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THE DISCIPLINE OF ORTHOPEDICS AND TRAUMATOLOGY

Anatomical correlations between the anterior cruciate ligament and neighboring structures: the intercondylar notch and the posterior cruciate ligament

SUMMARY OF THE DOCTORAL THESIS

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Content

Anterior cruciate ligament (ACL) reconstruction has greatly evolved over the past 3 decades. This is largely due to a better understanding of the anatomy of the ACL, as well as complex description of the insertion points, femoral and tibial, of the two fascicles that it is formed of, the anteromedial (AM) and the posterolateral (PL). Around 1950-1960, the diagnosis of anterior cruciate ligament tear was more difficult to observe, because of the shortcomings of the existing clinical tests at that time. With the introduction of other parameters in the diagnosis of ACL tears, doctors were able to make a more detailed clinical diagnosis, which subsequently helped in improving surgical techniques.

The main hypothesis based on which the current research started was to establish the relationships between the two cruciate ligaments of the knee, anterior and posterior, and the anatomy of the intercondylar notch, and to see to what extent these relationships can impact surgical treatment, so that graft failure rate is reduced. Optimizing the size of the graft is mostly based on the anatomy of the ACL and the intercondylar notch, and whether the parameters of the intercondylar fossa can be accurately measured. In this way, surgical difficulties can be anticipated, such as when dealing with large grafts [1] thus avoiding a notchplasty.

The key structure of the knee, the anterior cruciate ligament (ACL) connects the femur joint to the tibial joint. Consisting of a band of connective tissue, it provides stability against anterior tibial translation and internal rotation. Talking about its origins, in the tibial part, anteriorly, it is between the intercondylar eminences, and in the posterior part it is attached to the posteromedial portion of the lateral femoral condyle [2-5].

The anatomy of ACL has been intensively studied in recent years, research focusing on the differences between specific groups of patients, the structure, the number of fascicles, but also the macroscopic or microscopic characteristics. A notable difference in ACL morphology is that between genders: the cross-sectional area of the ACL in women is approximately 30% smaller than in men. Women has also a smaller width of the femoral notch [6].

The two fascicles in the ACL structure have different roles in anterior-posterior stabilization and the rotational complex [2], also have a different isometry. When the knee is extended, the PM bundle is tense while the AL bundle is relaxed. When the knee is flexed,

the two beams will reverse their function [7] and at 110 degrees of flexion, they are no longer parallel [3]. Another difference between the two bundles is their length when the knee is in full extension, with the AM bundle longer than the PL measuring 22.5 mm [8].

Dupthon et al., support the hypothesis that the bony attachment of the ACL is located at the posterior part of the inner surface of the lateral femoral condyle and not at the roof of the intercondylar notch, as was sometimes stated [3]. An important aspect that the authors draw attention to is that the ACL occupies superior lateral aspect of the notch when the flexed knee joint is viewed anteriorly, with the bone attachment size varying from 11 to 24 mm [3].

The ACL plays a crucial role in stabilizing the knee joint and together with the posterior cruciate ligament PCL provides stabilisation to the back and front of the knee. Acting as a primary stabilising element, the ACL prevents the tibia from moving away from the femur, while also being a secondary stabilizer against external rotation of the tibia and valgus angulation of the knee, especially in obese or overweight patients [3].

ACL rupture occurs when the ligament is overstretched or disrupted and can be classified as mild or severe and can be divided into contact and non-contact injury. Among them, non-contact injuries are the most common [9]. The incidence of ACL lesions varies according to the population studied; in athletes the risk can be 0.062 injuries per 1000 exposures [10] and in adolescents it can be 2.98 knee injuries per 10,000 athletic exposures, globally [11].

Among the factors that contribute to the incidence of ACL injuries are gender, age, but also the type of sport practiced. Analysis of these factors shows that women are more likely to develop an ACL rupture than men, with a 1.5 times higher risk in female athletes than in male athletes [12]. In the age group, the incidence among young people has increased considerably in recent years, with a review in Nordic countries showing that out of 10,000 athletes, 76 girls and 47 boys underwent ACL reconstruction surgery, annually [13].

Depending on the type of severity, ACL lesions are classified by degrees. We thus have injuries of:

• grade I- where there is no tear, the fibres are stretched,

• grade II- the ligament is partially torn,
• grade III- the ligament is completely torn [14].

ACL injury often occurs in association with trauma to nearby structures, such as meniscal tears or cartilage injuries [15-19]. The most common mechanism of injury to the ACL is a non-contact valgus trauma combined with internal rotation of the knee [20]. Their correlation and potential clinical significance may impact how the ACL lesion is managed, therefore early and comprehensive diagnosis is required.

The incidence of other injuries associated with ACL injury varies depending on the structure injured. Various studies show a correlation between medial meniscus tear and ACL injury in up to 54% of cases [2, 21, 22]. Another concomitant injury is medial collateral ligament injury. The incidence of medial collateral ligament rupture has been reported to be between 20% and 38% of all ACL injuries [23].

Frequently encountered in sports, the ACL injury affects young and active people, with women having a higher risk than men [13, 24, 25]. Its impact is quite large on patients and society and can have devastating consequences on the patient's daily activity and quality of life [18, 26]. Also, the risk of developing long-term knee osteoarthritis is significantly higher, leading to long-term functional impotence, especially in young athletes [27-30].

In the last decade, several studies have tried to demonstrate the risk factors for ACL injury, these being divided into intrinsic and extrinsic risk factors. These risk factors most likely act in combination to influence the risk of ACL injury [31].

An important anatomical risk factor associated with ACL lesion is the notch width index (NWI), and for ACL lesions associated with NWI the risk factors are stenotic and narrower notch [32-35].

As for the potential mechanism of ACL lesions, it is likely multifactorial, with multiple studies attempting to explain the underlying mechanisms of ACL lesions, and the factors presented being both modifiable and non-modifiable. ACL lesions are contact (30%) and non-contact (70%) [36]. Non-contact ACL injury resulting during sudden deceleration [37] or from the impact of loading force on the ACL.

Made up of 3 bones, the knee it's a hinge type joint, with the ACL being one of its main stabilizers. The ACL is attached to the lateral condyle of the femur and the intercondylar eminence of the tibia [38]. The intercondylar fossa also known as the intercondylar notch is a deep open space found between the medial and lateral condyle of the femur and houses the important knee ligaments ACL and PCL.

The intercondylar fossa is a non-articular part of the knee and has a roof and a floor, its roof can be estimated radiographically as the Blumensaat line, while the floor is formed by the intercondylar area of the tibial plateau and contains the insertions of the cruciate ligaments [30]. According to radiographic studies, the intercondylar fossa is subject to changes throughout life, narrowing distally and widening proximally. Also, the form undergoes changes throughout life. In the early stage of life, it is A-shaped and then in later stages, it is Ω-shaped [40] the morphology of the femoral condyle, the place of origin of the ACL, having an important role in the reconstruction of the ACL.

Considering the numerous structures found in the notch, changes in the intercondylar fossa could influence the health of these structures, especially the ACL, their morphology being influenced. What we know is that women have a smaller notch than men [41-43] but also a smaller femoral volume [44]. Pathological factors, such as arthrosis, modifying the intercondylar fossa, influencing the structures inside [45, 46].

It is well known that the intercondylar fossa plays an important role in the biomechanics of knee injuries, containing the most important knee ligaments responsible for maintaining stability. The space available for these ligaments is determined by the dimensions of the fossa, including depth, width, and shape [47]. The literature has identified three main notch shape categories: A-, U-, and W-shaped [48-50]. A more recent study by Hirtler et al., introduced an A-shaped, inverted U-shaped and Ω-shaped notch classification [40].

A fossa form is defined as a shape that has narrowed from the base to the midsection to the apex by visual inspection [47]. In a clinical cohort study that assessed fossa shape using a Kappa coefficient, it found that "A-shaped" fossae were narrower at the base, middle, and apex than "U-shaped" fossae, this being important information in prevention and in surgical technique [48].

The shape of the intercondylar fossa undergoes changes throughout life [40] being also the case in patients suffering from comorbidities such as osteoarthritis, with studies showing that the shape of the fossa is significantly different in patients with osteoarthritis than in the control group [51]. A narrower femoral notch is also associated with ACL lesions [52] with type A (60%) and B (40%) fossae being present in patients with ACL lesions compared to 45% of controls (fossa type A), 45% (type B) and 10% type C [52].

Notch wide index (NWI) is part of the geometry of the intercondylar fossa and was presented by Souryal et al. as a predisposing factor for bilateral ACL tears. The NWI is used to measure and compare the width of the intercondylar fossa using "tunnel view" radiographs [8] and is defined as the ratio of the width of the intercondylar fossa at the level of the popliteal groove divided by the bicondylar width at the same level, measured on a "notch view" radiograph with the knee in flexion from 45°. A minus of this formula is that it does not take body weight into account.

Another morphometric parameter of the intercondylar fossa is the notch shape index (NSI) and the notch area index (NAI), the NSI being determined by dividing the width of the intercondylar notch by the notch height, and the NAI by dividing the notch area intercondylar to the area of the condyles [53]. The correlation between the geometry of the intercondylar notch, such as the dimensions of the intercondylar notch and the ACL lesion, has been extensively studied in the last two to three decades [54, 55] however we can speculate that more information is needed regarding geometry of the intercondylar fossa to standardize ACL surgery.

The second cruciate ligament that makes up the knee joint is the posterior cruciate ligament (PCL) and apart from the relationship with the ACL, it also has relationships with the menisci and other ligaments, therefore requiring the clinician to have a good knowledge and understanding of its anatomy complex to be able to evaluate PCL lesions [56].

It consists of two fibrous bundles, AL and PM, having as the femoral insertion point the lateral aspect of the medial condyle and the posterior aspect of the tibial plateau, approximately 1 cm distal to the joint line [57] The AL bundle tenses when the knee is in flexion and it relaxes in extension, and the PM bundle tenses when the knee is in extension and relaxes in flexion [58].

Studies carried out as part of doctoral research

During the doctoral research, 3 studies were carried out:

The **first study** analysed the geometry of the anterior intercondylar notch in relation to the size of the native anterior cruciate ligament, highlighting the fact that the shape of the notch was associated with internal and external meniscus injuries, but also that the cross-sectional area of the anterior cruciate ligament was strongly correlated with the area of the antero-superior notch when the shape of the notch is type A or W.

The **second study** analysed the area of the anterior-superior notch for the 3 geometric types, an individualised approach to the choice of graft size in ACL reconstruction and concluded that the area of the anterior intercondylar fossa varies significantly for each notch type, does not correlate with height, aspect which should be considered in choosing the graft.

The **third study** studied the balance of the anterior and posterior cruciate ligaments in adults, and the findings showed that the correlation between ACL and PCL helps to understand the balance of the central pivot of the knee.

The study is a retrospective, cross-sectional research conducted in a single centre, on a group of 63 participants, of whom 31 were women and 32 were men. In total the 63 study participants had 65 MRI examinations (two male participants having bilateral knee MRI), individuals who had not undergone knee MRI examination in our department, the duration being 4 years, starting from September 2019 and until September 2022. The patients who took part in the study signed the informed consent. All stages being carried out in accordance with the best practice guidelines of the Declaration of Helsinki. The Ethics Committee of the Hospital approved the research (no. 404 / 17.09.2020).

After reviewing each medical record, we included in a sequential manner all adult participants, over 18 years of age, who reported non-contact knee discomfort. Exclusion criteria that were used:

• a history of trauma;
• a history of previous surgery
• history of fracture in the knee region

• age greater than 50 years at the time of assessment
• the presence of morphological anomalies such as arthrosis;
• the length of the femur and tibia was less than 5 cm;

Nominal qualitative variables were presented as percentages, count (%), while continuous variables were presented as median with standard deviation in the case of normal distributions and median with range (min – max) for those with abnormal distributions. For a bivariate analysis Spearman's rho coefficient for continuous variable was used to identify associations such as that between the intercondylar notch and the ACL area. Spearman's rho test is a non-parametric test that compares relationships between two variables

Also, the Mann-Whitney test was used to compare two subgroups of a dichotomous variable. When more than two subgroups were analyzed, a Kruskal Wallis test with post hoc ANOVA analysis was performed (eg, notch shape: A, W, or U shape). In all tests, p values less than 0.05 were considered statistically significant. IBM SPSS Statistics software, version 25.0 for Windows (Armonk, NY, IBM Corp.) was used.

MRI examinations were performed by two 1.5-T machines with similar protocols, both creating 3-mm sections of the knee obtained in the standard orthogonal three-axis technique (axial, coronal, and sagittal) with a combination of fluid-sensitive sequences, either T2 weighted (T2W) non-fat-saturated (NFS) or proton density weighted (PDW), and T1 weighted (T1W) NFS sequences. PD weighted sequences with and without fat saturation are usually the basis. The examination sometimes included the T2 NFS sequence as a substitute for the PD fat-saturated (FS) sequence in the axial plane.

For our study, we mainly used real axial T2W NFS or PDW FS images, using post-processing tools to create two custom planes by applying references from the sagittal and coronal planes.

1. The first customized plane is oriented along the ACL axis (slightly angled to the intercondylar roof of Blumensaat's line) in the sagittal plane and along a line parallel to the posterior femoral intercondylar line in the coronal plane. As a result, the plane is perpendicular to the ACL axis and parallel to the posterior intercondylar line.

2. The second customized plane is oriented along the ACL axis in the first 2 thirds in the sagittal plane and along a line parallel to the inter-epicondylar axis in the coronal plane. As a result, the plane is perpendicular to the PCL axis and parallel to the inter-epicondylar line.

The processed images were analysed by two physicians: an orthopaedic surgeon and a radiologist, and following the assessment and measurement of the aspects of the ACL and the intercondylar notch, the intercondylar notch was assigned to one of three categories:

- A-shaped
- U-shaped
- W-shaped

We then proceeded to measure the maximum width of the notch and its surface area. Area measurement was made by drawing an inscribed circle of cortical bone on 3 out of 4 sides (anterosuperior, left and right). The area of the two ligaments in the plane was measured by marking its outline with the closed polygon tool in the DICOM viewer. When possible, the area of the ACL was measured in the same section as the circle; if this was not possible, it was measured on a different section at a maximum of 3 sections difference (cranial or caudal).

The other sequences were used to observe and quantify associated knee injuries, with the following associated injuries counted:

- internal, external or patellar chondropathy,
- ruptures of the internal or external meniscus,
- patella alta and trochlear dysplasia.

Study Summary 1: *Geometry of the anterior intercondylar notch in relation to the size of the native anterior cruciate ligament.*

One of the proposed risk factors for non-contact ACL injuries is the morphometric anatomy of the knee, characterized mainly by the appearance of the anterior cruciate ligament (ACL) and the intercondylar notch (ICN) [62] Meniscal injuries, which are one of

the most common worldwide orthopedic problems, are in a close relationship in the physiological morphometry of the knee [63].

The aim of this study was to evaluate the associations between the cross-sectional area of the intercondylar fossa and the cross-sectional area of the anterior cruciate ligament in different notch shapes, as well as the association of the notch shape with structural changes in patients who underwent magnetic resonance imaging of the knee (MRI), for non-contact knee pain.

To the best of our knowledge, this is the first study that aims to correlate the anterior part of the intercondylar notch (ICN) with the size of the ACL. Previous studies have focused on the overall appearance of the notch or the width of the notch and its correlation with the risk of injury or the anatomy of the ACL.

MRI examinations were performed by two 1.5-T machines. For this study, we mainly used real axial T2W NFS or PDW FS images, using post-processing tools to create a customized plane by applying references from the sagittal and coronal planes, which was oriented along the ACL axis in the sagittal plane and along a line parallel to the posterior femoral condylar line in the coronal plane. The plan was called the custom axial plan. (CAP) (fig. 6.1).

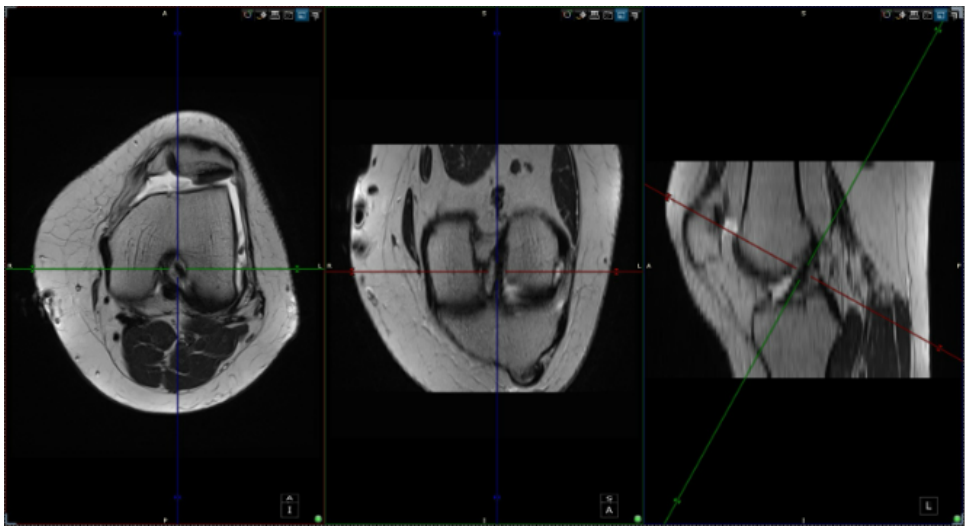

Fig. 6.1 Personalized axial plan (CAP) done for measuring

We assigned the intercondylar notch to one of three categories: A-shaped, U-shaped, and W-shaped, and then measured the maximum width and the anterosuperior surface of the notch. The area was measured by drawing a circumscribed circle of cortical bone on 3 out of 4 cardinal points (anterosuperior, left and right), and was defined as the area of the anterosuperior notch (aICN). The ACL area in the CAP was created by contouring it with the closed polygon tool in the software. Other measurements that were performed in all cases: intercondylar notch width (ICN), ACL area, Insall-Salvati index and lateral trochlear inclination (LTI).

A number of 65 cases were analysed (33 men and 32 women), the ACL area was 0.48 cm2 (0.2-0.8), with higher values in males compared to females, 0, 55 cm2 vs 0.41 cm2, p=0.002. Also, aICN area and ICN width are significantly greater in men compared to women, 0.96 cm2 vs 0.52 cm2, p=0.0008 and 23.87 mm vs 20.53 mm, p<0, respectively. 0001), respectively.

Table VI.1: Descriptive statistics

Parameter	Total N=65	Male N1=33	Female N2=32	p
Age, years	35 (13-52)	34 (13-51)	35 (15-52)	0,680
Aria ACL, cm ^{2}	0,48 (0,2-0,8)	0,55 (0,3-0,8)	0,41 (0,2-0,7)	0,0002
Aria aICN, cm ^{2}	0,75 (0,15-3,60)	0,96 (0,22-3,60)	0,52 (0,15-1,68)	0,0008
Width ICN, mm	22.23 (12.80-31.00)	23.87 (19.00-31.00)	20.53 (12.80-28.00)	<0,0001
ICN type A, N (%)	23 (35,38%)	6 (26,09%)	17 (73,91%)	0,004

ICN type W, N (%)	17 (26,15%)	8 (47,05%)	9 (52,95%)	0,720
ICN typeU, N (%)	25 (38,46%)	19 (76%)	6 (24%)	0,020
LTI, º	19.15 (3.00-31.00)	21.58 (10.00-30.00)	16.66 (3.00-31.00)	0,0009
Abbreviations: ACL – anterior cruciate ligament; ICN = intercondylar notch; LTI – lateral trochlear inclination; aICN = the anterior-superior intercondylar notch; A p value of less than 0.05 was considered statistically significant.				

Using bivariate analysis, we found that the ACL area was correlated with the aICN area in all groups (rho=0.66, p value<0.0001), as well as in the subgroup defined according to the shape of the notc (A-, W- and U -, respectively). The results show that the correlation between ACL area and aICN area was very strong for A form, strong for W form and only moderate for U form, **Table VI.2**.

Table VI.2. Bivariate analysis for associations between anterior superior notch area and anterior cruciate ligament area

Notch intercondylar	**Aria ACL cm ^{2}**	**Aria aICN cm ^{2}**	**rho**	**value p**
Group total (N = 65)				
Type A (n_1 = 23; 35,4%)	0,40 (0,20-0,80)	0,47 (0,15-0,95)	0,820	< 0,001
Type W (n_2 = 17; 26,2%)	0,40 (0,30-0,80)	0,37 (0,15-0,81)	0,608	0,010
Type U (n3 = 25; 38,5%)	0,50 (0,20-0,80)	1,16 (0,57-3,60)	0,416	0,036
Abbreviations: ACL – anterior cruciate ligament; aICN = the anterior-superior intercondylar notch; rho = Sperman's rho coefficient A p value of less than 0.05 was considered statistically significant.				

The study also demonstrated that the values of ACL area, aICN area and ICN width were significantly higher in cases with U-shaped notch, while there is no correlation for LTI.

Regarding the shape of the notch, the results show that in men the U shape was the predominant shape. Analyzing the frequency of injuries associated with notch shape, internal meniscal injuries were more common for the U-type notch, while external meniscal injuries were more common for the W-type notch.

The research of the literature conducted led us to the conclusion that it is the first study to analyse the relationship between the ACL and the anatomy of the anterior-superior notch. This research may be subject to additional follow-up studies of these patients to assess the risk of further injury. This may provide a chance to prevent some of the injuries and anticipate degenerative changes.

Another important aspect is the use of the unanticipated correlation between ACL thickness and internal meniscus injuries for biomechanical studies that can prove the different levels of knee constraint with a thick ACL likely to be very stiff, prevention protocols can be developed depending on the specifics of the knee.

The results of the study show that for A/W notches, ACL area is strongly/very strongly correlated with anterior superior notch (aICN) area. Associated external meniscal injuries are more common in the W-notch, whereas the A-notch had no external meniscal injury.

We believe it is important to note that a narrow anterosuperior notch (A/W) is correlated with a smaller native ACL size, and this could lead to bone-graft conflict and the need for notchplasty during ACL reconstruction due to of a graft larger than the area of the anterior-superior notch (aICN).

In the case of a U-type notch there is a low correlation between the size of the ACL and the area of the aICN, but the area of the ACL remains larger in this type. Also, internal meniscus injuries are more common in the U-type notch, and this type of notch is more common in males.

Among the limitations of the study is the statistical limitation given by the small number of patients. Also, this study does not correlate morphological measurements with

knee phenotypes or coronal plane alignment of the knee, and there is also a lack of correlation between patient height and the area of the anterior-superior intercondylar notch.

In summary, our study provides evidence that ACL cross-sectional area is strongly correlated with anterior-superior notch area when the notch shape is A or W-type. A thick ACL is correlated with more internal meniscal injuries. Type A notch has fewer external meniscal injuries than types W and U. In the future, studying the anatomy of the notch in relation to other morphological aspects of the knee may lead to a better understanding of injury patterns and surgical decisions.

Study Summary 2: *Antero-superior notch area for the 3 geometric types, an individualized approach to graft size selection in ACL reconstruction.*

In this study we analysed 65 cases using MRI examinations were performed by two 1.5-T machines. Through this study we wanted to present the average size of the anterior-superior notch for each geometric type. Knowing the diameter range for each notch type, we also propose an ACL graft size planning model for each notch type to avoid bone-graft conflict.

We also obtained in this study a personalized axial plane, perpendicular to the ACL axis and parallel to the posterior condylar line.

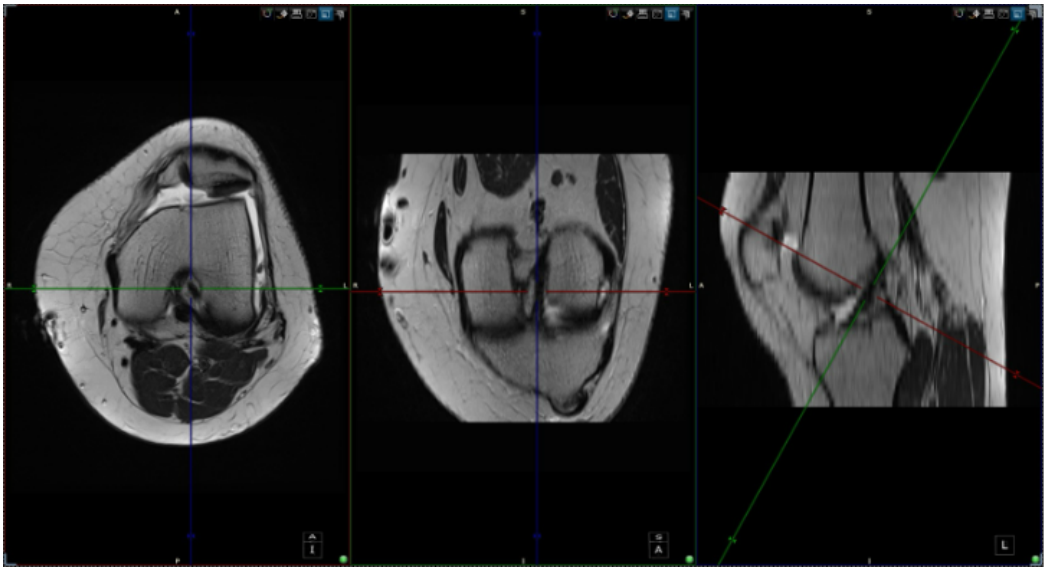

Fig 7.1. Personalised axial plan (CAP)

We divided the notch into one of 3 categories and then measured the area by drawing a circumscribed circle of cortical bone on 3 of 4 cardinal points (anterosuperior, left and right), and the area of the anterosuperior notch was defined (anterior intercondylar notch = aICN).

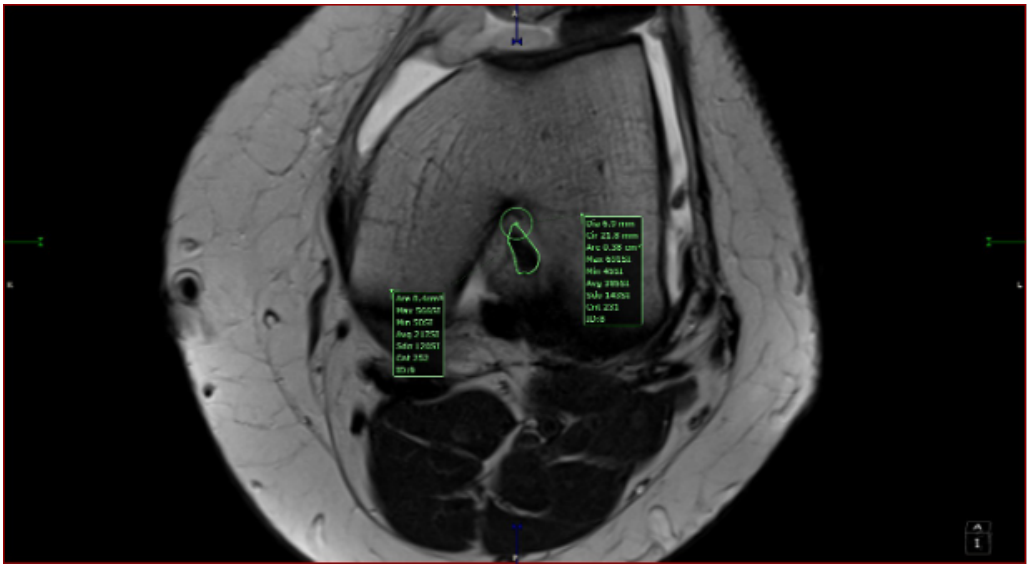

Fig 7.2. Measurements of the area of the anterior intercondylar notch (aICN) and the area of the ACL in the same section at an A-type notch

Measurements were performed by an orthopedic surgeon and a radiologist using the aICN area definition. In this study one of the subjects had a circular ACL in section, which was measured intraoperatively, during the surgical treatment of a related lesion. The area of the ACL was measured to be 0.38 cm2 on MRI, and the diameter was measured in vivo to be 7 mm. This corresponds to an area of 0.3848 cm2 and a radius of 3.5 mm.

Upon analysis, the results showed that (aICN) was higher in men than in women, with values of 0.75 cm2 (0.2-0.8) compared to 0.96 cm2 vs 0.52 cm2, p=0.002. Also, the values of the area of the anterior-superior intercondylar notch are significantly higher in cases with a U-shaped notch, the U-shape being more common in men.

In the case of the A-type notch, the values ranged from 0.15 cm2 to 0.95 cm2, with the ACL in close contact with the walls of the anterior superior notch (aICN) in extension.

Therefore, using a hamstring graft with a diameter larger than the size of the aICN area will result in conflict. In the case of the W-type notch, the values range from 0.15 cm2 to 0.81 cm2, being in close contact with the walls of the aICN in extension, the size of the graft can be made using the intraoperative measurement of the diameter of the aICN. In the U-notch, the values range from 0.56 to 3.6 cm2, which gives a range of diameters from 8.4 mm to 21.4 mm.

The limitation of this study is given by the lack of interobserver agreement, the measurement technique not being validated.

A summary of the results of this study shows that aICN varies significantly for each notch shape and does not correlate with height, an aspect that is considered in the choice of graft size for ACL reconstruction.

Study Summary 3: *Anterior and Posterior Cruciate Ligament Balance in Adults*

The two cruciate ligaments ACL and PCL are essential components of the knee joint, providing stability during movements, both of which are quite frequently injured, especially in the case of athletes. I believe that a better understanding of the balance between PCL and PCL is essential to the development of better treatment, prevention and recovery strategies.

The study was carried out on 62 cases, using MRI images performed by two 1.5-T machines. A customized axial plan was made for ACL and PCL.

Images were evaluated by an orthopaedic surgeon and a radiologist, and analysis was performed using descriptive statistics, including mean and standard deviation. Other methods used were the Shapiro-Wilk test, the Kruskal-Wallis test with Bonferroni correction, and to determine the magnitude of the difference between the ACL area in relation to the PCL area, the formula (ACL area – PCL area)/PCL area was used.

We found that the median difference between ACL area and PCL area is statistically significant ($p = 0.02$). A significant difference in anterior cruciate ligament area (ACL) was detected between A and U notch types ($p = 0.02$), while no significant differences were found between A and W type or between W and U type after post hoc corrections ($p > 0.05$).

That study has a number of limitations. Among these we list: lack of interobserver agreement, measurement technique not being validated, small number of participants, racial diversity, most posterior cruciate ligaments in knees with ACL injury are angulated. The study summary shows that the correlation of ACL-PCL dimensions helps to understand the balance of the central pivot of the knee. In our study, in more than half of the studied patients, the ACL area is not less than 60% of the PCL area and not more than 120%.

The research also contains a technical note in choosing the isometric graft implantation point in anterior cruciate ligament reconstruction. The rate of ACL reconstruction has increased significantly over the past decades, with new additions to surgical techniques, as well as "tips and tricks" for current techniques.

As in any field there are differences of opinion, but there is also a degree of consensus regarding the direct link between the optimization of the femoral and tibial insertion points of the neoligament and the favourable postoperative result, and the ways of determining the optimal femoral isometric point, both visually and by means of instruments dedicated are multiple.

The technical note suggests visualizing the posterior condyle with the knee in wide flexion, to more easily identify the anterior portion of the isometric area of the external femoral condyle. The technique is a simple and efficient method for determining the isometry of the external femoral condyle. The described landmarks can be used by any orthopaedic surgeon experienced in ACL reconstruction.

Conclusions and personal contributions

The purpose of this research is to define the close relationship between the anterior cruciate ligament (ACL) and the anatomy of the anterior intercondylar notch, as well as the relationship between the ACL and the PCL. The idea came during the surgery and had as main objectives:

• Finding size correlations between native ACL and anterior intercondylar notch size in knees without history of trauma / osteoarthritis / history of previous surgery, on native MRI.

• Finding the correlation between the different types of notch and the different lesions discovered on native MRI in knees without a history of trauma / osteoarthritis / history of previous surgery.

• Correlation between the diameter of the anterior-superior notch and the diameter of the graft used for ACL reconstruction.

• Finding size correlation between native ACL and native PCL on native MRI in knees without history of trauma / osteoarthritis / history of previous surgery.

The three studies carried out provide important evidence for surgical practice. Related to study one, this provides evidence that the area of the anterior ACL section is strongly correlated with the area of the anterior-superior notch when the notch shape is type A or W. Also, a thick ACL is correlated with more internal lesions of meniscus. Type A notch has less external meniscus damage than types W and U.

In study two we showed that in a small A and W notch, a small autologous/hybrid/artificial graft can be planned and reconfirmed during surgery using in vivo measurements, while for a U notch it can a graft of at least 8 mm should be planned due to the low risk of bone-graft conflict.

Study three is the first study to look at ACL-PCL balance using cross-sectional area. The study shows that when examining the ACL-PCL balance, using the formula ACL area – PCL area / PCL area, no significant difference was found between the size of the ACL area in relation to the PCL area in the three types of notch, but 68% of the ACL areas were found to be within [-0.4 to +0.2] × PCL area, while 95% of ACL areas were within [-0.7 to +0.6] × PCL area, with negative values representing an area of the ACL smaller than the area of the PCL and positive values representing the opposite.

The current research brings significant novelties from which to build other studies. ACL is a thoroughly debated topic in orthopaedics due to its importance in knee stability. Here are some aspects of personal contributions to this research. In the first study, I evaluated only the anterior-superior part of the notch, which is in close contact with the ACL, and focused on the correlation between the two structures.

Another novelty brought by the current research is the introduction of the concept of the area of the anterior intercondylar notch (aICN area) as a different anatomical parameter that can be investigated in relation to the size of the native ACL. I believe that the balance between the two structures is intimate and important in deepening the reconstruction of the ACL.

Using real axial MRI images and using post-processing tools we created a custom plane by applying references from the sagittal and coronal planes. The custom plane is oriented along the ACL axis (slightly angled to the intercondylar roof of the Blumensaat line) in the sagittal plane and along a line parallel to the posterior femoral condylar line in the coronal plane. As a result, the plane is perpendicular to the ACL axis and parallel to the posterior condylar line. We named this plan the customized axial plan of the ACL (aCAP).

Using the same principle, we created a plane perpendicular to the proximal third of the PCL. We named this plane the custom axial plane of the PCL (pCAP). Using the two custom planes I was able to accurately measure the cross-sectional area of the two cruciate ligaments.

The current research is of international interest and has an interdisciplinary character. Although our studies had some limitations, the evidence from these studies is a starting point for other studies in larger cohorts of patients, resulting in a better understanding of these anatomical landmarks, necessary in graft optimization in ACL reconstruction.

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1.Cernat E M, Neagu A, Betianu C, et al., Balancing Anterior and Posterior Cruciate Ligaments in Adults. Cureus, (May 05, 2024), 16(5): e59683. doi:10.7759/cureus.59683

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Chapter 8 (pag. 89-100)

2.Cernat EM, Dima A, Popescu C, Neagu A, Betianu C, Moga M, Manolescu LSC, Barbilian A. Anterior Intercondylar Notch Geometry in Relation to the Native Anterior Cruciate Ligament Size. *Journal of Clinical Medicine*. 2024; 13(2):309. Factor de impact: 962 views. Web of Science: 1. https://doi.org/10.3390/jcm13020309.

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3.Cernat EM, Neagu A, Betianu C, Georgescu DE, Barbilian A, Cornelia LS. The Anterior Notch Area for 3 Types of Notch Geometry, an Individualized Approach for Choosing the ACL Graft Size. *Chirurgia (Bucur)*. 2024;119(eCollection):1-10.

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Chapter 7 (pag. 74-88)