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In-vivo Morphometric Study of the Cruciate Ligaments of the Knee Joint

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ABSTRACT
Introduction: since the in vivo morphometric data about the ACL and PCL are scarce, we aimed to study their length, thickness and angle by using the MRI.
Material and Methods: the present study included 34 MRI images of the knee joints. The length and thickness were measured in sagittal section T1 weighted and T2 weighted images of the 1.5 Tesla MRI. The angles were measured by using the coronal section of the MRI images. The online software, RadiAnt DICOM viewer was used to perform the measurements.
Results: the mean length of the ACL and PCL was 36.8 ± 4 mm and 39 ± 4 mm respectively. The thickness of the ACL at the femoral end, midpoint and tibial end were 12.4 ± 1.7 mm, 6.8 ± 0.9 mm and 13.2 ± 1.8 mm respectively. The thickness of the PCL at the same topographical location was 8.2 ± 1.2 mm, 4.8 ± 0.9 mm and 8.1 ± 0.8 mm respectively. The ACL coronal tibial angle, Blumensaat angle and PCL angle were 60.2 ± 4.8º, 11.5 ± 2.7º and 128.8 ± 9.2 º respectively.
Conclusion: the present study has provided novel information about the length, thickness and angle of the cruciate ligaments in Indians, which can be used to establish standard dimensions of the normal ACL and PCL as an aid to arthroscopic surgeries of the knee joint.
Keywords: Anterior cruciate ligament; Arthroscopy; Posterior cruciate ligament.

Introduction

The cruciate ligaments are often teared in soccer, tennis, basketball and volleyball players. ACL tears are due to rotation injury, when the athletes stop and quickly change the directions when they are running[1]. PCL injuries are usually direct contact injuries due to a blow or falling over the knee while it is flexed, like in dash board injury[2]. ACL is among the commonly teared structures in the knee joint, which requires surgical intervention to cure the knee pain and joint instability[3]. The unhappy triad of the knee joint includes tearing of three intra-capsular ligaments, which are medial meniscus, ACL and tibial collateral ligament. Lesions of ACL can occur individually, but majority of the PCL tears are part of combined lesions of intracapsular ligaments of knee joint[4]. The anatomical knowledge of ACL is important because of its frequent injury, the importance of its morphology during the surgical repair. There is high chance of risk of osteoarthritis because of the ACL tear[5]. The ACL and PCL tears require surgical intervention and managed with arthroscopic surgery. The ACL and PCL reconstruction have become routinely performed arthroscopic surgeries because of the advanced research from the anatomical, clinical and kinematic studies[6]. The reconstruction procedures of these cruciate ligaments require the morphometric data about these structures in that particular population. The morphometric data is also essential to understand the topography of the upper and lower attachments of these cruciate ligaments. Successful reconstructions of the PCL depend on the accuracy in the analysis of the anatomy of the injured PCL[7]. Magnussen *et al.*[8] opined that, postoperative ACL displacement is inversely proportional to the thickness of the graft used. There exists diversity in the dimensions and morphology of ACL as the insertion sites are variable[9]. It was reported that the dimensions of ACL like length and thickness, have implications in the ACL injury[10]. The dimensions of cruciate ligaments are also essential to understand their function. Due to these clinical implications and since not many in vivo studies being reported about the dimensions of cruciate ligaments from the Indian population, this present investigation was performed. The goal of the present investigation was to determine the in vivo thickness and length of the ACL and PCL

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of the knee joint in Indian population by using the MRI films. The objectives were to measure the in vivo coronal ACL tibial angle, ACL Blumensaat angle and PCL angle in MRI.

Material and Methods

This descriptive institutional research is a cross sectional study, which utilized routine MRI of the knee joints, which were available in the department of radio diagnosis. The age of the patients ranged between 11 and 57 years. The MRI which revealed congenital anomalies and injured intra-capsular ligaments of the knee joint, were excluded. The images of people with history of degenerative changes like osteoarthritis and rheumatoid arthritis in the lower limb, bony contusion, osteochondral fractures and meniscal injuries were also excluded from the present study. The present study has the approval of our institutional ethics committee. We state that research is in accordance with the international ethical standards, as per Padulo *et al.*[11] We included 34 MRI knee joint, among them 15 were right sided and 19 were left sided, from 21 males and 13 females. Mean age distribution of the participants in the study was 33 ± 12.5 years. The weight and stature of the patients was not considered in the present study. The sample size was estimated as per the previous study by Saxena *et al.*[12]

The morphometry of the cruciate ligaments was performed in the MRI (Seimens Avento, Germany, 1.5 Tesla) by using the RadiAnt DICOM viewer (64-bit, version 5.5.1, Poland). Only the images which exhibited full views of the cruciate ligaments are included. Measurement of the length of the ACL and PCL were performed from their attachments at the femur to the tibia (Fig. 1). The ACL thickness (Fig. 2) and PCL thickness (Fig. 3) were measured at three points namely femoral end, tibial end and at the midpoint. The angle between the most medial border of the long axis of ACL and a line between the two condyles of tibia is considered as the coronal ACL-tibial angle[13]. Measurement of coronal ACL-tibial angle was as per the suggestion by Kim *et al.*[14] The angle between Blumensaat line and the most anterior part of the ACL in a sagittal image is considered as the Blumensaat line-ACL angle (Fig. 4). Blumensaat line-ACL angle (Fig. 4) was measured using the technique described by Gentili and co-workers[13]. The coronal PCL angle was also similarly measured in this study (Fig. 5). The measurements were performed with the help of an inbuilt software by the same researcher to prevent the inter-observer error. The data of this study was statistically analysed by using the online SPSS software (version 25). The mean and SD were calculated for all the measurements. To compare the data between males and females, right sided and left sided, 'unpaired' and 'paired' 't' tests.

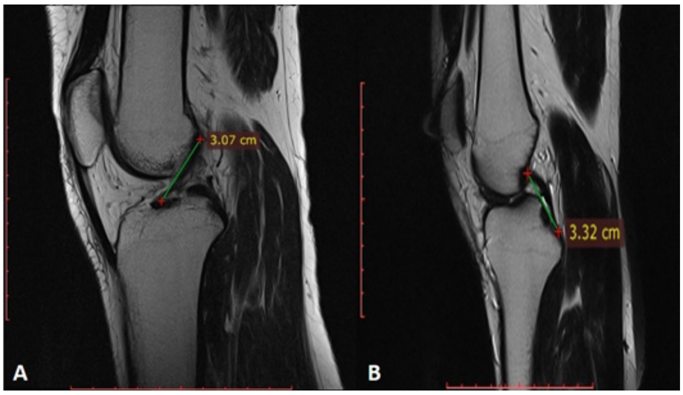


Figure 1. Sagittal MRI displaying the measurement of lengths of ACL (A) and PCL (B) in the present study.

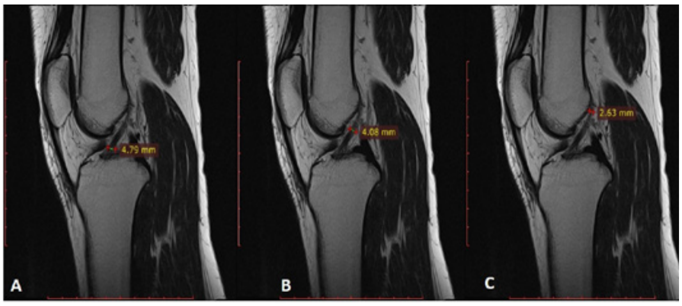


Figure 2. Sagittal MRI showing the measurement of thickness of ACL at the femoral end (A), midpoint (B) and tibial end (C) respectively.

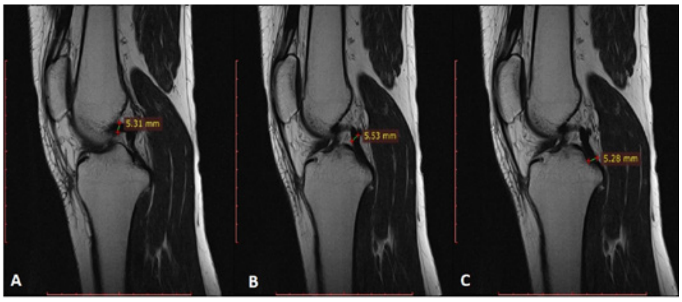
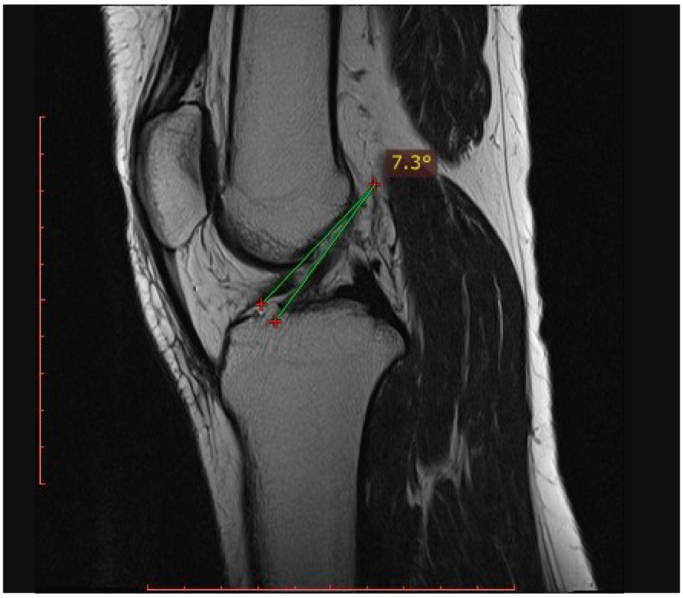


Figure 3. Sagittal MRI showing the measurement of thickness of PCL at the femoral end (A), midpoint (B) and tibial end (C) in this study.



Figrure 4. Sagittal MRI showing the measurement of Blumensaat angle of the ACL.

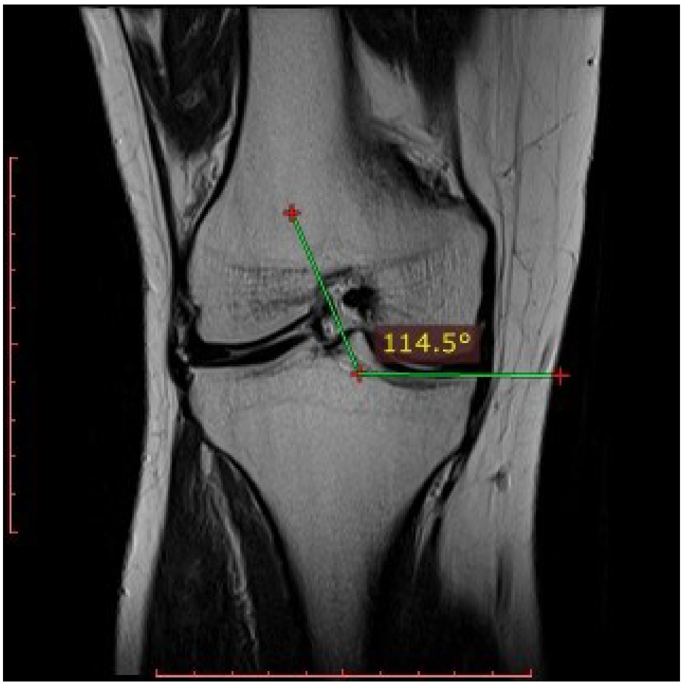


Figure 5. Coronal MRI showing the measurement of the PCL angle.

Results

The ACL and PCL mean length, thickness at the femoral end, midpoint and tibial end, the ACL coronal tibial angle, Blumensaat angle and PCL angle of the present study are represented in table 1. The comparison of the data of the ACL and PCL with respect to males and females are represented in table 2 and table 3 respectively. The right side and left side comparison of the ACL and PCL are represented in table 4 and table 5 respectively. It was observed that, both the ACL and PCL were longer (tables 2 and 3) in males than in females (p<0.05). The ACL was thicker (table 2) in the males at the femoral and tibial ends, in comparison to the females (p<0.05). The statistically significant difference was not observed (table 2) in the thickness at the mid region, coronal tibial angle and Blumensaat angle with respect to the ACL, when compared between males and females (p>0.05). The statistically significant difference was not observed for the thickness of PCL at the femoral end, tibial end and midpoint regions between male and female (p>0.05) in this study (table 3). The comparison of PCL angle among males and females, also yielded no statistically significant difference (p>0.05, table 3). None of the parameters measured in this study revealed statistically significant difference (p>0.05), when the comparison was performed between the right and left sides (tables 4 and 5).

Table 1. Showing the morphometric data of the cruciate ligaments (n=34) in the present study

Parameter	ACL	PCL
Length (mm)	36.8 ± 4	39 ± 4
Thickness FEM (mm)	12.4 ± 1.7	8.2 ± 1.2
Thickness TIB (mm)	13.2 ± 1.8	8.1 ± 0.8
Thickness MIDPT (mm)	6.8 ± 0.9	4.8 ± 0.9
Coronal tibial angle (º)	60.2 ± 4.8	-
Blumensaat angle (º)	11.5 ± 2.7	-
Angle (º)	-	128.8 ± 9.2

Table 2. Showing the gender based comparison of the data of the ACL

Parameter	Male (n= 21)	Female (n = 13)	p value
Length* (mm)	38.8 ± 3	33.4 ± 2.9	0.00
Thickness FEM* (mm)	13.1 ± 1.2	11.2 ± 1.5	0.00
Thickness TIB* (mm)	13.8 ± 1.7	12.3 ± 1.7	0.02
Thickness MIDPT (mm)	7 ± 0.9	6.5 ± 1	0.11
Coronal tibial angle (º)	60.2 ± 5	60.2 ± 4.6	0.99
Blumensaat angle (º)	11.9 ± 2.9	10.7 ± 2.4	0.18

Independent samples ‘t’ test, *statistical significance, p<0.05

Table 3. Showing the gender based comparison of the data of the PCL

parameter	Male (n= 21)	Female (n = 13)	p value
Length* (mm)	40.5 ± 3.7	36.6 ± 3.5	0.00
Thickness FEM (mm)	8.4 ± 1.2	7.9 ± 1.1	0.19
Thickness TIB* (mm)	8.3 ± 0.8	7.7 ± 0.8	0.03
Thickness MIDPT (mm)	4.9 ± 0.9	4.6 ± 1	0.33
PCL angle (º)	130.2 ± 8.6	126.6 ± 10.1	0.28

Independent samples ‘t’ test, *statistical significance, p<0.05

Table 4. Showing the side based comparison of the data of the ACL

Parameter	Right (n= 15)	Left (n = 19)	p value
Length (mm)	35.8 ± 3.2	37.5 ±.4.4	0.24
Thickness FEM (mm)	11.8 ± 1.8	12.8 ± 1.4	0.86
Thickness TIB (mm)	12.9 ± 1.9	13.4 ± 1.8	0.49
Thickness MIDPT (mm)	6.8 ± 1	6.7 ± 0.9	0.78
Coronal tibial angle (º)	61.4 ± 4.9	59.2 ± 4.5	0.18
Blumensaat angle (º)	10.8 ± 2.7	11.9 ± 2.7	0.24

paired samples ‘t’ test, *statistical significance, p<0.05

Table 5. Showing the side based comparison of the data of the PCL

Parameter	Right (n= 15)	Left (n = 19)	p value
Length (mm)	38.4 ± 3.8	39.5 ± 4.3	0.42
Thickness FEM (mm)	8.3 ± 1.1	8.1 ± 1.3	0.65
Thickness TIB (mm)	7.9 ± 0.9	8.3 ± 0.8	0.20
Thickness MIDPT (mm)	4.9 ± 0.8	4.7 ± 1	0.64
PCL angle (º)	128.5 ± 9.8	129.1 ± 9	0.85

paired samples ‘t’ test, *statistical significance, p<0.05

Discussion

The football and basketball players are often involved in the ACL and PCL tears and require the reconstruction of intracapsular ligaments of the knee joint. This can be achieved by hamstring tendons autografts. This surgical procedure requires the knowledge about the basic anatomical dimensions of these intracapsular ligaments. Accuracy in the grafting procedure will provide better range of motion and knee stability[6]. The reference value for the ACL dimensions could be obtained from the contralateral uninjured knee during the bone tunnelling for the graft positioning, performed for the unilateral ACL tear. The length of ACL as per Girgis *et al.*[15] ranged between 31-38 mm and Awadelsied[16] reported the length of ACL as 37 mm in their radiological measurements. The length of ACL in this present investigation, 36.8 ± 4 mm agrees with the previous reports of radiological and anatomical measurements. Length of the ACL was 43.5 mm and 41.9 mm in males and females respectively as per Yelicharla *et al.*[17] The length of ACL in the males and females in the present investigation was 38.8 ± 3 mm and 33.4 ± 2.9 mm, this dictates that the length is higher in males. The present study observed that ACL was thicker in males than in females at both the femoral and tibial ends ($p<0.05$). But there was no statistical significance between males and females observed at the middle of it. Westermann *et al.*[18] Opined that, small sized ACL-grafts are associated with higher stress. It is also interesting to note that, ACL tears are higher in females, because of its smaller dimension in comparison to males[19]. The coronal ACL, Blumensaat and PCL angles can help in making the diagnosis of ruptured ACL[20]. The inclination of injured ACL angle and the reconstructed ACL grafts have been studied to check the progress of graft recreation and normal position of the ACL[21]. Iriuchishima *et al.*[21] reported that ACL angle may range between 65° and 76° coronally. In the present study, the ACL angle was slightly smaller than this range and it was 60.2° ± 4.8°. According to Iriuchishima *et al.*[21], there is no normative data for the ACL coronal angle and it has to be analyzed by using patient demographics. It was reported that, if the Blumensaat angle is less than 0° or more than 15°, there is likely of ACL injury. In the present study of normal knee joints, the mean Blumensaat angle was 11.5° ± 2.7°.

Girgis *et al.*[15] and Covey[22] reported that PCL measures 38 mm in length. Pope *et al.*[23], in their radiological book mentioned that length of PCL may range between 22 and 38 mm. In the present study, PCL length was 39 ± 4 mm, which is almost similar to this description of PCL length in the literature. Yelicharla *et al.*[17], reported the length of the PCL in males and females, 35.9 mm and 37.1 mm respectively. The present study observed higher value for the PCL length in males. The PCL length was 40.5 ± 3.7 mm and 36.6 ± 3.5 mm in male and female participants. This comparison was statistically significant ($p<0.05$). Rodriguez Jr *et al.*[24] reported that PCL measures about an average of 9.6 mm in thickness. It was reported that PCL is up to twice thicker as the ACL[25]. The present study measured the PCL thickness at the three regions, femoral end, tibial end and mid-point. It was 8.2 ± 1.2 mm, 8.1 ± 0.8 mm and 4.8 ± 0.9 mm in these regions. It was described that the PCL angle ranges between 114° and 123° [26]. If there is increase in PCL angle, this can suggest the ACL injury. But in the present study, the mean PCL angle was 128.8° ± 9.2°. This is slightly higher in comparison to the normative data.

MRI can assess the ACL size accurately than the ultrasound[27]. The understanding of the gender based differences in the ACL and PCL, may be beneficial to judge the female's susceptibility to the ACL and PCL tears[19]. In this context, the morphometric information of the present study can be used as a morphological database for the Indian population. However, the present study has some limitations like the age and stature of the participants was not taken into consideration. The dimensions of the present study can be more accurate with a still larger sample size. The study did not correlate the dimensions of cruciate ligaments with the femoral intercondylar notch. The cruciate ligament width is also not measured in this study.

Conclusion

The present in vivo radiological investigation has provided the normative data of the length and thickness of the cruciate ligaments in Indian population, which will help the arthroscopic surgeon. The study also provided the data about the ACL angle, Blumensaat angle and PCL angle, which will be enlightening to the radiologist during the interpretation of tears of cruciate ligaments of the knee joint. Morphological knowledge of these dimensions are furthermore supportive during the precise tunnel employment of ACL and PCL, while performing the surgical reconstruction procedure.

References

1. Kobayashi H, Kanamura T, Koshida S, *et al.* Mechanisms of the anterior cruciate ligament injury in sports activities: a twenty-year clinical research of 1,700 athletes. J Sports Sci Med. 2010;9:669.
2. Fowler PJ, Messieh SS. Isolated posterior cruciate ligament injuries in athletes. Am J Sports Med. 1987;15:553-7.
3. Dunn WR, Lyman S, Lincoln AE, Amoroso PJ, Wickiewicz T, Marx RG. The effect of anterior cruciate ligament reconstruction on the risk of knee reinjury. Am J Sports Med. 2004;32:1906-14.
4. Clancy WG, Sutherland TB. Combined posterior cruciate ligament injuries. Clin Sports Med. 1994;13:629-47.
5. Lalwani R, Srivastava R, Kotgirwar S, Athavale SA. New insights in anterior cruciate ligament morphology: implications for

anterior cruciate ligament reconstruction surgeries. Anat Cell Biol. 2020;53:398-404.
6. Dargel J, Pohl P, Tzikaras, P. Koebke J. Morphometric side-to-side differences in human cruciate ligament insertions. Surg Radiol Anat. 2006;28:398-402.
7. Harner CD, Xerogeanes JW, Livesay GA, *et al*. The human posterior cruciate ligament complex: an interdisciplinary study. Ligament morphology and biomechanical evaluation. Am J Sports Med. 1995;23:736-45.
8. Magnussen RA, Lawrence JT, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. Arthroscopy. 2012;28:526-31.
9. Gali JC, Camargo DB, Felipe AM, Rafael HN, Phelipe AC. Descriptive anatomy of the anterior cruciate ligament femoral insertion. Revista Brasileira de Ortopedia. 2018;53:421-6.
10. Arendt EA. Anterior cruciate ligament injuries. Curr Womens Health Rep. 2001;1:211-7.
11. Padulo J, Oliva F, Frizziero A, Maffulli N. Muscles, Ligaments and Tendons Journal - Basic principles and recommendations in clinical and field Science Research: 2016 Update. Muscles Ligaments Tendons J. 2016;6:1-5.
12. Saxena A, Ray B, Rajagopal KV, D'Souza AS, Pyrtuh S. Morphometry and magnetic resonance imaging of anterior cruciate ligament and measurement of secondary signs of anterior cruciate ligament tear. Bratisl Lek Listy. 2012;113:539-43.
13. Gentili A, Seeger LL, Yao L, Do HM. Anterior cruciate ligament tear: Indirect signs at MR Imaging. Radiology. 1994;193:835-40.
14. Kim HK, Laor T, Shire NJ, Bean JA, Dardzinski BJ. Anterior and posterior cruciate ligaments at different patient ages: MR imaging findings. Radiology. 2008;247:826-35.
15. Girgis FG, Marshall JL, Jem AA. The cruciate ligaments of the knee joint: anatomical. functional and experimental analysis. Clin Orthop Relat Res. 1975;106:216-31.
16. Awadelsied MH. Radiological study of anterior cruciate ligament of the knee joint in adult human and Its surgical implication. Universal Journal of Clinical Medicine. 2015;3:1-5.
17. Yelicharla AK, Gajbe U, Singh B. Morphometric study on cruciate ligaments of knee with gender differences: a cadaveric study. Asian Pac J Health Sci. 2014;1:285-91.
18. Westermann RW, Wolf BR, Elkins JM. Effect of ACL reconstruction graft size on simulated Lachman testing: a finite element analysis. Iowa Orthop J. 2013;33:70-7.
19. Wang HM, Shultz SJ, Ross SE, *et al*. Sex comparisons of in vivo anterior cruciate ligament morphometry. J Athl Train. 2019;54:513-8.
20. Cvjetko I, Dovzak I, Banić T, Bakota B, Borić I. MRI study of the ACL in children and adolescents. Coll Antropol. 2011;35:1281-4.
21. Iriuchishima T, Tajima G, Ingham SJ, Shirakura K, Fu FH. PCL to graft impingement pressure after anatomical or non-anatomical single-bundle ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2012;20:964–9.
22. Covey DC. Injuries of the posterolateral corner of the knee. J Bone Joint Surg. 2001;83:106-18.
23. Pope T, Bloem HL, Beltran J, Morrison WB, Wilson DJ. Musculoskeletal Imaging E-Book. Elsevier Health Sciences. 2014.
24. Rodriguez Jr W, Vinson EN, Helms CA, Toth AP. MRI appearance of posterior cruciate ligament tears. AJR Am J Roentgenol. 2008;191:1031.
25. Raj MA, Mabrouk A, Varacallo M. Posterior Cruciate Ligament Knee Injuries. In: StatPearls [Internet]. Treasure Island (FL); StatPearls Publishing. 2021.
26. Chang MJ, Chang CB, Choi JY, Je MS, Kim TK. Can magnetic resonance imaging findings predict the degree of knee joint laxity in patients undergoing anterior cruciate ligament reconstruction? BMC Musculoskelet Disord. 2014;15:214.
27. Mahajan PS, Chandra P, Negi VC, Jayaram AP, Hussein SA. Smaller anterior cruciate ligament diameter is a predictor of subjects prone to ligament injuries: an ultrasound study. Biomed Res Int. 2015;Article ID 845689.

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