EFFECT OF REAMER DESIGN ON POSTERIORIZATION OF THE TIBIAL TUNNEL DURING ARTHROSCOPIC TRANSTIBIAL ACL RECONSTRUCTION

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Introduction:

As the understanding of anterior cruciate ligament anatomy continues to progress, the need for anatomical ACL reconstruction to improve joint kinematics and post-operative knee function is increasingly being recognized.[5] ACL deficiency has been shown to result in increased anterior translation, medial translation, and internal rotation of the tibia during various loading maneuvers.[4, 12, 13] Following ACL reconstruction with restoration of native ACL insertion sites and ligament orientation, knee kinematics and stability are markedly improved.[7, 8, 11, 21] When ACL reconstructive procedures fall short and knee instability persists post-operatively, there is a predictively higher risk for osteoarthritis of the knee, failure to return to previous level of play, and poor subjective and objective knee outcome scores.[18]

Despite an improved understanding of ACL biomechanics over the last several decades, the optimal surgical technique for ACL reconstruction remains unclear, largely because no ACL reconstruction procedure has been shown to exactly replicate the biomechanics of the native ACL.[9, 14, 26] Small alterations in femoral tunnel positioning significantly affect ACL length, tensioning patterns, as well as alter force vectors and joint kinematics.[1, 2, 16, 20] Loh et al showed that grafts placed higher on the femoral wall in ACL reconstruction—a less coronally oblique orientation—do not effectively resist rotatory loads as compared with grafts placed lower on the femoral wall.[20] Decreased sagittal plane obliquity has also been implicated, predominantly because such an orientation less effectively opposes anterior translational loads as compared with the native ACL.[1, 3, 6, 19]

To date, much of the focus regarding anatomically reconstructing anterior cruciate ligaments has been placed on more accurately recreating the femoral ACL footprint; however, correct tibial tunnel position within the native tibial footprint may be equally as critical.[5] Posterior tibial tunnel placement will result in a graft which is more vertical in the sagittal plane compared to normal ligament anatomy. As noted by Bedi and colleagues, a knee with an ACL graft placed in a tibial tunnel on the posterior aspect of the tibial footprint had no significant difference in anterior translation during Lachman and pivot-shift testing compared to an ACL deficient knee.[5]

During femoral tunnel preparation in the transtibial technique, a guide wire (Beath pin) is placed through the reamed tibial tunnel via an "over the top" femoral guide into its position on the femur. To remain anatomic on the femur, the guide pin is regularly placed posterolateral to the center of the tibial tunnel's intra-articular aperture. Passing a femoral reamer through the tibial tunnel over the Beath pin in this position consistently removes several millimeters of bone from the posterolateral aspect of the tibial tunnel rim, in a trajectory defined by the guide wire's position. To date, no study has quantified the amount and extent of posteriorization of the tibial tunnel during femoral reaming and its effect on the tibial insertional anatomy. The senior author uses a half-fluted reamer in this situation which is passed into the joint without reaming, thus preserving the tibial tunnel articular aperture.

The purpose of this study is to compare the amount of inadvertent posteriorization of the ACL tibial tunnel anatomy during transtibial ACL femoral reaming in the "over-the-top" position with a full femoral reamer versus a half femoral reamer, in comparison to the native tibial ACL footprint. It is hypothesized that the half reamer will result in less distortion of tibial tunnel anatomy and improved anatomic footprint coverage, primarily due to its improved ability to obliquely navigate the tibial tunnel intra-articular aperture.

Methods

Eight fresh-frozen adult knee specimens (mid thigh to mid knee, 4 right, 4 left) without ligamentous injury or significant degenerative joint disease were thawed over 24 hours. Demographic characteristics for the specimens are provided in **Table 1**. Taking care to preserve soft tissues about the knee joint, skin, muscle and subcutaneous tissue were removed from tibial and femoral diaphyses. Specimens were then mounted in 90° of flexion on a stationary custom designed mount on a laboratory table stabilized to floor (**Figure 1**). This flexion angle was chosen as it is the most common position of the knee during transtibial reconstruction techniques. In order to ensure that the necessary exposures of the ACL insertions did not destabilize the knee and result in aberrant motion of the tibia and femur, a three-point coordinate system was arbitrarily defined on each specimen by choosing and marking a point on the femur, tibia, and laboratory table. As was done in previous studies[25] with this equipment, the *x, y,* z coordinates of each of these points were measured and repeatedly referenced throughout the study to assure a static relationship between the femur, tibia, and digitizer (MicroScribe™; CNC Services, Amherst, Virginia) accurate to 0.05 mm.

After fixing the specimen on the custom designed mount, the lateral femoral condyle was further secured to the lateral tibial plateau with 2 divergent K-wires. With the exception of the lateral collateral ligament and the posterior capsule, extra-articular soft tissues about the knee joint were then removed using sharp dissection and the intact nature of the articular cartilage, meniscal attachments and cruciate ligaments was confirmed. The superior border of the pes anserinus and anterior edge of the medial collateral ligament (MCL) were marked on the proximal tibia prior to removal. The length of the central third of the patellar tendon was measured with a ruler for each specimen, from distal patella to tendo-osseous junction on the tibial tubercle prior to removal.

To allow a post-hoc three dimensional analysis, the knee joint's femoral and tibial surface anatomy was then recorded using the digitizer to log extensive point cloud arrays of both bones. In addition to articular surfaces and bony landmarks, soft tissue structures such as the anterior horn of the lateral meniscus, the medial meniscus, and the anterior face of the posterior cruciate ligament (PCL) at the posterior edge of the tibial plateau were fully digitized to better appreciate the anatomical relationship of the ACL to these structures.

Using an oscillating saw, the medial femoral condyle was then carefully removed with great precaution taken to avoid damage to the femoral ACL insertion. The ACL was then sharply divided and removed with care to allow the tibial and femoral footprints to be digitized after being marked with a pen. The *x, y,* z coordinates of the three arbitrary points on the tibia, femur, and laboratory were measured once again to confirm the static relationship between the femur, tibia, and digitizer had not changed.

Surgical Technique

As recently described by Piasecki et al, there is an optimal tibial tunnel starting point (15.9 mm below the medial plateau, 9.8 mm posteromedial to the medial margin of the tibial tubercle) which best allows for anatomic femoral tunnel drilling using a transtibial technique.[25] Using this tibial tunnel starting point, a guide pin was drilled using a standard ACL tibial tip aimer (Smith & Nephew Endoscopy, Andover, MA) to the center of the marked tibial footprint. The tibial tunnel was then reamed with an 11mm cannulated reamer (Smith & Nephew Endoscopy, Andover, MA) in standard fashion. Upon completion of reaming, the intra-articular and extra-articular tibial tunnel apertures were carefully digitized to allow for tibial tunnel three-dimensional mapping and measurement of the tunnel location in relation to the native ACL tibial and femoral footprint anatomy.

Following tibial tunnel creation, a 7-mm offset aimer was inserted through the tibial tunnel and hooked around the posterior aspect of the intercondylar notch. In order to best achieve the "over the top" position, the aimer was placed in the posterolateral corner of the tibial tunnel and externally rotated to permit low pin position on the femoral notch's lateral wall. The center position of the native ACL femoral footprint had been previously marked and the guide was rotated to allow placement of the pin at the center point of the native ligament. The anatomic center point of the femoral footprint was achieved in all specimens. A Beath pin was then inserted through the aimer and provisionally drilled into the femur to exit the lateral femoral cortex.

A 10mm half femoral reamer (Smith & Nephew Endoscopy, Andover, MA) was then passed over the Beath pin while in the off position. Because the Beath pin was placed posterolateral to the center of the tibial tunnel's intra-articular aperture, the blades of the half-reamer were anteriorly positioned in order to obliquely navigate the tibial tunnel while in the off position (**Figure 2D**). Upon entering the joint and contacting the femur, the reamer was started and a standard 10mm tunnel was drilled to a depth of 25mm. Following femoral tunnel drilling, the half-reamer was again turned off and removed by once again positioning the blades anteriorly to allow easier passage through the tibial tunnel to minimize change to the intra-articular aperture. The digitizer was once again utilized to record the tibial tunnel intra-articular aperture and tunnel location compared with the native anatomy.

After femoral reaming with a half-reamer, a 10mm full fluted femoral reamer (Smith & Nephew Endoscopy, Andover, MA) was then utilized in the same manner. However, because of the Beath pin's oblique position within the tibial tunnel, the full reamer's blades were unable to clear the intra-articular tibial tunnel aperture while in the off position (**Figure 2B**). The reamer was therefore turned on, resulting in the removal of several millimeters of bone from the posterolateral aspect of the tibial tunnel rim. Following entrance into the joint, the reamer was easily positioned into the previously reamed femoral tunnel while off, confirming no change in trajectory with that of the half-reamer. The tibial tunnel intra-articular aperture, now slightly wider and more oblong, was re-digitized as done previously. The digitizer was also used to record the edges of the femoral tunnel on the lateral wall of the notch for comparison with the native ACL femoral footprint. A visual comparison of the half-reamer and full-fluted reamer is shown in **Figure 3**.

Analysis

Several subsequent analyses were performed using the three-dimensional point cloud arrays recorded with the digitizer. Rhino software (McNeel, Seattle WA) was used to geometrically determine the center of the native tibial footprint and measure in millimeters the anatomic relationship of this point with other anatomic structures. The software was also used to calculate the following: surface areas of the tibial tunnel aperture—both before and after use of the half-reamer and full-reamer in the femur; tibial tunnel length; center of tibial tunnel intra-articular aperture (before and after femoral reaming); amount of tibial tunnel posteriorization after femoral reaming. The percentage overlap of the tibial tunnel surface area with that of the native tibial insertion was directly computed. Statistical analysis of continuous variable data was performed with *t* tests with alpha set to 0.05 using GraphPad Software (La Jolla, CA); *P* values below this were deemed significant. Pre-hoc sample size for comparison of tibial tunnel sizes was determined by a power analysis (G*Power 3.0, Dusseldorf, Germany). Assuming a 50% increase in tunnel size and a standard deviation of 0.25 the mean value, to achieve a power of 0.80 with a two-tailed analysis, 6 specimens were required.

Results

All eight knee specimens were observed to have intact cruciate ligaments and menisci as well as no significant degenerative joint disease. In all testing situations for all specimens, the digitizer and three-point coordinate system was used to reference the precise spatial orientation of the tibia and femur in order to ensure a static relationship between testing conditions, within 0.1mm.

Digitized measurements of anterior cruciate ligament insertional anatomy in the anteroposterior plane demonstrated that the center of the native ACL tibial footprint (combination of anteromedial and posterolateral bundle footprints) was 2.0 ± 0.49mm (range 1.1–2.7 mm) anterior to the posterior aspect of the lateral meniscus' anterior horn, a value slightly more anterior than some previously published values for single bundle ACL reconstruction tibial tunnel placement.[17, 22, 23] (**Figure 4**) Additional values demonstrating the anatomical relationships of the ACL footprints to the anterior aspect of the lateral meniscus and the posterior aspect of the medial meniscus are provided in **Table 2**.

After the use of the 11mm tibial reamer, tibial tunnel length was found to be 32.07 ± 2.62 mm, a value consistent with other published values.[25] Tibial-articular ACL footprint area was 111.45 ± 16.40 mm^2, compared to the native size of 151.53 ± 28.95 mm^2 (**Table 3**). Femoral reaming with the 10 mm half fluted reamer centered on the femoral footprint with an over-the-top guide increased the tibial-articular ACL footprint to 120.29 ± 12.43 mm^2 but did not significantly increase the aperture of the tibial tunnel created during tibial reaming (p=0.24). Repeated femoral reaming with the 10 mm full reamer centered on the femoral footprint in the same over-the-top trajectory produced a tibial tunnel intra-articular aperture surface area of 189.94 ± 22.13 mm^2, a value significantly larger than the initial tibial tunnel intra-articular aperture after 11mm tibial reaming (p<0.0001).

In comparing the location of the ACL tibial-articular footprint with relation to joint anatomy, distances from each landmark were found to vary as reaming progressed (**Table 3**). While the center of the native tibial footprint was digitized to be 18.03 ± 2.53 mm anterior to the PCL at the level of the tibial plateau (**Figure 5**), a finding similar to the distances identified by other authors[29], the center of the tibial footprint of the 10mm half fluted reamed tunnel measured 17.39 ± 5.06 mm anterior to the PCL. The 10 mm full reamed tibial tunnel footprint was further posterior, with a distance of 14.50 ± 3.59 mm anterior to the PCL. The distance from the posterior edge of the ACL tibial-articular footprint to the PCL at the tibial plateau was also measured to investigate the presence of posteriorization with femoral reaming. As shown in **Table 4**, use of the 10 mm full femoral reamer produced significant posteriorization of the ACL tibial-articular footprint, with a distance of only 6.31 ± 2.62 mm from the posterior edge of the footprint to the tibial plateau compared to 10.66 mm (± 4.57) for the half reamed footprint (p=0.049). Use of this full reamer resulted in posteriorization of the center of the tibial articular aperture by 5.44 ± 1.84 mm, which then produced a 59.62 ± 28.1% expansion of the tunnel area at the posterior surface (p<0.0001 when compared with aperture surface are after femoral reaming with half reamer).

When comparing the location of reamed tibial tunnel aperture with the native ACL footprint, both the 10mm full femoral reamer and the 10mm half femoral reamer resulted in a similar percentage of native tibial ACL footprint overlap by the tibial intra-articular aperture (tunnel aperture area overlapping with footprint/ACL footprint total area, **Table 5**). However, when area of tibial aperture outside of ACL native footprint was evaluated in relation to total tibial aperture area, the 10mm full femoral reamer resulted in an aperture that was significantly more extra-anatomic than the 10mm half femoral reamer (p=0.006, **Table 6**).

Finally, the distance from the center of the ACL's tibial footprint to the posterior aspect of the lateral meniscus' anterior horn remained fairly constant from the native location (7.53 ± 0.77 mm) to the time of the 10 mm half reaming (7.70 ± 3.14 mm, Table 2), a value consistent with other anatomic studies.[29] However, this distance decreased to 5.70 ± 1.42 mm when the full reaming of the femur was performed. These trends in posteriorization with subsequent reaming are depicted in **Figure 6**.

Discussion

As understanding of ACL biomechanics and kinematics continues to advance, the need for anatomic tunnel placement during ACL reconstructive surgery is increasingly being recognized.[5, 11, 25, 28] While much attention thus far has been directed towards modifying surgical techniques for more properly creating femoral tunnels, techniques and descriptions for precise and accurate tibial tunnel placement remain poorly defined. Posteriorization of the tibial tunnel results in a vertical graft in the sagittal plane with subsequent loss of function. The findings of this study demonstrate that use of a standard reamer for femoral tunnel drilling during transtibial ACL reconstruction results in significant expansion and posteriorization of the tibial tunnel articular aperture as compared to a half-fluted femoral reamer and native ACL footprint anatomy.

The modified transtibial ACL reconstruction technique has been demonstrated to have equal efficacy in improving knee joint biomechanical stability as ACL reconstructions performed via an anteromedial portal technique and an outside-in technique. Sims et al performed a controlled laboratory study using a robotic testing system to place uniform anteroposterior loads on cadaveric knees with reconstructed ACLs using one of three endoscopic approaches.[27] The authors concluded that the modified transtibial technique, the anteromedial portal technique, and the outside-in technique were biomechanically comparable in restoring normal knee joint laxity and in situ ACL forces.[27] Such findings confirm the utility of the modified transtibial approach, assuming anatomic placement of femoral and tibial tunnels.

However, difficulty with precise tibial tunnel positioning within the native tibial footprint is compounded by the large shape of the tibial footprint, reported by some to be 3.5 times larger in area larger than the midsubstance cross-sectional area of the ACL.[15] Because of this large shape, various arthroscopic landmarks such as the PCL or anterior horn of the lateral meniscus have been used for proper tibial tunnel positioning, particularly in the anteroposterior plane.[10, 17, 22-24] As noted in some anatomic studies, the recommended position for the center of the tibial tunnel during single bundle ACL reconstruction is in line with the posterior aspect of the lateral meniscus or 7mm anterior to the femoral PCL attachment.[17, 22, 23, 29]

Through the use of a highly precise digitizer and analysis of spatial relationships, the findings of this study demonstrate that the true center of the native tibial ACL footprint may actually lie approximately 2mm anterior to the posterior aspect of the anterior horn of the lateral meniscus. This suggests that previously recommended tibial tunnel positions[17, 22, 23] in single bundle ACL reconstruction may have been slightly too posterior. These results are corroborated by more recent reports on tibial tunnel footprint anatomy that also suggest a more anterior position.[29] Additionally, the findings of this study show that further posteriorization of the tibial tunnel intra-articular aperture may inadvertently occur from transtibial femoral tunnel reaming if a standard full-fluted reamer is used in the "over-the-top" position as opposed to a half-reamer. This distortion of tibial tunnel intra-articular aperture occurs because a guide pin placed anatomically on the femoral ACL footprint is generally positioned posterolateral to the center of the tibial tunnel's intra-articular aperture. Full reamers, unable to obliquely navigate a tibial tunnel, require removal of bone at the posterolateral edge in order to allow entry to the joint and femoral tunnel creation. Half reamers, in contrast, have a lower profile which better optimizes navigation over the tibial tunnel edge when introduced by hand in the off position.

Excessive posteriorization of tibial tunnel position in ACL reconstruction procedures has been demonstrated to significantly weaken the biomechanical stability of the knee joint. Bedi and colleagues, in a cadaveric study investigating the effect of tibial tunnel position on knee kinematics and stability, performed ACL reconstruction in 10 paired cadaveric knees.[5] The testing protocol involved varying the tibial tunnel position in the sagittal plane while keeping femoral tunnel position constant. Using a computer navigation system to record the 3-dimensonal motion during standardized Lachman testing, the authors found that a knee with a tibial tunnel placed in the posterior aspect of the tibial ACL footprint was no different than an ACL deficient knee during Lachman testing.[5] Anterior translation of the tibia during standardized pivot-shift testing was also significantly higher in knees with posteriorized tibial tunnels in comparison with constructs with more anterior tunnels.[5] The authors concluded that the anterior positions for tibial tunnel placement are more effective in controlling anteroposterior translation during the Lachman and pivot-shift, but must be balanced against an increased risk of graft impingement.

It is possible that poor biomechanics seen in ACL reconstructed knees with posteriorized tibial tunnels may in part be explained by increased sagittal plane vertical orientation of the graft. By posteriorizing the tibial tunnel center, the tibial tunnel intra-articular aperture is brought closer to the femoral footprint, thereby reducing sagittal plane obliquity. Increased verticality of ACL grafts resulting from flawed tunnel creation has consistently been associated with poor outcomes and altered ACL force vectors. Loh et al showed that grafts placed higher on the femoral wall in ACL reconstruction—a less coronally oblique orientation—less effectively resists rotatory loads as compared with grafts placed lower on the femoral wall.[20] More recently, decreased sagittal plane obliquity has also been implicated, predominantly because such an orientation less effectively and less efficiently opposes anterior translational loads as compared with the native ACL.[1, 3, 6, 19]

The primary strength of this study is the precise digitization—accurate to 0.5mm—of tibial tunnel anatomy and posteriorization following tibial tunnel reaming. This is the first time such technology has been applied in such a manner to identify tibial tunnel relationships. Regarding limitations, the study's controlled laboratory study design using cadaveric specimens inherently restricts our ability to draw in vivo conclusions regarding the effects of tunnel posteriorization.

Conclusions:

The anatomic center of the ACL tibial footprint lies 2mm anterior to the posterior edge of the anterior horn lateral meniscus. Half-fluted femoral reamers may be more advantageous than full-fluted femoral reamers when performing a single-bundle ACL reconstruction using a transtibial technique as they result in more anatomic tunnel placement with significantly less posteriorization of the tibial tunnel intra-articular aperture.

Tables

Table 1. Demographics of knee specimens. (n=8 specimens).

Demographic Category	*Characteristic*
Left/right	4 right 4 left
Age	47.2 ± 5.6 years Range (36-53 years)
Gender	Male - 6 (75%) Female - 2 (25%)
Cause of death	Renal failure - 1 (12.5%) Carcinomatosis – 2 (25%) Malignant lung neoplasm – 1 (12.5%) Metastatic colon cancer – 1 (12.5%) Retroperitoneal hemorrhage – 2 (25%) Acute myelogenous leukemia – 1 (12.5%)

Table 2. Digitized anatomic relationships observed (mm). Note that distance measurements listed below are in axial plane of the knee. In the anteroposterior plane, the center of the native ACL tibial footprint (combination of anteromedial and posterolateral bundle footprints) was digitized to be 2.0 ± 0.49mm (range 1.1–2.7 mm) anterior to the posterior aspect of the lateral meniscus' anterior horn, a value slightly more anterior than some previously published values for single bundle ACL reconstruction tibial tunnel placement.[17, 22, 23]

ACL Tibial-Articular Footprint Anatomic Relationships (mm)

Footprint Center	**PCL (Tibia Plateau)**	**Posterior Aspect-Lateral Meniscus, Anterior Horn**	**Anterior Aspect-Lateral Meniscus, Anterior Horn**	**Posterior Aspect-Medial Meniscus, Anterior Horn**
Native	18.03 (±2.53)	7.53 (±0.77)	8.75 (±0.53)	11.55 (±1.17)
11mm Full Tibial Reamer^{+}	17.90 (±4.90)	7.69 (±3.31)	8.14 (±1.30)	11.50 (±3.56)
10mm Half Femoral Reamer^{++}	17.39 (±5.06)	7.70 (±3.14)	8.67 (±1.27)	11.82 (±3.48)
10mm Full Femoral Reamer^{++}	14.50 (±3.59)	5.70 (±1.42)	10.17 (±1.92)	15.31 (±2.45)

$^{+}$Tunnels were reamed with guide centered on Tibial-Articular ACL Footprint with no subsequent Femoral reaming

$^{++}$Tunnels were reamed with guide centered on Femoral-Articular ACL Footprint in "over-the-top" position with subsequent Femoral reaming

Table 3. Surface areas of tibial intra-articular apertures created after tibial and femoral reaming. Note the significant expansion in tibial tunnel intra-articular aperture surface area after use of the 10mm full-fluted femoral reamer in comparison with half-reamer.

Surface Area Expansion of Tibial Tunnel Aperture

Measured structure	Surface area	Comparison to 11mm tibial tunnel aperture surface area
Native ACL tibial footprint	151.53 (±28.95)	--
11mm Full Tibial Reamer^{+}	111.45 (±16.40)	--
10mm Half Femoral Reamer^{++}	120.29 (±12.43)	p=0.244
10mm Full Femoral Reamer^{++}	189.84 (±22.13)	p<0.0001

$^{+}$Tunnels were reamed with guide centered on Tibial-Articular ACL Footprint with no subsequent Femoral reaming
$^{++}$Tunnels were reamed with guide centered on Femoral-Articular ACL Footprint in "over-the-top" position with subsequent Femoral reaming

Table 4. Posteriorization of tibial tunnel after femoral reaming with half vs. full 10mm reamer.

Posteriorization of ACL Tibial-Articular Footprint

Footprint Posterior Edge	Distance to PCL at Tibial Plateau	Comparison to 11mm tibial tunnel
11mm Full Tibial Reamer^{+}	11.44 (±4.56)	--
10mm Half Femoral Reamer^{++}	10.66 (±4.57)	p=0.57
10mm Full Femoral Reamer^{++}	6.31 (±2.62)	p=0.049

$^{+}$Tunnels were reamed with guide centered on Tibial-Articular ACL Footprint with no subsequent Femoral reaming
$^{++}$Tunnels were reamed with guide centered on Femoral-Articular ACL Footprint in "over-the-top" position with subsequent Femoral reaming

Table 5. Percentage of native tibial footprint overlapped by reamed tibial intra-articular aperture (tunnel aperture area overlapping with footprint/ACL footprint total area). Note that the 10mm Full reamer's tibial tunnel aperture results in a higher (but not significant) percentage due to its oblong shape.

Percentage of Native Tibial Footprint Overlapped By Reamed Aperture

	11mm Full	10mm Half**	10mm Full**
Averages	59.03% (±15.35%)	64.75% (±15.34%)	72.15% (±9.79%)
P-value (10mm Half vs Full)			P=0.31

+Tunnels were reamed with guide centered on Tibial-Articular ACL Footprint with no subsequent Femoral reaming

++Tunnels were reamed with guide centered on Femoral-Articular ACL Footprint in "over-the-top" position with subsequent Femoral reaming

Table 6. Percentage of reamed aperture that is outside of native ACL tibial footprint (area of tibial aperture outside of ACL native footprint/total tibial aperture area). Note that the 10mm full-reamer produced an aperture that reached significantly beyond the borders of the native ACL's tibial footprint.

Percentage of Reamed Aperture Outside the Native Tibial Footprint

	11mm Full	10mm Half**	10mm Full**
Averages	19.52% (±22.99%)	19.23% (±19.38%)	43.05% (±7.58%)
P-value (10mm Half vs Full)			P=0.006

+Tunnels were reamed with guide centered on Tibial-Articular ACL Footprint with no subsequent Femoral reaming

++Tunnels were reamed with guide centered on Femoral-Articular ACL Footprint in "over-the-top" position with subsequent Femoral reaming

Figures

Figure 1. Specimens were mounted in 90° flexion on a custom designed mount stationary on a laboratory table stabilized to floor. In order to ensure that the necessary exposures of the ACL insertions did not destabilize the knee and result in aberrant motion of the tibia and femur, a three-point coordinate system was arbitrarily defined on each specimen by choosing and marking a point on the femur, tibia, and laboratory table. The *x, y,* z coordinates of each of these points were measured and repeatedly referenced throughout the study to assure a static relationship between the femur, tibia, and digitizer (MicroScribe™; CNC Services, Amherst, Virginia) accurate to 0.05 mm.

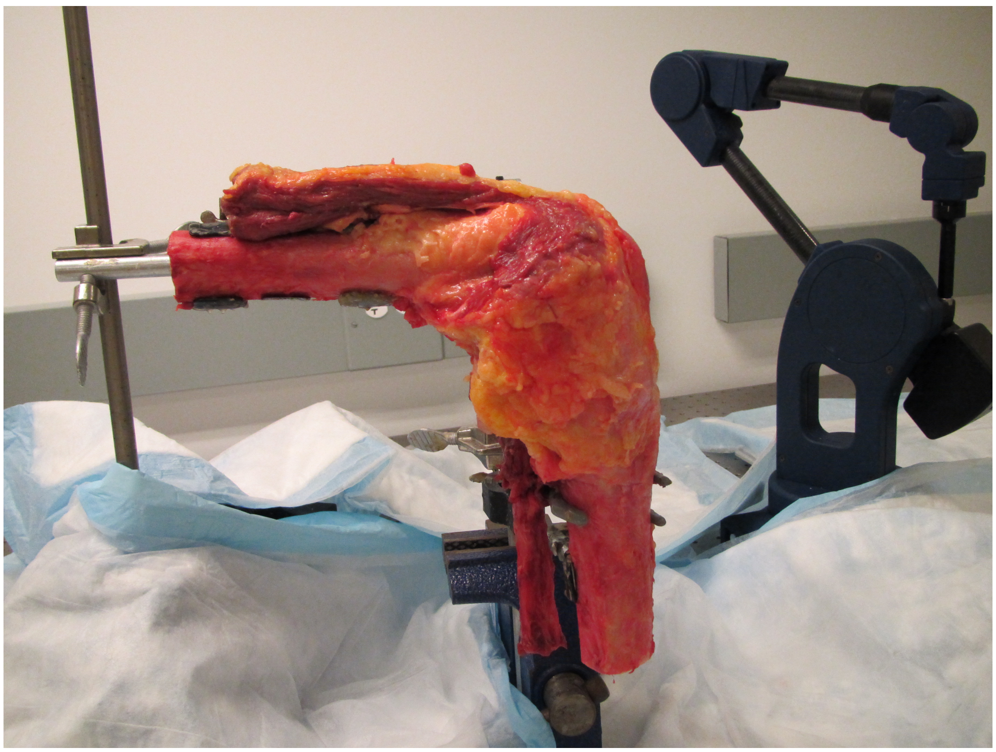


Figure 2. Comparison of a full vs. half-fluted femoral reamer during passage through the tibial tunnel intra-articular aperture before femoral transtibial reaming. **A)** 11mm tibial tunnel with beath pin aligned along posterolateral edge in over-the-top position. **B)** 10mm full-fluted femoral reamer. Note the reamer's inability to obliquely navigate the tibial tunnel while in off position. In order to enter the joint, the reamer must be started—this in turn results in the removal of the posterior edge of the tibial tunnel aperture. **C)** A different 11mm tibial tunnel with beath pin aligned along posterolateral edge in over-the-top position. **D)** 10mm half-fluted femoral reamer. Because the reamer's smaller width, it is able to obliquely navigate the tibial tunnel while in the off position resulting in less posterior expansion of the aperture.

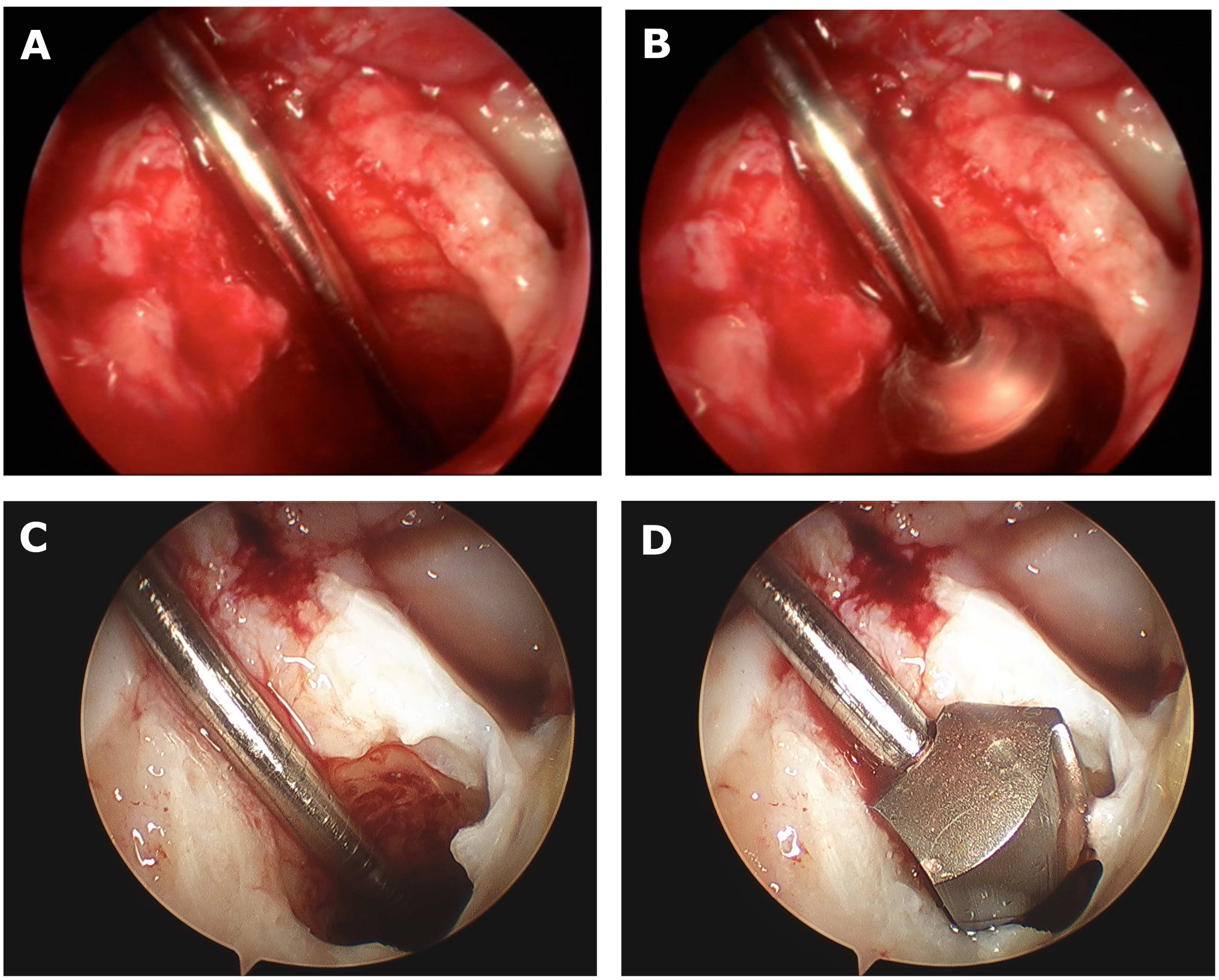


Figure 3. 10mm full-fluted standard femoral reamer (top) vs. 10mm half-fluted reamer (bottom) used for transtibial femoral tunnel creation in over-the-top position. Reamers courtesy of Smith and Nephew Endoscopy (Andover, MA).

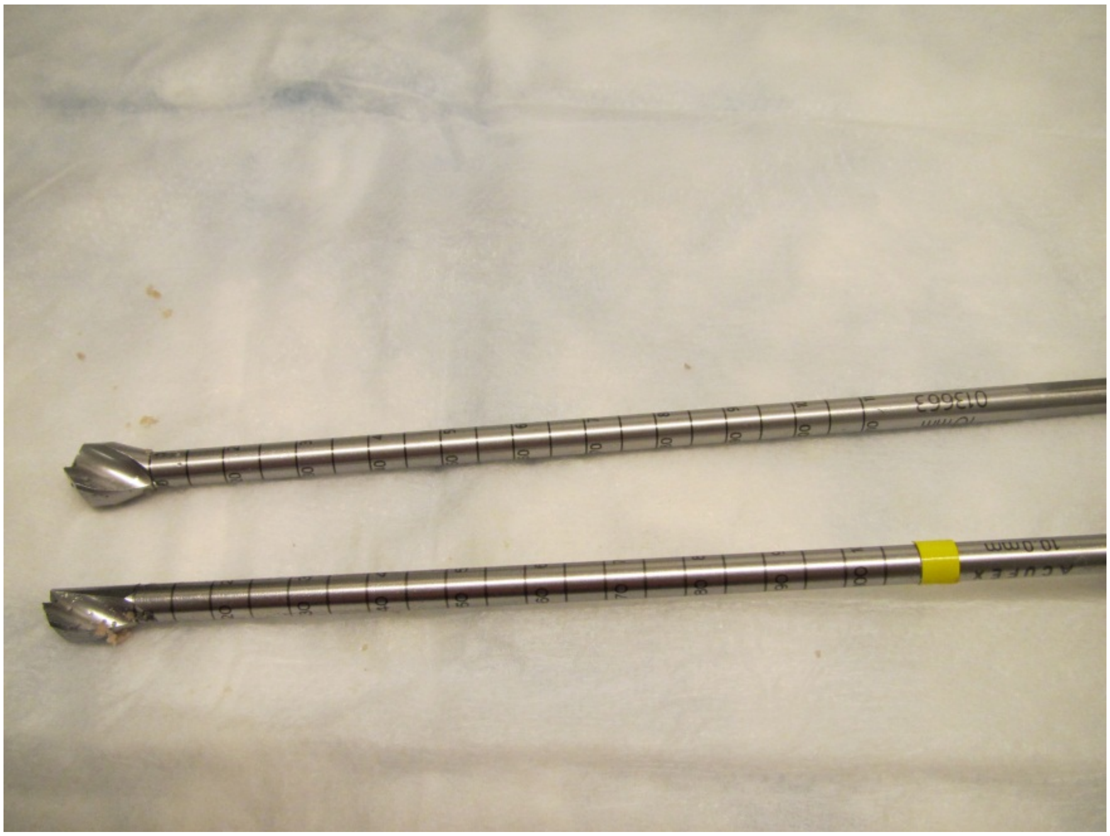


Figure 4. Anatomic relationship of center of native ACL tibial footprint (blue) and posterior edge of anterior horn lateral meniscus as seen in a typical anterior arthroscopic view of the knee. Note that the center of the native tibial ACL footprint is 2.0 ± 0.49mm anterior to the posterior edge of the lateral meniscus' anterior horn in the anteroposterior plane, a value slightly more anterior than previously reported in some studies.[17, 22, 23]

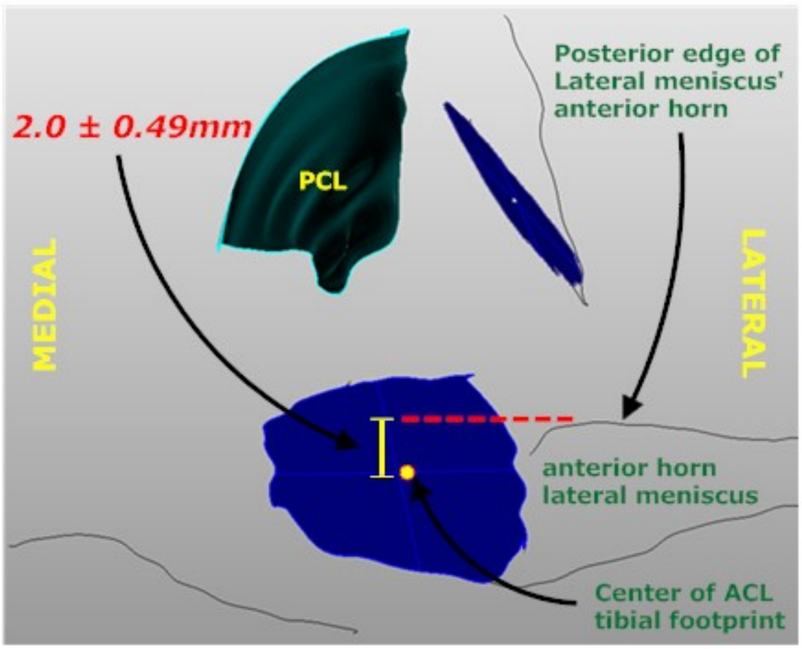


Figure 5. Visual depiction of how distance from posterior edge of ACL footprint to PCL at level of tibial plateau was digitized.

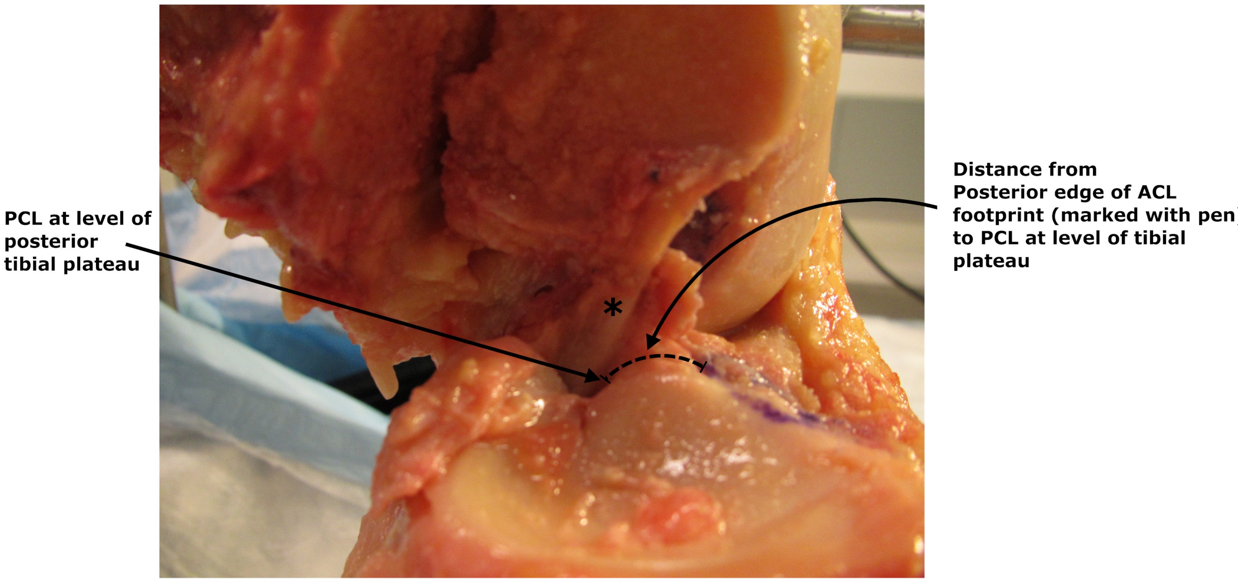
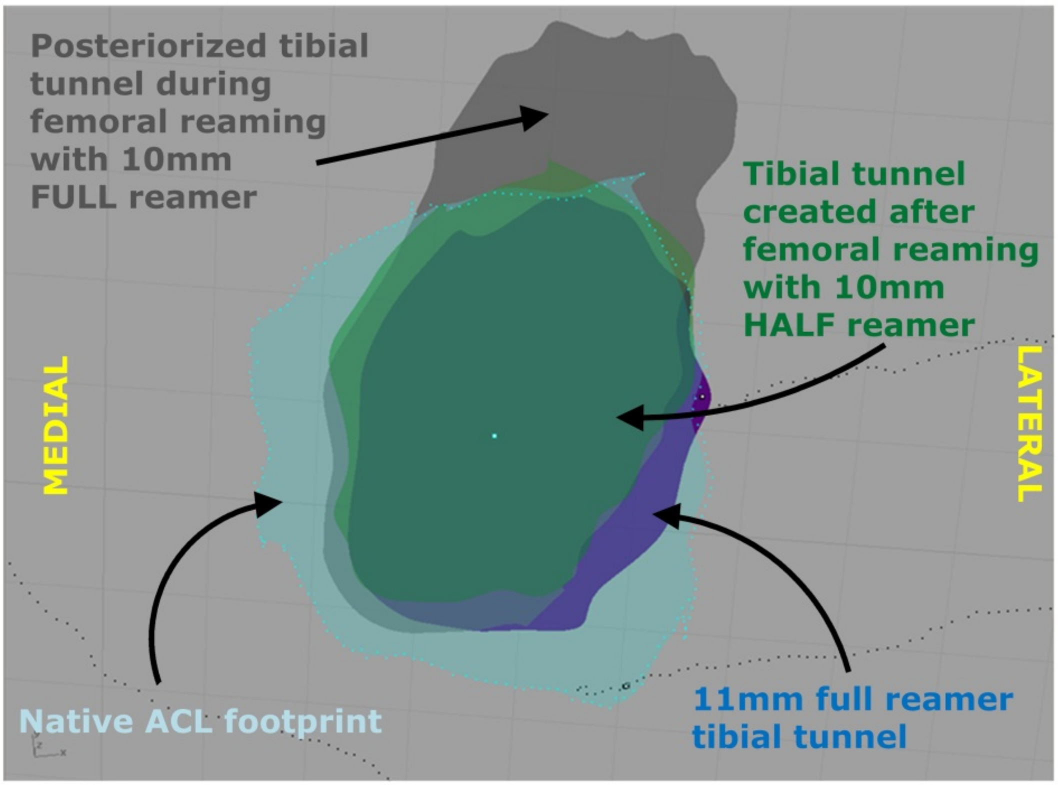


Figure 6. Native tibial ACL footprint (light blue) in left knee with outline of tibial tunnels created using various reamers. Note posteriorization of tibial tunnel footprint during femoral reaming with 10mm full reamer.



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