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The proximal posterior cartilage of the lateral femoral condyle can be used as a reference for positioning the femoral tunnel in ACL reconstruction

Ricardo de Paula Leite Cury[1] · Leandro Jun Aihara[1] · Victor Marques de Oliveira[1] · Felipe Monteiro Uerlings[2] · Victor Picchi Zaccharias[2] · Luiz Gabriel Betoni Guglielmetti[1]

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Abstract

Purpose To describe the femoral insertion of the ACL using the posterior proximal cartilage of the lateral femoral condyle as the anatomical reference.

Methods Twenty knees were dissected. The X-axis (deep-shallow) and Y-axis (high-low) were determined using the femoral diaphysis and the proximal cartilage of the lateral femoral condyle (point C) as a reference, which were easily identified by direct visualization through the anteromedial portal. The distances to the center of the anteromedial and posterolateral bands and to the center of the ACL were measured.

Results The mean distances were 7.2 mm (SD: 0.7) between the center of the anteromedial bundle and the Y-axis (AM-Y), 9 mm (SD: 1.1) between the center of the ACL and the Y-axis (M-Y), and 12.7 mm (SD: 0.9) between the center of the posterolateral bundle and the Y-axis (PL-Y). Regarding the distance (from point C to the distal cartilage along the X-axis), the center of the anteromedial bundle (AM) was 35% (SD: 4.9%), the center of the posterolateral bundle was 62% (SD: 3.7%), and the center of the ACL (M) was 44% (SD: 7%) of the CD distance on average.

Conclusion Given the similarity among the specimens in terms of the height of the ACL on the Y-axis in relation to the proximal posterior cartilage of the femoral lateral condyle (point C), this point can be used as an arthroscopic intraoperative parameter to define the position of the femoral tunnel in ACL reconstruction for single- or double-bundle techniques.

Keywords Cadaver · Dissection · Knee · Anterior cruciate ligament · Anatomy

Introduction

The anatomy of the anterior cruciate ligament (ACL) has been studied for more than a century [15]. Nonetheless, it is still subject to debate regarding issues, such as the presence or absence of two bundles [10], the ribbon-like appearance of the two bundles when flexing the knee [25], the presence of direct and indirect fibers with different functions [17] and the different functions of the bundles or anteromedial and posterolateral regions [16, 21]. Nevertheless, biomechanical studies indicate that the anteromedial region or bundle is the main element related to knee stabilization [11, 16], and there are also studies showing that direct fibers are more important than indirect fibers [13, 25, 27].

Due to the anatomical and functional controversies pertaining to the ACL, there are also controversies regarding where the center of the femoral tunnel should be positioned for reconstruction with either a single bundle or a double-bundle [22, 29]. Some recent studies indicate that reconstruction with the tunnel in the center of the anteromedial bundle is ideal [3, 4], but many surgeons prefer the central position (in the middle of the native ACL) [21, 30], and others argue for intermediate positioning between the central position and the position in the center of the anteromedial bundle [18].

✉ Ricardo de Paula Leite Cury
rcury1@me.com

[1] Knee Surgery Group, Department of Orthopedics and Traumatology, School of Medical Sciences, Faculdade de Ciências Médicasda Santa Casa de Misericórdiade SãoPaulo, R. Dr. CesárioMotaJúnior, 61, Vila Buarque, SãoPaulo 01221-020, Brazil

[2] Department of Orthopedics and Traumatology, School of Medical Sciences, Santa Casa of São Paulo, Sao Paulo, SP, Brazil

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Another difficulty is intraoperatively determining the exact location of these points (the center of the ACL and the center of the anteromedial and posterolateral bundles). Some parameters can be used, such as arthroscopic visual parameters (the lateral femoral intercondylar crest, bifurcated wall, distal joint margin, posterior intercondylar sulcus, and anterior horn of the lateral meniscus) [7, 24] or radiographic parameters, such as the quadrants of Bernard et al. [2]. Another little-used parameter is the relationship between the posterior proximal cartilage of the lateral femoral condyle and the ACL in both the anteroposterior and distal proximal planes [9, 14, 23].

The aim of this study was to evaluate the relationship of the proximal and posterior limits of the lateral femoral condyle cartilage with the femoral origin of the ACL in cadaveric specimens to determine the possibility of using this relationship as an intraoperative anatomical parameter to guide the positioning of the femoral tunnel. It was hypothesized that the position of the ACL in relation to the proximal posterior cartilage of the femoral lateral condyle is similar among specimens and that this point can be used as an arthroscopic intraoperative parameter.

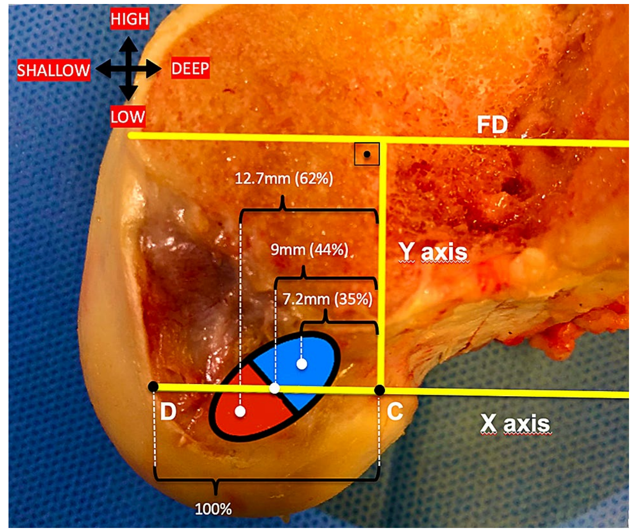

Fig. 1 Mean values obtained from the measurements of the center of the anteromedial band of the ACL (12.7 mm), the center of the ACL (9 mm) and the center of the posterolateral band (7.2 mm) relative to the Y-axis. Percentage of measurements of the center of the anteromedial band of the ACL (35%), the center of the ACL (44%) and the center of the posterolateral band (62%) to the Y-axis relative to the CD distance. *FD* axis of the femoral diaphysis, *C* most proximal and posterior point of the cartilage of the lateral femoral condyle, *D* point at which the X-axis intercepts the cartilage of the lateral femoral condyle

Materials and methods

The study was approved by the institution's Research Ethics Committee (43,878,621.5.0000.5479, Santa Casa de São Paulo Hospital). Knees with signs of trauma, previous surgery or macroscopic signs of arthrosis were excluded. Twenty knees were studied. The knees were stored in a 10% formaldehyde solution and refrigerated at 5.3 °C. The dissections were performed 2–21 days after amputation [19]. All specimens were identified according to sex, age, dissected side, date of amputation and date of dissection.

The anatomical points for performing the measurements were marked with metal pins. As represented in Fig. 1, the axis of the femoral diaphysis (FD) was first determined, and a parallel line was drawn passing through the most proximal portion of the cartilage of the lateral femoral condyle (point C), generating the X-axis (deep-shallow). A line was plotted perpendicular to this X-axis that passed through point C, creating the Y-axis (low/high). Once these parameters (the X-axis, Y-axis, and point C) were created, the centers of the anteromedial bundle (AM), posterolateral bundle (PL) and ACL (M) were identified.

To define the AM, PL, and M points, the ligament was dissected by removing the entire synovium covering the ligament, and the bundles were visually identified. At this time, the ACL was resected, the bifurcated ridge was used as an arbitrary reference for separation into bundles, and the area occupied by each bundle and by the ACL as a whole was drawn with a pen. The longest axes of each bundle and of the entire ACL were measured, the axis perpendicular to the longest axis was defined, and the centers of each bundle and the ACL were defined at the midpoint of these axes. The following distances were then measured: AM-X, PL-X, M-X, AM-Y, PL-Y and M-Y. Negative values indicate that the center of the AM, PL, or M was below point C on the Y-axis.

For ease in describing and orienting the ACL regions, knee visualization was standardized in the 90-degree flexion position, with the anterior region of the knee given the anatomical nomenclature of high, the posterior region designated as low, the distal portion designated as shallow, and the proximal portion designated as deep, as shown in Figs. 1 and 2. The distances from the center of the anteromedial and posterolateral bundles and center of the ACL to the Y-axis (AM-Y, PL-Y and M-Y) were also evaluated as a percentage of the CD distance, i.e., the distance from point C to the distal cartilage (point D) through the X-axis, as represented in Fig. 1, to determine the percentages referred to as %AM/CD, %PL/CD and %M/CD.

The specimens were photographed using a 12 megapixel digital camera. To maximize accuracy, each measurement was performed three times by a single surgeon at a single time with a digital caliper with 0.01-mm precision (Mitutoyo™). For statistical analysis, the mean of the three measurements of each variable was considered.

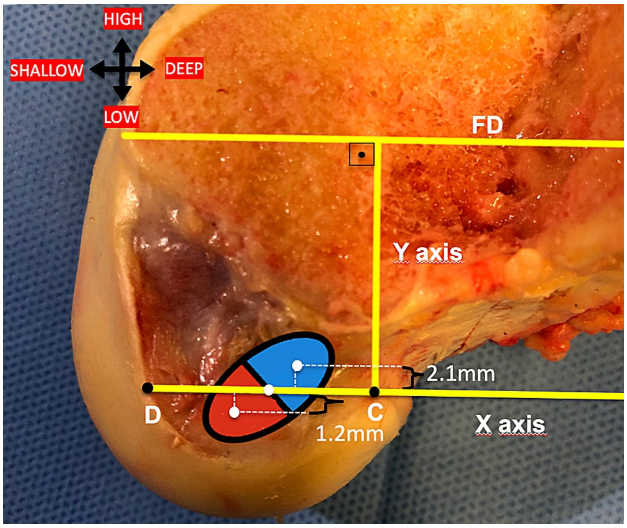

Fig. 2 Mean values obtained from the measurements of the center of the anteromedial band of the ACL (2.1 mm) and the center of the posterolateral band (1.2 mm) relative to the X-axis. Note that the center of the ACL remained at the level of the X-axis (mean of 0.3 mm). *FD* axis of the femoral diaphysis, *C* most proximal and posterior point of the cartilage of the lateral femoral condyle, *D* point at which the X-axis intercepts the cartilage of the lateral femoral condyle

Table 1 Descriptive statistics and variability measures (*N* 20)

	Mean (SD)	CV	Min	Max	CI
AM-Y	7.17 (0.66)	9%	6.10	8.60	0.29
PL-Y	12.65 (0.94)	7%	10.50	14.60	0.41
M-Y	9.03 (1.11)	12%	7.30	10.98	0.48
AM/CD%	35.2% (4.9%)	14,0%	29.5%	47.8%	2.2%
PL/CD%	61.7% (3.7%)	6,0%	54.1%	67.4%	1.6%
M/CD%	44.2% (7.0%)	15,8%	33.8%	57.2%	3.1%
AM-X	2.14 (0.53)	25%	0.90	3.15	0.23
PL-X	(–) 1.25 (0.81)	65%	– 3.00	0.00	0.35
M-X	0.32 (0.45)	140%	0.00	1.20	0.20
CD	20.56 (1.65)	8%	17.30	23.80	0.72

AM-Y distance from the anteromedial bundle to the low/high axis, *%AM/CD* percentage of the anteromedial bundle distance relative to the CD distance, *PL-Y* distance from the posterolateral bundle to the low/high axis, *%PL/CD* percentage of the distance from the posterolateral bundle relative to the CD distance, *M-Y* distance from the center of the anterior cruciate ligament to the low/high axis, *%M/DC* percentage of distance from the center of the anterior cruciate ligament relative to the CD distance, *AM-X* distance from the anteromedial bundle to the deep/shallow axis, *PL-X* distance from the posterolateral bundle to the deep/shallow axis, *M-X* distance from the center of the cruciate ligament anterior to the deep/shallow axis, *SD* standard deviation, *CV* coefficient of variation, *CI* confidence interval

Statistical analysis

To obtain the sample number, sample calculation was made, based on the variability of data of a previous pilot study with seven knees. The statistical and nominal errors were taken into consideration for the calculus, and standard deviation of all variables of the pilot sample was determined. Assuming a statistical error of 5% and an error of 45% of the standard deviation (nominal error), the final sample number obtained was of 19 knees.

Between June and December 2019, 26 knees from transfemoral amputations performed exclusively for vascular complications were dissected. Knees with signs of trauma, previous surgery or macroscopic signs of arthritis were discarded, therefore, 20 knees were included in this study which is consistent with previous studies [16, 19].

The data collected were analyzed and interpreted using descriptive statistics, and variability measures, such as standard variation (SV), confidence interval (CI) and coefficient of variation (CV), were used to determine the consistency of these measures between the examined knees.

Results

Twenty knees (13 right knees and seven left knees) were dissected; 12 were from males, and eight were from females, and the donors had a mean age of 64 years (ranging from 48 to 76 years). In all the specimens, the ACL was identified as a ribbon-like structure with insertion posterior to the intercondylar crest. The measured distances (AM-Y, PL-Y, M-Y, AM-X, PL-X and M-X) and the statistical analysis are shown in Table 1 and illustrated in Fig. 1.

The distance between the Y-axis and the center of the anteromedial bundle (AM-Y) had a mean value of 7.2 mm and ranged between 6.1 mm and 8.6 mm; the distance between the Y-axis and the center of the PL bundle (PL-Y) had a mean value of 12.7 mm and ranged between 10.5 mm and 14.6 mm; and the distance between the Y-axis and the center of the ACL (M-Y) had a mean value of 9 mm and varied between 7.3 mm and 11 mm.

The distance between the X-axis and the center of the anteromedial bundle (AM-X) had a mean value of 2.1 mm and ranged between 3.2 mm and 0.9 mm; the distance between the X-axis and the center of the posterolateral bundle (PL-X) had a mean value of -1.2 mm and varied between 0 mm and -3 mm; and the distance between the X-axis and the center of the ACL (M-X) was 0.3 mm and varied between 0 mm and 1.2 mm. Therefore, the AM bundle was above point C, the PL bundle was at or below point C, and the center of the ACL (M) was at or slightly above the level of point C in all cases and was at the same level as point C in 11 of the 20 cases (55%). The other measures of variability are shown in Table 1.

The CD distance presented low variability, with a mean of 20.6 ± 0.7, ranging from 19.8 to 21.3, showing homogeneous knees in relation to the CD distance measurement. When the percentages of the AM-Y, PL-Y, and M-Y distances were evaluated in relation to the CD distance (the distance from point C to the distal cartilage through the X-axis), as represented by Fig. 1, the center of the AM was an average of 35% of the CD distance, with a range of 29 to 48%; the center of the PL was an average of 62%, with a range of 54 to 67%; and the center of the ACL (M) was an average of 44%, with a range of 34 to 57%.

In terms of variability measures, the AM-Y, PL-Y and M-Y distances showed higher CIs than the AM-X, PL-X and M-X distances, indicating less variation in the distances (AM-X, PL-X and M-X). The lowest variation was the M-X distance (CI: 0.20), followed by the AM-X distance (CI: 0.23).

Discussion

The most important finding of this study is the proximity of the center of the ACL (position M) to the level of point C on the Y-axis. In all knees, position M was at or above point C on the Y-axis, with the mean position being 0.3 mm above the level of point C, i.e., very close to the level of point C. In no case was position M below the level of point C, and the maximum distance above the level of point C was 1.2 mm, with an SD of 0.5 and a CI of 0.2 (the lowest). This finding indicates that positioning the femoral tunnel at or slightly above point C (up to 1.2 mm, which would correspond to an icepick tip) would create a tunnel in a position that respects the anatomy of the knees along the Y-axis. The AM position in the Y-axis also presented a low CI (0.2), indicating low variability of these positions.

The second interesting analysis is related to the X-axis through the percentage of the CD distance occupied by the M-Y distance. In the present study, a mean of 44% was found. Other studies have indicated the use of this percentage as an intraoperative parameter. Oh et al. [22] showed in a systematic review that the center of the ACL was at 43%, and Xu et al. [29] reported that the center was at 50% on the same axis. However, in the present study, this percentage varied from 34 to 57%: in six cases (30%), it was located between 30 and 40% of the CD distance; in 10 cases (50%), it was located between 40 and 50%; and in four cases (20%), it was located between 50 and 60%. Therefore, using the mean value of 44% as a parameter would position many tunnels outside the real center of the ACL. Considering this, the authors propose that the M-Y distance and the percentage of the CD distance (%M/CD) should be used with great caution and as secondary parameters during the arthroscopic procedure.

Although there is no consensus on the ideal point for perforation of the femoral tunnel, the central region of the ACL, the center of the AM bundle or the region between these two sites is likely to be a mechanically efficient site [18, 23, 26]. The present study did not aim to determine the best site for the tunnel but rather to evaluate the relationship of point C (the most proximal and posterior point of the lateral femoral condyle cartilage) with the femoral origin of the ACL, since determining the ideal point for the tunnel requires another study design that would biomechanically compare knees in different positions, which is extremely difficult. During the arthroscopic procedure, point C is easily identified (Fig. 3), and if a similar relationship between this point and the position of the ACL was identified in different individuals, we could use this ratio as an intraoperative parameter to define the center of the femoral tunnel during ACL reconstruction.

In contrast, the level of the center of the tunnel on the Y-axis relative to point C was more reliable due to the similarity of the results among cases; the identification of this parameter represents the most important finding of the present study. Some surgeons place the femoral tunnel in

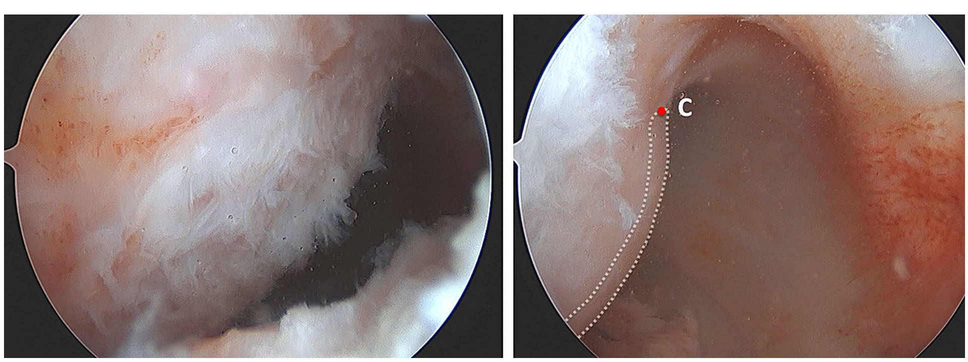

Fig. 3 Left image: arthroscopic view of the ACL footprint seen through the anteromedial portal [note that the limit of the posterior and proximal cartilage of the lateral femoral condyle is not observed (point C)]. Right image: Point C (shown in red) can also be observed through the anteromedial portal, with the arthroscope positioned more posteriorly. The white dotted line represents the limits of the cartilage of the lateral femoral condyle

the anteromedial region, as some studies report excellent results with this positioning [5, 6, 20]. In no case was the AM position below point C on the Y-axis, and the mean distance between the center of the anteromedial bundle and the X-axis (AM-X) was 2.1 mm, ranging between 3.2 mm and 0.9 mm (CI 0.2). The results obtained in the present study can also help when selecting the positioning of the tunnels in this place (AM) and even for surgeons performing double-bundle reconstruction using the PL measures obtained.

The anatomical positioning of the femoral tunnel using the remaining ACL as a reference is an interesting method in cases of acute injury and preserved anatomy, as some studies have shown [28]. In cases where there is no remaining ligament, it is important to use anatomical parameters with methods or references for the correct positioning of the femoral tunnel, such as the clockface method, bone references and radiographic parameters, as developed by Bernard and Hertel [2]. The intraoperative use of the most proximal and posterior portion of the cartilage of the lateral femoral condyle as a reference has been previously described, and some studies [8, 12] have reported that the insertion of the ACL is separate from the posterior cartilage, but others have reported that the insertion is continuous with or close to the posterior cartilage [16, 22, 29]. Despite this controversy, in this study, during dissection, we observed the existence of periligamentous synovial tissue that after being removed, showed the insertion of the ACL as a distinct structure that was noncontiguous with the posterior cartilage.

The parameters presented in the present study should be used in association with parameters previously used by knee surgeons. Point C in relation to the Y-axis provides an additional parameter that can aid the selection of a good location for tunnel perforation, which is important because misalignment of this tunnel is the major cause of ACL reconstruction failure [1, 4]. Point C is an anatomical landmark that is easy to visualize and is present in all knees; thus, it can be used as a reference during surgery for positioning the femoral tunnel.

Even though sample size calculation was performed, the small sample size of 20 knees can be considered a limitation to the present study. Another limitation is the mean age of the cadaveric specimens (64 years), as it is possible that with younger knees, the identification of the ACL anatomy would be different; however, this is a very common limitation in anatomical studies with cadavers.

Conclusion

Due to the similarity among specimens in the height of the ACL on the Y-axis in relation to the proximal posterior cartilage of the femoral lateral condyle (point C), this point can be used as an arthroscopic intraoperative parameter to define the position of the femoral tunnel in ACL reconstruction for single- or double-bundle techniques.

Authors' contributions LGBG, LJA and RPLC have made substantial contributions to conception and design, FMU and VPZ have made acquisition of data and LGBG, VMO and RPLC have made analysis and interpretation of data. LGBG, LJA have been involved in drafting the manuscript and RPLC and VMO have been involved in revising it critically for important intellectual content. RPLC have given final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Declarations

Conflict of interest The authors above declare that they have no conflict of interest.

Ethical approval The study protocol for obtaining, use and disposal of human tissue specimens received approval, permit number CAAE 08884712.8.0000.5479.

Informed consent All patients provided written informed consent prior to participation.

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