



Original Article

Descriptive anatomy of the anterior cruciate ligament femoral insertion[☆]



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ARTICLE INFO

Article history:

Received 22 January 2017

Accepted 2 March 2017

Available online 8 June 2018

Keywords:

Femur

Anterior cruciate ligament

Anatomy

Orthopedic procedures

ABSTRACT

Objective: To evaluate the morphology of the anterior cruciate ligament (ACL) femoral insertion in order to describe its anatomical features and insertion site location, with the aim of verifying if the ACL femoral insertion has individual characteristics and to provide information for appropriate femoral tunnel placement on anatomic ACL reconstruction.

Methods: Sixteen knees obtained from amputations were studied. The ACL femoral bundles and insertion shape were observed macroscopically, and the ligaments insertion length and thickness were measured with a digital caliper. The distances between the limits of the ligament to the articular cartilage, and the measurement of the area of insertion were checked using ImageJ software.

Results: The ACL femoral insertion site was eccentric, closer to the deep condyle cartilage. In ten knees (62.5%), the ACL femoral insertion was oval; the mean length of the insertion was 16.4 mm, varying from 11.3 to 19.3 mm, the mean thickness varied from 7.85 to 11.23 mm, and the mean area of the insertion was 99.7 mm², varying from 80.9 a 117.2 mm². The mean distances between the limits of the ligament to the superficial, deep, and inferior articular cartilage were 9.77 ± 1.21, 2.60 ± 1.20, and 1.86 ± 1.15 mm, respectively.

Conclusion: There was a 30% to 40% difference between the minimum and maximum results of measurements of ACL femoral insertion length, thickness, and area demonstrating an important individual variation. The insertion site was eccentric, closer to the deep cartilage of the lateral femoral condyle.

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<https://doi.org/10.1016/j.rboe.2018.05.004>

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Anatomia descritiva da inserção femoral do ligamento cruzado anterior

R E S U M O

Palavras-chave:

Fêmur
Ligamento cruzado anterior
Anatomia
Procedimentos ortopédicos

Objetivo: Avaliar os aspectos morfológicos da inserção femoral do ligamento cruzado anterior (LCA) para definir suas características anatômicas e a localização de seu sítio de inserção, com a finalidade de verificar se essa inserção tem características individuais e para prover informações para o posicionamento adequado do túnel femoral na reconstrução anatômica do LCA.

Métodos: Foram examinados 16 joelhos originados de amputações. Nesses, foram observados macroscopicamente o número de bandas e o formato das inserções ligamentares. Foram medidos, com um paquímetro digital, o comprimento e a espessura dessas inserções. As distâncias entre os limites do ligamento e a cartilagem articular e a medida da área de inserção ligamentar foram avaliadas com o *software ImageJ*.

Resultados: A localização do sítio de inserção ligamentar do LCA no côndilo femoral lateral foi excêntrica, mais próxima da cartilagem condilar profunda. Em dez joelhos (62,5%) as inserções foram ovais; o comprimento médio das inserções foi de 16,4 mm, variou de 11,3 a 19,3 mm; a espessura variou de 7,85 a 11,23 mm (média de 9,62). A área média das inserções foi de 99,7 mm², variou de 80,9 a 117,2 mm². As distâncias médias entre os limites do ligamento até a cartilagem articular superficial, profunda e inferior foram, respectivamente, $9,77 \pm 1,21$; $2,60 \pm 1,20$ e $1,86 \pm 1,15$.

Conclusão: Houve uma diferença de 30% a 40% entre os resultados mínimo e máximo das mensurações do comprimento, da espessura e da área das inserções femorais do LCA, evidenciou uma variação individual importante. O sítio de inserção do LCA foi excêntrico, mais próximo da cartilagem articular profunda do côndilo femoral lateral.

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Introduction

Data from Swedish statistics show that the prevalence of anterior cruciate ligament (ACL) injuries among soccer athletes ranges from 0.5 to 6% in women and from 0.6 to 8.5% in men.¹ In the United States, 90% of the individuals who suffer an ACL injury are eventually treated for surgical reconstruction of this ligament.²

From the 1990s until the early 2000s, most of the ACL reconstructions sought to be isometric, i.e., with a minimal alteration in the distance between the femoral and tibial insertions of the ACL replacement with the knee in flexion.³ However, isometric placement was an ideal goal that was never achieved, since only a few ACL fibers are almost isometric during total knee mobility.⁴

In the first decade of the 2000s, a change in the tendency was observed, now favoring anatomical reconstructions, defined as those that seek functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites in order to try to reproduce the normal anatomy, restore kinematics, and provide long-term joint health.⁵

In fact, accurate placement of the tunnels at the natural insertion site of the ligament appears to be the most important factor for the ACL reconstruction to be anatomic, making no difference whether surgery is performed with a single bundle or a double bundle,⁶ since it is well known that a femoral tunnel placed distally and anteriorly to the original ligament insertion is associated with graft failure in 62.5% of the cases.⁷

Recently, the concept of anatomical reconstruction has evolved to that of individualized reconstruction. In individualized ACL surgeries, the type and size of the graft are customized and molded to the patient's native insertion site,⁸ aiming to reproduce the natural ligament insertion of each patient as close as possible.⁹ In turn, according to Sasaki et al.¹⁰ the location of the ACL femoral insertion is still controversial.

This study is aimed at evaluating the morphology of the ACL femoral insertion, in order to establish the anatomical characteristics and position of the insertion site of this ligament, so as to confirm the existence of an individual character of the femoral insertion of this ligament and to provide the precise placement of the femoral tunnel in the anatomic reconstruction of the ACL.

Methods

This study was approved by the Ethics Committee of this institution. Information on patients weight and height was obtained from hospital records of the institution where the study was conducted.

The terminology used in the present study (upper, lower, deep, and superficial) is in accordance with that suggested by a group of international experts, considering that the arthroscopic visualization of the graft is done with the knee in flexion, unlike the anatomical nomenclature, which is related to the knee in extension (Fig. 1).¹¹

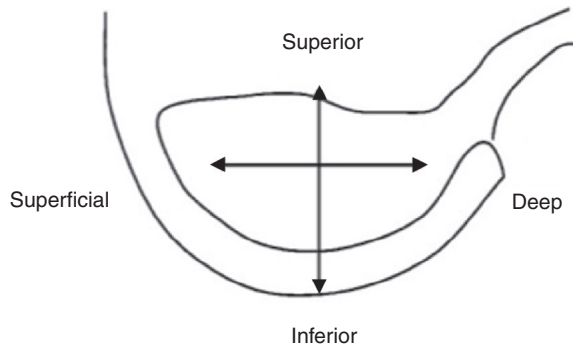


Fig. 1 – Representation of the arthroscopic visualization and the terminology used to locate the ACL insertion.

The femoral insertion of the ACL was studied in 16 knees originating from amputations. Eleven specimens were from males and five, from females. There were a total of three right and 13 left knees.

The age of the patients who had their knees amputated ranged from 57 to 96 years, with a mean of 74.5 years and standard deviation (SD) of ± 13.1 . The mean weight of patients was 63.6 kg (range: 49.0 to 89.0 kg, SD ± 11.5) and height ranged from 1.53 to 1.75 m (mean: 1.65 m; SD ± 0.07).

All knees had intact ACL and posterior cruciate ligaments, and there were no osteophytes in the medial region of the lateral femoral condyle (LFC) that could interfere with the measurements of distances between the ACL boundaries and the articular cartilage of this condyle.

Prior to dissection, the specimens were submitted to a 10% formaldehyde fixative solution and stored in a mixture of 2.5% phenol, 2.5% formaldehyde, and 1% sodium chloride. Subsequently, the specimens were kept for 60 days in liquid glycerin.

In order to assess the ACL insertions, the distal femurs were sectioned in a sagittal plane with a circular electric saw, passing through the intercondyles, in order to remove the medial femoral segment; care was taken to avoid injury to the ligament or its bony insertion.

For the analyses, the authors used glasses with 4x magnifying lenses. The delimitation of the ACL insertions was made delicately using a No. 11 scalpel blade, dissecting forceps, and Metzenbaum scissors. The peripheral fibrous expansions were carefully removed to mark the insertions (Fig. 2).

The macroscopic observation showed the number of ACL bundles and the shape of the femoral inserts, which were classified according to Sasaki et al.¹⁰ into type A (oval), B (semicircular), or C (small semicircular). The length and thickness of the ACL insertions was measured in millimeters with a 150 mm Pd150 digital caliper (Vonder®, OVD, Curitiba, PR, Brazil). Subsequently, the ligaments were removed to expose the bony portions corresponding to the ligament insertions (Fig. 3).

The limits of the ligament insertions were marked with small dots of ink. A reference marker was used and the specimens were photographed using a D3100 digital camera (Nikon, Melville, NY, USA).

On the photographic images, a line was traced crossing Blumensaat's line or the intercondylar roof, and another line

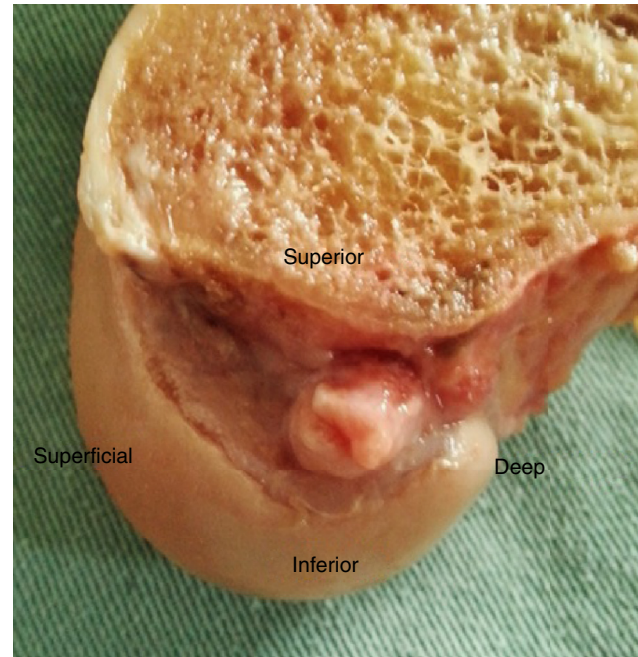


Fig. 2 – Medial aspect of the lateral femoral condyle, showing the ACL insertion.

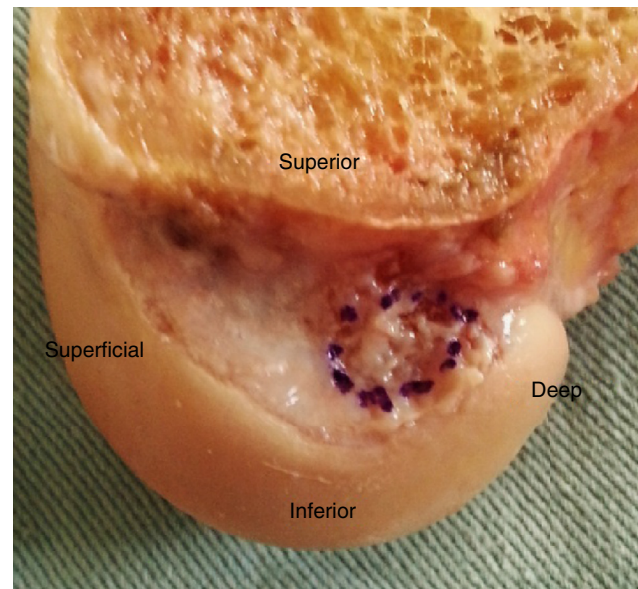


Fig. 3 – View of the medial region of the lateral femoral condyle, after removal of the ACL insertion, with demarcation of the limits of its insertion.

was traced parallel to the first one, passing through the lowest portion of the LFC cartilage. The distances between the limit of the ACL insertion and the superficial (DSC) and deep articular cartilage (DDC) were assessed on a line parallel to the two previously drawn lines; the distance between the limits of the ligament and the lower articular cartilage (DIC) was calculated on a line perpendicular to the drawn lines (Fig. 4). All distances were measured in mm.

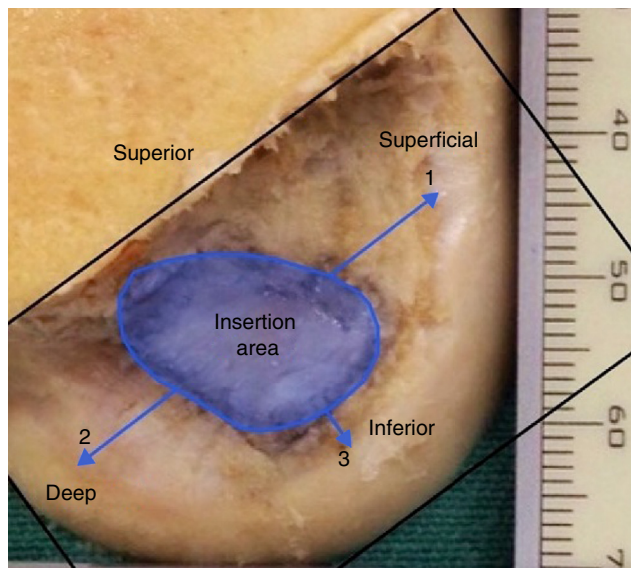


Fig. 4 – A schematic medial view of the LFC, with the lines drawn and the delimitation of the ACL insertion area in blue. (1) Distance between the limit of the ACL insertion and the deep articular cartilage of the LFC (DDC); (2) distance between the limits of the insertion and the surface cartilage of the LFC (DSC); (3) distance between the limits of the insertion and the inferior articular cartilage (DIC) of the LFC. Source: File provided by the institution.

The areas of ACL insertion were measured in mm². The measurements were made by a single author, who repeated them at random after ten days.

The ImageJ program was used to measure the distances between the limits of the ACL insertion and the articular cartilage and to measure the area of ligament insertion.

Statistical analysis

To evaluate the correlation between the several quantitative variables, Pearson’s correlation was used; the concordances were considered to be statistically significant only when $p < 0.05$. The Kappa test was used to measure intraobserver reliability, with a 95% confidence interval. Creative Research Systems® software was used to calculate the sample size, with a confidence level of 95%.

Results

The intraobserver agreement of 0.92 (range: 0.88 to 0.95) for the various measurements was considered to be strong. The confidence interval for the sample size was 21.99. Table 1 presents all the quantitative and qualitative variables of the study.

In ten knees (62.5%), the femoral insertions of the ACL were classified as oval; in four (25.0%), semicircular; and in two (12.5%), small semicircular. The ACL insertion site was eccentrically located, closer to the deep articular cartilage than to the superficial cartilage of the LFC.

The mean insertion length was 16.4 mm, ranging from 11.3 to 19.3 mm, with a SD of ± 2.12 mm; the thickness ranged from 7.85 to 11.23 mm (mean: 9.62 and $SD \pm 0.93$ mm). The mean area of the inserts was 99.7 mm² (80.9 to 117.2 and $SD \pm 11.3$ mm²).

Table 1 – Distribution of the quantitative and qualitative variables of the study.

	Age (years)	Gender	Weight (kg)	Height (m)	BMI	Femoral insertion of the ACL			Distance between ACL limit and articular cartilage			Type of insertion
						Length (mm)	Thickness (mm)	Area (mm ²)	Anterior (mm)	Posterior (mm)	Distal (mm)	
1	96	F	49	1.54	20.66	16.24	9.82	86.92	8.13	2.84	3.93	A
2	76	M	70	1.70	24.22	11.38	7.85	90.10	8.71	3.20	3.05	C
3	58	M	78	1.73	26.6	18.76	9.45	103.49	8.72	2.30	1.09	A
4	58	F	54	1.60	21.09	15.63	8.79	98.74	8.56	2.67	1.43	A
5	70	M	65	1.64	24.17	14.90	8.20	84.82	10.11	3.32	3.60	C
6	68	M	60	1.65	22.04	18.76	9.78	105.67	9.78	2.34	0.27	B
7	57	M	80	1.75	26.12	17.29	10.74	106.63	12.05	4.19	2.49	A
8	92	F	52	1.56	21.37	16.92	10.10	117.21	10.20	4.5	2.08	A
9	73	M	89	1.75	29.06	13.65	8.56	80.90	8.10	0.81	0.93	B
10	92	M	60	1.65	22.04	18.87	10.12	105.52	9.39	4.29	2.42	A
11	65	M	74	1.72	25.01	16.75	9.89	92.80	11.28	0.73	0.52	B
12	70	M	58	1.65	21.30	17.35	11.23	109.89	10.22	3.40	2.98	A
13	74	F	56	1.53	23.92	14.45	9.80	87.6	11.02	1.10	0.56	A
14	66	M	60	1.70	20.76	16.85	10.60	111.47	9.34	0.98	0.75	B
15	87	F	51	1.58	20.43	19.30	9.89	113.97	11.39	3.30	2.12	A
16	91	M	63	1.68	22.32	16.81	9.03	101.12	9.25	2.05	1.61	A
Mean	74.56	M	63.69	1.65	23.16	16.49	9.62	99.77	9.77	2.60	1.86	
SD	13.18	11	11.55	0.07	2.47	2.12	0.93	11.33	1.21	1.20	1.15	
Max.	96	F	89.00	1.75	29.06	19.30	11.23	117.21	12.05	4.29	3.93	
Min	57	5	49.00	1.53	20.43	11.38	7.85	80.90	8.10	0.73	0.27	

Source: File provided by the institution.

Table 2 – Description of the various measurements of the ACL femoral insertion.

Reference	Length (mm)	Thickness (mm)	Area (mm ²)
Odensten & Gillquist ¹² (1985)	18 ± 2	11 ± 2	NA
Mochizuchi et al. ¹⁹ (2006)	15 ^a	4.7 ± 0.6	NA
Ferreti et al. ¹⁵ (2007)	17.2 ± 1.2	9.9 ± 0.8	196.8 ± 23.1
Siebold et al. ¹⁶ (2008)	15 ± 3	8 ± 2	83 ± 19
Iwahashi et al. ²⁰ (2010)	17.4 ± 0.9	8.0 ± 0.5	128.3 ± 10.5
Sasaki et al. ¹⁰ (2012)	17.7 ± 2.7	4.6 ± 0.7	NA
Smigielski et al. ¹³ (2014)	16.0 (12.7–18.1)	3.54 (2.0–4.8)	NA
Present study	16.49 ± 2.12	9.62 ± 0.93	99.77 ± 11.33

Source: File provided by the institution.
 NA, not assessed.
^a Sum of the anteromedial and posterolateral bundles.

In other words, the smallest ACL femoral insertion length was 58.5% of that of the largest length observed; the largest thickness observed was 43% higher than the lowest thickness, and the smallest area of ACL insertion corresponded to 69% of the highest area.

In all samples, a space was observed between the boundaries of the ligaments and the articular cartilage. The mean distances DSC, DDC, and DIC in mm, their minimum and maximum limits and SD were, respectively: 9.77 (8.10–12.0; SD ± 1.21); 2.60 (0.73–4.29; SD ± 1.20); and 1.86 (0.27–3.93; SD ± 1.15).

No significant correlations were observed in the analysis of the quantitative variables studied.

Discussion

The main findings of the present study were that the ACL femoral insertion site presented individual characteristics in relation to its shape, measurements, and area. In addition, this site was always eccentric, i.e., located closer to the deep articular cartilage than to the superficial cartilage of the LFC.

In the present study, a 30% to 40% variation was observed between the minimum and maximum results of measurements of the length, thickness, and area of the ACL femoral insertions, which requires the identification of the particular aspects of each patient when planning a ligament reconstruction procedure. Moreover, perfect knowledge of the location of the ACL femoral insertion may aid in the positioning of the femoral tunnel in the anatomical reconstruction of this ligament.

In macroscopic analysis, only one bundle was visualized in all the ligaments of the anatomical specimens studied. Similarly to the present study, other authors have reported that the ACL has only one bundle.^{12,13} Smigielski et al.¹³ believe that the “double-bundle effect” is created by the twisted-tape structure of the ACL from the femur to the tibia, which gives the impression of two or three bundles as the knee is flexed.

In turn, some authors have reported that the ACL does have two bundles, one anteromedial and one posterolateral,^{14–17} and Amis and Dawkins¹⁸ even refer to the existence of a third bundle, the intermediate one. However, these authors used a dissector to separate the fibers and reported that it was sometimes difficult to separate the ligament into distinct bundles.

In the present study, in order to demarcate the femoral insertions of the ACL, the authors sought to cautiously remove peripheral fibrous expansions. Using this same methodology, Mochizuki et al.¹⁹ identified the functional nucleus of the femoral insertion site of the ACL. Subsequently, Iwahashi et al.,²⁰ through histological examination, began to refer to this nucleus as the direct insertion of the ACL. From another perspective, Sasaki et al.¹⁰ reported that the macroscopically observed ACL femoral insertion corresponds to the direct insertion observed under the microscope.

The shape of most of the femoral ACL insertions of the knees evaluated in the present study was oval, which is in accordance with the findings by Sasaki et al.¹⁰ However, for Harner et al.,²¹ these insertions would be circular; in contrast, Giron et al.,⁴ and Girgis et al.,¹⁷ described the insertions as a segment of a circle: the posterior region was convex and the anterior, straight. Mochizuki et al.¹⁹ reported that, after removal of the superficial fibromembranous tissue, the ACL femoral insertion is not oval, but flattened resembling lasagna.

Table 2 presents a comparison of the present results of length, thickness, and area with others found in the literature. It was observed that the results of the different authors, when compared among themselves and with the present results, did not show great discrepancy. The only exception was the insertion area, which would be much larger according to Ferreti et al.¹⁵ Iwahashi et al.²⁰ believe that this disparity may have occurred because of a possible inclusion of soft tissue, since that study was performed using a 3D laser digitizer.

The macroscopic visualization indicated that the location of the ACL insertion is eccentric, closer to the deep articular cartilage than to the superficial.

The positioning of the ACL femoral insertion observed in the present study was in agreement with what has been published by other authors, for whom the direct insertion of the ACL in the femur is located 4.4 ± 0.5 mm from the posterior limit of the articular cartilage and an average of 22.3% from the distance between the anterior and posterior edges of this cartilage.¹⁰ These authors used the radiographic terminology to define the ACL insertion, which changes if the knee is in flexion or extension.²²

The present study has some limitations. Firstly, the number of knees studied may be considered small; secondly, the sample consisted of specimens originating from amputations of patients whose mean age was high. However, the absence of osteophytes in the medial region of the LFC did

not interfere with the measurements performed. A third limitation is that the measurements were made by only one researcher. Nonetheless, the intraobserver agreement was considered strong. Finally, no microscopic observations of the ACL insertions were made. However, as already reported, Sasaki et al.¹⁰ believe that the microscopic observation of the ACL is equivalent to the direct insertion seen macroscopically.

As clinical relevance, this study suggests that there is an individual variation in the morphology of the ACL femoral insertion that may influence the choice of which graft to be used in the surgical treatment of ligament lesions, when it is intended to reproduce the natural ACL insertion as closely as possible for each patient. As a perfect visualization of the remaining ligament is not always possible, knowledge of the insertion site is important to assist the correct site for femoral tunnel perforation in anatomical ACL reconstructions.

Conclusion

There is an individual diversity in the length, thickness, area, and shape of the ACL femoral insertion. The insertion sites were eccentrically located, closer to the deep articular cartilage of the LFC.

Conflicts of interest

The authors declare no conflicts of interest.

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