

The Posterior Cruciate Ligament: An Anthropometric Study in Asians and Evaluation of Safe Limits for Bony Tunnel Creation During Reconstruction

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Abstract

Introduction: Quantitative data regarding the dimensions of the posterior cruciate ligament (PCL) and its insertions have not been studied in Asians, and concerns have been raised regarding the danger of vascular injury when the bony tunnels are created during arthroscopically-assisted reconstruction. **Materials and Methods:** Ten male cadavers were used in this study, incorporating dissection and procedural arms. In the procedural arm, the path of the drill bit was tracked fluoroscopically as the tibial and femoral tunnels were created during simulated reconstructive surgery, and the effect of varying knee flexion angles was studied. Fluoroscopic images were analysed using specialised image processing software. **Results:** The mean length of the PCL at full extension was 37.7 ± 1.9 mm, and the mean mid-substance width was 13.7 ± 1.7 mm. The mean sagittal distance between the exit point of the tibial tunnel and the anterior surface of the popliteal artery, across all knee flexion positions, was merely 6.0 mm (range, 2.8 to 10.2 mm). This distance tended to increase with increasing knee flexion, but this was not statistically significant. The mean distance between the exit point of the femoral tunnel and the femoral artery was 51.1 mm (range, 42.1 to 59.0 mm). **Conclusions:** The dimensions of the PCL and its insertions in Asians do not vary greatly from those reported for Western subjects. The distance from the exit point of the tibial tunnel to the popliteal artery is very small and, although this distance increases with increasing knee flexion, the improvement in the safety margin may neither be clinically nor statistically significant. The margin of safety for drilling of the femoral tunnel is much greater.

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Introduction

The posterior cruciate ligament (PCL) provides the main restraint to posterior translation of the tibia on the femur¹ and is stronger than its anterior counterpart. Indeed, it has been regarded by some authors as the primary stabiliser of the knee.^{2,3} PCL injuries are believed to be rising, although they still occur far less frequently than those involving the anterior cruciate ligament (ACL),⁴ with estimated injury rates averaging between one-tenth to one-twentieth of those reported for its anterior counterpart.⁵ O'Donoghue⁶ has reported figures as low as 3.4% while Clendenin et al⁷ have published rates as high as 20% of all ligamentous knee injuries, but the actual figure is probably in between at about 8%.⁸

Management of these injuries remains controversial, but reconstruction is increasingly being advocated for chronic, symptomatic insufficiency, especially when associated

with other ligamentous injuries and posterolateral instability.^{8,9} Reconstruction is increasingly being performed using either autografts or allografts via arthroscopically-assisted techniques.¹⁰⁻¹³ This has led to renewed interest in the anatomy, physiology and biomechanics of the PCL. A thorough appreciation of these characteristics allows accurate reproduction of PCL anatomy during reconstructive surgery, which is essential for achieving good functional results.

Critical parameters that have to be considered during reconstruction of the PCL include the size and length of the graft, as well as the position and dimensions of the femoral and tibial footprints.^{13,14} The available anthropometric data have been derived almost exclusively from Western subjects, and we felt that a study involving Asian subjects was necessary to define any significant racial differences. We also felt that such data, although basic, would prove

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useful to those who may have an interest in the emerging field of ligament engineering.

Injury to the popliteal artery has also been reported as an uncommon but potentially catastrophic morbid event during surgery, and this has been said to occur primarily during the creation of the tibial tunnel as the guide pin or drill bit exits from the posterior tibial cortex at the insertion of the native PCL.^{10-12,15,16} In this study, we attempted to define the spatial relationships between the posterior vascular structures and the exit points of the guide pins/drills during creation of the tibial as well as the femoral tunnels. This would lead to a better appreciation of the safe anatomic limits during arthroscopically-assisted PCL reconstruction.

Materials and Methods

There were two main arms in this study: a dissection arm to provide quantitative data for the dimensions and insertion sites of the PCL in Asians, and a procedural arm which aimed to define the relationships between the posterior exit point of the drill/guide pin and the posterior vascular structures during PCL reconstruction using an arthroscopically-assisted trans-tibial technique.

Specimens

Ten cadaveric lower limbs were harvested by disarticulation at the hip. It was felt that disarticulation would be least likely to lead to any disruption of the anatomic relationships of the popliteal neurovascular bundle in the region of the knee. The cadavers were all Asian males aged above 50 years. In preparation for vascular imaging, each limb was thawed before identifying and cannulating the femoral artery proximally. 10% phosphate-buffered formalin was injected until backflow was noted around the cannula. This was followed by approximately 100 mL of latex solution containing 30 g of micronised barium sulphate as a contrast agent. The limbs were then kept frozen in the refrigerator for another 48 hours to allow the latex to

coagulate within the arterial system.

Procedural Study and Specimen Imaging

Insertion of the tibial tunnel guide pin was achieved under direct vision through a mini-arthrotomy using a custom guide (Smith & Nephew, Andover, MA). The insertion point of the guide pin was 10 mm distal and 10 mm medial to the tibial tubercle, and the direction of insertion was fixed by the guide at an angle of 55° to the horizontal (Fig. 1). The tibial tunnel was drilled in an antero-posterior direction with the exit point on the posterior tibia located about 10 mm below the tibial plateau just lateral to the midline, which approximates the insertion point of the native PCL.^{10,13,17-19} The femoral tunnel guide pin was then inserted under direct vision via the same arthrotomy incision. The insertion point was on the medial femoral condyle, approximately 10 mm posterior to the anterior edge of the intercondylar notch and just behind the mid-point of the femoral footprint of the native PCL. The pin was directed towards the medial epicondyle.

The passage of the guide pins and drill bits, as they were driven through the tibia and the femur during the creation of the respective tunnels, were monitored fluoroscopically (Philips, Holland) with both antero-posterior and lateral views (Fig. 2). In all the limb specimens, the pre-treated popliteal artery could be clearly delineated radiographically. Every effort was made to ensure that the distance between the specimens and the X-ray tube remained constant throughout.

The tibial guide pins were inserted with the knee in 3 differing amounts of flexion (60°, 90° and 120°) as we hoped to investigate the effect of knee flexion on the relationship of the artery to the posterior knee. However, the femoral guide pin could only be inserted with the knee in 30° of flexion as it was technically difficult and impractical to do so in any other position.

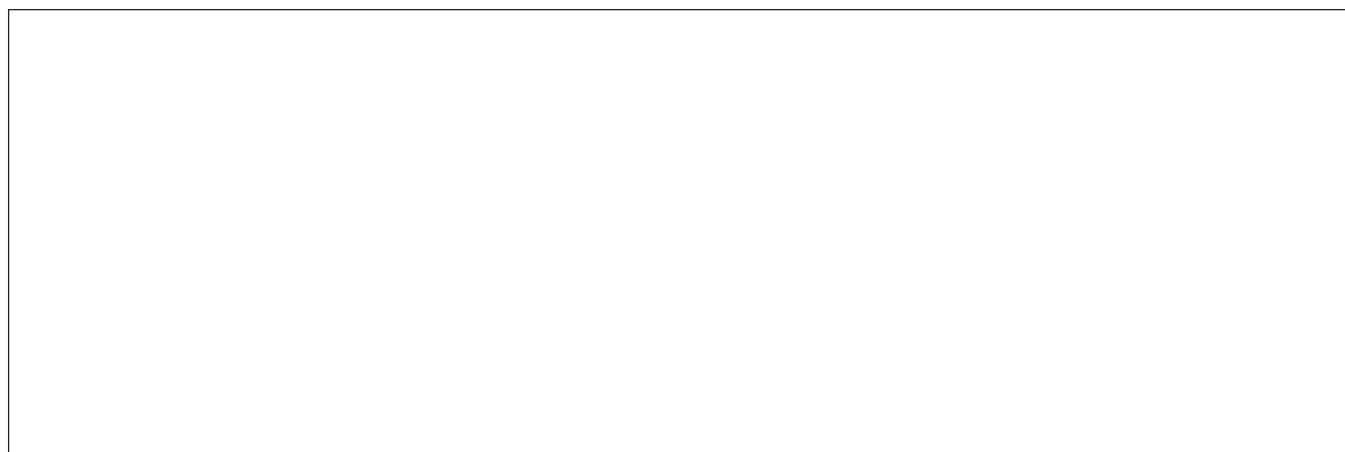


Fig. 1. Drilling of tibial tunnel using custom guide with knee flexed to 90°.



Fig. 2. Passage of the guide pin is tracked with an image intensifier.

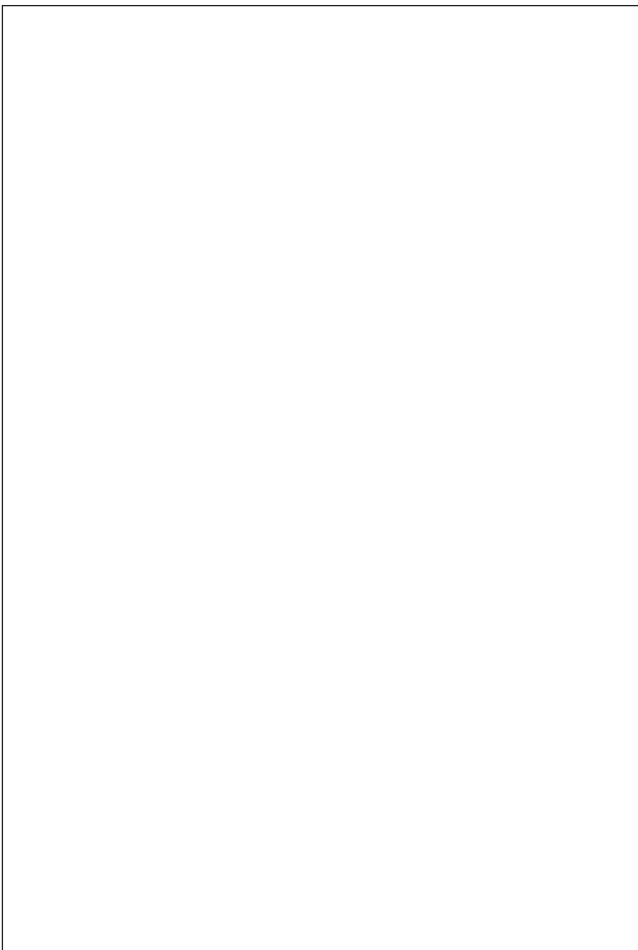


Fig. 3. Lateral fluoroscopic image of the knee demonstrating the opacified popliteal artery and the tip of the guide pin as it exits from the anatomic location of the tibial insertion of the PCL.

Image Analysis and Measurements

All fluoroscopic images were recorded on VHS videotape and transferred to a computer workstation running a specialised program (Carl Zeiss, Germany) that had been designed for radiographic image analysis and mensuration.

This program was used to calculate the distance in the sagittal plane between the tip of the guide pins at the tibial and femoral exit points, and the popliteal and femoral arteries, respectively (Fig. 3). The position of the guide pin was also referenced from the medial joint line. Distances in the axial plane were not recorded.

Dissection and Anthropometric Measurements

Following the procedural study described above, the specimens were dissected via a posterior midline longitudinal incision. The posterior knee capsule was split and the PCL and menisco-femoral ligaments identified. The length and widths of the PCL were measured in different degrees of knee flexion after first flexing and extending the knee repetitively to reduce the effect of crimp. The dimensions of the tibial and femoral footprints were also recorded. All measurements were performed using a micrometer, and each measurement was repeated until two identical readings were obtained. An attempt was also made to isolate the antero-lateral from the postero-medial bundles of the PCL.

Statistical Analysis

All statistical analyses were performed with SPSS software. The Wilcoxon signed ranks test was used for non-parametric analysis of the effect of knee flexion angle on the separation between the popliteal artery and the posterior exit point of the tibial tunnel. A *p* value of less than 0.05 was considered statistically significant.

Results

Anthropometric measurements were performed *in situ* following specimen dissection. The mean lengths of the PCL at 0°, 30°, 60° and 90° of flexion were 37.7 ± 1.9 mm, 36.0 ± 0.7 mm, 35.5 ± 1.2 mm and 34.4 ± 1.3 mm, respectively. The mean mid-substance width (medial-lateral) was 13.7 ± 1.7 mm (range, 12.0 to 18.0 mm). The mean mid-substance thickness (antero-posterior) was 5.8 ± 0.8 mm (range, 5.0 to 7.0 mm). The mean dimensions of the femoral footprint were 20.8 ± 1.8 mm in the long axis and 19.3 ± 1.3 mm in the short axis, and tended to be virtually circular in cross-section. Conversely, the tibial footprint tended to be rectangular in shape, and the mean dimensions were 20.2 ± 1.8 mm and 12.4 ± 1.3 mm in the long and short axes, respectively. The mean ratio of the area of the tibial footprint to the mid-substance cross-sectional area of the PCL was 3.2. We also estimate that the area of the femoral footprint is generally about 5 times that of the tibial footprint.

The distance between the exit point of the tibial guide pin and the anterior surface of the popliteal artery in the sagittal plane, as measured on the lateral fluoroscopic images, was recorded at varying angles of knee flexion. The mean

distance when all flexion positions were considered was merely 6.0 mm, with measurements ranging fairly widely from 2.8 to 10.2 mm. This distance tended to increase with increasing amounts of knee flexion, although this increase was not statistically significant (Table I).

The distance between the femoral exit point of the guide pin and the postero-medial curvature of the femoral artery as it lies behind the distal femur was also measured. This distance ranged from 42.1 mm to 59.0 mm, with a mean of 51.1 mm.

Discussion

The optimal management of PCL injuries has yet to be adequately defined due to the lack of properly-designed prospective studies, but the weight of the available evidence tends to suggest that symptomatic PCL tears when combined with other ligamentous injury or other evidence of instability should best be addressed by reconstructive surgery. Accurate reproduction of PCL anatomy and biomechanics, as well as safe placement of the bony tunnels, are two critical considerations for PCL reconstruction.¹⁰⁻¹³

A primary objective of this study was to define the basic anthropometric parameters of the PCL in Asian knees, and compare this data with those published elsewhere in the Western literature.^{17,20} The PCL inclines forward at an angle of between 30° to 56° in the sagittal plane, depending on the degree of knee flexion. The PCL is more vertical in extension and more horizontal in flexion.¹⁷ We measured the length of the PCL at various degrees of knee flexion, and expectedly the length was maximum in full extension (37.7 ± 1.9 mm) and minimum at 90° flexion (34.4 ± 1.3 mm). This is comparable to the quoted figure by Girgis et al¹⁷ of a mean length of 38.1 mm when measured with the knee in full extension. In the same study, Girgis et al also found the mean mid-substance width of the PCL to be 13.4 mm, which is comparable to our figure of 13.7 mm.

Our data on the shapes and dimensions of the femoral and

tibial insertion sites also correlate closely with recently reported measurements by Harner and co-workers.²¹ Assuming that both the mid-substance PCL and its tibial insertion are fairly rectangular in cross-section, a premise which stems from observations by our group and also by others,^{22,23} our study estimates that the mid-substance cross-sectional area of the PCL is approximately three times that of its tibial insertion.

During dissection, we attempted to physically separate the anterolateral and posteromedial bundles of the PCL but were generally unsuccessful, although differential tensioning of the fibres of the two bands was discernible by palpation during flexion-extension of the knee. Thus, we are of the opinion that the division of the bundles appears to be more of a functional rather than an anatomical nature, and that a single graft of appropriate dimensions placed isometrically and positioned accurately would be able to simulate the function of the native PCL fairly closely.

There have been reports of inadvertent injury to the popliteal artery during drilling of the tibial tunnel. Although uncommon, this is a potentially catastrophic occurrence.¹⁵ Several measures have been proposed to circumvent this hazard, from simple measures such as fluoroscopic visualisation of drill passage,¹⁵ and direct palpation of the drill via a posterior arthrotomy,^{15,16} to more specialised techniques using cupped drill stops^{11,16} or a curved curette¹² to control drill advancement. A recent cadaveric study by Matava et al,²⁴ utilising magnetic resonance imaging (MRI), had focused on defining the optimal knee flexion angle that would minimise the risk of this injury during drilling of the tibial tunnel. We had similarly been interested in defining safe limits for the creation of both the tibial and femoral tunnels, by following the passage of the guide pin/drill fluoroscopically, and characterising their paths in relationship to the posterior vascular structures.

We found, as Matava and his co-workers did, that the tibial insertion of the PCL, where the guide pin/drill bit exits during creation of the tibial tunnel, is perilously close to the popliteal artery. Indeed, our dissection has shown that the only structures separating the tip of the drill bit from the vessel is the posterior capsule and a layer of loose areolar tissue. The average distance in the sagittal axis between the exit point and the popliteal artery, when all knee flexion angles are considered, is merely 6 mm, and although it is observed that this distance tends to increase with increasing knee flexion, the magnitude of this increase seems to be neither statistically nor clinically significant. There seems to be considerable variation in the measured distances, both within the same knee flexion group and also between different knee flexion groups—2.9 to 8.9 mm at 60° and 5.0 to 10.2 mm at 120° of knee flexion. The separation in the axial plane has also been previously

TABLE I: MEAN DISTANCE IN THE SAGITTAL PLANE BETWEEN THE EXIT POINT OF THE TIBIAL TUNNEL AT THE TIBIAL INSERTION OF THE PCL AND THE POPLITEAL ARTERY, ACCORDING TO KNEE FLEXION ANGLE[†]

Knee flexion angle	Distance from popliteal artery (sagittal plane) Mean $\pm$ SD (range) (mm)	Comparison of means (reference flexion angle = 60°)
60°	5.9 $\pm$ 2.0 (2.8 – 9.9)	NA
90°	5.3 $\pm$ 1.9 (3.0 – 9.8)	$P = 0.31$ (ns)
120°	6.9 $\pm$ 2.0 (5.0 – 10.2)	$P = 0.29$ (ns)

NA: not applicable; ns: not significant; PCL: posterior cruciate ligament

[†] The mean distance at the reference knee flexion angle of 60° is compared with the means obtained at angles of 90° and 120°, respectively.

reported to be similarly slight. On the other hand, the exit point for the guide pin/drill bit during creation of the femoral tunnel is relatively distant from the artery in the sagittal plane, and its path is also directed medially away from the vessel. Hence, the potential for vascular injury is much less when compared to tibial tunnel creation.

It should be noted that this study was performed in non-inflated knees, and this margin of safety would be further reduced in the inflated knee during surgery. Another limitation of our study is that the specimens were all fairly elderly male cadavers, and the pre-mortem heights and weights could not be determined. It has previously been noted that the PCL is narrower in women compared to men.²⁰

Conclusion

The dimensions of the PCL and its insertions in Asians do not appear to vary greatly from those reported for Western subjects. The distance in the sagittal plane between the tibial insertion site and the popliteal artery is very small, and although the margin of safety for the drill or guide pin as it advances through the tibial insertion may be improved by increasing the knee flexion angle, this improvement may neither be clinically nor statistically significant. In addition to those techniques mentioned earlier, other possible approaches to enhancing the margin of safety may involve measures to create a more vertical and medially-based tibial tunnel. This could be achieved by moving the starting point and/or increasing the angle of entry when drilling.

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