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CLINICAL STUDY

Morphometry and magnetic resonance imaging of anterior cruciate ligament and measurement of secondary signs of anterior cruciate ligament tear

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Abstract: Injuries or over-stretching of the anterior cruciate ligament (ACL) may lead to its malfunctioning. ACL tear, partial or complete, canto the result of contact or non-contact injuries. To conduct morphometry of ACL, twenty six knees (14 right and 12 left) were examined in 21 male and 5 female formalin fixed cadavers. Measurement of tibial foot print of ACL, distance of its anterior edge from the anterior margin of tibia, length and width of ACL were determined with the help of digital caliper. Indirect signs of ACL tear (sagittal ACL-tibial angle, coronal ACL - tibial angle, Blumensaat line - ACL angle and angle of inclination of the intercondylar roof) complement the magnetic resonance imaging (MRI) diagnosis of ACL injury. We also studied the consequences of meniscal and posterior cruciate ligament injuries on above mentioned angles. In addition 84 MRI images of knees of patients aged between 18 – 74 years were evaluated for diagnosis of any disruption in the morphology of ACL. In our study, mean length of the tibial foot print of ACL was 18.34 ± 3.49 mm, mean width of tibial foot print was 15.26 ± 2.01, mean distance from the anterior edge of tibia to anterior margin of attachment of ACL was 13.11 ± 2.34, length and width of ACL were 32.5 ± 4.33 mm and 9.38 ± 1.58 mm, respectively. The present study will be useful for enhancing the knowledge of anatomy of ACL and may act as a valuable guide for radiologists in evaluating the injury to knee involving ACL, menisci and PCL *(Tab. 5, Fig. 9, Ref. 17)*. Full Text in PDF *www.elis.sk.*
Key words: anterior cruciate ligament, magnetic resonance imaging, posterior cruciate ligament, meniscus, tibia, tear, injury.

Anterior cruciate ligament (ACL) is attached to the anterior intercondylar area of the tibia partly blending with the anterior horn of the lateral meniscus. It ascends posterolaterally, twisting on itself and fans out to get attached to the posteromedial aspect of the lateral femoral condyle (1). The ACL consists of two bundles, anteromedial and posterolateral, named according to their insertion site on the tibial plateau (2).

The posterior cruciate ligament (PCL) is attached to the lateral surface of medial femoral condyle and extends up to the anterior part of the roof of the intercondylar notch. It is attached to the posterior intercondylar area of tibia and posterior horn of lateral meniscus. The menisci are crescentic laminae deepening the articulating tibial surface that receives the femur (1). The susceptibility of ACL to injury leads to alteration in the kinetics and kinematics of knee joint (3). ACL tear is the result of combination of external rotation and abduction forces, complete knee joint dislocation and direct posterior violence (4). About 70 % of ACL tears are caused by non contact sports related injuries during pivoting, decelerating and jumping activities (5).

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Magnetic resonance imaging (MRI) corroborates the diagnosis of any disruption in the morphology of ACL. In most of the cases, diagnosis of torn ACL is mainly assessed on sagittal images. Primary signs of ACL tear include wavy contour, lack of continuity and focal or diffuse high signal intensity within the substance of the ligament on T2-weighted images. Though MRI maintains accuracy, false-positive and false-negative results have been reported (6). Oblique coronal sections with MRI improve the specificity and accuracy of ACL tear detection (7). Change in alignment of the ACL on MRI is one of the best secondary signs of its tear with high sensitivity and specificity (6). Alterations in ACL-tibial angle, Blumensaat line-ACL angle, angle of inclination of intercondylar roof were considered indirect signs of ACL tear (6, 8).

The objective of the study was to analyze morphometric data on ACL in cadaveric specimens and to observe the consequences of complete and partial ACL, PCL and meniscal tear on the angles which are indirect signs of ACL tear on the basis of MRI findings.

Material and methods

A morphometric study was performed on 14 right and 12 left knees from 21 male and 5 female adult cadavers, perfusion fixed in embalming liquid containing 10 % formaldehyde. Knees with ACL tear, macroscopic degenerative changes or any evidence of trauma were excluded from the study. Length and width of tibial

Tab. 1. The showing of comparison of morphometry of ACL between the present and previous studies.

REFERENCES	ACL (mm)		TIBIAL FOOT PRINT (mm)		Distance from anterior edge of tibea to anterior edge
	LENGTH	WIDTH	LENGTH	WIDTH	Of ACL (mm)
Present study	*32.5±4.33*	*9.38±1.58*	*18.34±3.49*	*15.26±2.01*	*13.11±2.34*
Girgis et al	—	—	29.3 (23-38)	—	—
Odensten et al	31±3(25-35)	10±2 (7-12)	17±3	11±2	—
Staubli et al	—	—	15±3	—	—
Morgan et al	—	—	18 (14-21)	10 (8-12)	—
Moneta et al	—	—	17±2.4	11±1.6	—
Colombet at al	—	—	17.6±2.1	12.7±2.8	13.1
Edwards et al	—	—	18±2	9±2	—
Kennedy et al	39 (37-41)	—	—	—	—
Doi et al	—	—	—	—	13.1±2.3(7.5-19)
Siebold et al	—	—	14±2 (9-18)	10±2(7-15)	—
Cuomo et al	—	—	17±2 (12-19)	9±2(7-16)	—
Trent et al	22	—	—	—	—

Tab. 2. The showing of comparison of control group with complete or partial ACL, PCL, medial and lateral meniscal tear with respect to sagittal ACL-tibial angle on MRI.

	SAGITTAL ACL-TIBIAL ANGLE					
	Normal	Complete ACL tear	Partial ACL tear	PCL tear	Medial Meniscal tear	Lateral Meniscal tear
Mean	51.34	33	39.3	43.92	46.53	42.06
S.D	3.99	6.38	8.06	9.22	8.42	11.48
p value	—	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05

Tab. 3. The showing of comparison of control group with complete or partial ACL tear, PCL tear, medial and lateral meniscal tear with respect to coronal ACL-tibial angle on MRI.

	CORONAL ACL-TIBIAL ANGLE					
	Normal	Complete ACL tear	Partial ACL tear	PCL tear	Medial Meniscal tear	Lateral Meniscal tear
Mean	73.5	75.9	72.21	65.48	73.7	77.21
S.D	6.82	7.48	8.62	11	9.16	5.9
p value	—	p>0.05	p>0.05	p<0.05	p>0.05	p<0.05

Tab. 4. The showing of comparison of control group with PCL tear, medial and lateral meniscal tear with respect to Blumensaat ACL-tibial angle on MRI.

	BLUMENSAAT ACL-TIBIAL ANGLE			
	Normal	PCL tear	Medial Meniscal tear	Lateral Meniscal tear
Mean	7.06	8.13	7.28	6.15
S.D	1.44	2.14	1.91	1.06
p value	—	p<0.05	p>0.05	p<0.05

foot print of ACL, distance from its anterior edge to anterior edge of tibia and length and width of the ligament were measured with the help of digital caliper by positioning each knee in 90° flexion (Figs 1– 9). Digital photographic documentation of anatomical landmarks was done.

In addition 84 MRI images of knees of patients (67 male and 17 female) aged between 18–74 years were evaluated. The findings were tabulated (Tab 2 – 5). Twenty four cases served as control, 11 had complete ACL tear, 13 had partial ACL tear, 5 cases of PCL tear, 22 cases of medial meniscal tear and 9 with lateral meniscal tear were observed. Indirect signs of ACL tear, i.e. sagittal ACL-tibial angle, coronal ACL-tibial angle, Blumensaat line-ACL angle and angle of inclination of the intercondylar roof were measured by 0.5 Tesla MRI. Patients with degenerative changes, bony contusion, osteochondral fractures and multiple cruciate and meniscal injuries were excluded from the study.

Sagittal ACL-tibial angle is the angle between the most anterior margin of the ACL and the reference line parallel to the mid-lateral tibial plateau. Coronal ACL-tibial angle is the angle between the most medial margin of the long axis of ACL and a line between the medial and lateral condyle of tibia (6). Blumensaat line-ACL angle is the angle between the Blumensaat line and the most anterior margin of ACL on sagittal view (8, 9). Angle of inclination of

Tab. 5. The showing of comparison of control group with complete or partial ACL tear, PCL tear, medial and lateral meniscal tear with respect to angle of inclination of intercondylar roof.

	ANGLE OF INCLINATION OF INTERCONDYLAR ROOF					
	Normal	Complete ACL tear	Partial ACL tear	PCL tear	Medial Meniscal tear	Lateral Menisci tear
mean	44.24	43.74	46.08	41.43	43.34	42.99
S.D	3.64	3.58	3.37	6.54	3.85	3.43
p value	—	p>0.05	p<0.05	p<0.05	p>0.05	p>0.05

Fig. 1. Picture showing the method of measurement of length of tibial footprint of ACL in cadaveric knee.

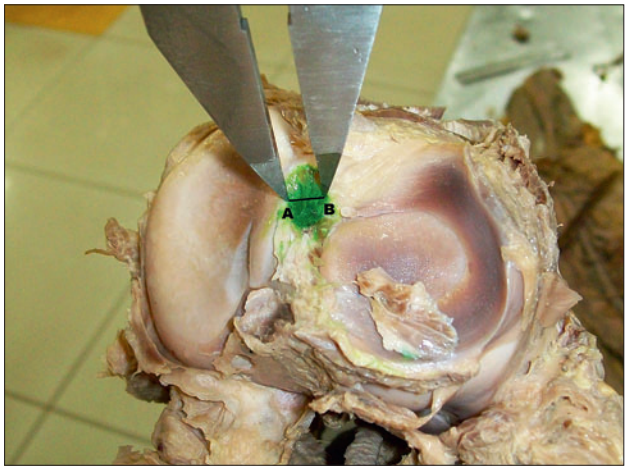

Fig. 2. Picture showing the method of measurement of width of tibial footprint of ACL in cadaveric knee.

the intercondylar roof is between a line drawn along the intercondylar roof and long axis of femur on a midline sagittal image (8).

Sagittal ACL tibial angle and Blumensaat line-ACL angle were measured using the technique described by Gentili and coworkers (6). Measurement of coronal ACL-tibial angle and angle of inclination of intercondylar roof were done by applying the method used by Kim et al (8).

Results

Morphometric Study

Morphometric studies on ACL were performed and its results were recorded (Tab. 1). Chi- square test did not show any significant difference between genders.

MRI Study

Indirect signs of ACL tear were recorded. Independent sample t-test was performed to compare the mean angles of control group

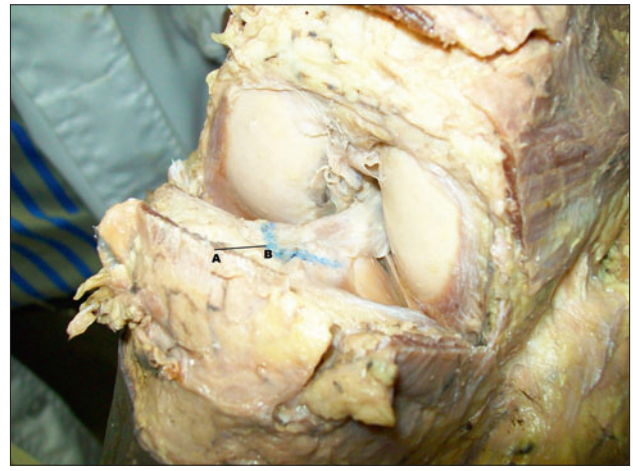

Fig. 3. Picture showing the method of measurement of distance from anterior edge of tibia to anterior edge of ACL in cadaveric knee.

Fig. 4. Picture showing the method of measurement of length of ACL in cadaveric knee.

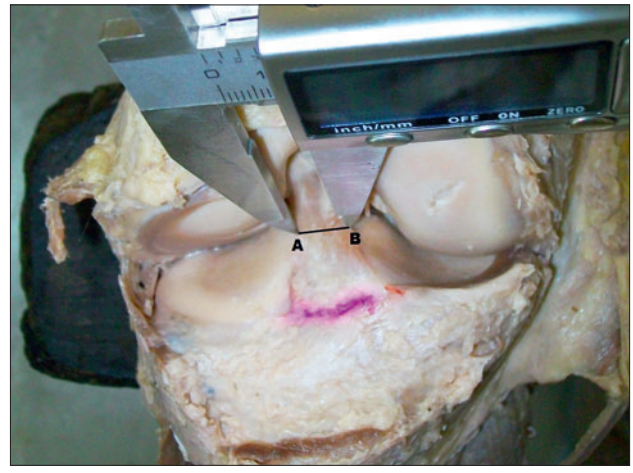

Fig. 5. Picture showing the method of measurement of width of ACL in cadaveric knee.

Fig. 6. Sagittal ACL – tibial angle – Sagittal MRI image obtained from right knee of 37 years old male patient. The plane of the tibial plateau forms an angle with the most anterior margin of ACL.

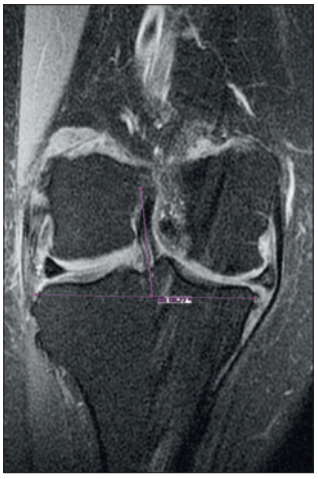

Fig. 7. Coronal ACL – tibial angle – Coronal MRI image from right knee of 37 years old male patient. The plane of tibial plateau forms an angle with most medial margin of long axis of ACL.

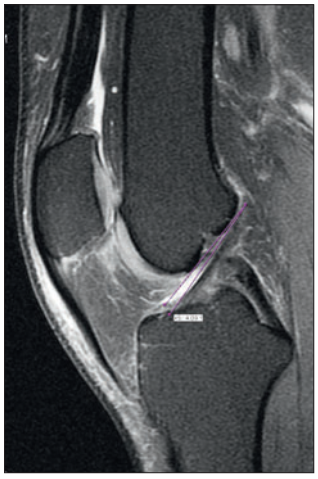

Fig. 8. Blumensaat ACL – tibial angle – Sagittal MRI image from right knee of 37 years old male patient. The Blumensaat line forms an angle with the most anterior margin of ACL.

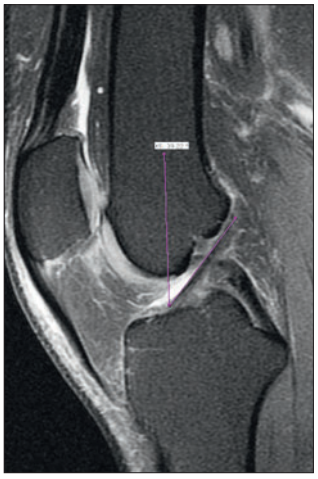

Fig. 9. Sagittal MRI image shows MRI image of angle of inclination of intercondylar roof in right knee of 37 years old male patient. Angle is measured between a line drawn along the intercondylar roof and long axis of femur.

and those with complete or partial ACL tear, PCL tear, medial and lateral meniscal tear (Tab 2 – 5). The level of significance was set to $p < 0.05$.

Discussion

Morphometric studies on the length of tibial foot print of ACL yielded results similar to previous studies except that of Girgis et al, whereas the width in the present study was higher when compared to earlier reports (Tab. 1) (10). It is presumed that larger surface area of tibial foot print will provide more support to ACL, thereby decreasing the probability of its tear. The distance from anterior edge of tibia to anterior margin of attachment of ACL was consistent with previous literature (Tab. 1). The present findings on the length of ACL were consistent with Odensten et al but there was a notable difference with the findings of Kennedy et al and Trent et al. The width, however, was similar (Tab. 1) (4, 11, 12).

The anatomical knowledge of ACL attachment is helpful for accurate tunnel placement of ACL while performing reconstruction. During physiologic impingement in full extension of knee, the fibres of ACL are in contact with the roof of intercondylar notch, as well as the distal third of anterior part of the ligament comes in close contact with intercondylar fossa (13).

Literature data up to date show that only Siebold et al presented the results categorically based on gender (14). Their study revealed greater length of ACL and bigger area of the attachment on tibia in men in contrast to women, although there was no difference in width. Furthermore, they reported significantly smaller femoral ACL attachment on right side in comparison to the left side. On the contrary, findings of another study were consistent with our findings (15).

The findings of Gentili and his colleagues showed mean sagittal ACL-tibial angle in patients without an ACL tear was 55.6° (6). Kim et al reported that the mean sagittal ACL-tibial angle was 55.5 ± 6.7° in females and 53.9 ± 5.8° in males. However, there was no data showing the mean angle measurement in the 2 sexes (8). In the present study mean sagittal ACL-tibial angle was found to be 51.34° ± 3.99.

According to Gentili and his co-workers, mean sagittal ACL-tibial angle for patients with ACL tear was significantly smaller, 29.9° (6). In the present study, the angle in cases with complete ACL tear was 33° ± 6.38 and in cases with partial ACL tear 39.3° ± 8.06. Significant reduction in the angle in cases with ACL tear is due to the fact that distal portion of the torn ligament lies more horizontally.

In our study, sagittal ACL-tibial angle was 43.92° ± 9.22 in cases with PCL tear, 46.53° ± 8.42 in cases with medial meniscal tear and 42.06° ± 11.48 in cases with lateral meniscal tear. Statistically the angle showed significant difference between the control and those with tear.

According to Kim et al. on the coronal images, the mean ACL-tibial angle was 62.9° ± 10.0 in females and 60.7° ± 9.8 in males (8). Sonin et al. reported a mean coronal ACL-tibial angle of 76° in normal adults (16). In the present study, coronal ACL-tibial angle was 73.5° ± 6.82 in control. It was 76° ± 7.5 in cases with complete ACL tear, 72.21° ± 8.62 with partial ACL tear, 65.48° ± 11with PCL tear, 74° ± 9.16 with medial meniscal tear and 77.21° ± 5.90 in cases with lateral meniscal tear.

Statistically significant differences in coronal ACL-tibial angle were found in controls and in cases with PCL and lateral meniscal tears. Differences in the angle with complete or partial ACL tear and medial meniscal tear were found to be statistically insignificant ($p > 0.05$).

Gentili et al reported that the mean angle between the ACL and Blumensaat line in control group was -1.6°, while in our study the angle measured 7.06° ± 1.44. In a study by the same author

mean Blumensaat line-ACL angle for patients with an ACL tear was 25.8° (6). We found that the angle was 8.13° ± 2.14 in cases with PCL tear, 7.28° ± 1.91 with medial meniscal tear and 6.15° ± 1.06 where there was lateral meniscal tear. We could not measure Blumensaat line-ACL angle in cases of complete or partial ACL tear as proximal portion of ligament was not well visualized in these cases.

Differences of Blumensaat line-ACL angle in controls and in cases with PCL and lateral meniscal tears were found to be statistically significant ($p < 0.05$). The differences observed in cases of medial meniscal tear were not statistically significant ($p > 0.05$).

Kim et al. mentioned that the angle of inclination of intercondylar roof was 44.4° ± 5.1 in females and 46.5° ± 5.3 in males (8). The mean measurement of the angle was 44.24° ± 3.64 in both sexes in his study. In the present study the angle was 43.74° ± 3.58 in cases with complete ACL tear, 46.08° ± 3.4 with partial ACL tear, 41.43° ± 6.54 with PCL tear, 43.34° ± 3.85 with medial meniscal tear and 43° ± 3.43 in cases with lateral meniscal tear.

Differences in the angle of inclination of intercondylar roof between controls and cases with partial ACL tear and PCL tear were statistically significant ($p < 0.05$). Differences with complete ACL tear, medial and lateral meniscal tears were statistically insignificant ($p > 0.05$).

This is the first reported study on indirect signs of ACL tear in patients with injury to neighboring structures, i.e. PCL and menisci. From the present MRI study, it may be concluded that the indirect signs of ACL tear may not be diagnostic as the results in different injuries were variable. These signs may be considered as suggestive but not conclusive in diagnosing ACL tear.

References

1. Standring J et al. Gray's Anatomy (40th ed). London: Churchill Livingstone, 2005, 1397 – 1401.

2. Casagranda BC, Maxwell NJ, Kavanagh EC, Towers JD, Shen W, Fu FH. Normal appearance and complications of double-bundle and selective-bundle anterior cruciate ligament reconstructions using optimal MRI techniques. AJR 2009; 192: 1407 – 1415.

3. Widuchowski W, Widuchowski J, Trazaska. Articular cartilage defects. Knee 2007; 14: 177 – 182.

4. Kennedy JC, Weinberg HW, Wilson AS: The anatomy and function of the anterior cruciate ligament. As determined by clinical and morphological studies. J Bone Joint Surg Am 1974; 56: 223 – 235.

5. Haim A, Pritsch T, Yosepov L, Arbel R. Anterior cruciate ligament injuries: Harefah 2006; 145: 208 – 214.

6. Gentili A, Seeger LL, Yao L, Do HM. Anterior cruciate ligament tear: Indirect signs at MR Imaging. Radiology 1994; 193: 835 – 840.

7. Hong SH, Choi JY, Chung HW, Kang HS. Grading of anterior cruciate ligament injury: Diagnostic efficacy of oblique coronal magnetic resonance imaging of the knee. J Comput Assist Tomogr 2003; 27: 814 – 819.

8. 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 – 835.

9. Jacobsen K, Bertheussen K, Christian C. Gjerloff. Characteristics of the Line of Blumensaat: An Experimental Analysis. Acta Orthop Scand 1974; 45: 764 – 771.

10. Girgis FG, Marshall JL, Monajem A. The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. Clin Orthop Relat Res 1975; 106: 216 – 231.

11. Trent PS, Walker PS, Wolf B. Ligament length patterns, strength and rotational axis of knee joint. Clin Orthop 1976; 117: 263 – 270. In: Amis AA, Dawkins GP. Functional anatomy of the anterior cruciate ligament: Fibre bundle actions related to ligament replacements and injuries. J Bone Joint Surg Br 1991; 73: 260 – 267.

12. Odensten M, Gillquist J. Functional anatomy of the anterior cruciate ligament and a rationale for reconstruction. J Bone Joint Surg Am 1985; 67: 257 – 262.

13. Colombet P, Robinson J, Christel P, Franceschi JP, Djian P, Bellier G, Sbihi A. Morphology of anterior cruciate ligament attachments for anatomic reconstruction: a cadaveric dissection and radiographic study. Arthroscopy 2006; 22: 984 – 992.

14. Siebold R, Ellert T, Metz S, Metz J. Tibial insertions of the anteromedial and posterolateral bundles of the anterior cruciate ligament: Morphometry, arthroscopic landmarks, and orientation model for bone tunnel placement. Arthroscopy 2008; 24: 154 – 161.

15. Dargel J, Pohl P, Tzikaras P et al. Morphometric side-to side differences in human cruciate ligament insertions. Surg Radiol Anat 2006; 28: 398 – 402. In: Kopf S, Musahl V, Tashman S, Szczodry M, Shen W, Fu FH. A systemic review of the femoral origin and tibial insertion morphology of the ACL. Knee Surg Sports Traumatol Arthrosc 2009; 17: 213 – 219.

16. Sonin AH, Hsieh P, Dunfee W, Traina S. MR imaging assessment of the normal ACL angle in the coronal plane. Presented at the 28th annual meeting of the Society for Skeletal Radiology, Orlando, Fla, March 13–16, 2005. In: 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 – 835.

17. Odensten M, Gillquist J. Functional anatomy of the anterior cruciate ligament and a rationale for reconstruction. J Bone Joint Surg Am 1985; 67: 257 – 262.

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