Original Communication

ANATOMICAL STUDY OF THE MORPHOMETRY OF THE TIBIAL AND FEMORAL ATTACHMENT SITES OF THE POSTERIOR CRUCIATE LIGAMENT

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RESUMEN

Aunque las lesiones aisladas del ligamento cruzado posterior (LCP) se tratan a través de la rehabilitación no quirúrgica, su reconstrucción anatómica se ha tornado cada vez más importante. Este estudio proporciona información sobre la posición y la variabilidad de los sitios de unión de la tibia, las dimensiones de las inserciones femorales, la comparación de éstos entre los sexos, y entre la derecha rodilla y la izquierda. Se examinaron treinta y un (15 rodillas derecha y 16 izquierda) de 9 cadáveres mujeres y 7 cadáveres del sexo masculino (edad media 77 años). La marca del LCP fue identificado a partir de la longitud y ancho antero-lateral y postero-mediales (PM) de la tibia (AL). Los resultados fueron 8,7mm y 10,9mm, y 7,3mm y 13,44mm respectivamente. La longitud media y la anchura de la marca de la tibia en el sexo masculino y femenino fueron 10,2 mm y 10,3mm y 7,7mm y 11,4mm para la fibra AL, 8.2 mm y 14.2mm y 6,7mm y 12,9mm para la fibra PM, respectivamente. La posición anatómica media de los tendones AL y PM fueron 51% y 50% del diámetro mediolateral del platillo tibial. Las longitudes y anchuras medias de la inserción femoral PCL fueron 9,4mm y 12,8mm para el tendón AL y 7,5mm y 11,4 mm para el tendón PM, el lugar de inserción del tendón AL siendo significativamente mayor (P=0,034) en los hombres. No se observó ninguna diferencia entre las rodillas derecha e izquierda. Los datos presentados aquí ayudarán en la toma de decisiones adecuadas para la reconstrucción anatómica PCL.

Palabras claves: *Ligamento cruzado posterior; tendón anterolateral; tendón posteromedial; reconstruction anatómica*

ABSTRACT

Although isolated injuries of the posterior cruciate ligament (PCL) are managed through non-operative rehabilitation, its anatomic reconstruction is becoming increasingly important. This study provides information regarding the position and variability of its tibial attachment sites, dimensions of the femoral insertions, comparing these between males and females, and between right and left knees. Thirty one cadaveric knees (15 right, 16 left) from 9 female and 7 male cadavers **(**mean age 77 years) were examined. The PCL footprint was identified from which the mean length and width of the tibial anterolateral (AL) and posteromedial (PM) bundles were 8.7mm and 10.9mm, and 7.3mm and 13.4mm respectively. The mean length and width of the tibial footprint in males and females were 10.2mm and 10.3mm, and 7.7mm and 11.4mm for the AL bundle and 8.2mm and 14.2mm and 6.7mm and 12.9mm for the PM bundle respectively. The mean anatomical position of the AL and PM bundles were 51% and 50% of the mediolateral diameter of the tibial plateau. The mean lengths and widths of the PCL femoral attachment were 9.4mm and 12.8mm for the AL bundle and 7.5 mm and 11.4mm for the PM bundle, with the AL bundle attachment being significantly larger (P= 0.034) in males. No difference between right and left knees were observed. The data presented here will aid in making appropriate decisions to achieve anatomic PCL reconstruction.

Keywords: *Posterior cruciate ligament; anterolateral bundle; posteromedial bundle; anatomic reconstruction*

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INTRODUCTION

The posterior cruciate ligament (PCL), the stronger of the cruciates (Petersen et al, 2006), is the primary knee joint stabilizer and principal restraint against posterior tibial translation (Li et al, 2008). Functionally, it consists of 2 bundles: a larger, stiffer, longer anterolateral (AL) bundle, which tightens in flexion, and a smaller, weaker, shorter posteromedial (PM) bundle which is taut in extension (Girgis et al, 1975).
The strong PCL (Harner et al, 2001) accounts for its lower incidence of injury than the ACL (Schulz et al, 2003). Nevertheless, PCL injuries account for 3 - 44% of all knee injuries, with motor vehicle and athletic injuries being the most common causes (Schulz et al, 2003): because PCL injuries are often asymptomatic they tend to be underdiagnosed (Shelbourne et al, 1999). While most athletic injuries result in isolated PCL injury, the majority of motor vehicle injuries result in multiple ligament damage (Fanelli et al, 2005). The majority of athletes with isolated PCL injury return to competitive sport after non-operative rehabilitation involving physical therapy, which improves knee stability through compensatory muscle function to resist excessive posterior tibial translation (Colvin and Meislin, 2009). Chandrasekaran et al (2012), in their review of non-operative management of PCL injury, confirmed the early activation of the gastrocnemius-soleus complex as the major compensatory mechanism.

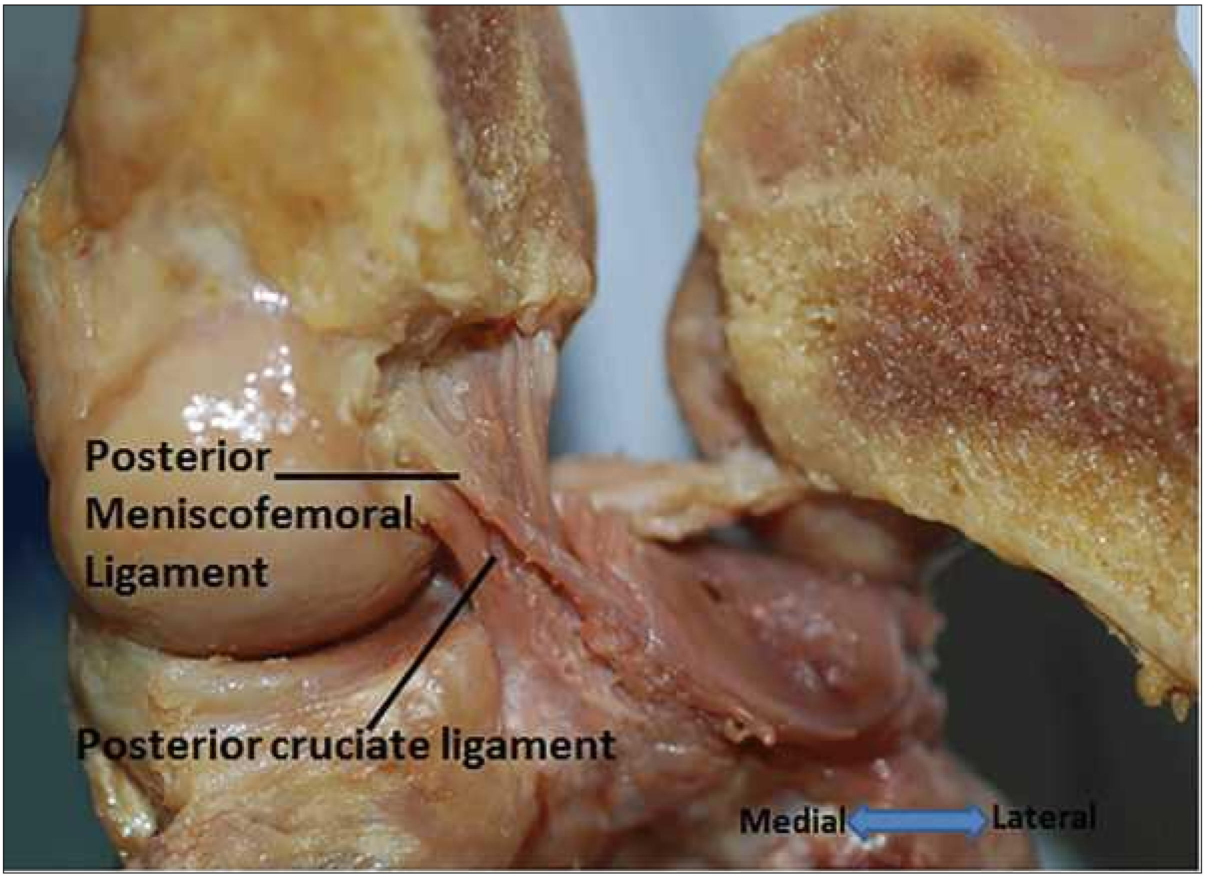

Figure 1: The relationship between the meniscofemoral and posterior cruciate ligaments.

PCL reconstruction is becoming increasingly important due to early degenerative changes arising from chronic instability as a result of unrepaired PCL tears (Dandy and Pusey, 1982), with the prevalence of articular degeneration ranging from 15 - 88%, increasing from the time of injury (Shelbourne et al, 1999). PCL reconstruction is usually performed using either the double bundle technique, which reproduces the anterolateral and posteromedial bundles, or the inlay technique (Christel, 2003; Hoher et al, 2003; Wind et al, 2004). A sound appreciation of PCL anatomy is essential to understanding the function of its two bundles, as well as improving the outcomes of reconstructive surgery (Takahashi et al, 2006; Lopes et al, 2008). Information concerning the dimensions of the attachment sites of each bundle would help surgeons make appropriate decisions on the type of technique to perform and graft to use. However, there is not much data available on these dimensions (Takahashi et al, 2006). Gender differences in these dimensions should also be considered in PCL reconstruction as both sexes are vulnerable to injury: little has been published concerning these differences.

The present anatomical study aims to provide detailed information on the dimensions of both the tibial and femoral attachment sites of the PCL. Such findings could aid in achieving anatomic PCL reconstruction, thereby restoring normal anatomy.

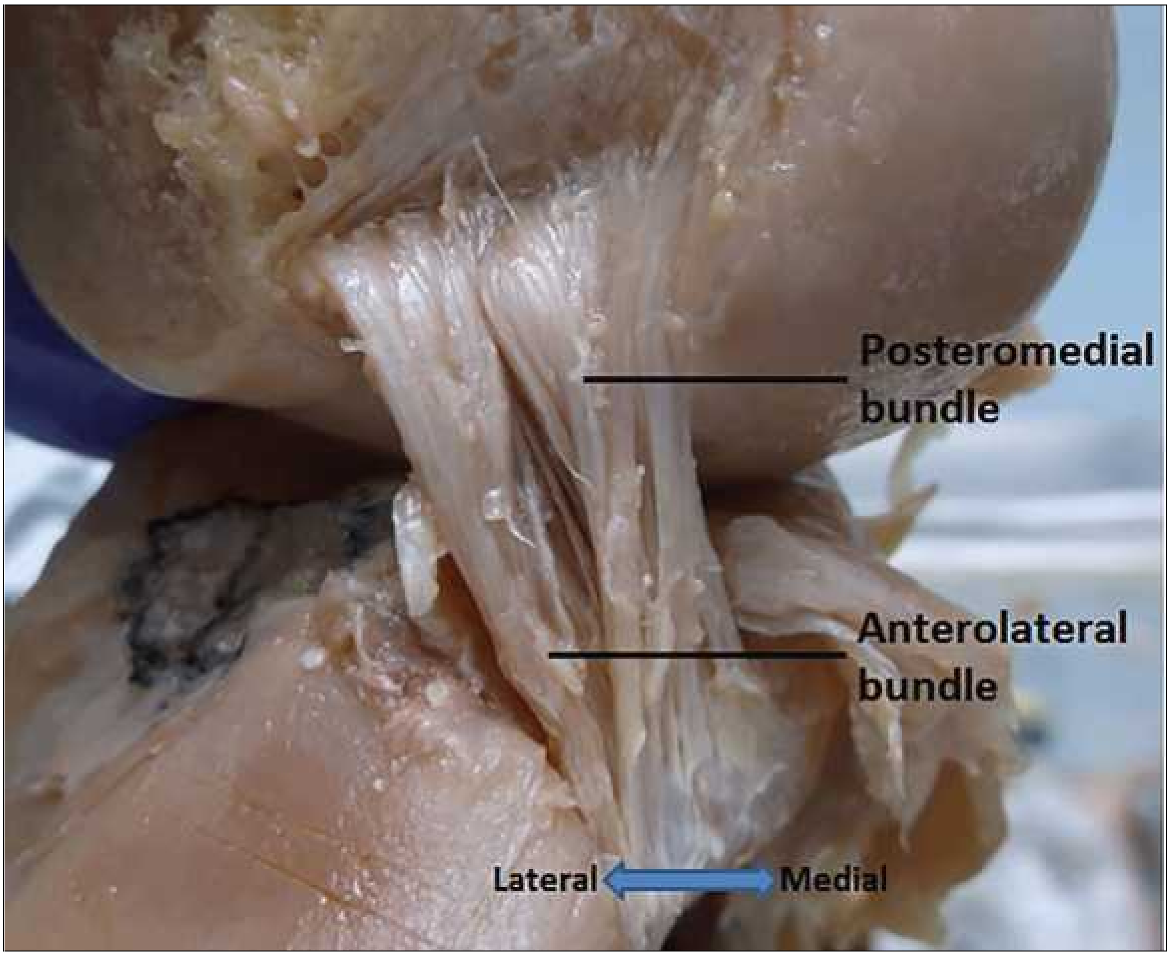

Figure 2: The tense posteromedial (PM) and lax anterolateral (AL) bundles of the posterior cruciate ligament.

MATERIALS AND METHOD

Fifteen right and sixteen left side knees were available for study from 9 female and 7 male Thiel-embalmed white Caucasian cadavers, with an average age of 77 years. The knees examined were from individuals who had donated their bodies for medical, educational and scientific research in accord with the Human Tissues Act (Scotland) 2006: consent is implicit on signing the relevant bequest forms. Knees with any evidence of surgical scars or of clinical deformity, e.g. macroscopic osteoarthritis were excluded. The study relied on the experience and expertise of RWS, who has over 30 years anatomical teaching and research experience, with research interests in clinical anatomy, especially of the vascular and musculoskeletal systems.

Each knee was dissected to expose the ACL and PCL by clearing all adjacent tissues. The menisco-femoral ligaments (MFLs), when present, were preserved to avoid damaging the PCL and to facilitate delineation of its femoral footprint as the femoral attachment of the MFL is closely related to that of the PCL (Figure 1). The intercondylar portion of the femur was sectioned using a circular saw ensuring the ACL and PCL attachment sites remained intact: the medial half of the femur contained the PCL attachment (Figure 1), with each bundle readily identifiable (Figure 2). Each bundle was harvested from its bony attachment after black ink marker was used to outline the attachment sites. The dimensions of the attachment sites were then measured three times and the mean determined. The anteroposterior and mediolateral diameters of the tibial attachment sites were recorded as length and width respectively, while the proximodistal and anteroposterior diameters of the femoral footprints were recorded as length and width respectively. All measurements were undertaken using a digital Vernier caliper (Mitutoyo calliper 550 series, Komatsukuoki Co Ltd, Japan: accuracy 0.03 mm).

To determine the position of the tibial attachment sites the following footprint parameters were measured: DA and DB being the distances between the medial edges of the bundles and the medial edge of the tibial plateau (Figure 3); DT, the width (i.e. mediolateral diameter) of the tibial plateau; DC, the distance between the attachment site and the anterior edge of the tibial plateau; DE, the length of the footprint on the posterior surface of the tibia distal to the articular surface. The mediolateral position of the bundles were expressed as proportions of the width: AL= DA + half-length of AL/DT x 100; PM = DB + half-length of PM/DT x 100.

Differences between gender (male and female) and side (right and left) were determined using analysis of variance (ANOVA) with significance set at $P \leq 0.05$. Pearson correlation coefficient (r) and coefficient of determination (R^2) were used to determine the relationship between the different dimensions of the attachments. Statistical analysis was undertaken using SPSS software (IBM SPSS statistics 19).

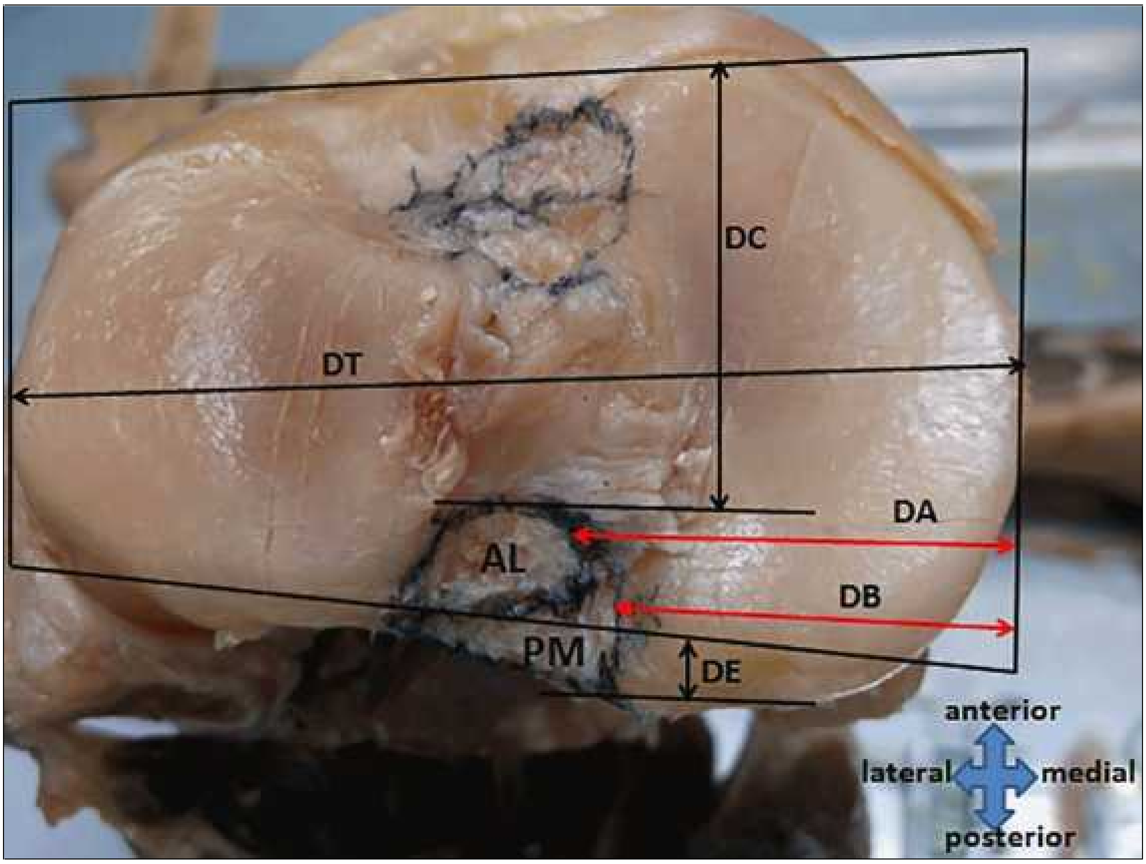

Figure 3: Measurements taken from the tibial plateau with respect to the posterior cruciate ligament footprint (outlined with black ink). DA, distance between the medial margin of the tibial articular surface and the anterolateral bundle attachment; DB, distance between medial margin of the tibial articular surface and the posteromedial bundle attachment; DC, distance between the anterior margin of the tibial articular surface and tibial attachment; DE, distance between the posterior margin of the tibial articular surface and distal edge of the insertion site; DT, mediolateral diameter.

	Tibial insertion: AL bundles Length/width (mm)	Tibial insertion: PM bundles Length/width (mm)	Tibial insertion: PCL site Length/width (mm)	Femoral insertion: AL bundles Length/width (mm)	Femoral insertion: PM bundles Length/width (mm)	Femoral insertion: PCL site Length/width (mm)
Mean	8.7/10.9	7.3/13.4	16.0/13.7	9.4/12.8	7.5/11.4	16.9/15.4
SD	2.4/2.0	3.1/3.0	3.6/2.8	2.2/3.4	2.1/2.4	3.7/2.3
Range	4.3-14.3/ 5.6-13.8	2.6-19.2/ 7.2-21.4	10.3-25.4/ 7.7-21.4	6.5-17.0/ 8.3-22.4	3.3-16.7/ 7.5-18.3	12.5-33.5/ 12.0-22.4
Right knee	8.7/11.0	8.0/13.6	16.7/13.9	9.7/13.3	7.2/11.2	16.9/15.3
Left knee	8.7/10.8	6.7/13.3	15.4/13.5	9.2/12.4	7.8/11.6	16.9/15.4
Male	10.2/10.3	8.2/14.2	18.3/14.3	10.3/14.3	7.7/11.7	17.9/15.8
Female	7.7/11.4	6.7/12.9	14.3/13.2	8.8/11.8	7.4/11.2	16.1/15.1

Table 1: Dimensions of the tibial and femoral posterior cruciate ligament (PCL) attachment sites, including those of the anterolateral (AL) and posteromedial (PM) bundles separately. SD, standard deviation.

RESULTS

Table 1 presents the length and width of the PCL tibial and femoral attachments, with males having a wider AL femoral attachment than females (P= 0.034): no difference was observed in length and width between right and left knees. The shape of the tibial PM bundle footprint was observed to reflect the orientation of the midsubstance of the PCL in relation to the AL bundle (Figure 2), with its thickest portion located posteromedial to the AL bundle (Figure 3). The lateral PM fibres posterior to the AL bundle were relatively thinner than other parts: the PM bundle therefore has a two-arm shape. The relative position of each PCL bundle on the tibial plateau is presented in Table 2. Pearson's correlation showed that the AL and PM bundles tend to have a similar impact on the size of the femoral footprint.

	Anterior margin of PCL to AMAP (mm)	Posterior tibial rim to posterior margin of insertion (mm)	Mediolateral Position (%)	
			AL	**PM**
Mean	39.5	10.7	51	50
SD	3.4	1.6	0.0	0.0
Range	35.2-47.7	4.7-14.1	42-58	44-56
Right knee	39.7	10.7	50	52
Left knee	39.3	10.8	50	51
Male	42.1	10.9	49	53
Female	37.6	10.6	51	50

Table 2: Location of the tibial footprint of the posterior cruciate ligament (PCL) on the tibial plateau. AL, anterolateral bundle; PM, posteromedial bundle; PCL, posterior cruciate ligament; AMAP, Anterior margin of articular plane; SD, standard deviation.

Some PCL tibial parameters showed significant correlations, these being between (i) total length and AL length (r=0.515, P=0.003) and PM length (r=0.766, P=0.000), and (ii) total width and PM width (r=0.993, P=0.000). Similarly, some femoral parameters also showed significant correlations, these being between: (i) total length and AL length (r=0.884, P=0.000) and PM length (r=0.867, P=0.000), (ii) total width and AL width (r=0.795, P=0.000) and PM width (r=0.718, P=0.000), and (iii) AL length and PM length (r=0.535, P=0.002).

DISCUSSION

The data collected regarding the tibial and femoral PCL attachments is in agreement with Dargel et al (2006), who also reported no significant difference in the total area of cruciate ligament attachments between left and right side specimens. This observation is useful in PCL reconstruction since the size and type of graft, as well as the type of procedure (single or double bundle), are normally determined by the dimensions and positions of the attachment sites as well as gender and side differences.

The orientation of the PCL passing posterior, inferior and lateral to the ACL from the medial condyle of the femur to the posterior aspect of the tibial plateau between the posterior aspect of the medial and lateral tibial plateaux agrees with Anderson et al (2012). Indeed, most studies (Takahashi et al, 2006; Cury et al, 2011; Geiner et al, 2011; Anderson et al, 2012; Osti et al, 2012) on PCL attachments have concentrated on providing reference points for their location as an aid to the accurate placement of both tibial and femoral tunnels.

There is a disagreement in the literature regarding the length and width of the tibial AL and PM bundle insertions. Tajima et al (2009) reported mean lengths and widths of the tibial AL and PM insertions as 7.8±1.5mm and 9.2±1.6 mm, and 9.4±1.4mm and 15±2.7mm, respectively, while Edwards et al (2007) reported 8±2mm and 9±2mm, and 6±1mm and 10±2mm. In contrast, Gali et al (2013), in their study on formalin preserved knees, reported lengths and widths of 5.7mm and 7.2mm for the AL and 5.5mm and 8.1mm for the PM bundles respectively. These differences may be due to the different measurement techniques used, with Edwards et al (2007) and Gali et al (2013) using computer software to take measurements from uploaded photographs, while Tajima et al (2009) used three-dimensional laser photography analysed using specific software. The present study, using a manual method, observed the length and width of the tibial footprint to be 8.7±2.4mm and 10.9±2.0mm for the AL bundle and 7.3±3.1mm and 13.4±3mm for the PM bundle, similar to those of Tajima et al (2009). All studies, except Edwards et al (2007), found the tibial attachment site of the PM bundle to be larger than that of the AL bundle. Tajima et al (2009) supports this, reporting the area of the total PCL, AL and PM bundles attachments as 243.9±38.2mm, 93.1±16.6mm and 150.8±31mm^2 respectively. However, Anderson et al (2012), in their arthroscopic study, reported areas of 219, 88mm^2 and 105mm^2. The more recent observations of Anderson et al (2012) are similar to those of Takahashi et al (2006), who had earlier reported AL and PM bundle tibial attachment areas of 46.7±15.6mm^2 and 115.8±54.6mm^2 respectively. Irrespective of the magnitude of the dimensions observed all studies reported the PM attachment to be greater than that of the AL. Only Harner et al (1999), using a digitizing system, reported that the mean AL attachment area (70±26mm^2) as being greater than the PM (62± 17mm^2), thereby supporting Edward et al (2007); however the difference was not significant.

The two-arm shape of the PM tibial attachment observed in this study supports the report of Anderson et al (2012), who also found the thickest portion of the PM bundle to be at its functional centre. The close proximity of the tibial attachments of AL and PM bundles makes it practical to consider a single tibial tunnel for both single and double bundle PCL reconstruction. Moreover, it would be difficult to reproduce the two-armed shape of the PM bundle with a single round tunnel. Consequently, an appropriately placed single tibial reconstruction tunnel at the functional centre of the PM bundle directly posteromedial to the AL bundle could encompass this region (Anderson et al, 2012). The observation of a strong relationship between PM length and width, and the whole of the PCL attachments suggest that the PM bundle greatly influences the size of the PCL tibial footprint.

With respect to the tibial attachment to the posterior surface of the tibia Girgis et al (1975) reported it as 2-3mm, Cosgarea and Jay (2001) as 10-15mm, Edwards et al (2007) as 7±2mm and Takahashi et al (2006) as 4.6±3.6mm, with the latter stating that it comprised the PM bundle only as the AL bundle attached onto the articular plane. The present study observed the posterior extension to be 10.7±1.6mm, similar to that of Cosgarea and Jay (2001). The current study also determined the distance between anterior margins of the tibial articular surface and the PCL footprint as 39.5mm. These data could aid in determining the most appropriate location of the tibial tunnel. Taking measurements from the medial edge of the tibial articular surface Takahashi et al (2006) gave the location of the centre of tibial attachment site of the AL amd PM bundles as 48.2mm and 47.4mm respectively. Several reports have given the anatomical position of the tibial footprint (Table 3): values determined by the current study are similar to those of Takahashi et al (2006).

Study	N	Mediolateral position (%)		
		AM	PL	Mean
Takahashi et al (2006)	33	51.0	50.0	50.5
Edwards et al (2007)	39	-	-	48.0
Tajima et al (2009)	21	47.1	43.8	45.5
Greiner et al (2011)	10	-	-	49.0
Osti et al (2012)	15	48.0	51.0	49.5
Present study	**31**	**51.0**	**50.0**	**50.5**

Table 3: Comparison of previous reports of the position of the tibial posterior cruciate ligament (PCL) attachment site with those observed in the present study. N, Number of specimens; AM, anteromedial bundle; PL, posterolateral bundle

Edwards et al (2007) reported the centre of the AL bundle femoral attachment as being 7±2 mm from the articular cartilage at 10.20±00.30 o'clock using the clock face system. However, Takahashi et al (2006) gave the distance from the anterior articular cartilage to the centre of the femoral insertion of the AL and PM bundles as 9.6mm and 10.6mm respectively. Earlier Harner et al (1999) reported the area of the total femoral footprint as 128±22mm^2, with that of the AL being slightly greater than that of the PM bundle. However, Takahashi et al (2006) reported that the PM bundle footprint was greater than that of the AL (64.6±24.7 mm^2 and 58±25.4 mm^2 respectively). This difference may be due to the different measurement methods employed, as well as ethnic and gender differences in the populations studied. The observations of the current study (Table 1) were similar to those of Takahashi et al (2006). The correlation between the AL and PM bundles suggests that they would have a similar impact on the size of the femoral footprint. Consequently, both bundles should be considered when deciding the position and type of tunnel to be used in anatomical PCL reconstruction.

It is acknowledged that the present study has some limitations. Firstly, the mean age of the specimens examined does not give a true representation of the population that experience PCL rupture and undergo reconstruction: the mean age of the specimens were quite higher. Secondly, the number of knees examined is considered inadequate to show a broad spectrum of variations: nevertheless the number examined compares favourably with most previous PCL studies. Thirdly, some errors may have been introduced in the data collection process due to the manual method employed, which relied on human judgement. Notwistanding these limitations, the current study provides anatomical measurements of the PCL footprints that could be useful in determining the position of tunnel, type of graft and technique (i.e. single or double) employed during anatomical PCL reconstruction.

Conflict of Interest
None.

Funding
None.

Informed Consent and Ethical Approval
All the donors and their families had agreed to their use in medical, educational and scientific research, with all donations following the guidelines of the Human Tissues Act (Scotland) 2006. Given that no data allowing the identification of the individuals were presented, the publication of this study poses no ethical problem.

Contributions
The authors hereby confirm that this manuscript is original and has not been published or is awaiting publication in any other journal. The contributions of the authors are as described below: PII: Conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article, final approval of the version to be submitted. RWS: Conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article, final approval of the version to be submitted.

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