

# Evaluation of Intercondylar Notch, Condylar Morphology and Tibial Slope on Magnetic Resonance Imaging and their Influence on Rupture of the Anterior Cruciate Ligament

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## Abstract

**Introduction:** To measure the medial and lateral posterior tibial slopes separately on conventional Magnetic Resonance Imaging (MRI) and to investigate whether this method can be used in the prediction of anterior cruciate ligament (ACL) rupture.

**Methods:** This study included 31 consecutive patients with a definitive diagnosis of isolated ACL rupture and 31 healthy subjects. The medial and lateral posterior tibial slopes, intercondylar notch distance, notch width index (NWI), distal femur width, medial and lateral condylar width and depth were measured by MRI in both groups. The difference between patients with ACL rupture and controls were studied using the Student's t-test.

**Results:** The lateral posterior tibial slope and lateral condylar depth measurements were significantly higher, and the distal femur width was lower in the group with ACL rupture when compared to controls ( $p < 0.005$ ).

**Discussion and Conclusion:** MRI is the modality to measure lateral and medial tibial slopes separately. A combination of increased lateral posterior tibial slope, lateral condylar depth and decreased distal femur width could be a risk factor in ACL rupture.

**Keywords:** Anterior cruciate ligament (ACL); ACL rupture; tibial slope.

An anterior cruciate ligament (ACL) is one of the two cruciate ligaments of the knee and responsible for dynamic and static stabilization of the knee joint. ACL is the most commonly injured ligament of the knee. In the previous decades before the introduction of magnetic resonance imaging (MRI), imaging of the knee was primarily performed with arthroscopy, which is an invasive method; however, MRI has enabled us to evaluate the knee joint with non-invasive way and has already replaced the arthroscopy

as a primary imaging method for the knee pathologies<sup>[1]</sup>. MRI has sensitivity and specificity that reaches up to 90-95% in meniscal pathologies and 100% in cruciate ligament pathologies, but the efficiency of MRI in the diagnosis of ACL is significantly reduced in the presence of multiple ligaments injury<sup>[2, 3]</sup>. The relationship between the posterior tibial slopes (PTS) and an ACL injury has been extensively studied in recent years<sup>[4-7]</sup>.

Herein, we measured intercondylar notch width, condy-

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lar morphology, and PTS of the patients diagnosed with the ACL injury and compared these measurements with healthy controls to evaluate the relationship between these parameters and ACL injury.

## Materials and Methods

### Patient Population

The local ethics committee approved this retrospective study. Informed consent was obtained from all of the participants. We retrospectively reviewed all of the knee MRI examinations that were performed between January 2010 and January 2014 using our hospital picture archiving and communicating system (PACS, Extremepacs, Ankara/Turkey). Patients with isolated ACL injury were enrolled in this study. Patients with operation or fracture history of the femur or tibia, a skeletal anomaly in the lower limbs, associated posterior cruciate ligament (PCL) or collateral ligament injury, and finally, patients who had meniscus operation were excluded from the study.

### MR Imaging

All of the examinations were administered with 1.5 Tesla MRI unit (Magnetom Avanto, Siemens medical solution, Germany) using a 16-channel knee specific array coil. All of the examinations were carried out in the supine position while the concerned knee fixed in the middle part of the coil. MRI protocols included sagittal, coronal and axial fat-saturated proton density (FSPD) turbo spin-echo (TSE), sagittal T1-weighted TSE and T2-3D volumetric sequences. Detailed acquisition parameters of the procedures were the following: FSPD TSE: TR/TE 2110-26 msn, ETL (echo train length): 57, band width: 130 kHz, FOV: 16 cm, slice thickness/slice gap; 4 mm/0.4mm, NEX: 1, matrix: 384x270 for the proton density images; TR/TE 475-11 msn, ETL (echo train length): 48, band width:167 kHz, FOV: 16 cm, slice thickness/slice gap 4mm/0.4 mm, NEX: 2, matrix:384x270 for the T1-weighted images; and TR/TE 19.44-7.02, band width:193 kHz, FOV: 19 cm, slice thickness; 1 mm, NEX: 1, matriks:190x256.

### Image Analyses

The MR images were retrieved from our hospital PACS system, and two radiologists performed all of the measurements in a consensus. Measurements consisted of two steps. First, On FSPD images, distal femur width, intercondylar notch width, lateral and medial condylar width and depth were measured. Distal femur width was measured on coronal images at the level of the popliteal

groove, as Sonery-Cottet et al. described [8]. All of the measurements mentioned above were performed using the same slice. Notch width index (NWI), which is the ratio of intercondylar notch width to distal femur width, was calculated as described by Souryal et al.[9, 10]. Figure 1 depicts the NWI measurement of a patient.

Second, the medial and lateral PTS were calculated. We selected a T1-weighted image, in which ACL attachment point at the tibial intercondylar eminence, anterior and posterior cortex could be clearly identified. Two circles, one cranially and other caudally, drew onto the tibial head. Computer software was used for the standardization of these circles. We meticulously placed these circles in contact with the upper, anterior and posterior tibial cortex (Fig. 2).

In cases, which we could not determine borders between cortex and medulla, the middle part of the transitional zone, area between the adjacent cortex and medulla, was accepted as a reference point. To standardize distance between two circles, the central point of the caudal circle was determined as the point, which the lower part of the cranial circle passed. The line that connects the central point of the circles was defined as a tibial longitudinal axis. Afterwards, this longitudinal axis was fixed at a position where it could be visualized on all of the sagittal T1-weighted TSE sequences. Finally, the image where the medial tibial plateau



**Figure 1.** Calculation of the NWI. Ratio of intercondylar notch width (a) to distal femur width (b) at the level of popliteal groove (arrow) yields NWI.



**Figure 2.** The line, which passes through the center of the nested circles at the proximal tibia, yields tibial long axis.

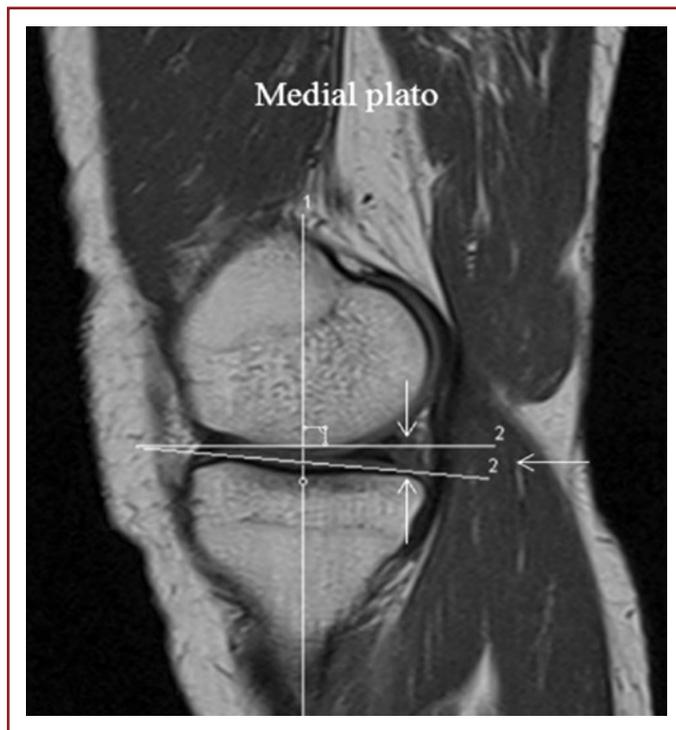
could be visualized was determined on T1-weighted TSE sequences. The line, which passes the upper cortex of the tibia, and tangentially extends to tibial medial plateau, was placed. The angle between the tangential line and a line that extending perpendicularly to the tibial longitudinal axis form medial PTS can be seen in Figure 3. Figure 4 demonstrates the calculations of lateral PTS, which is calculated using the same steps with medial PTS.

### Statistical Analyses

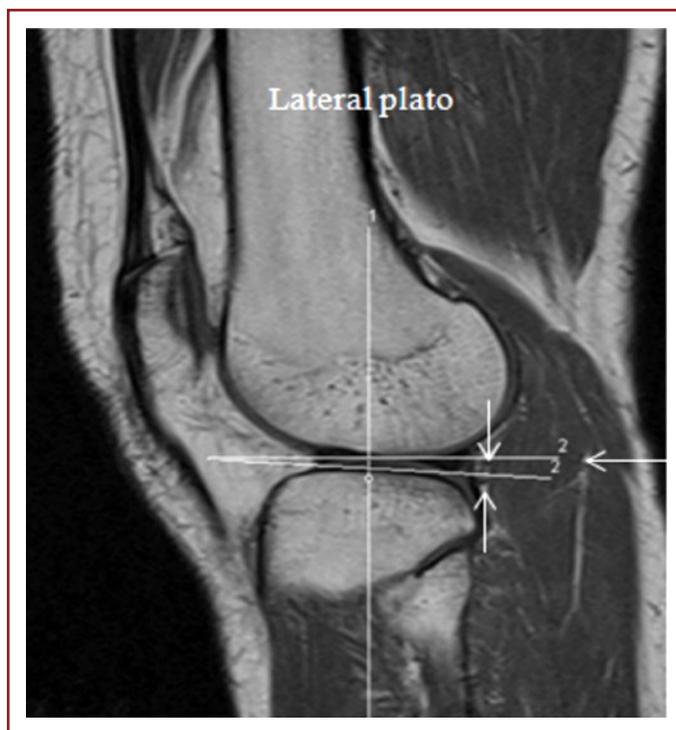
Commercial software (SPSS version 16.0®, SPSS, Chicago IL, USA) was used for the statistical analysis. We used the Kolmogorov–Smirnov test to analyze the normal distribution of our dataset. Measurements of the patients and the healthy controls were compared using a Student’s t-test. The relationship between the variables was examined with Spearman correlation analysis.  $P < 0.05$  was accepted as statistically significant.

### Results

A total number of 31 patients, 31 male (100%), and 31 healthy controls, 31 male (100%), were enrolled in this study. The mean age of the patients and the controls was 28.7 years old (range 15-46 years old). ACL injury was in the right knee in 15 of the 31 patients (48.4%), and in the left side 16 of the 31 patients (51.6%)



**Figure 3.** Calculation of the medial PTS. The angle between the tangential line to the medial plateau (upward arrow) and the line that extending perpendicularly to the tibial longitudinal axis (downward arrow) form medial PTS (side-facing arrow).



**Figure 4.** Calculation of the lateral PTS. The angle between the tangential line to the medial plateau (upward arrow) and the line that extending perpendicularly to the tibial longitudinal axis (downward arrow) form lateral PTS (side-facing arrow).

### Distal Femur Width

Distal femur width was measured at the level of the popliteal groove on the coronal FSPD TSE image. A significant difference was observed between the mean values of the patients (7.73±0.36 cm) and healthy controls (8.05±0.35 cm) (p<0.001).

### Intercondylar Notch Distance

Intercondylar notch distance was measured at the level of the popliteal groove on the coronal FSPD TSE image. No difference was observed between the mean values of the patients and healthy controls (p<0.05)

### NWI

We measured NWI as defined by Souryal et al. (ratio of intercondylar notch width to distal femur width at the level of the popliteal groove) (62, 63). A statistical difference was observed between the mean value of the patients (0.25±0.3) and the healthy controls (0.23±0.02) (p=0.041)

### Medial Condylar Width

Medial condylar width was measured at the level of the popliteal groove on the coronal FSPD TSE image. No significant difference was observed between the patients and controls (p>0.05).

### Lateral Condylar Width

Lateral condylar width was measured at the level of the popliteal groove on the coronal FSPD TSE image. No significant difference was observed between the patients and controls (p>0.05).

### Medial Condylar Depth

Medial condylar depth was measured at the level of the popliteal groove on the coronal FSPD TSE image. No significant difference was observed between the patients and controls (p>0.05).

### Lateral Condylar Depth

Lateral condylar depth was measured at the level of the popliteal groove on the coronal FSPD TSE image. A statistical difference was observed between the mean value of the patients (0.59±0.08 cm) and the healthy controls (0.51±0.08 cm) (p=0.002).

### Medial PTS

No significant difference was observed between the mean value of the patients (9.61±2.67) and controls (9.3±3.4) (p>0.05).

### Lateral PTS

A statistical difference was observed between the mean value of the patients (8.51±3.28) and the healthy controls (5.54±3.38) (p<0.001).

Tables 1 and 2 summarize the measurements of the patients and healthy controls.

### Discussion

PTS is defined as the angle between the perpendicular line to the tibial longitudinal axis and the line drawn tangentially to the upper tibial cortex in lateral radiographs<sup>[11, 12]</sup>. Recent studies have demonstrated that increased PTS makes ACL more prone to injury<sup>[13–16]</sup>. However, contrary results have also been reported in the literature<sup>[17]</sup>.

Studies that focus on the knee biomechanics have proposed the increased change of non-traumatic ACL injury in case of increased PTS. These studies suggested increased PTS leads to a shortening of the quadriceps muscle, which causes the anterior displacement of the tibia during the muscle contraction. Therefore, the tension in the ACL be-

**Table 1.** The mean, minimum and maximum measurements' values of the patients

Patients	Mean	Minimum	Maximum	SD
Distal femur width	7.73	7.05	8.54	0.362
Intercondylar notch distance	1.96	1.44	2.32	0.230
NWI	0.25	0.19	0.31	0.029
Medial condylar width	2.62	2.28	2.92	0.167
Lateral condylar width	2.95	2.49	3.38	0.194
Medial condylar depth	0.53	0.41	0.77	0.085
Lateral condylar depth	0.58	0.39	0.79	0.087
Medial PTS	9.61	2.00	14	2.666
Lateral PTS	8.51	2.00	16	3.285

\*All units are expressed as cm; SD: Standard Deviation.

**Table 2.** The mean, minimum and maximum measurements' values of the healthy controls

Healthy controls	Mean	Minimum	Maximum	SD
Distal femur width	8.05	7.36	8.71	0.346
Intercondylar notch distance	1.89	1.39	2.27	0.185
NWI	0.23	0.18	0.27	0.021
Medial condylar width	2.63	2.26	3.30	0.222
Lateral condylar width	2.93	2.41	3.50	0.194
Medial condylar depth	0.51	0.34	0.71	0.078
Lateral condylar depth	0.51	0.35	0.68	0.080
Medial PTS	9.38	4	17	3.499
Lateral PTS	5.54	1	16	3.384

\*All units are expressed as cm; SD: Standard deviation.

comes prominent, which eventually makes the ACL vulnerable to the injuries<sup>[18–21]</sup>.

PTS constitutes an indispensable role in the knee biomechanics, which is a three-dimensional complex osseous compartment, but information obtained from PTS is derived from a two-dimensional method. As a result, medial and lateral parts superimpose and become indistinguishable from each other; therefore, the clinical use of this method is limited<sup>[11, 12, 22, 23]</sup>. Furthermore, some authors suggested that the knee has very complex anatomy, which could not be defined by only defined by this angle<sup>[24, 25]</sup>.

Despite the increased understanding and appreciation of the PTS, yet no standardized measurement technique has been established, and various techniques and normal values have been introduced. Hence, normal PTS values ranging from 4° to 14° have been reported<sup>[11]</sup>. Moreover, rotation of the tibial shaft in the x-ray beams may lead to inaccurate measurements up to 13°, and even at the proper position, inaccurate measurements up to 5° have been reported<sup>[22]</sup>. Furthermore, some authors highlighted the variations of PTS between the cadaveric and radiologic studies<sup>[22, 26–29]</sup>.

The principal purpose of this study was to separately measure the medial and lateral posterior tibial slopes on conventional MRI and to investigate whether this method could be used in the prediction of ACL rupture. Moreover, we also assessed the distal femur width, femur intercondylar notch width, lateral and medial condylar width, and NWI.

Our data using MRI and a case-control design suggest that an increase in the lateral PTS was significantly associated with an increased risk of ACL injury. The mean lateral PTS was  $8.51 \pm 3.28$  in the ACL-injured knees and  $5.54 \pm 3.38$  in the control knees. In addition to this, an increase in the lateral condylar depth and a decrease in the distal femur width might be a risk factor for ACL injury. There was no significant difference between the medial PTS in the ACL-injured and control knees ( $9.61 \pm 2.67$  vs.  $9.3 \pm 3.4$ ).

Stijak et al.<sup>[26]</sup> reported no significant difference between patients with an ACL injury and healthy controls regarding medial PTS, while observed significant difference regarding lateral PTS, which is consistent with our results.

Apart from PTS, many authors have investigated the relationship between ACL injury and distal femur and intercondylar notch size using radiography, MRI, CT, or cadaver<sup>[9, 10, 30–40]</sup>. However, it is hard to compare our findings with these studies owing to inconsistent results and variations in the methods of measurements. However, many authors reported that ACL is prone to injury if intercondylar notch and distal femur are narrow<sup>[9, 10, 40–42]</sup>. We also

identified reduced distal femur width in ACL injury. However, inconsistent with the aforementioned studies, we did not find a significant difference between the patients and healthy controls regarding intercondylar notch width.

To our knowledge, this is the first study concerning the association between lateral-medial condylar and ACL injured knees. Our study provides robust evidence that lateral condylar depth is increased in ACL-injured knees, yet no statistical difference was observed between medial condylar depth and ACL injury.

There were several drawbacks in our study. Firstly, this study was a retrospective case-control study with a relatively small sample size. Secondly, we did not concern the size, volume, or orientation of the ACL in both groups. Thirdly, all of the measurements were performed on the sagittal plane, whereas Hashemi et al. measured the tibial plateau on coronal MRIs<sup>[43]</sup>. Future studies should consider the combination of the sagittal and coronal plane measurements of both medial and lateral tibial plateaus on MRI. Fourthly, we did not record patients' body mass index; therefore, we did not be able to assess the relationship between BMI and ACL injury. Finally, all of the patients in our study consisted of the males; thus, we did not evaluate the effects of gender over ACL injury. Todd et al. reported an increased incidence of ACL injury in females with increased PTS, yet they observed no difference in males<sup>[16]</sup>. On the other hand, lack of information regarding the etiology of ACL might also be included in the limitations factors of our study.

## Conclusion

In conclusion, in contradistinction to lateral radiography, in MRI medial and lateral plateau could separately be visualized and increased lateral PTS, lateral condylar depth and decreased distal femur width might be a significant risk factor for ACL injury.

**Ethics Committee Approval:** The Ethics Committee of Istanbul University Cerrahpasa Faculty of Medicine provided the ethics committee approval for this study (05/06/2014-83045809/604/02-15543).

**Peer-review:** Externally peer-reviewed.

**Authorship Contributions:** Concept: F.E.U., C.S.; Design: F.E.U., D.A.; Data Collection or Processing: F.E.U., C.S., D.A.; Analysis or Interpretation: F.E.U., C.S.; Literature Search: F.E.U., C.S., D.A.; Writing: F.E.U., C.S.

**Conflict of Interest:** None declared.

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