An Evaluation of the Association Between Radiographic Intercondylar Notch Narrowing and Anterior Cruciate Ligament Injury in Men: The Notch Angle Is a Better Parameter Than Notch Width

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Purpose: To evaluate the association of anterior cruciate ligament (ACL) injuries with the intercondylar notch angle and notch width in male patients. The secondary purpose was to evaluate the association of these injuries with other novel morphologic parameters. **Methods:** Male patients undergoing primary ACL reconstruction between 2010 and 2013 for injury through noncontact mechanisms with preoperative magnetic resonance imaging were compared with an age-matched control group of male patients (patients who underwent knee operations other than ACL reconstruction) regarding the following magnetic resonance imaging–assessed parameters: intercondylar notch angle, width, and depth; condylar width; medial/lateral condylar widths; medial/lateral posterior tibial plateau slopes; anterior sagittal tibial slope (corresponding to the level of the tibial ACL footprint); coronal tibial slope; and angle between the Blumensaat line and anterior tibial slope. **Results:** In both the coronal and axial planes, patients with ACL injury had a significantly lower intercondylar notch angle ($P < .001$ and $P = .008$, respectively) than the control group, but there were no significant between-group differences for intercondylar notch width ($P = .9$ and $P = .97$, respectively). In the sagittal plane, patients with ACL injury had significantly higher medial ($P < .001$) and lateral ($P = .02$) posterior tibial slopes, a significantly lower anterior tibial slope ($P = .01$), and a significantly higher angle between the Blumensaat line and anterior tibial slope ($P = .02$) than the control group. **Conclusions:** Narrowing of the intercondylar notch may be associated with ACL injury in male patients. However, the intercondylar notch angle may be a better parameter to evaluate notch narrowing and its potential association with ACL injuries compared with the notch width. The association between the angle formed by the Blumensaat line and anterior tibial slope and ACL injuries in male patients needs more investigation. This study further suggests that increased posterior tibial slope may be associated with ACL injury in male patients. **Level of Evidence:** Level III, case-control study.

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Anterior cruciate ligament (ACL) injuries are one of the most common severe injuries in sports.[1] Despite a huge scientific effort to optimize the surgical treatment, this injury still causes a high amount of health impairment and high economic costs, even in the ACL-reconstructed individual.[2,3] Therefore prevention of ACL injuries is the most effective strategy to avoid these undesired consequences. A crucial aspect for prevention strategies is a thorough understanding of risk factors.

The risk of ACL injury in women is higher than that in men.[4-6] Although there has been a huge research effort focused on risk factors for ACL injuries, a recent systematic review showed that the amount of available information regarding risk factors in men is lower compared with women.[4-7] In addition, several studies have found differences in anatomic risk factors between men and women.[8-12] For all these reasons, the results regarding risk factors for ACL injury between injured and uninjured individuals should be reported separately for men and women and not as a mixed sample. The investigation of anatomic risk factors comparing men and women is affected by the fact that more risk factors are present in women. Therefore the differences observed between the genders for a certain anatomic risk factor may be explained not only by this factor but also by the influence of anatomic, hormonal, neuromuscular, or biomechanical factors in women. We believe the investigation of anatomic risk factors for ACL injury should differentiate between men and women rather than mixing or comparing the genders.

Studies related to anatomic risk factors have emphasized the intercondylar notch dimensions and posterior tibial slope in both genders.[7,13-15] Although there is greater consensus on the higher risk of ACL injury with increased posterior-lateral tibial plateau slope in men,[8,10,16] the role of the medial plateau slope[8-11,16,17] and the intercondylar notch width[12,18-20] in the risk of ACL injuries remains controversial. In addition, there is a poor understanding of the role of other femoral and tibial morphologic parameters (condylar width, lateral condylar width, medial condylar width, intercondylar notch angle and depth, coronal tibial slope, anterior tibial slope, and Blumensaat line) in the risk of ACL injuries.

The principal purpose was to evaluate the association of ACL injuries with the magnetic resonance imaging (MRI)—assessed intercondylar notch angle and notch width in male patients. The secondary purpose was to evaluate the association of these injuries with other novel MRI-assessed morphologic parameters. It was hypothesized that a narrow intercondylar notch by means of narrow angle values instead of narrow width values would be associated with ACL injuries in male patients and that an increased anterior tibial slope, anterior tibial slope—Blumensaat angle, and medial and lateral plateau posterior slope would be associated with these injuries as well.

Methods

The inclusion criteria for this study were all male patients undergoing primary ACL reconstruction between 2010 and 2013 for a torn ligament through noncontact mechanisms with preoperative MRI performed at our institution (Fig 1). Female patients, patients with contact ACL injuries, cases with previous surgery (i.e., ipsilateral ACL reconstruction, high tibial osteotomy, osteochondral allograft, microfracture, or any procedure associated with notchplasty), or cases with MRI obtained at an outside hospital or with insufficient quality (evident blurring because of patient movement during MRI performed either at an outside institution or at our institution) were excluded from this investigation (Fig 1). Female patients were

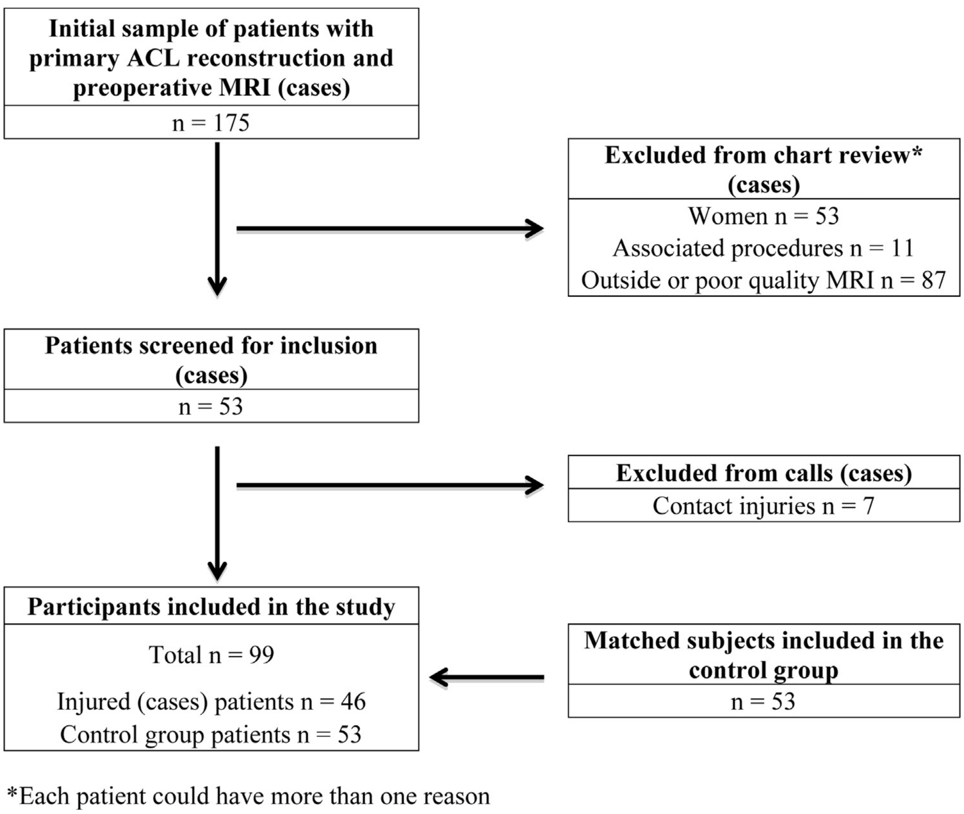

Fig 1. Flowchart showing selection of patients for this study. (ACL, anterior cruciate ligament; MRI, magnetic resonance imaging.)

excluded because the risk of ACL injury (and what is known regarding risk factors) is not comparable with their male counterparts.[4-7] Institutional review board approval was received for this study.

Tibial and femoral morphologic characteristics were compared between male patients with ACL injury (cases) and an age-matched sample of male individuals without ACL injury (controls). Control individuals were included if they had an MRI study obtained for meniscal or other injuries, such as patellar tendinopathy, patellofemoral pain syndrome, or plica syndrome, without previous ACL injuries. All medical records were reviewed to evaluate for any exclusion criteria and obtain demographic characteristics. The mechanism of injury was determined by directly questioning the patient through a phone call. Contact injuries were excluded because these injuries might occur regardless of the presence or absence of risk factors if the producing energy is high enough. A noncontact injury was defined as an injury occurring in the absence of player-to-player contact.[6] Noncontact ACL injuries with preceding perturbation (contact with an opponent creating a performance modification during a certain playing action) were also included.[6] Tibial and femoral morphologic characteristics were measured on preoperative MRI studies using iPACS software (General Electric, Fairfield, CT) in both groups. Data collection was performed by a trained unblinded orthopaedic surgeon, who was unaware of the actual study purpose and hypothesis. All measurements were obtained twice by the same researcher after 3 meetings with the main researchers to establish a systematic measurement method. After we clearly explained how all measures had to be obtained, several trials for quantification of all parameters were performed before commencement of data collection. The trials were performed in random patients not included in this study. The interval between both measurements (used to calculate the intraclass correlation coefficient) was 1 month.

Morphologic Measurements

The MRI assessment methods were standardized for all patients, per institutional protocols. All MRI examinations were obtained using the same scanner machine with patients lying supine and knees at maximum knee extension. The morphologic parameters evaluated in the sagittal plane included the posterior-medial tibial slope, posterior-lateral tibial slope, anterior tibial slope, and angle between the Blumensaat line and the anterior tibial slope. In the coronal plane, the coronal tibial slope, intercondylar depth, intercondylar width, intercondylar angle, condylar width, intercondylar width—condylar width index, medial condylar width, lateral condylar width, and lateral condylar width—medial condylar width index were obtained. The parameters obtained in the axial plane were the same as those obtained in the coronal plane except for the coronal tibial slope.

The femoral measurements were obtained for the coronal and axial planes as described by Stein et al.[21] In both planes, a cut showing the popliteal groove was used to calculate the femoral morphologic parameters. For the axial plane, a posterior bicondylar line and its perpendicular from the top of the intercondylar notch were determined. The intercondylar depth was the distance from the top of the intercondylar notch to the bicondylar line. The intercondylar width was obtained at the anterior third of the intercondylar depth in the axial plane. At the same level, the width of the medial and lateral condyles was obtained. The condylar width was considered the sum of the intercondylar width, the medial condylar width, and the lateral condylar width. The intercondylar angle was formed by a line from the top of the intercondylar notch to the most inferior aspect of the notch at the medial and lateral condyles. The same method was used to collect these parameters in the coronal plane. This measurement method has shown adequate reproducibility.[21]

Measurements of the osseous posterior and coronal tibial slopes were obtained following the methods described by Hashemi et al.[22] and Matsuda et al.,[23] which showed adequate reproducibility. For measurements in the sagittal plane, an axial view of the tibial plateau was used to determine the location of both the medial and lateral tibial plateaus, as well as the location of the center of the tibia. Then, a simultaneous sagittal plane corresponding to the center of the tibia obtained in the axial plane was loaded into the computer and used to calculate the longitudinal tibial axis. This was achieved by determining, in the sagittal plane, the anterior and posterior cortices of the tibia at two points 4 to 5 cm apart and obtaining the midpoint at both levels. These midpoints formed the longitudinal axis of the tibia. This method to calculate the longitudinal axis of the tibia has shown excellent interobserver and intraobserver reliability.[24] A minimum diaphysis distance of 10 cm on the sagittal MRI scan was required to ensure an accurate measurement method for the longitudinal axis of the tibia. Once the longitudinal axis was obtained, a perpendicular line from this axis was drawn. Then, a sagittal-plane image of the medial plateau corresponding to the level determined in the axial plane was also loaded into the computer. The posterior-medial tibial slope angle was determined as the angle between the perpendicular line with respect to the longitudinal axis and the line running from the peak anterior and posterior points of the medial tibial plateau. The same procedure was then conducted for the posterior-lateral tibial slope. Medial and lateral tibial slopes were considered positive angles if posteriorly oriented (i.e., the slope line was below the line perpendicular to the tibial longitudinal axis).

The coronal tibial slope was calculated through a similar method.[22] First, an axial view at the top of the tibial plateau was used to draw a line from the medial to the lateral plateau. The corresponding coronal-plane image was simultaneously loaded into the computer, and the diaphyseal axis was calculated in the same way as the sagittal axis. The coronal tibial slope angle was determined between the perpendicular line to the longitudinal axis and the line joining the peak points on the medial and lateral aspects of the tibial plateau at the level of the centered line previously obtained for the axial plane. The coronal tibial slope angle was considered positive when the slope line was directed toward the medial plateau.

The determination of the anterior tibial slope was based on the method of Stijak et al.[16] A coronal plane was loaded into the computer and the ACL tibial footprint identified. The sagittal plane was then simultaneously loaded into the computer, and the cut showing the ACL tibial footprint along with the Blumensaat line was determined. By taking the same longitudinal axis and its perpendicular line, as previously described in the sagittal plane, the anterior tibial slope angle was considered the angle between this perpendicular line and a line passing through the ACL tibial footprint. The validity and reproducibility of this measure have not been previously evaluated. Values of anterior tibial slope were considered negative angles (above the perpendicular line) but, for easier understanding, are reported as positive values. The mean value of posterior-lateral and -medial tibial slopes was also reported as the mean posterior tibial slope. Finally, the angle between the Blumensaat line and the anterior tibial slope, in the same cut used to determine the latter, was obtained. Figure 2 summarizes some of the main parameters evaluated on the MRI scans.

Statistical Analysis

Descriptive statistics were used to summarize all demographic, complementary (leg dominance, sports, family history of ACL injury, or contralateral ACL injury), and main outcome variables. An independent *t* test was used to compare morphologic and demographic parameters between groups. The intraclass correlation coefficient was used to determine the reliability of the physician performing the MRI measurements. A sample size calculation was conducted based on preliminary data involving 20 patients in each group. In these patients a specific sample size calculation was performed for the intercondylar notch width, intercondylar notch angle, anterior tibial slope, angle between the Blumensaat line and anterior tibial slope, coronal tibial slope, posterior slope of the medial tibial plateau, and posterior slope of the lateral tibial plateau. The highest number of patients needed corresponded to the sample size calculation for intercondylar notch width. On the basis of preliminary data, considering a power of 80% to detect statistically significant differences in the hypothesis testing through a 2-tailed, unpaired *t* test; taking into account an α level of 5%; and assuming a difference in the mean values of the injured and control groups of 1.5 mm in notch width, as well as an SD in the control group of 3 mm, we determined that 32 patients were needed in each group. All statistical analyses were conducted with SPSS software (SPSS, Chicago, IL). The α level was set at .05.

Results

From an initial sample of 175 patients with ACL injuries undergoing primary ACL reconstruction, 46 were included (Fig 1). Fifty-three individuals were included in the control (non−ACL-injured) group. There were no significant differences in demographic characteristics between the groups (Table 1). In the ACL-injured group, there were 9 patients (19.5%) with a family history of ACL injury and 5 patients (10.9%) with contralateral ACL injury. Regarding the 5 patients with bilateral ACL injuries, only 1 knee could be included in this study because the MRI examination for the other knee was performed at an outside institution. Most of the patients (78.2%) were playing sports at the time of injury: soccer, 55.5%; skiing, 8.3%; basketball, 5.5%; indoor soccer, 5.5%; and other sports, 25%. The comparison of tibiofemoral morphology in the sagittal, coronal, and axial planes between the groups, as well as the intraclass correlation coefficient for the physician researcher performing the morphologic measurements, is shown in Table 2. The ACL-injured patients showed a significantly narrower intercondylar notch angle in both the coronal and axial planes compared with the uninjured individuals ($P < .001$ and $P = .008$, respectively).

Discussion

The principal findings of this study were as follows: (1) A narrow intercondylar notch angle, but not notch width, may be associated with ACL injuries in male patients; (2) a lower anterior tibial slope may be associated with ACL injuries in male patients; (3) a higher angle between the Blumensaat line and anterior tibial slope may be associated with ACL injuries in male patients; and (4) an increased posterior tibial slope of the medial and lateral plateaus may be associated with ACL injuries in male patients. The intercondylar notch angle may have a greater clinical relevance than the notch width and, therefore, may be more useful to evaluate intercondylar notch narrowing.

There have been a large number of investigations related to the tibial slope and intercondylar notch dimensions as risk factors for ACL injury.[13-15] The investigation of intercondylar notch dimensions has been based on notch width and notch width index

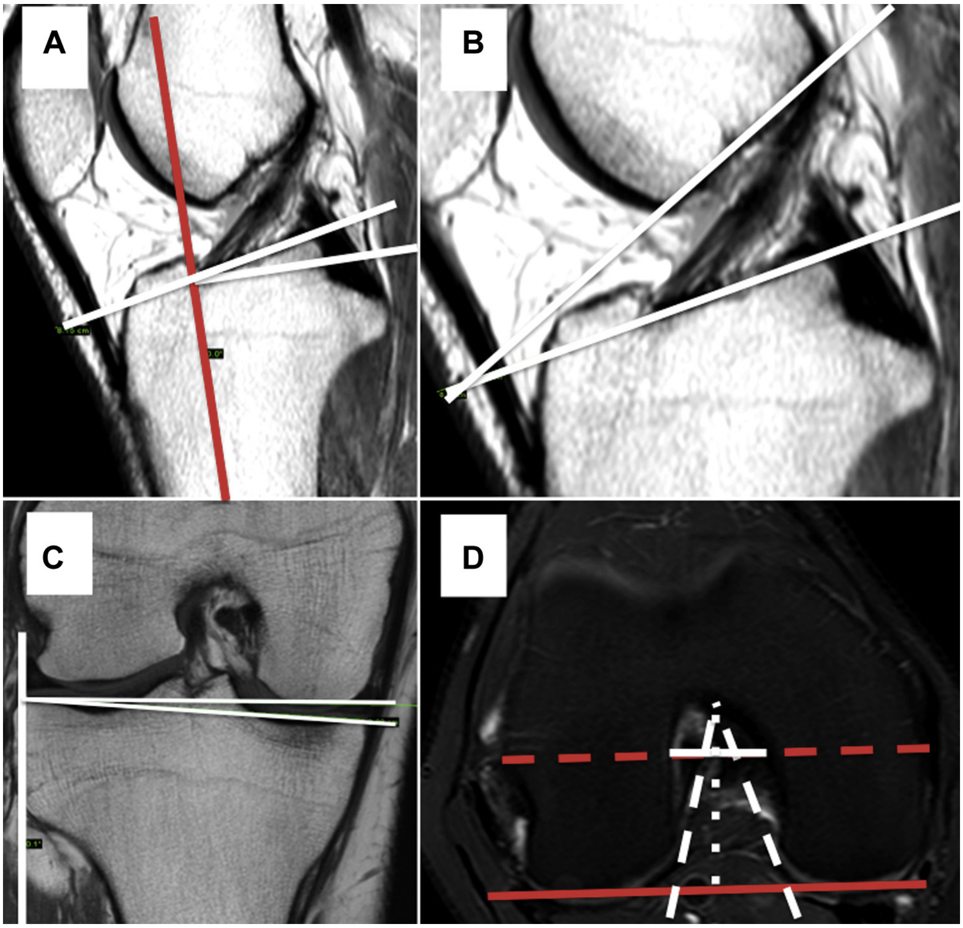

Fig 2. Summary of principal femoral and tibial parameters evaluated on magnetic resonance imaging. (A) T1-weighted sagittal magnetic resonance image of a right knee showing the anterior tibial slope, that is, the angle formed by the 2 white lines. A midpoint between the anterior and posterior cortex of the tibial diaphysis is taken and is joined to another midpoint at least 5 cm distally. This creates the longitudinal axis of the tibia (red line). The anterior tibial slope is then determined by the angle between a line passing through the anterior cruciate ligament tibial footprint (superior white line) and a perpendicular line (inferior white line) with respect to the longitudinal axis. (B) T1-weighted sagittal magnetic resonance image of a right knee showing the angle between the Blumensaat line and anterior tibial slope, that is, the angle formed by the 2 white lines. (C) T1-weighted coronal magnetic resonance image of a right knee showing the coronal tibial slope, that is, the angle formed by the 2 horizontal white lines. The longitudinal axis of the tibia is determined first (vertical white line), using the same method as described for the sagittal plane but taking the midpoints with respect to the medial and lateral cortex of the tibial diaphysis. The coronal tibial slope is determined by the angle between a line joining the peak points on the medial and lateral aspects of the tibial plateau (inferior horizontal white line) and a perpendicular line (superior horizontal white line) with respect to the longitudinal axis. (D) T2-weighted axial magnetic resonance image of a right knee showing the intercondylar notch dimensions: intercondylar notch width (solid white line), intercondylar notch angle (dashed white lines), and intercondylar notch depth (dotted white line). An axial plane showing the popliteal groove is loaded into the computer, and then the posterior bicondylar line is drawn. The intercondylar notch depth (dotted white line going from the top of the notch to the bi-epicondylar line) is used to calculate the intercondylar notch width (solid white line representing the distance between the medial and lateral femoral condyle walls at the anterior third of the intercondylar depth). The intercondylar notch angle is formed by the 2 lines going from the top of the notch to the most inferior aspect of the notch at the medial and lateral condyles. The red lines represent the width of the medial and lateral condyles.

(ratio between intercondylar notch width and condylar width).[15] The relevance of both parameters in terms of the risk of ACL injury in male patients is controversial.[7] Some studies have found that notch width has no influence,[18,20,25] whereas others have found that a narrow intercondylar notch increases the risk of ACL injury in male patients (Table 3).[12,15,19] The absolute values of notch width and notch width index found in our investigation were similar to those in the previous literature on ACL-injured patients (Table 3).[12,18-20,25,26] However, the control patients in this study had notch width index values similar to those of injured patients in previous studies (i.e., close to 0.25).[26] The principal hypothesis of this study was that ACL injuries would be

Table 1. Comparison of Demographic Characteristics Between ACL-Injured and Non−ACL-Injured Individuals

Variable	ACL-Injured Individuals	Non−ACL-Injured Individuals	*P* Value
Age, yr	33.1 (16-49)	33.7 (16-51)	.7
Height, m	1.77 (1.6-1.9)	1.76 (1.6-1.9)	.7
Weight, kg	81.4 (55-114)	77.9 (44-111)	.2
BMI, kg/m^2	25.9 (17.7-33.9)	24.9 (14.9-34.2)	.1
Leg dominance, n (%)			.6
Right	19 (51.4)	30 (56.6)	
Left	18 (48.6)	23 (43.4)	

NOTE. Data are presented as mean (range) unless otherwise indicated.
ACL, anterior cruciate ligament; BMI, body mass index.

associated with narrowing of the intercondylar notch measured through the intercondylar notch angle rather than the intercondylar notch width. This investigation found no significant differences in notch width and notch width index between the groups but found a lower intercondylar notch angle in both the coronal and axial planes in the ACL-injured individuals compared with the non−ACL-injured individuals.

The intercondylar notch angle has been poorly investigated in the ACL injury−related literature.[21,27,28] Some authors suggested that a notch angle equal to or less than 50° would increase the risk of ACL injury.[27,28] Whereas Stein et al.[21] could not show an increased risk of these injuries when comparing individuals with an intercondylar notch angle below or above 50°, our investigation seems to support the previous literature regarding the cutoff point of 50° for the intercondylar notch angle.[27,28] Values below (or near) 50° would be associated with ACL injury compared with higher values. The mismatch between the influence of intercondylar notch angle and width in the risk of ACL injury may indicate that the shape of the notch is also an important aspect to consider.[27,29] It is likely that a rounded notch with stenosis at the base would have acceptable values of notch width but unacceptably low values of notch angle (Fig 3). In fact, the influence of notch shape on the risk of ACL injury has recently been shown.[29] Al-Saeed et al.[29] observed that a reduced notch width index was not associated with ACL injuries whereas a type A notch (narrow notch at the base,

Table 2. Comparison of Tibiofemoral Morphology Between ACL-Injured and Non−ACL-Injured Individuals

Variable	ACL-Injured Individuals		Non−ACL-Injured Individuals		*P* Value	ICC (95% CI)
	Mean	95% CI	Mean	95% CI		
Sagittal, °						
Posterior-medial tibial slope	6.4	0.3 to 12.5	3.4	−4.8 to 10.1	< .001	0.91 (0.86 to 0.95)
Posterior-lateral tibial slope	6.2	−3.2 to 15.6	4.1	−3.9 to 12.1	.02	0.94 (0.9 to 0.96)
Mean Posterior tibial slope	6.3	−0.2 to 12.8	4.1	−3.4 to 12.1	.003	—
Anterior tibial slope	−8.7	−21 to 3.6	−12	−35.5 to −24.1	.01	0.95 (0.89 to 0.97)
Angle between Blumensaat line and anterior tibial slope	35.9	16.5 to 55.3	31.7	16.4 to 93.8	.02	0.93 (0.9 to 0.96)
Coronal						
Coronal tibial slope, °	4	−1.9 to 9.9	4.7	−8.2 to 13.9	.48	0.94 (0.88 to 0.97
Intercondylar depth, cm	2.4	1.8 to 3	2.4	2 to 7.1	.69	0.96 (0.94 to 0.98)
Intercondylar width, cm	1.8	1.2 to 2.4	1.9	1.3 to 5.6	.14	0.9 (0.86 to 0.95)
Intercondylar angle, °	51.2	35.5 to 66.9	60.1	41.7 to 177.9	< .001	0.99 (0.99 to 0.99)
Condylar width, cm	7.7	6.5 to 8.9	7.8	6.4 to 23.1	.35	0.8 (0.7 to 0.89)
Intercondylar width−condylar width index	0.23	0.2 to 0.3	0.24	0.2 to 0.7	.17	—
Lateral condylar width, cm	3.1	2.1 to 4.1	3.1	1.9 to 9.2	.9	0.7 (0.61 to 0.79)
Medial condylar width, cm	2.8	2.4 to 3.2	2.8	2.4 to 8.3	.36	0.72 (0.6 to 0.81)
Lateral-medial condylar width index	1.1	0.7 to 1.5	1.1	0.7 to 3.3	.97	—
Axial						
Intercondylar depth, cm	3.1	2.3 to 3.9	3.1	2.3 to 9.2	.54	0.93 (0.88 to 0.95)
Intercondylar width, cm	1.9	1.5 to 2.3	1.9	1.5 to 5.6	.72	0.97 (0.95 to 0.99)
Intercondylar angle, °	46.5	30 to 63	50.7	37.2 to 150	.008	0.98 (0.97 to 0.99)
Condylar width, cm	7.8	6.8 to 8.8	7.6	6.4 to 22.5	.87	0.96 (0.88 to 0.98)
Intercondylar width−condylar width index	0.25	0.2 to 0.3	0.25	0.2 to 0.7	.47	—
Lateral condylar width, cm	3	2.4 to 3.6	3	2 to 8.9	.91	0.88 (0.82 to 0.93)
Medial condylar width, cm	2.9	2.5 to 3.3	2.8	2.4 to 8.3	.56	0.93 (0.9 to 0.95)
Lateral-medial condylar width index	1	0.8 to 1.2	1	0.6 to 3	.95	—

ACL, anterior cruciate ligament; CI, confidence interval; ICC, intraclass correlation coefficient.

Table 3. Summary of Studies Investigating Intercondylar Notch Narrowing and Posterior Tibial Slope as Risk Factors for ACL Injuries in Male Patients

Study	Type of Study	Assessment Method	ACL Injury Group*	Control Group*	*P* Value
Intercondylar notch width					
Souryal and Freeman,[19] 1993†	Prospective cohort	Radiographs	n = 7 NWI, 0.21	n = 760‡ NWI, NR for male individuals‡	< .001
Teitz et al.,[20] 1997†	Case control	Radiographs	n = 20 NWI, 0.25 ± 0.03	n = 20 NWI, 0.26 ± 0.03	> .05
Uhorchak et al.,[12] 2003	Prospective cohort	Radiographs	n = 16 NWI, 0.18 ± 0.02	n = 695 NWI, 0.21 ± 0.03	< .001
Evans et al.,[18] 2012	Case control	Radiographs	n = 37 18.1 ± 3.1 mm	n = 1,397 18.3 ± 3 mm	> .05
Van Diek et al.,[25] 2014	Case control	MRI	n = NR‡ 21.8 mm	n = NR‡ 23.3 mm	> .05
Medial tibial plateau posterior slope					
Brandon et al.,[17] 2006	Case control	Radiographs	n = 66 10.8° ± 3.9°	n = 49 8.4° ± 3.4°	< .001
Stijak et al.,[16] 2008§	Case control	Radiographs, MRI	n = 33 5.2° ± 3.6°	n = 33 6.6° ± 3.2°	.066
Hashemi et al.,[8] 2010	Case control	MRI	n = 22 6° ± 2.7°	n = 22 3.7° ± 3.1°	.007
Todd et al.,[11] 2010	Case control	Radiographs	n = 95 9.2° ± 2.7°	n = 126 8.6° ± 2.7°	.113
Hohmann et al.,[9] 2011	Case control	Radiographs	n = 199 5.5° ± 3.4°	n = 199 5.8° ± 3.1°	> .05
Hudek et al.,[10] 2011	Case control	MRI	n = 24 4.3° (3.1°-5.5°)	n = 24 3° (1.9°-4.2°)	> .05
Lateral tibial plateau posterior slope					
Stijak et al.,[16] 2008§	Case control	Radiograph, MRI	n = 33 7.5° ± 3.4°	n = 33 4.4° ± 2.3°	.001
Hashemi et al.,[8] 2010	Case control	MRI	n = 22 7.2° ± 2.7°	n = 22 5.4° ± 2.8°	.02
Hudek et al.,[10] 2011	Case control	MRI	n = 24 4.3° (3.1°-5.5°)	n = 24 3° (1.9°-4.2°)	> .05

ACL, anterior cruciate ligament; MRI, magnetic resonance imaging; NR, not reported; NWI, notch width index.
*Data are presented as mean ± standard deviation or mean (95% confidence interval).
†The NWI (ratio of the width of the intercondylar notch to the width of the distal femur at the level of the popliteal groove) was reported as opposed to the absolute value of notch width in millimeters.
‡The number and/or NWI values for male individuals without injury from the whole sample were not specified.
§The values for male individuals were not specified (values shown correspond to entire sample).

where the notch angle is indeed measured) was associated with ACL injuries. Therefore their results are consistent with the findings observed in our study. A narrow intercondylar notch angle may be related to ACL injury because of impingement with anterior translation force and forced knee valgus.[4,6,30-32] Further investigations are required to better define the relation between notch width or notch angle and the type of notch shape, as well as the influence of the inner angle of the lateral femoral condyle on the risk of ACL injury.[33] Although the latter angle is not the same as the intercondylar notch angle, the findings of Miljko et al.[33] also showed that the notch width might be an insufficient morphologic parameter to investigate the risk of ACL injury.

There were 2 novel parameters evaluated in our investigation: anterior tibial slope and angle between the Blumensaat line and anterior tibial slope. It was hypothesized that increased anterior tibial slope would be associated with ACL injuries because of a potentially increased ACL inclination angle. However, the findings of our study go against this hypothesis because the risk was significantly increased with a lower angle of anterior tibial slope. Van Diek et al.[25] were not able to find differences in ACL inclination angle between injured and uninjured individuals. No clear explanation was found for the differences in anterior tibial slope between the groups. In this regard, further research is needed to better know the potential relation between the anterior tibial slope and the risk of ACL injury, as well as between the former and the ACL inclination angle. We also hypothesized that an increased angle between the Blumensaat line and anterior tibial slope could be associated with ACL injuries because of a

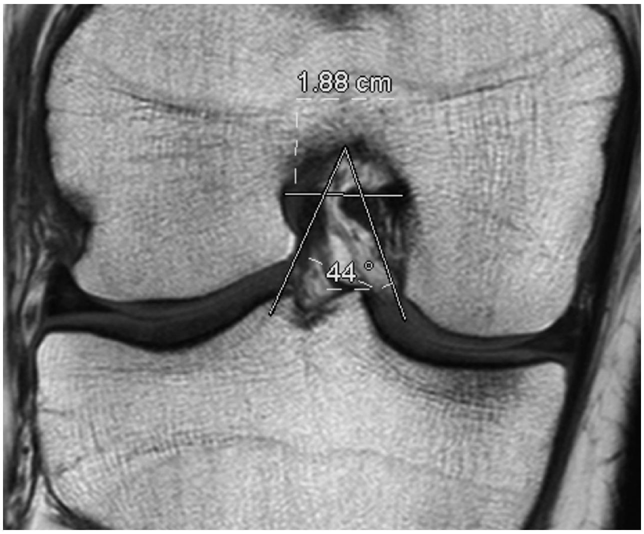

Fig 3. T1-weighted coronal magnetic resonance image of a right knee showing acceptable values of intercondylar notch width but unacceptably low values of notch angle.

potential anterior impingement mechanism, especially at low knee flexion angles.[34] The results of our study confirmed this hypothesis. However, there are 2 potential limitations to this finding. This angle is influenced by knee flexion, and extension lag was not evaluated in our sample. Although all MRI examinations were performed with patients in the same position (complete knee extension), the influence of extension lag (especially considering that patients had an injured knee) may not be negligible. In addition, the increased angle may be explained by a lower anterior tibial slope instead of a more vertical Blumensaat line. Overall, both anterior tibial slope and the angle between the Blumensaat line and anterior tibial slope have not been studied for validity and reproducibility, and their significance on the risk of ACL injury needs further investigation. Some authors have evaluated the intercondylar roof using the angle formed by the Blumensaat line and the longitudinal axis of the femur.[34] This measurement system would not be influenced by knee extension but would take into account neither the ACL inclination angle nor the tibial slope at the ACL footprint. A potential parameter to be evaluated in further research as an anatomic risk factor for ACL injury might be the ACL—Blumensaat line angle.

Other parameters evaluated were coronal tibial slope and lateral condylar width. To our knowledge, coronal tibial slope has only been studied by Hashemi et al.[8,22] This group found coronal tibial slope values slightly inferior to those observed in our study: 3.27° in injured and 3.51° in uninjured male patients. However, they reported 2 common findings with respect to our investigation: Control individuals had higher values of coronal tibial slope than ACL-injured patients, and there were no significant differences between the groups. The exact role of coronal tibial slope in the risk of ACL injury needs to be further investigated. Regarding condylar width dimensions, it was hypothesized that a decreased lateral condylar width with respect to the condylar width or the medial condylar width would be a risk factor for injury because of a predisposition to knee valgus collapse.[4,6,30-32] However, our investigation was not able to show any difference in these parameters. Van Diek et al.[25] did not find significant differences in lateral condylar width in male patients, but they did find significant differences in female patients. Nonetheless, injured female patients had a larger lateral condylar width than uninjured individuals.[25] The influence of lateral condylar width on the risk of ACL injury needs to be better defined in further investigations.

The role of the MRI-measured posterior slope of the medial tibial plateau in the risk of ACL injury is more controversial compared with the lateral tibial plateau.[13,14] In male patients, although an increased posterior-medial plateau slope was associated with a higher risk of injury in some studies,[8,17] others found no relation between both variables.[9-11,16] In contrast, a higher posterior-lateral plateau slope has been more consistently related to an increased risk of ACL injury in male patients.[8,10,16] It was hypothesized that an increased medial and lateral posterior tibial slope would be associated with ACL injuries. The results of our investigation regarding tibial slope confirmed this hypothesis and agree with several previous investigations (Table 3).[8,10,13,14,16,17] In addition, the absolute values of tibial slope for both the medial and lateral tibial plateaus fell within the reported range for both ACL-injured and healthy control individuals (Table 3).[13,14] An increased posterior tibial slope may be associated with ACL injuries because of an increased anterior motion of the tibia relative to the femur (during closed kinetic chain exercises) or intense quadriceps contraction (during open kinetic chain exercises).[35,36] In addition, an increased posterior tibial slope may be associated with ACL injuries because of increased torsional loads in cases of differences in the medial and lateral tibial slopes.[35,37] The investigation of the posterior tibial plateau is still pertinent because it has been found that patients with an increased slope have a higher risk of ACL reinjury after ACL reconstruction.[38] Further research should determine the role of tibial plateau depth and meniscal slope in the risk of ACL injury in male patients.

Limitations

This study has some limitations. First, prospective cohort studies are better study designs to evaluate risk factors for ACL injury. The retrospective nature of this study also made assessment of parameters more difficult, which would not have been the case in standardized prospective studies in which MRI could be better controlled. However, the exclusion of MRI examinations with insufficient quality or those obtained at an outside hospital contributed to improve data accuracy. Second, radiographic measurements were performed by only 1 individual. However, measurements were obtained from a homogeneous sample with physicians trained in the evaluation methods used, and repeated measures with test-retest reliability were reported. Third, the validity and reproducibility of some parameters (anterior tibial slope, coronal tibial slope, and angle between Blumensaat line and anterior tibial slope) have not been evaluated. Finally, this study only assessed anatomic risk factors, but the risk of ACL injury is likely related to many other parameters not controlled for in this investigation (e.g., weather conditions, playing surface, neuromuscular characteristics, or biomechanics of playing actions).

Conclusions

Narrowing of the intercondylar notch may be associated with ACL injury in male patients. However, the intercondylar notch angle may be a better parameter to evaluate notch narrowing and its potential association with ACL injuries compared with the notch width. The association between the angle formed by the Blumensaat line and anterior tibial slope and ACL injuries in male patients needs more investigation. This study further suggests that increased posterior tibial slope may be associated with ACL injury in male patients.

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