ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 16, Issue, 04, pp. 27836-27842, April, 2024
DOI: https://doi.org/10.24941/ijcr.47051.04.2024

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

MORPHOMETRY OF ANTERIOR CRUCIATE LIGAMENT IN HUMAN CADAVERS

[1,*]Dr. Ujwala Bhanarkar and [2]Dr. Biswabina Ray

[1]Assistant Professor, Department of Anatomy, All India Institute of Medical Sciences, Kalyani, West Bengal, India; [2]Professor and Head, Department of Anatomy, All India Institute of Medical Sciences, Kalyani, West Bengal, India

ARTICLE INFO

Article History:
Received 20th January, 2024
Received in revised form
19th February, 2024
Accepted 15th March, 2024
Published online 25th April, 2024

Key words:
Anterior Cruciate Ligament Tear, Knee Joint, Knee Injury, Femur, Tibia.

Corresponding author:
Ujwala Bhanarkar

ABSTRACT

Background: The anterior cruciate ligament (ACL) provides stability and facilitates proper joint movement. Understanding the morphology of the ACL is essential for improving surgical techniques, developing effective rehabilitation protocols, and enhancing overall knowledge of knee biomechanics. Aim of the study was to observe the normal morphology of ACL in human cadavers, shedding light on the anatomical intricacies that influence clinical outcomes. **Material and Methods**: A total of 30 knees from 15 cadavers were dissected in the present study. After exposing the ACL, the morphometric parameters were measured using digital Vernier calliper. The angle between the bundles of ACL in horizontal plane and direction of bundles of ACL were measured using goniometer. The collected data was subjected to statistical analysis. **Results**: The mean length, width at the proximal attachment, width at the distal attachment, and thickness of the right knee ACL were 28.35–32.4 mm, 9.2–10.3mm, 10.3–9.46 mm, 4.16–3.84 mmrespectively. All the morphometric parameters of the ACL in males were higher than the females, but there was no significant statistical difference. On the left and right sides, the length and width of the tibial footprints, mean cross-sectional surface areas at the middle, tibial insertion area, and at femoral insertion area of the ACL were statistically not significant. The direction of the ACL of both the sides was upward, backward, and laterally.ACL showed synovial sheath and blood vessels. **Conclusion**: During surgical procedures, it is imperative to be aware of the average morphometric distinctions when individually reconstructing ACL.

Citation: ***Dr. Ujwala Bhanarkar and Dr. Biswabina Ray*, 2024.** "Morphometry of Anterior Cruciate Ligament in Human Cadavers.". *International Journal of Current Research*, 16, (04), 27836-27842.

INTRODUCTION

The anterior cruciate ligament (ACL) maintain the knee joint stability. The ACL is intracapsular, located deep within the knee, and it runs diagonally from the posterior aspect of the femur to the anterior aspect of the area of between two condyles of tibia. The proximal end of the ACL originates from the lateral femoral condyle on its medial aspect, just anterior and lateral to the intercondylar notch. The distal end of the ACL inserts onto the anterior intercondylar area of the tibia, forming a broad and flat attachment site known as the tibial footprint. The attachment is situated between the tibial spines, anterior to the posterior cruciate ligament (PCL).[1]The ACL resist anterior displacement of the tibia over the femur, preventing hyperextension of the knee and providing stability during activities such as running, jumping, and cutting. Additionally, the ACL plays a crucial role in rotational stability, contributing to the overall integrity of the knee joint. A notable rise in the incidence of ACL injuries has been observed in recent times because of an increase in road traffic accidents and increasing sports activities worldwide. In India alone, most of the acute knee injury Consequently, ACL reconstruction became a common surgical procedure conducted by orthopaedic surgeons globally, including in India. This prevalence is anticipated to grow in the future, especially among females who exhibit a higher susceptibility to ACL injuries. [2,3] Several key morphological variations in the ACL have been reported. These variations included differences in size, with some individuals exhibiting a thicker or thinner ACL. Shape differences were also noted, ranging from a more ribbon-like appearance to a broader, flatter structure.[4]The ACL is composed of dense, collagenous tissue, predominantly Type I collagen. This collagen arrangement provides the ligament with strength and resilience. Fibroblasts within the ligament are responsible for maintaining the extracellular matrix and supporting tissue repair. Standard anatomical textbooks describethat it is made up of two or possibly three bundles. [1]Despite the majority of published research, it was observed disagreement on the presence of two bundles in the ACL. Based on the femoral attachments, the earlier researchers described two bundles, anteromedial and posterolateral bundles. Thus, thereremains persistent ambiguity on this matter. [5]The ACL has a limited blood supply, mainly derived from the middle genicular artery. This characteristic makes the ACL prone to poor intrinsic healing capability. The ligament is sparsely innervated, contributing to the challenge of early detection of injuries and limited pain sensation associated with ACL tears. Understanding the morphological variations of the ACL can aid orthopedic surgeons in tailoring treatment approaches to the specific anatomical features of each patient. This individualization is particularly relevant in surgical planning for procedures such as ACL reconstruction. Knowledge of the ACL's morphology can influence the selection of grafts for reconstruction surgeries. Surgeons can make informed decisions based on the patient's unique anatomy, optimizing the chances of successful graft integration and overall surgical outcomes.ACL morphology influences the biomechanics of the knee joint, which, in turn, impacts rehabilitation strategies. Awareness of individual variations helps rehabilitation specialists design personalized exercise programs that address specific anatomical considerations, contributing to more effective recovery. Certain morphological characteristics may enhance the probable risk of ACL tears. Understanding these factors can contribute to the development of targeted injury prevention programs, especially in high-risk populations such as athletes. Ongoing research into ACL morphology may lead to innovations in surgical techniques, graft selection, and fixation methods. Improved understanding of the ligament's anatomy can contribute to the refinement of existing procedures and the development of novel approaches. Studies on ACL morphology contribute to the development and improvement of imaging techniques. This, in turn, enhances the accuracy of diagnostic procedures, allowing for more precise identification and characterization of ACL-related pathologies. Knowledge of ACL morphology is relevant in sports medicine for optimizing athletic performance. Understanding how variations in ACL anatomy may influence biomechanics can aid in developing training regimens that minimize the risk of injuries and enhance overall athletic performance. [3]

The present study seeks to expand the existing database on ACL morphometry within the context of the India. The primary objective is to investigate and analyze the relationships involving measurement data concerning the length and width of the ACL, along with its tibio-femoral footprints in both right and left knees. Furthermore, our research endeavors to discern alterations in these measurements during different stages of ACL dynamics, particularly during knee flexion. This information holds potential significance for achieving anatomically precise ACL reconstruction. The individualization of surgical procedures based on this data may lead to improved surgical outcomes and reduced failure rates. Such precision is especially critical, as inaccuracies in anatomical data could result in misguided choices related to tunnel placement and the type of bundle replacement. This variability may deviate from Western literature and differ from findings in neighbouring Asian countries.

MATERIAL AND METHODS

A total of 30 limbs from 15 cadavers were randomly selected from the available cadavers in the department of anatomy at AIIMS, Kalyani, West Bengal. All embalmed cadavers fit to be dissected were included in the study. Cadavers with any evidence of damage or loss of tissues in the region of knee joint were excluded. Total 15 right and 15 left knees were used for the study. The Institutional Research Committee and Institutional Ethical Committee approved the present as per the institutional norms. The cadaver number, sex, age, and side of the knee were recorded without collecting personal identification of deceased individual (de-identified manner).
The cadaver was placed in a supine position with the knee extended. Bony major landmarks, i.e., femur, tibia, and patella, were identified. A midline incision was given on the anterior aspect of the knee, starting above the thigh and extending to the tibia. Subcutaneous tissue was dissected to expose the patella. The patellar ligament was reflected to reveal the patellar surface. The quadriceps tendon above the patella was identified and followed it down to the joint capsule. The joint capsule was reflected to expose the synovial membrane lining the interior of the joint. The ACL and PCL were then identified which were located within the synovial membrane. The ACL was separated from surrounding structures, including other ligaments, tendons, and joint capsule fibers. The structure of the ACL was examined, noting its fibrous composition and any variations in thickness or orientation. The bundles of the ACL and their directions were identified and noted. The presence of synovial sheath covering ACL, presence of (if any, then number) of blood vessels in ACL were noted. Following that, to visualize the femoral attachments of the bundles, the PCL was excised. Subsequently, their attachment sites were marked with a marker before the bundles were cut away from the bone. The morphometric parameters of ACL including length and width near proximal and distal attachments and width in the center, width and length of tibial footprint, length, and width at proximal and distal attachments of bundles of ACL were measured using digital Vernier calliper. The angle between the bundles of ACL in horizontal plane and direction of bundles of ACL were measured using goniometer. The shape of bundles of ACL at proximal and distal attachments and relationship of bundles of ACL were noted. At the tibial and femoral attachment sites, using a digital Vernier caliper, the maximum horizontal diameter of and the areas of the footprints were measured.

For each parameter, the average of the findings of two independent observers were taken. The dimensions of the ACL tibial insertion were assessed by measuring the maximum distance between the anterior and posterior edges, while the width was determined at its widest point on the tibial condyle. The maximal flexion of the knee joint was applied for the measurement of the femoral insertion. The distance between the proximal-most point of femoral attachment and the distalmost point of the tibial attachment was considered as the length of the ACL. The maximum side-to-side diameter in the middle was considered as the width of the ACL, whereas the maximum anteroposterior diameter was considered as the thickness of the ACL. In knee flexion at 90^0, the distance between the anterior edge of the tibial insertion to the medial half of the femoral insertion was considered as the length of the anteromedial (AM) bundle of the ACL. The distance between the posterior edge of the tibial insertion to the lateral half of the femoral insertion was considered as the length of the posterolateral (PL) bundle. The recorded measurements were organized into a table and subjected to analysis. The data was then presented in the form of means ± standard deviation. The values on the right and left sides were analyzed using an unpaired t-test. The proportions and percentages were analyzed using the Chi-square test. All the statistical analysis was carried out at a 95% level of confidence (statistically significant difference considered at p-value < 0.05).

RESULTS

The presence of ACL was observed in all knee joints, and their attachments were found to be within the normal range according to standard textbooks (Figure 1).

Figure 1. Dissected specimen showing the left anterior cruciate ligament with synovial sheath (shining surface)

The average age of cadavers in the present study was 70 years. Out of 15 cadavers dissected, 6 were female, and 9 were male. The average height of the cadaver was 168.26 cm. The mean length, width at the proximal attachment, width at the distal attachment, and thickness of the right knee ACL were 28.35 mm, 9.2 mm, 10.3 mm, and 4.16 mm, respectively (Figure 2).

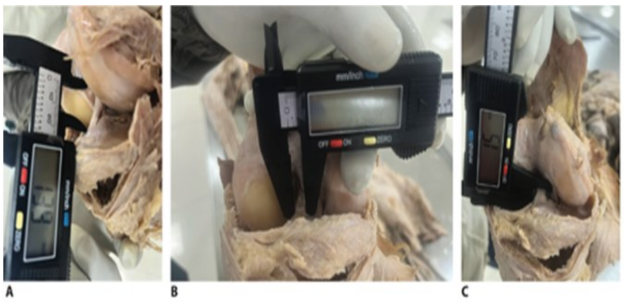

Figure 2. Morphometric measurements of ACL. A. Length, B. Width, C. Thickness

The mean length, width at the proximal attachment, width at the distal attachment, and thickness of the left knee ACL were 32.4 mm, 10.3 mm, 9.46 mm, and 3.84 mm, respectively (Table 1). The measurement of parameters of right and left ACL were statistically indifferent (p>0.05).

Figure 3. Morphometric measurements of ACL, Width at the distal attachment

Figure 4. Tibial footprint

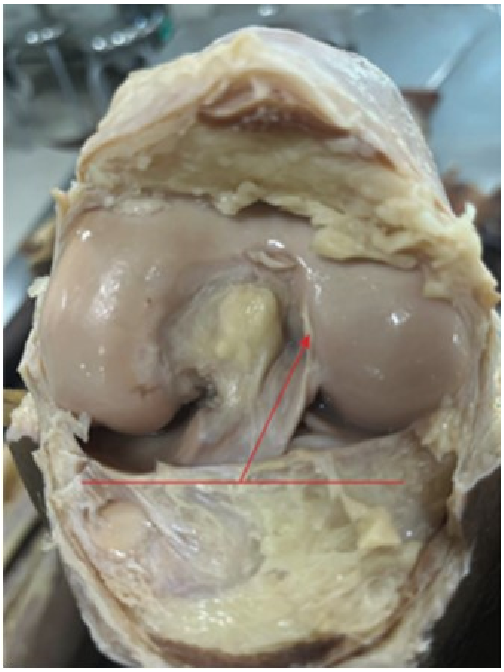

Figure 5. Direction of ACL

The mean length, width, and thickness of ACL in males were 32.54 mm, 10.49 mm, and 4.95 mm, respectively. The mean length, width, and thickness of ACL in females were 30.57 mm, 9.67 mm, and 3.72respectively (Table 2). All the above-mentioned morphometric parameters of the ACL in males were higher than the females, but there was no significant statistical difference ($p>0.05$).

In the present study, the ACL attachments on the femur and tibia were studied. The mean length and width of the tibial footprint in right knee ACL were 13.4 mm and 9.3 mm, respectively (Figure 3). The mean length and width of the tibial footprint in the left knee ACL were 14.1 mm and 7.9 mm, respectively. The mean length and width of the femoral footprint in the right knee ACL were10.9 mm and 6.3 mm, respectively. The mean length and width of the femoral footprint in the left knee ACL were 11.2 mm and 7.4 mm, respectively. The parameters of the left and right sides were statistically indifferent (Table 3). The removed ACL was cross-sectioned in the middle and at the point of attachments, and the surface area was noted.

The mean cross-sectional surface area at the middle, tibial insertion area, and at femoral insertion area of the right side ACL were 102.9 mm^2, 168 mm^2, and 140 mm^2, respectively. The mean cross-sectional surface area at the middle, tibial insertion area, and the femoral insertion area of the left side ACL were 99.1 mm^2, 159 mm^2, and 151 mm^2, respectively (Figure 4, Table 4). These parameters of the left and right sides were statistically indifferent. The direction of ACL and angle between horizontal planes and ACL were measured with the help of goniometer. The direction of the ACL of both the right and left knees was upward, backward, and laterally (Figure 5).

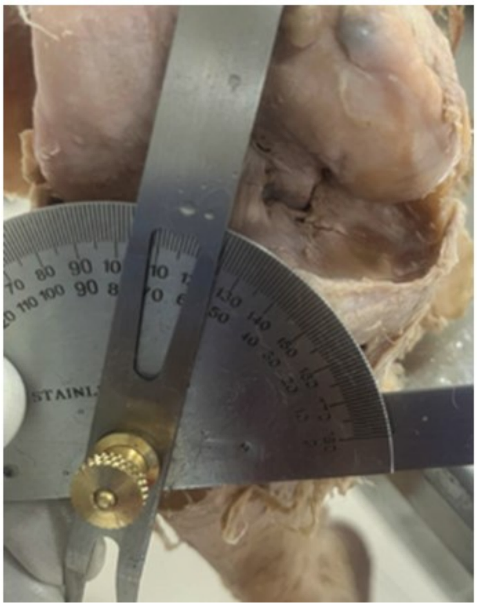

Figure 6. Angle of ACL with horizontal plane

The angle between horizontal plane and ACL on right and left sides were $48^0$and 45^0 respectively (Figure 6, Table 5). In the present study, two bundles (anteromedial and posterolateral) were found in both right and left knees ACL. Also each ACL showed synovial sheath and blood vessels (Figure 7, Table 6).

Figure 7. Bundles of fibers of ACL (anterolateral and posteromedial bundles

Table 1. Length, width, and thickness of anterior cruciate ligament

Parameter	Right side Mean ± SD (mm)	Left side Mean ± SD (mm)
Length	28.35 ± 4.19	32.4 ± 6.24
Width at the proximal attachment	9.2 ± 2.5	10.3 ± 2.7
Width at the distal attachment	10.3 ± 3.4	9.46 ± 3.6
Width at the centre	5.89 ± 4.0	4.94 ± 1.5
Thickness	4.16 ± 0.52	3.84 ± 0.67

Table 2. Sex-wise distribution of length, width, and thickness of anterior cruciate ligament

Parameter	Length of ACL Mean ± SD	Width of ACL Mean ± SD	Thickness of ACL Mean ± SD
Male	32.54 ± 3.56	10.49 ± 1.95	4.95 ± 1.52
Female	30.57 ± 2.6	9.67 ± 1.14	3.72 ± 0.82

Table 3. Tibial and femoral insertion areas of ACL

Parameter	Right side Mean ± SD (mm)	Left side Mean ± SD (mm)
Length of the tibial footprint	13.4 ± 2.8	14.1 ± 3.4
Width of the tibial footprint	9.3 ± 3.5	7.9 ± 4.2
Length of the femoral footprint	10.9 ± 4.7	11.2 ± 5.4
Width of the femoral footprint	6.3 ± 2.4	7.4 ± 3.1

Table 4. Cross-sectional area, tibial and femoral insertion areas of ACL

Parameter	Right side Mean ± SD (mm^2)	Left side Mean ± SD (mm^2)
Cross-sectional area in the middle	102.9 ± 9.8	99.1 ± 10.1
Tibial insertion area	168 ± 66	159 ± 76
Femoral insertion area	140 ± 47	151 ± 53

Table 5. Direction of ACL and angle between horizontal planes and ACL

Parameter	Right side Mean ± SD (degree)	Left side Mean ± SD (Degree)
Direction	Upward, backward and laterally	Upward, backward and laterally
Angle between horizontal plane and ACL	$48^0 \pm 2.7^0$	$45^0 \pm 4.1^0$

Table 6. Number of bundles, synovial sheath and blood vessels in ACL

Parameter	Right side	Left side
Number of bundles	2	2
Presence of synovial sheath	Yes	Yes
Presence of blood vessels	Yes	Yes

DISCUSSION

The need for a comprehensive understanding of the precise anatomy of the ACL arises due to the high frequency of ACL injuries, the significance of anatomy in surgical repair, and the potential of injured ACLs to contribute to osteoarthritis. However, limited studies addressing the morphology of the ACL have revealed uncertainties regarding its size, fiber-bundle structure, number, and arrangement. Recognizing the preference for near-anatomical ACL repair as the treatment of choice, the present study was designed to provide a detailed description of ACL morphology. The intra-articular length of the ACL is vital for ensuring optimal stability in the knee joint. A longer ACL can result in heightened movement and potential graft impingement, while a length shorter than normal values may compromise anteroposterior stability. The length of ACL fibers fluctuates as it was considered as a single bundle in present study. Boisgard S et al, Clement B et al, Tan JL et al, Stijak L et al also considered ACL as a single bundle while measuring length. [10,11,12,13]. There was variation in the findings of length in different studies. Yellicharla*et al.* found length of ACL to be 43.5mm, and 41.9mm and width of ACL to be 12.1 ± 2.4mm and 11 ±1.8mm in males and females respectively which is on higher side as compared to the present study. [7]. Geetha rani *et al* (2019) found the ACL length to be 37.14 ± 3.916mm respectively which exceeds the value of the present study. [14]Rajarshi Dutta *et al* (2017) found length of ACL to be 20.06mm and 20.02mm of right and left knees ACL which is found to be on lower side as compared to present study. [15] The length of ACL in the present study co-incised with the range of Iriuchishima T *et al* (2010), Sampath Kumar*et al* (2019). [16,17]Smilegski*et al* found the width of ACL to 11.4mm at the centre which is more than the present study. [18]Seibold R*et al* and Smigielski R*et al*found the cross-sectional area of ACL which co-incised with the present study. [18,19] The tibial insertion area of the present study was 168 ± 66 mm^2 and 159 ± 76 mm^2 for right and left knees respectively which co-insides with the studies of Yelicharla AKR *et al*, Tampere T *et al*, Araki D *et al*, Tashiro Y *et al*, Triantafyllidie *et al*, Pujol N *et al* and Iriuchishima T *et al*. [7, 20, 21, 22, 23, 24, 25].

The femoral insertion area of the present study was 140 ± 47 mm^2 and 151 ± 53 mm^2 for right and left knees respectively.The findings of Harner CD *et al*, Dargel J *et al*, Luites WH *et al*, Ferretti M *et al*, Iwahashi T *et al*, Otsubo H *et al*, Pujol N*et al*, Mochizuki T *et al*) co- insides with the present study.[24, 26, 27, 28, 29, 30, 31, 32] However, the findings of Iriuchishima T *et al*, Triantafyllidi E *et al* and Yelicharla AKR *et al* were found to have lower femoral insertion areas than the present study.[7, 23, 25] The number of bundles in the present study were 2 in numbers on both sides which co-insides with the studies of Luites WH *et al*, Steckel H *et al*, Adriaensen ME *et al*, Ng AW *et al* and Hara K *et al*.[28, 33, 34, 35, 36]However 3 bundles were found in the studies of Otsubo H *et al*, Kato Y*et al* and Tantisricharoenkul G*et al*.[24, 37, 38]

CONCLUSION

This study enhances our understanding of the morphometric characteristics of knee joint ACL. The morphometric information pertaining to ACL holds significant importance in determining the appropriate graft quantity for surgical intervention in cases of ligament damage. It is imperative to be aware of the average morphometric distinctions when individually reconstructing ACL during surgical procedures.

REFERENCES

1. Standring S. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 42th ed. Edinburgh: Elsevier Churchill Livingstone;2020. 1627 p.
2. Unwin A. (iii) What's new in anterior cruciate ligament surgery? Orthop Trauma. 2010;24(2):100-106. DOI:10.1016/j.mporth.2010.03.001.
3. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. Am J Sports Med. 1995;23(6):694-701. DOI: 10.1177/036354659502300611.
4. Mishra S, Mylarappa A, Satapathy D, Samal S. Morphometric analysis of anatomy of anterior cruciate ligament of knee and its attachments - a cadaveric study in Indian population. Malays Orthop J. 2021;15(3):8-14. DOI: 10.5704/MOJ.2111.002. PMID: 34966489; PMCID: PMC8667243.
5. Fu FH, Shen W, Starman JS, Okeke N, Irrgang JJ. Primary anatomic double-bundle anterior cruciate ligament reconstruction: A preliminary 2-year prospective study. Am J Sports Med. 2008;36(7):1263-74. DOI: 10.1177/0363546508314428.
6. Ahmed MAAS. Morphometric study of anterior cruciate ligament and histological comparison with the patellar and hamstring tendons and a unique case of pes anserinus variant. Life SciJ. 2013;10(1):1402-1411.
7. 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(3):285-291.
8. Van Zyl R, Van Schoor AN, Du Toit PJ, Louw EM. Clinical anatomy of the anterior cruciate ligament and preoperative prediction of ligament length. SA Ortho J. 2016;15(4):47-52.
9. Hollis JM, Takai S, Adams DJ, Horibe S, Woo SY. The effects of knee motion and external loading on the length of the anterior cruciate ligament (ACL): a kinematic study. J Biomech Eng. 1991;113(2):208-14.
10. Boisgard S, Levai JP, Geiger B, Saidane K, Landjerit B. Study of the variations in length of the anterior cruciate ligament during flexion of the knee: use of a 3D model reconstructed from MRI sections. SurgRadiol Anat. 1999;21(5):313-7. DOI: 10.1007/BF01631331. PMID: 10635094.
11. Clément B, Drouin G, Shorrock G, Gely P. Statistical analysis of knee ligament lengths. J Biomech. 1989;22(8-9):767-74. DOI: 10.1016/0021-9290(89)90059-6. PMID: 2613711.
12. Tan JL, Chang PC, Mitra AK, Tay BK. Anthropometry of anterior cruciate ligament in Singaporean Chinese. Ann Acad Med Singap. 1998;27(6):776-9. PMID: 10101548.

13. Stijak L, Bumbasirević M, Kadija M, Stanković G, Herzog R, Filipović B. Morphometric parameters as risk factors for anterior cruciate ligament injuries - a MRI case-control study. Vojnosanit Pregl. 2014;71(3):271-6. DOI: 10.2298/vsp1403271s. PMID: 24697014.
14. Geetha Rani B.G, VarshaMokhasi, TamsirRong P. MORPHOMETRIC ANALYSIS OF CRUCIATE LIGAMENTS. Int J Anat Res 2019;7(4.3):71497154. DOI: 10.16965/ijar.2019.332.
15. Dutta R,Bhattacharya A, Poddar R, Sinha I,GhosalAK.Morphometric study of cruciate ligaments of knee joints: A cadaveric study in Eastern Indian population. IndJ Basic Applied Med Res. 2017:7(1),26-35.
16. Iriuchishima T, Ingham SJ, Tajima G, Horaguchi T, Saito A, Tokuhashi Y, Van Houten AH, Aerts MM, Fu FH. Evaluation of the tunnel placement in the anatomical double-bundle ACL reconstruction: a cadaver study. Knee Surg Sports TraumatolArthrosc. 2010;18(9):1226-31. DOI: 10.1007/s00167-010-1128-y. PMID: 20390250.
17. Sampath K AD, Manimekalai MR, cadaveric study of morphometric analysis of anterior cruciate ligament and its significance.Internat JOrtho Traumatol Sur Sci 2019;5(1):232-235.
18. Śmigielski R, Zdanowicz U, Drwięga M, Ciszek B, Ciszkowska-Łysoń B, Siebold R. Ribbon like appearance of the midsubstance fibres of the anterior cruciate ligament close to its femoral insertion site: a cadaveric study including 111 knees. Knee Surg Sports TraumatolArthrosc. 2015;23(11):3143-50. DOI: 10.1007/s00167-014-3146-7. Epub 2014 Jun 28. PMID: 24972997; PMCID: PMC4611008.
19. Siebold R, Schuhmacher P, Fernandez F, Śmigielski R, Fink C, Brehmer A, Kirsch J. Flat midsubstance of the anterior cruciate ligament with tibial "C"-shaped insertion site. Knee Surg Sports TraumatolArthrosc. 2015;23(11):3136-42. DOI: 10.1007/s00167-014-3058-6.
20. Tampere T, Van Hoof T, Cromheecke M, Van der Bracht H, Chahla J, Verdonk P, Victor J. The anterior cruciate ligament: a study on its bony and soft tissue anatomy using novel 3D CT technology. Knee Surg Sports TraumatolArthrosc. 2017;25(1):236-244. DOI: 10.1007/s00167-016-4310-z. Epub 2016 Sep 13. PMID: 27624179.
21. Araki D, Thorhauer E, Tashman S. Three-dimensional isotropic magnetic resonance imaging can provide a reliable estimate of the native anterior cruciate ligament insertion site anatomy. Knee Surg Sports TraumatolArthrosc. 2018;26(5):1311-1318. DOI: 10.1007/s00167-017-4560-4. Epub 2017 Jun 13. PMID: 28612204; PMCID: PMC5729064.
22. Tashiro Y, Lucidi GA, Gale T, Nagai K, Herbst E, Irrgang JJ, Nakashima Y, Anderst W, Fu FH. Anterior cruciate ligament tibial insertion site is elliptical or triangular shaped in healthy young adults: high-resolution 3-T MRI analysis. Knee Surg Sports TraumatolArthrosc. 2018;26(2):485-490. DOI: 10.1007/s00167-017-4607-6. Epub 2017 Jun 24. PMID: 28647841.
23. Triantafyllidi E, Paschos NK, Goussia A, Barkoula NM, Exarchos DA, Matikas TE, Malamou-Mitsi V, Georgoulis AD. The shape and the thickness of the anterior cruciate ligament along its length in relation to the posterior cruciate ligament: a cadaveric study. Arthroscopy. 2013;29(12):1963-73. DOI: 10.1016/j.arthro.2013.09.007. PMID: 24286796.
24. Pujol N, Queinnec S, Boisrenoult P, Maqdes A, Beaufils P. Anatomy of the anterior cruciate ligament related to hamstring tendon grafts. A cadaveric study. Knee. 2013;20(6):511-4. DOI: 10.1016/j.knee.2012.10.006. Epub 2012 Nov 15. PMID: 23157968.
25. Iriuchishima T, Yorifuji H, Aizawa S, Tajika Y, Murakami T, Fu FH. Evaluation of ACL mid-substance cross-sectional area for reconstructed autograft selection. Knee Surg Sports TraumatolArthrosc. 2014;22(1):207-13. DOI: 10.1007/s00167-012-2356-0. Epub 2012 Dec 22. PMID: 23263230.
26. Harner CD, Baek GH, Vogrin TM, Carlin GJ, Kashiwaguchi S, Woo SL. Quantitative analysis of human cruciate ligament insertions. Arthroscopy. 1999;15(7):741-9. DOI: 10.1016/s0749-8063(99)70006-x. PMID: 10524822.
27. Dargel J, Pohl P, Tzikaras P, Koebke J. Morphometric side-to-side differences in human cruciate ligament insertions. SurgRadiol Anat. 2006;28(4):398-402. DOI: 10.1007/s00276-006-0107-y. Epub 2006 Apr 11. PMID: 16607464.
28. Luites JW, Wymenga AB, Blankevoort L, Kooloos JG. Description of the attachment geometry of the anteromedial and posterolateral bundles of the ACL from arthroscopic perspective for anatomical tunnel placement. Knee Surg Sports TraumatolArthrosc. 2007;15(12):1422-31. DOI: 10.1007/s00167-007-0402-0. Epub 2007 Sep 27. PMID: 17899008; PMCID: PMC2082657.
29. Ferretti M, Ekdahl M, Shen W, Fu FH. Osseous landmarks of the femoral attachment of the anterior cruciate ligament: an anatomic study. Arthroscopy. 2007;23(11):1218-25. DOI: 10.1016/j.arthro.2007.09.008. PMID: 17986410.
30. Iwahashi T, Shino K, Nakata K, Otsubo H, Suzuki T, Amano H, Nakamura N. Direct anterior cruciate ligament insertion to the femur assessed by histology and 3-dimensional volume-rendered computed tomography. Arthroscopy. 2010;26(9Suppl):S13-20. DOI: 10.1016/j.arthro.2010.01.023. Epub 2010 Jul 29. PMID: 20667684..
31. Otsubo H, Shino K, Suzuki D, Kamiya T, Suzuki T, Watanabe K, Fujimiya M, Iwahashi T, Yamashita T. The arrangement and the attachment areas of three ACL bundles. Knee Surg Sports TraumatolArthrosc. 2012;20(1):127-34. DOI: 10.1007/s00167-011-1576-z. Epub 2011 Jun 22. PMID: 21695467.
32. Mochizuki T, Fujishiro H, Nimura A, Mahakkanukrauh P, Yasuda K, Muneta T, Akita K. Anatomic and histologic analysis of the mid-substance and fan-like extension fibres of the anterior cruciate ligament during knee motion, with special reference to the femoral attachment. Knee Surg Sports TraumatolArthrosc. 2014;22(2):336-44. DOI: 10.1007/s00167-013-2404-4. Epub 2013 Jan 24. PMID: 23344119.
33. Steckel H, Starman JS, Baums MH, Klinger HM, Schultz W, Fu FH. Anatomy of the anterior cruciate ligament double bundle structure: a macroscopic evaluation. Scand J Med Sci Sports. 2007 Aug;17(4):387-92. DOI: 10.1111/j.1600-0838.2006.00579.x. Epub 2006 Jun 28. PMID: 16805782.
34. Adriaensen ME, Hogan B, Al-Bulushi HI, Kavanagh EC. Double-bundle depiction of the anterior cruciate ligament at 3 Tesla. Skeletal Radiol. 2012;41(7):831-4. DOI: 10.1007/s00256-011-1303-3. Epub 2011 Oct 14. PMID: 21997671.

35. Ng AW, Lee RK, Ho EP, Law BK, Griffith JF. Anterior cruciate ligament bundle measurement by MRI. Skeletal Radiol. 2013;42(11):1549-54. DOI: 10.1007/s00256-013-1705-5. Epub 2013 Aug 18. PMID: 23955581.
36. Hara K, Mochizuki T, Sekiya I, Yamaguchi K, Akita K, Muneta T. Anatomy of normal human anterior cruciate ligament attachments evaluated by divided small bundles. Am J Sports Med. 2009;37(12):2386-91. DOI: 10.1177/0363546509340404. PMID: 19940312.
37. Kato Y, Ingham SJ, Maeyama A, Lertwanich P, Wang JH, Mifune Y, Kramer S, Smolinski P, Fu FH. Biomechanics of the human triple-bundle anterior cruciate ligament. Arthroscopy. 2012;28(2):247-54. DOI: 10.1016/j.arthro.2011.07.019. Epub 2011 Oct 21. PMID: 22019233.
38. Tantisricharoenkul G, Linde-Rosen M, Araujo P, Zhou J, Smolinski P, Fu FH. Anterior cruciate ligament: an anatomical exploration in humans and in a selection of animal species. Knee SurgSports TraumatolArthrosc. 2014;22(5):961-71. DOI: 10.1007/s00167-013-2463-6. Epub 2013 Mar 8. PMID: 23471530.

****