, patellar tendon scarring,
malalignment, osteoarthritis, and the presence of a prominent nail tip. All of these may ultimately lead patients to seek out a sports medicine physician. Interestingly, iatrogenic injury to the anterior medial (AM) meniscal root after IM reaming may be a significant contributor to anterior knee pain postoperatively, yet this potential origin has only recently been elucidated in the literature.

In a recent case report, disruption of the AM meniscal root was reported after the insertion of a reamed IM nail to treat a tibial shaft fracture. This report, along with 2 recent anatomic studies, has raised concerns about whether the currently recommended entry point guidelines for tibial IM nailing overlap with the AM meniscal root footprint. The currently recommended starting point for nail insertion is, on average, 9 mm lateral to the midline of the tibial plateau and 3 mm lateral to the center of the tibial tubercle, corresponding radiographically to a point just lateral to the tibial tubercle, corresponding radiographically to a point just medial to the tibial tubercle, and adjacent to the tibial plateau were taken to quantify the medial-lateral and anterior-posterior length of each meniscal root.

Area Measurements

The attachment areas of the AM meniscal roots for both the native and reamed groups were measured using a coordinate measuring device (MicroScribe MX Series; GoMeasure3D) with a single point repeatability of 0.414 mm, as previously described. The attachment areas of each root were defined using 24 data points distributed evenly along the periphery of the AM meniscal root. Specifically, this technique used a clock-face method to collect data points at the 12-o’clock (most anterior), 3-o’clock, 6-o’clock (most posterior), and 9-o’clock positions, with 5 data points taken between each of these positions. This permitted standardization and equal distribution of data points during collection. The Heron formula was used to calculate the attachment area. Additional measurements of the tibial plateau were taken to quantify the medial-lateral width and anterior-posterior length of each specimen.

Surgical Technique

After the AM meniscal root footprint area was measured, the precise location for guide pin placement in the reamed group was established by use of digital calipers (Swiss Precision Instruments Inc; manufacturer-reported accuracy of ±0.03 mm) and physical landmarks based upon previously published guidelines. This method allowed for standardization between the 12 reamed knees (6 male and 6 female specimens) to verify that the reaming site was placed in a consistent position. The entire width of the tibial tubercle was measured by use of the digital calipers. The currently recommended starting point has been reported to be, on average, 9.1 mm lateral to the midline of the tibial plateau, 3 mm lateral to the center of the tibial tubercle, and adjacent to the anterior margin of the tibial plateau. To place a guide pin at the recommended location, the width of the tibial

METHODS

Specimen Preparation

Twelve matched pairs (6 male, 6 female pairs) of fresh-frozen human cadaveric knees (n = 24) with no previous

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The tubercle at the distal insertion of the patellar tendon was measured by use of a digital caliper and marked with a surgical pen, and the midpoint of the tubercle was also marked. The calipers were then used to measure 3 mm lateral to the midpoint of the tubercle. A 3.2-mm guide pin was drilled perpendicular to this location at the edge of the anterior margin of the tibial plateau in line with the tibial shaft, centered in the safe zone as previously described. A 12.5-mm opening reamer (Trigen Meta-Nail, Tibial Nail System Entry Reamer; Smith & Nephew Inc) was then used to ream over the guide pin (Figure 1). Previous studies and clinical practice suggest that a 12.5-mm diameter reamer is a practical size that allows for the insertion of a standard IM nail. All reaming was performed by a sports medicine fellowship–trained orthopaedic surgeon (M.G.H.). When present, the anterior intermeniscal ligament was preserved and, upon inspection, was not injured during IM reaming. Placement of an IM nail through the reaming site was not performed because the specimens were not full tibias, and we believed that the addition of the nail would neither cause further damage to the AM meniscal root attachment site nor counter the effects of the AM meniscal root.

Postreaming AM Root Measurements

After reaming, the area of the AM meniscal root attachment site was recorded and quantified for the reamed group by use of the coordinate measuring device following the same clock-face method as the prereaming measurement. The outline of the AM meniscal root was measured by a custom steel fixture clamped to the base of a dynamic tensile testing machine. The anterior medial meniscal root was secured to the actuator within a clamp and pulled in line with the circumferential fibers until failure.

Biomechanical Testing

A custom steel fixture was used to orient and rigidly mount each tibia onto the base of a dynamic tensile testing machine (ElectroPuls E10000; Instron) (Figure 3). Measurement error of the testing machine was certified by Instron to be ±0.3% of the indicated force. In each knee, the medial meniscus was transversely sectioned in half and 24-gauge metal wire was wrapped around the AM meniscal root attachment site.
meniscus 1 cm from the bony attachment to provide additional interfacial surface area and friction for mechanical interlock once clamped. This technique was adapted from a similar testing protocol performed by Ellman et al13 and other recent studies.25,26 Each meniscus was secured in a custom-made steel clamp and pulled in line with its circumferential fibers, simulating a shear-type clinical failure mechanism.10,22 Each root was preconditioned from 10 to 50 N at a rate of 0.1 Hz for 10 cycles and subsequently pulled to failure at a rate of 0.5 mm/s.13 The ultimate failure load of each root was calculated in a similar fashion to previous studies that assessed meniscal root failure loads.14,22

Statistical Analysis

The nonparametric Wilcoxon signed rank test was used separately for the male and female groups to test whether the reamed specimen produced lower ultimate failure loads than its paired intact specimen. All statistical analyses were performed using SPSS Statistics (v 20; IBM Corp). A P value <.05 was considered statistically significant.

RESULTS

Overlap Area

Average overlap areas of the AM meniscal root and the reaming site for each sex were calculated (Table 1). Only 2 of the 6 male knees had a reduction in AM root attachment area, whereas all 6 female knees had a reduction in AM root attachment area.

Ultimate Failure Load

Ultimate failure loads are listed for both male and female groups in Table 1. The reamed female knees (351 ± 163 N) had significantly lower AM root failure loads compared with the native knees (544 ± 195 N) (P = .028), corresponding to a 37% reduction. There was no significant difference between the male reamed (617 ± 297 N) and native knees (566 ± 276 N) (P = .249). All menisci from male and female knees failed due to bony avulsion from the tibial plateau.

Tibial Plateau Measurements

The average anterior-posterior (AP) proximal tibial plateau length for male knees was 46 ± 4 mm, while the average AP length for female knees was 42 ± 2 mm. There was no apparent correlation between AP length and AM root damage in either sex. The average medial-lateral (ML) width for male knees was 77 ± 2 mm, while the average ML width for female knees was 68 ± 4 mm. Figure 4 depicts the negative correlation (R² = 0.77) between total overlap area and ML width in female knees. Only 2 of the 6 male AM roots were damaged, and there was no correlation between ML width and total overlap area as the 2 specimens that were damaged were also 2 of the 4 largest in ML width. All male ML widths were greater than 72 mm.

DISCUSSION

The most important finding of this study was that female knees were susceptible to iatrogenic damage to the AM meniscal root during reaming based on the current recommended guidelines for IM nail insertion. In contrast, male knees were not significantly affected by reaming. This study was the first to quantitatively assess the anatomic and biomechanical effect that reamed tibial nailing has on the structural properties of the AM meniscal root and, perhaps more important, compare these results between human male and female knees.

Based on the findings of this study, it is important for sports medicine physicians to be aware of the possibility of an AM meniscal root tear in both female and smaller patients who have anterior knee pain after intramedullary tibial nailing. In our experience, patients with this injury often have a palpable extruded anterior horn of the medial meniscus and anteromedial joint line pain in response to direct palpation and hyperextension. In these patients, the current standards for IM nailing18,29,35 place the AM meniscal root at risk for iatrogenic injury. On magnetic resonance imaging (MRI), the axial view may demonstrate the IM nail tunnel location on the tibia at the AM meniscal root attachment, while the sagittal and coronal views may demonstrate AM meniscal root detachment. A definitive diagnosis is obtained via arthroscopic examination and probing. This is important clinically because it may, at least in part, explain the cause of anterior knee pain in some patients after tibial nailing, and care should be taken to ensure slightly more lateral placement of the starting point or the use of smaller diameter entry reamers in these patients. It must be noted, however, that too far of a lateral starting point increases the risk of coronal plane malalignment and varus-valgus malunion.18 Therefore, a laterally adjusted starting point for female patients may not be optimal for fractures that require precise starting points for anatomic reduction, such as proximal one-third fractures, but may be more clinically relevant for mid-third and distal-third fractures. With regard to the optimal antero-posterior location, placement of the reaming site on the anterior margin of the tibial plateau did not induce iatrogenic articular cartilage injury in either male or female specimens; therefore, we believe that this landmark should continue to be used in all patients.

Injury to the posterior meniscal root attachment sites has been reported to significantly decrease the failure load, function, and tibiofemoral contact mechanics of the meniscus.1,13,24,28,32,33 To date, however, biomechanical effects after anterior meniscal root injury are less understood. In a clinical setting, Costa et al18 reported that all partial or complete AM meniscal root tears resulted in greater than 3 mm of meniscal extrusion, with a vast majority (89%) of these tears also exceeding 6 mm of meniscal extrusion. These findings, along with reports that greater than 3 mm of meniscal extrusion precedes...
male knees and 6 of 6 female knees, revealing that the central fibers are the greatest contributor to the native failure load of the AM root. In the present study, the attachment fibers of the AM root were injured in 2 of 6 specimens; thus, individual values are presented.

Table 1. Ultimate Failure Load and Attachment Area of Anterior Medial Meniscal Root Footprint Before and After Reaming

<table>
<thead>
<tr>
<th>Ultimate Failure Load, N</th>
<th>Tunnel-AM Overlap</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No. Damaged/Total</td>
</tr>
<tr>
<td>Male specimens</td>
<td></td>
</tr>
<tr>
<td>566 ± 276</td>
<td>2/6</td>
</tr>
<tr>
<td>Female specimens</td>
<td>544 ± 195</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SD unless otherwise indicated. AM, anterior medial meniscal root.

Figure 4. The tibial tunnel and anterior medial (AM) meniscal root overlap area versus tibial medial-lateral (ML) plateau width for female specimens. There was a negative correlation ($R^2 = 0.77$) between total overlap area and ML width.

degenerative joint disease and can ultimately leave the knee in a functionally meniscal-deficient state; suggest that partial or complete AM root tears may result in persistent anterior knee pain and significantly increase the risk for future osteoarthritis. Ellman et al. reported that the supplemental fibers of the AM root contribute up to 28.4% of the native root attachment failure load; therefore, the central fibers are the greatest contributor to the native failure load of the AM root. In the present study, the attachment fibers of the AM root were injured in 2 of 6 male knees and 6 of 6 female knees, revealing that complete or partial injury to these central fibers is theoretically possible even when the current recommendations for placing an IM nail are followed. In any circumstance, we believe that placement of the IM nail medial to the aforementioned safe zone should be avoided.

On the basis of the results of this study, we recommend use of radiographic and anatomic tools to identify the proper entry point for tibial IM nail insertion. Current guidelines insert the guide pin just medial to the dorsum of the lateral tibial eminence on the anteroposterior radiograph and slightly proximal to the anterior articular margin on the lateral view. When the same reference points are used, the AM root has been reported to be 17 mm medial to the lateral tibial eminence on anteroposterior radiographs and 4.8 mm posterior to the anterior edge of the tibial plateau on lateral views. Use of these radiographic reference points, as well as open or arthroscopic anatomic references, may help to correctly position the IM nail to avoid iatrogenic meniscal root injury. Further studies should be pursued to help elucidate whether smaller IM nails and/or reamers, or slight lateralization of the entry point in females and in smaller patients, can help mitigate damage to the AM root. Additional studies are recommended to determine whether injury to the AM meniscal root results in abnormal joint contact areas and pressures. Last, future clinical studies are necessary to determine the incidence of anterior knee pain and AM meniscal root injury as a function of tibial width.

Limitations of this study involve using anatomic landmarks for the starting point on an open, dissected knee in the laboratory. In a clinical setting, it is more difficult to place the guide pin in the correct position due to the presence of the patella and other structures of the knee. Nevertheless, an open approach was deemed to be the ideal testing approach because it allowed for the ability to study the best-case scenario if the tunnel was placed correctly in the recommended position. Additionally, the study was conducted in vitro, which does not take healing into consideration for ultimate failure load measurements. The variability of tissue quality could also affect the results; however, the use of matched pairs aged 62 years and younger helped to mitigate this risk.

Conclusion

Tibial reaming decreased the AM meniscal root attachment area and significantly decreased ultimate failure load in female but not in male knees, using currently recommended guidelines. On the basis of this study’s findings, it is recommended that smaller diameter reamers and, if possible, slight lateralization of the starting point be used for female patients and smaller patients with tibial shaft fractures. Given that the incidence of this iatrogenic injury remains unknown, future clinical studies should be performed to evaluate whether females and smaller patients have a higher risk of AM meniscal root injuries after IM nailing compared with male patients and, as a result, a greater incidence of anterior knee pain.

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REFERENCES


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