

# What is the impact of knee morphology on posterior cruciate ligament avulsion fracture in men and women: a case control study

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## Research article

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# Abstract

## Background

Several studies on the relationship between morphological parameters and traumatic diseases of the knee have already been conducted. However, few studies focused on the association between knee morphology and posterior cruciate ligament (PCL) avulsion fracture in adults. The objective of this study was to evaluate the impact of knee morphology on PCL avulsion fracture and determine risk factors in men and women separately.

## Methods

A retrospective case-control study of 48 patients (comprised 25 men and 23 women) with PCL avulsion fracture compared with 48 age- and sex-matched controls was performed from 2012 to 2018. MRI measurements of the knee were acquired in the sagittal, coronal, and axial sequences. The assessed measurements including intercondylar notch width index, medial/lateral posterior tibial slopes, and coronal tibial slope were compared between case and control groups in both women and men. Univariable and binary logistic regression analyses were used to identify independent risk factors that were associated with PCL avulsion fracture.

## Results

When female patients were analyzed, the notch width index (coronal) was significantly smaller, and the lateral posterior tibial slope was significantly higher in the case group. The binary logistic regression analysis showed that the notch width index (coronal) ( $B = -0.307$ ,  $OR = 0.735$ ,  $p = 0.025$ ) was found to be an independent factor. When male patients were analyzed, no radiographic parameter was found to have a statistical difference between the case and control groups.

## Conclusions

Notch width index (coronal) and lateral posterior tibial slope were found to affect PCL avulsion fracture in women, but no such measurements affected the PCL avulsion fracture in men. Furthermore, a smaller notch width index (coronal) in women was found to be a risk factor in PCL avulsion fracture.

## Background

The posterior cruciate ligament (PCL) is the strongest ligament in the knee, and injuries to the PCL occur less commonly than in the anterior cruciate ligament (ACL). PCL avulsion fracture represent a specific form of PCL injury and are less common than the typical intrasubstance PCL tear [1]. It often results from high-energy mechanisms in adults, such as a direct blow to the tibia with the knee in flexion (motor

vehicle collision) or severe hyperextension (sports-related trauma) [2]. However, as more people engage in sports, these injuries are likely to increase in number. MRI is an efficient and noninvasive modality that can reliably diagnose PCL avulsion fracture and evaluate knee morphology. It is generally agreed that a displaced PCL avulsion fracture should be anatomically reduced and fixed. Both open and arthroscopic methods of fixation have been reported to produce good outcomes [3–5].

Nowadays, several studies on the relationship between morphological parameters and traumatic diseases of the knee have already been conducted. Many studies have found different relationships between measurements of knee geometry and anterior cruciate ligament (ACL) injury, such as stenotic intercondylar notch type [6], intercondylar notch volume [7], medial tibial slope [8], lateral tibial slope [9], and tibial slopes (both bony and meniscal) [10]. Similarly, Song et al. reported that increased medial meniscal slope was associated with greater risk of ramp lesion of the meniscus in noncontact ACL injury [11]. Kocher et al. performed a comparison between tibial spine avulsion fractures and midsubstance ACL disruptions in skeletally immature patients and found a correlation between decreased notch width index (NWI) and midsubstance ACL disruption [12]. Recently, van Kuijk et al. reported that a smaller and more sharply angled intercondylar notch and a more flattened tibial eminence are related to PCL rupture [13]. In addition, Bernhardson et al. reported that decreased tibial slope appears to be a risk factor for primary PCL injury [14]. Furthermore, we are still unclear whether there is an association between magnetic resonance imaging (MRI) measurements of the knee and PCL avulsion fracture as a specific form of PCL injury in adults.

A higher prevalence of ACL injury in females has been recognized by numerous studies over the last decade. In addition, the differences in anatomic risk factors of ACL injury between men and women have been widely studied [15–18]. Similarly, we assumed that the risk factors of PCL avulsion fracture may differ between men and women, and the risk factors in men and women should be therefore analyzed separately rather than mixing or comparing the genders.

Therefore, we designed this case-control study to evaluate the impact of knee morphology on posterior cruciate ligament avulsion fracture and determine risk factors in men and women separately. Those measurements include notch width index, medial/lateral posterior tibial slopes, and coronal tibial slope. The hypotheses of this study were that certain parameters were highly associated with PCL avulsion fracture and that the risk factor differed between men and women.

## Methods

### Study Design

In the present study, we included 48 patients who suffer direct violence and were diagnosed with PCL avulsion fracture by MRI performed at our institution from 2012 to 2018. The study group comprised 25 men and 23 women whose mean age was 54.35 years (range, 27-82 years). There were 20 patients with complication of posterior root tears of the medial meniscus. The exclusion criteria for this study were age < 18 years, previous knee surgery, MRI obtained at an outside hospital or with insufficient quality (evident

blurring because of patient movement during MRI), tibia plateau fracture, old PCL avulsion fracture (more than 3 months), ACL avulsion fracture, and ACL injury. Age- and sex-matched controls who underwent MRI for knee injury were selected in a 1:1 ratio for comparison. Controls were included if they had a normal knee MRI or some injuries, such as patellar tendinopathy, patellofemoral pain syndrome, and plica syndrome. The investigation was approved by the hospital's institutional review board, and subjects provided written consent prior to participation.

Tibial and femoral morphological characteristics were measured on MRI studies using Philips Achieva 1.5-T and 3-T MRI system (Philips Medical Systems) in both groups. The MRI protocols included coronal, sagittal, and axial sequences. The sagittal sequence included the T1- and T2-weighted phases. All images were reviewed by 2 senior orthopedic surgery residents. All measurement collections were performed by two trained orthopedic surgeons using DICOM (version 3.1) viewer software (Neusoft PACS/RIS).

Morphological measurements of the coronal sequence include intercondylar notch width, medial condylar width, lateral condylar width, condylar width, coronal tibial slope, and notch width index. Morphological measurements of the axial sequence include intercondylar notch width, medial condylar width, lateral condylar width, condylar width, and notch width index. Morphological measurements of the sagittal sequence include medial posterior tibial slope and lateral posterior tibial slope. The assessed measurements including intercondylar notch width index, medial/lateral posterior tibial slopes, and coronal tibial slope were compared between injured and uninjured groups in both women and men.

## **Morphological Measurements**

Femoral measurements were obtained for the coronal and axial planes, as described by Stein et al. and Alentorn et al. [19, 20]. In both planes, a cut showing the popliteal groove was used to measure the femoral morphological parameters. For the axial plane, a posterior bicondylar line and its perpendicular line from the top of the intercondylar notch were determined. The intercondylar height (line B) was the distance from the top of the intercondylar notch to the bicondylar line (line A) (Fig. 1a). The intercondylar width (line C) was obtained at the anterior third of the intercondylar height (line B) in the axial plane (Fig. 1a). At the same level, the width of the lateral and medial condyles (line D, E) was obtained (Fig. 1b). The condylar width was considered the sum of the intercondylar, medial condylar, and lateral condylar widths. The same method was used to collect these measurements in the coronal plane (Fig. 1c and d). Moreover, the notch width index was the ratio of intercondylar notch width and condylar width.

The coronal slopes of the tibial plateaus were obtained as described by Hashemi et al. [21]. The first step was to identify a transverse plane passing through the tibiofemoral joint and showing the dorsal aspect of the tibial plateau (Fig. 2a). In this transverse image, the coronal plane that passed closest to the centroid of the tibial plateau was identified. The location of this plane is represented by the horizontal line in Fig. 2a, and the corresponding coronal plane is shown in Fig. 2B. Next, the orientation of the

longitudinal axis of the tibia was determined. This was obtained by determining the midpoint of the medial-to-lateral width of the tibia at two points located approximately 4 to 5 cm apart and as distally in the image as possible (locations 1 and 2 in Fig. 2b). The extended line connecting the two midpoints represents the longitudinal axis of the tibia in the coronal plane. The coronal tibial slope was then measured as the angle between a line joining the peak points on the medial and lateral aspects of the plateau (points A and B in Fig. 2c) and the line perpendicular to the longitudinal axis (line P in Fig. 2c). If point A is below the perpendicular line P, then the slope was designated as negative.

The sagittal slopes of the medial and lateral tibial plateaus were also obtained as described by Hashemi et al. [21]. In Fig. 3a, lines A and C show the corresponding locations of the sagittal planes in the medial and lateral tibial plateau. Line B shows the approximate location of the sagittal plane that was used to determine the orientation of the longitudinal axis. We used the plane that clearly showed the orientation of the tibia (Fig. 3b). As before, the anterior and posterior cortices of the tibial shaft at two points located approximately 4 to 5 cm apart and distal in the image (locations 1 and 2 in Fig. 3b) were determined. The midpoints of the lines representing the anterior-posterior thickness of the tibia were found, and the longitudinal axis (L) was constructed. The longitudinal axis was then reproduced in the medial plane as shown in Fig. 3c. The peak anterior and posterior points on the tibial plateau were identified (points A and B). The slope of the line extending through these two points represented the medial tibial slope and was measured with respect to the axis (P) perpendicular to the longitudinal axis (L). A similar approach was used to determine the lateral tibial slope (Fig. 3d). Because the peak anterior points on the tibial plateau are proximal to the peak posterior points in both Figs. 3c and d, the slopes of the medial and lateral tibial plateaus would be positive according to the existing convention.

To determine the inter- and intraobserver reproducibility, intraclass correlation coefficients (ICC) were calculated by randomly selecting 20 patients (10 from the case group and 10 from the control group) [9, 11]. ICC values of 0.9 were considered excellent, and values between 0.8 and 0.9 were considered good. Two trained orthopedic surgeons who were blinded to the study separately obtained the morphological measurements. In addition, 1 independent observer performed all the above MRI evaluations on each selected patient twice, two weeks apart.

## Statistical analysis

All analyses were performed by using SPSS version 22.0. Independent sample t-tests were performed to compare the measurements between the case and control groups. Separate analyses were completed for men and women. Additionally, binary logistic regression analysis was performed to determine the independent predictors of PCL avulsion fracture. The inter- and intraobserver reproducibilities were determined by the ICCs. Statistical significance was set at  $p < 0.05$ .

## Results

The intra- and interobserver reliabilities for the knee morphological features are presented in Table 1. The intraobserver ICC for all variants ranged from 0.699 to 0.949. Similarly, the interobserver ICC was 0.778 to 0.929, which revealed strong agreement between observers for all measurements.

Table 1 Intra- and inter-observer intraclass correlation coefficients (ICCs) for all variants of 20 random patients

Variable	Intra-observer ICC	Inter-observer ICC
Intercondylar notch width (axial)	0.934	0.894
Medial condylar width (axial)	0.949	0.913
Lateral condylar width (axial)	0.874	0.873
Intercondylar notch width (coronal)	0.802	0.860
Medial condylar width (coronal)	0.886	0.929
Lateral condylar width (coronal)	0.948	0.899
Coronal tibial slope	0.882	0.778
Medial posterior tibial slope	0.699	0.867
Lateral posterior tibial slope	0.705	0.914

The radiographic measurements of femoral condyle in the axial and coronal sequences were showed in Table 2. In women, we found that the notch width index (coronal) was significantly smaller, and the lateral posterior tibial slope was significantly higher in the case group (Table 3). In men, no radiographic parameter was found to have a statistical difference between the case and control groups (Table 4).

Table 2 The radiographic parameters of femoral condyle in the axial and coronal sequences

Variable	Women		Man	
	Cases (n = 23)	Controls (n = 23)	Cases (n = 23)	Controls (n = 23)
Intercondylar notch width (axial), mm	18.27±1.89	17.67±1.65	20.86±1.98	19.50±2.26
Medial condylar width (axial), mm	24.73±1.81	23.96±2.01	27.25±1.93	27.46±2.39
Lateral condylar width (axial), mm	25.44±3.22	25.55±1.74	30.57±2.91	30.23±2.92
Condylar width (axial), mm	68.44±3.90	67.18±2.69	78.68±4.27	77.19±5.13
Intercondylar notch width (coronal), mm	16.51±1.67	17.59±1.96	19.78±2.67	19.04±1.95
Medial condylar width (coronal), mm	25.50±2.90	24.81±1.37	27.93±1.95	28.41±2.73
Lateral condylar width (coronal), mm	29.28±3.08	27.93±2.94	32.90±2.25	31.60±3.13
Condylar width (coronal), mm	71.30±4.49	70.32±3.90	80.61±4.02	79.05±5.47

Table 3 The radiographic parameters of women in the case and control groups

Variable	Cases (n = 23)	Controls (n = 23)	P Value
Notch width index (axial)	0.27±0.03	0.26±0.02	0.779
Notch width index (coronal)	0.23±0.02	0.25±0.03	0.014*
Coronal tibial slope, °	3.48±3.42	3.70±2.74	0.813
Medial posterior tibial slope, °	8.39±4.21	6.35±2.39	0.050
Lateral posterior tibial slope, °	8.30±4.84	5.65±3.61	0.041*

Asterisks indicate statistical significance (p < 0.05)

Table 4 The radiographic parameters of men in the case and control groups

Variable	Cases (n = 25)	Controls (n = 25)	P Value
Notch width index (axial)	0.27±0.03	0.25±0.03	0.088
Notch width index (coronal)	0.25±0.03	0.24±0.02	0.632
Coronal tibial slope, °	3.28±2.37	3.44±2.43	0.815
Medial posterior tibial slope, °	8.16±2.85	7.32±3.71	0.374
Lateral posterior tibial slope, °	8.00±4.33	7.28±4.14	0.551

All predictors were included in a binary logistic regression analysis to determine the independent factors of PCL avulsion fracture (Table 5). In women, notch width index (coronal) (B = -0.307, OR = 0.735, p = 0.025) was found to be an independent factor.

Table 5 Independent predictive factors of PCL avulsion fracture in women

Variable	B	SE	Wald	p Value	Odds Ratio	95 % CI for EXP (B)	
						Lower limit	Upper limit
Notch width index (coronal)	-0.307	0.137	5.008	0.025*	0.735	0.562	0.963
Lateral posterior tibial slope	0.155	0.082	3.61	0.057	1.168	0.995	1.371

Asterisks indicate statistical significance (p < 0.05)

## Discussion

The main finding of the present study is that there are significant differences in bony morphology between patients with PCL avulsion fracture and those without. A smaller notch width index (coronal) in women was found to be related to PCL avulsion fracture. These results also demonstrated that the knee morphological measurements, which were mostly associated with the risk of sustaining a PCL avulsion fracture, differ between men and women.

Many studies have been performed previously to identify potential risk factors in ACL and PCL injuries, and the femoral notch has been the main topic of interest. Domzalski et al. [22] have suggested that a smaller notch width index can be correlated to an ACL rupture. Recently, van Kuijk et al. reported that a smaller and more sharply angled intercondylar notch is related to PCL rupture [13]. Interestingly, the findings of that study were consistent with the findings in our present study. In our study, notch width index (coronal) was also found to be an independent factor in women, This means that a smaller notch width index (coronal) may render the knee more susceptible to a PCL avulsion fracture. Previous research has shown that patients with smaller intercondylar notch also have smaller ACL and PCL [23, 24]. Moreover, a smaller PCL can resist less force than a larger PCL [13]. Therefore, a patient with a smaller intercondylar notch also has a smaller PCL, which may increase the risk of the avulsion fracture. The morphology of the intercondylar notch plays an important role in both PCL injury and PCL avulsion fracture. Further research is needed to better understand this relationship.

Previous studies have shown that the posterior tibial slope is significantly correlated with non-contact ACL and PCL injuries. A larger posterior tibial slope increases the risk of ACL rupture [8–10], while a smaller posterior tibial slope increases the risk of PCL rupture [14]. The mechanism of injury in ACL rupture shows an increase of tibial slope, leading to an increase of tibial forward displacement and stress in the ACL with weight-bearing activity [11, 25]. Similarly, under conditions where the tibia bears axial load and backward external force, the reduction of the tibial slope leads to an increase of the stress in the PCL which leads to rupture. Therefore, the increase of the tibial slope has a protective effect on the PCL, and the researchers found that a 1-degree increase in the posterior tibial slope decreased PCL force by 6 N [26–29]. Bernhardson et al. confirmed the above opinions and they found that a decreased posterior tibial slope was associated with patients who have PCL tears [14]. Although our study showed that the medial/lateral posterior tibial slopes were not risk factors, the medial posterior tibial slopes ( $p = 0.05$ ) and lateral posterior tibial slopes ( $p = 0.041$ ) of the case group were larger than those of the control group in women. Our results seem to contradict the study of Bernhardson. However, those two studies have different research subjects. PCL ruptures occur in the ligament portion, while PCL avulsion fractures occur in the bone tissue at the tibial insertion of the PCL. We believe that the posterior tibial slope plays an important role in the occurrence of these two conditions. When a sufficiently large retrograde force is applied to the proximal tibia, PCL rupture is prone to occur when the tibial slope is smaller. However, a PCL avulsion fracture is more prone to occur when the tibial slope is larger. Other factors such as the acceleration of direct force and the degree of osteoporosis may also play important roles in the occurrence of PCL avulsion fractures. Therefore, further studies are needed to verify the above hypothesis, such as a comparative study on the morphological parameters of the knee joint, especially the posterior tibial slope, between the PCL rupture group and the PCL avulsion fracture group.

Despite a considerable scientific effort to optimize surgical treatment, PCL injuries still cause a high degree of health impairment and involve high economic costs. This has served as the motivation for studies that focused on determining potential risk factors associated with PCL avulsion fracture. Because of the low prevalence of PCL avulsion fracture, screening only to determine the risk of sustaining a PCL avulsion fracture would likely not be cost efficient. However, several studies on the relationship between

morphological measurements and traumatic diseases of the knee including ACL injury [6–10], ramp lesion of meniscus [11], and tibial spine avulsion fractures [12], PCL injury [13, 14], have already been conducted, and more risk factors have been associated with knee-related sports injuries. All of these risk factors could be combined as a menu to find and help patients at risk for different types of knee injury [13]. For example, patients with smaller notch width index are more prone to ACL and PCL injuries, and PCL avulsion fractures. We think that more similar studies should be carried out in the future to discover more risk factors of other knee injuries so as to expand and enrich this menu. Furthermore, understanding knee morphology may have implications for PCL avulsion fracture mechanism, strategies for injury prevention, and perhaps treatment and prognosis.

Previous studies mainly focused on the surgical technique or clinical outcomes of this injury [3–5]. To our knowledge, our study is the first to identify the association between MRI measurements of the knee and PCL avulsion fracture and find the independent factor that may help explain the risk of PCL avulsion fracture and the predisposition of patients toward knee injury. The current report suggested that there exist independent risk factors of smaller notch width index (coronal) in women, which may render the knee more susceptible to PCL avulsion fracture. In addition, we believed that MRI was superior to CT and radiographs in measuring morphological parameters. The advantages of MRI include the ability to visualize the surface geometry of the articular cartilage, which allows better visibility of the functional point of tibial slope, absence of ionizing radiation, and excellent soft tissue contrast. Furthermore, MRI has been proven as the gold standard method of choice for noninvasive evaluation of ligament injuries, including those of the ACL and PCL, which can be used to exclude patients with complicated ACL or PCL injuries.

Our study had several limitations. First, this was a retrospective, single-center study, and the small sample size might have led to a selection bias. Second, while patients were matched for age and sex, they were not matched for height, weight, and levels and styles of external force. The absence of this information may confound our data. Third, some measurements could not be performed because of the fracture. For instance, the angle consisting of the superior and posterior margins of the tibial intercondylar eminence in sagittal sequence, which we called the posterior angle of intercondylar eminence, may be strongly associated with PCL avulsion fracture. Fourth, age may be an important factor. The femoral intercondylar notch may have bony hyperplasia, and the measurements of the intercondylar notch showed a difference as age increased. However, we did not take age into account in our study. Lastly, 20 patients had a complication of posterior root tears of the medial meniscus in the case group. However, the menisci play a role in anteroposterior stability of the knee joint and may influence the functional tibial slope [10, 30]. In the present study, we ignored the effects of the menisci on tibial slope.

## Conclusions

Notch width index (coronal) and lateral posterior tibial slope were found to affect PCL avulsion fracture in women, but no such measurements affected the PCL avulsion fracture in men. Furthermore, a smaller notch width index (coronal) in women was found to be a risk factor in PCL avulsion fracture.

# Declarations

## Ethics approval and consent to participate

The study design was approved by the Ethics Review Committee of Beijing Shunyi District Hospital (Registration number: QR-112-045-086) and the requirement for informed consent was waived due to the retrospective nature of the study.

## Consent for publication

Not applicable.

## Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## Competing interests

The authors declare that they have no competing interests.

## Funding

Not applicable.

## Authors' contributions

FN and ZY: design of the study, analysis of the data and writing of the manuscript. ZL and YC: design of the study, interpretation of the data, and revising manuscript critically for important intellectual content. YS, DP and LY: collection and processing patients data. ZQ and WJ: measurement of morphological parameters. All authors have read and approved the final manuscript.

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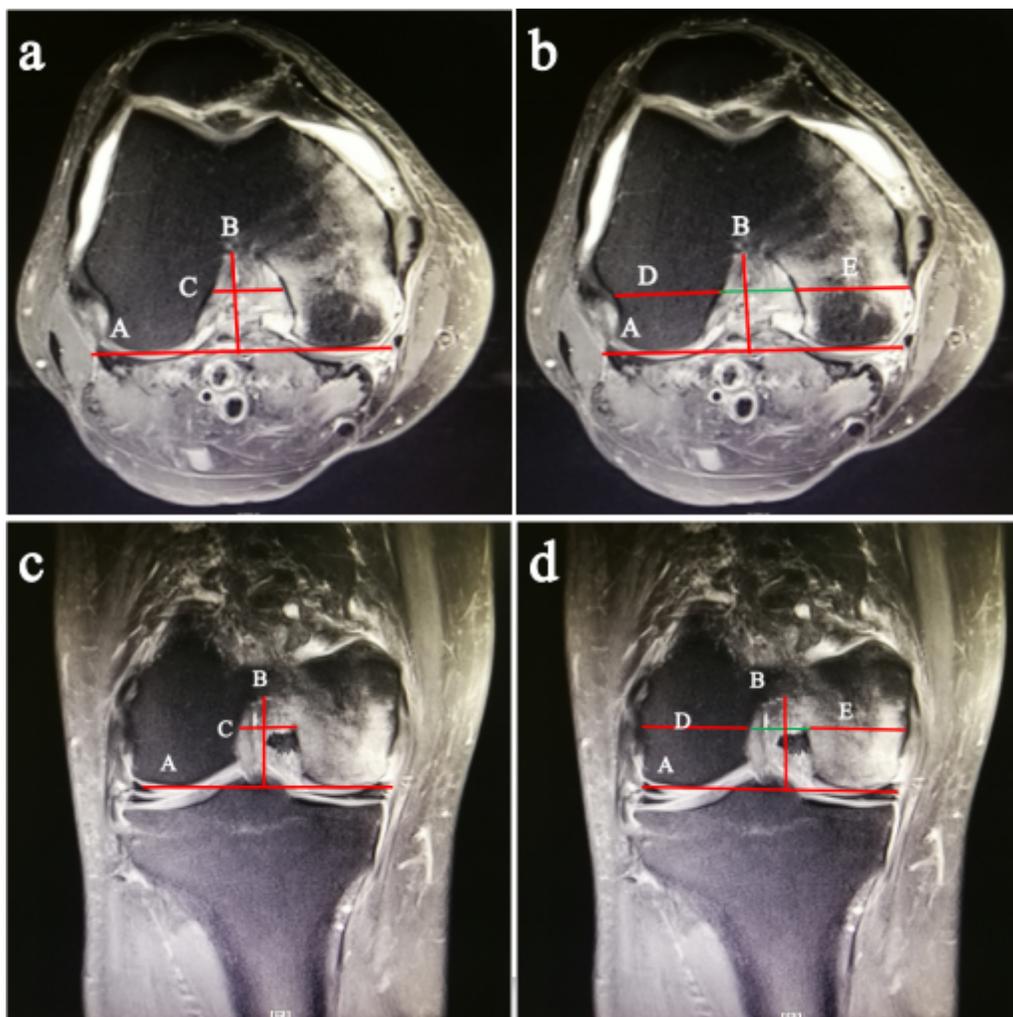
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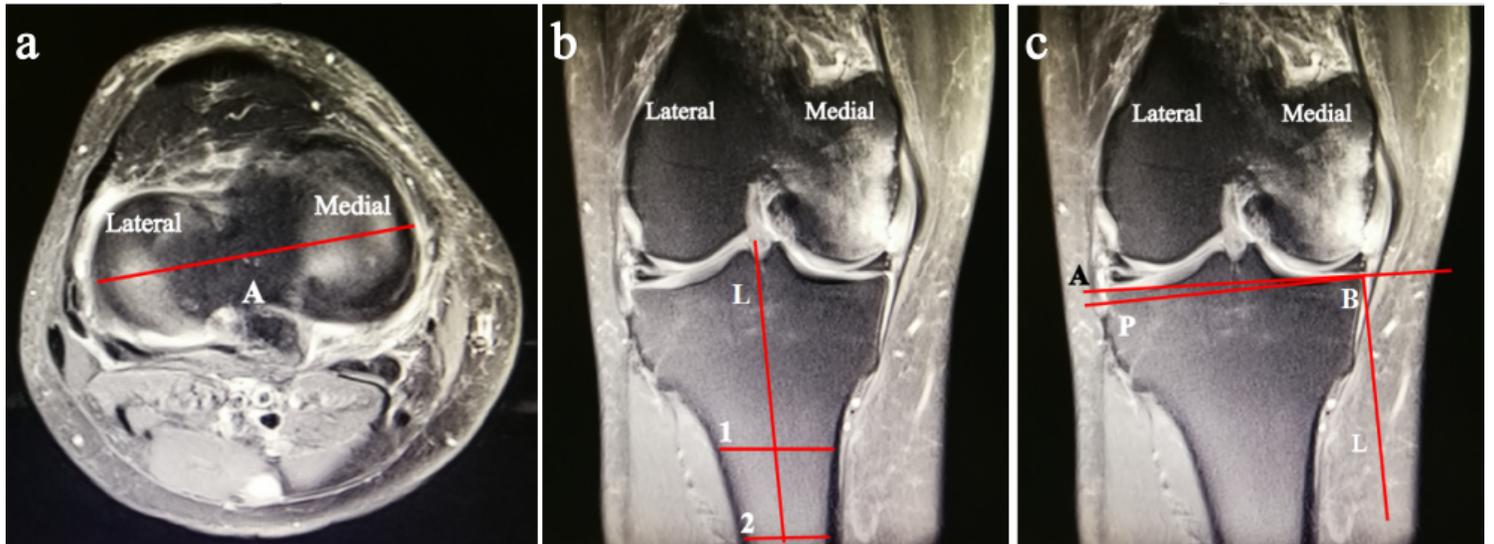
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## Figures



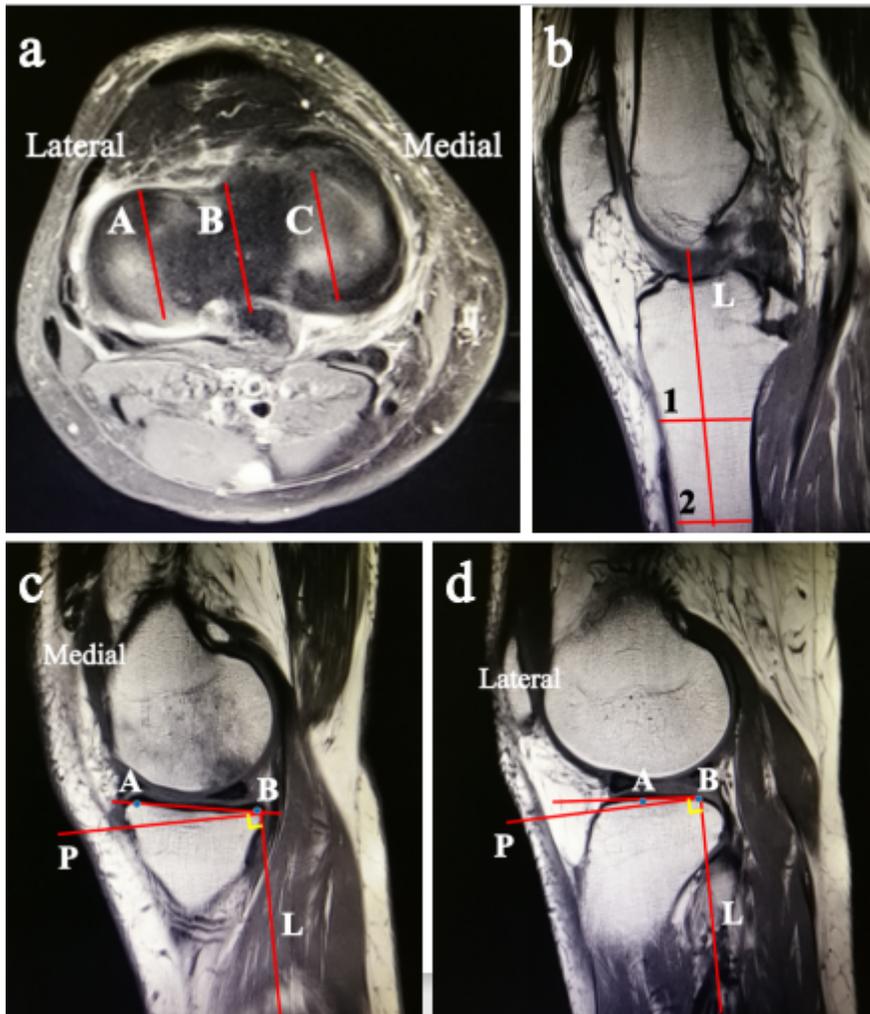
## Figure 1

Magnetic resonance images depicting the method used to obtain the femoral measurements in the axial plane. (a) The intercondylar height (line B) was the distance from the top of the intercondylar notch to the bicondylar line (line A). The intercondylar width (line C) was obtained at the anterior third of the intercondylar height (line B). (b) At the same level, the width of the lateral and medial condyles (line D, E) was obtained. The same method was used to collect these measurements in the coronal plane (c and d).



## Figure 2

Magnetic resonance images depicting the method used to obtain the coronal slopes. (a) This shows the transverse plane passing through the tibiofemoral joint and showing the dorsal aspect of the tibial plateau. Line A shows the location of the coronal plane that passed closest to the centroid of the tibial plateau. (b) The longitudinal axis (line L) of the tibia was obtained by determining the midpoint of the medial-to-lateral width of the tibia at two points located as distally in the image as possible (locations 1 and 2). (c) The coronal tibial slope was the angle between a line joining the peak points on the medial and lateral aspects of the plateau (points A and B) and line P perpendicular to line L.



**Figure 3**

Magnetic resonance images depicting the method used to obtain the sagittal slopes of the medial and lateral tibial plateaus. (a) This shows the transverse plane passing through the tibiofemoral joint and showing the dorsal aspect of the tibial plateau. Lines A and C show the corresponding locations of the sagittal planes in the medial and lateral tibial plateaus. Line B in the same figure shows the approximate location of the sagittal plane that was used to determine the orientation of the longitudinal axis. (b) The longitudinal axis (line L) of the tibia was obtained by determining the midpoint of the anterior and posterior widths of the tibia at two points located as distally in the image as possible (locations 1 and 2). (c) The medial tibial slope was the angle between a line joining the peak points on the medial plateau (points A and B) and line P perpendicular to line L. (d) The lateral tibial slope was the angle between a line joining the peak points on the lateral plateau (points A and B) and line P perpendicular to line L.