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Original Article

Radiology Section

MRI Correlation of Anterior Cruciate Ligament Injuries with Femoral Intercondylar Notch, Posterior Tibial Slopes and Medial Tibial Plateau Depth in the Indian Population

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ABSTRACT

Introduction: Injuries to the Anterior Cruciate Ligament (ACL) of the knee are common. Many anatomical factors like width and shape of intercondylar notch of femur, the posterior tibial slopes of the plateaus and depth of medial tibial plateau predispose to ACL tear. MRI evaluates these parameters and studies their relationship with ACL injury.

Aim: To study and correlate femoral intercondylar notch width and shape, posterior tibial slopes of medial and lateral plateaus and depth of the medial tibial plateau with ACL injury on MRI.

Materials and Methods: A retrospective study of 100 patients who underwent MRI knee in Department of Radio diagnosis, MS Ramaiah Hospitals, Bengaluru, India - 50 patients had no ACL injury (Group A), and fifty had ACL injury on MRI (Group B). Demographic data was also collected. Notch width index (NWI) and notch shape (Inverted U, A and Ω) were assessed on T2 Fat suppressed coronal sequences. Posterior Tibial Slopes (PTS) of medial and lateral plateaus and medial tibial plateau depth measured on sagittal reconstructed images of 3D PD coronal SPACE sequences. Statistical analysis was done and p-value and odds ratios calculated.

Results: Omega (Ω) shaped notch and Narrow femoral NWI were statistically significant in patients with ACL tear and latter measured 0.29 ± 0.02. NWI was significant in females and in age group of 31-45 years. Increased Medial Tibial Plateau Slope (MTPS) was significant with a p-value of 0.008 and measured 7.2 ± 3.7°. Decreased Medial Tibial Plateau Depth (MTPD) was not significant. Odds ratio showed males had more predilections for ACL tear. Increased MTPS and LTPS were more than two times associated with tear. Ω as compared to A showed 7.2 times more predilection. MTPD of less than 2.12 mm was predictive of ACL tear.

Conclusion: Low NWI and Ω shape of the femoral notch predisposed to ACL tear. Increased posterior tibial slope of medial plateau and shallow medial tibial plateau also predisposed to ACL tear.

Keywords: Anterior cruciate ligament tear, Femoral notch width index, Tibial plateau slope

INTRODUCTION

Knee is stabilised by a number of ligaments and bones and ACL is one of the most important stabilisers of the knee [1]. Many extrinsic and intrinsic factors [2,3] predispose to ACL injury including width and shape of intercondylar notch of femur, depth of medial tibial plateau and posterior inclination of the medial and lateral tibial plateaus also called as the posterior tibial slope [1]. Demographic data with regards to age and gender also show variable predisposition to ACL injury [3]. Separate assessment of both plateaus is needed as there can be significant difference in inclination of the two plateaus [4-6]. Narrow femoral intercondylar notch [2], omega shape, increased posterior tibial slopes [2] and shallow medial plateau depth [7] have all shown increased predisposition to ACL injury. The morphology of the intercondylar notch is not only of interest in ACL injury but is also associated with degenerative joint disease and osteochondritis dissecans [8]. Shallow medial plateau depth and increased posterior slope result in anterior tibial translation and ACL force in active gait [9]. MRI with its superb anatomic detail capability is an excellent tool to evaluate morphology of the femoral notch and the tibial condyles and also to study their relationship with ACL, which it exquisitely visualises.

MATERIALS AND METHODS

This retrospective study was conducted on 100 patients from January 2014 to October 2016 in the Department of Radiodiagnosis, Ramaiah Hospitals, Bengaluru, India. The inclusion criteria was patients aged 18 years and above with clinical suspicion of ACL injury and in whom MRI knee had been performed. These 100 patients were included after obtaining ethical clearance and informed patient consent. These 100 patients were further divided into two study groups of 50 patients each; Group A comprised of patients with no ACL injury on MRI and served as controls and Group B with evidence of ACL injury on MRI. Samples of each group were further subdivided according to age intervals [Table/Fig-1]. Various femoral (NWI, notch shape) and tibial measurements (MTPS, LTPS and MTPD) were then taken on MRI knee.

Age intervals (in years)	Group A (Absent Tear)	Group B (Present Tear)
<30	21	20
31-45	14	15
46-60	13	13
≥61	2	2

[Table/Fig-1]: Total number of patients according to age intervals.

Patients with previous knee surgery, old or new tibial plateau fractures, pathologies like osteoarthritis which altered the morphology of intercondylar notch and tibial plateau or patients with multiple ligament injury apart from ACL injury were excluded from the study.

MRI Technique and Measurements: Standard knee MRI was performed on a 1.5 T Siemens Avanto Magnetom dedicated 18 channel scanner and the measurements were made using commercially available IPACX OsiriX imaging software.

Femoral Measurements: The femoral notch width (including NWI) and shape were assessed on T2 coronal Fat Saturated sequences (TE: 69 ms, TR: 3890 ms slice thickness 3mm, Matrix: 256 x 256 and FOV: 160 mm).

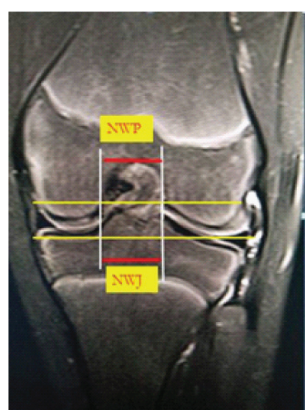
Notch Width Index: was calculated by dividing the Notch width at the level of popliteal groove with Bi-condylar width at the same level [8] [Table/Fig-2]. Shape of Intercondylar Notch (ICN) was assessed by comparing the Notch Width at the levels of Popliteal Groove (NWP) and Joint Line (NWJ). Three shapes of intercondylar notch were defined on the coronal sequence [8]. Inverted U shaped-NWP = NWJ (±1mm)] [Table/Fig-3]; A shaped-NWP < NWJ] [Table/Fig-4]; and Omega (Ω) shaped notch-NWP > NWJ [Table/Fig-5]

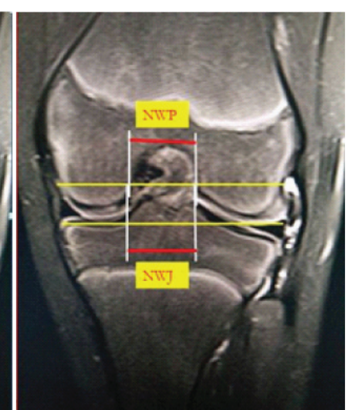
Tibial Measurements: Posterior Tibial slopes were calculated stepwise on a sagittal reconstructed image of a Proton density 3D SPACE coronal sequence (TE: 51 ms, TR: 1300 ms, slice thickness 0.7 mm, Matrix: 320 x160, FOV: 160 mm).

Tibial Longitudinal Axis: The first step was identification of midline sagittal image in which the tibial attachment of the Posterior Cruciate Ligament (PCL), the intercondylar eminence and concave shaped anterior and posterior tibial plateau were seen [1]. In the second step, on this mid sagittal section of tibia [10], the midpoint of the anterior to posterior diameter of the tibia at two points situated approximately 4-5 cm apart were marked, as caudally as possible . These two midpoints when connected represented the longitudinal axis of tibia. This axis was positioned as an overlay and remained in a fixed position on the sagittal image series [Table/Fig-6].

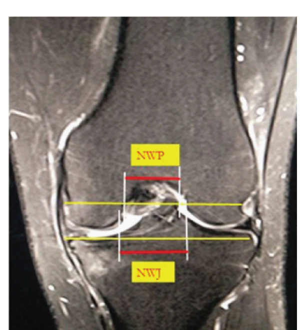
MTPS and LTPS Measurement: This longitudinal axis was then reproduced in the middle of the mediolateral centre of the medial tibial plateau in sagittal plane. On this image a tangent was drawn to the tibial plateau connecting the peak anterior and posterior cortical edges. The slope of the line (angle subtended) extending through these two points represented the MTPS, and it was measured with respect to the axis perpendicular to the longitudinal axis of the tibia [11]. Similarly, the LTPS was obtained [Table/Fig-7].

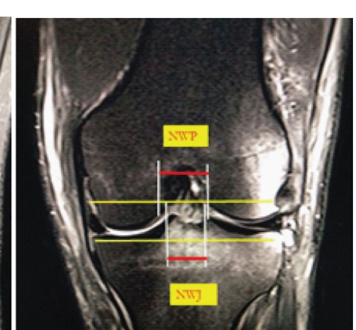
MTPD Measurement: It was calculated by [12] by drawing a line which connected the peak anterior and posterior points of the medial plateau to a line drawn tangential to the



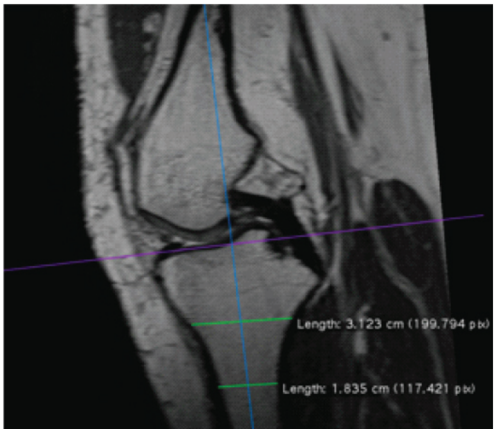


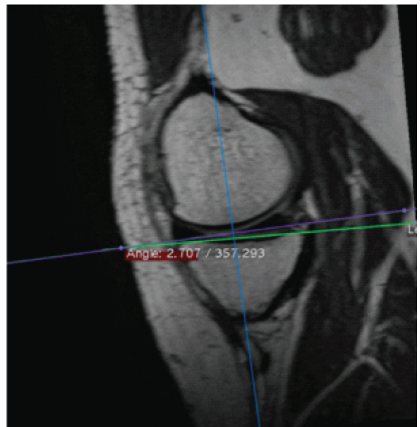
[Table/Fig-2]: Notch width index = Notch width at the level of popliteal groove (NWI). Bicondylar width at the same level.
[Table/Fig-3]: Inverted U shaped notch: NWP=NWJ (±1mm).

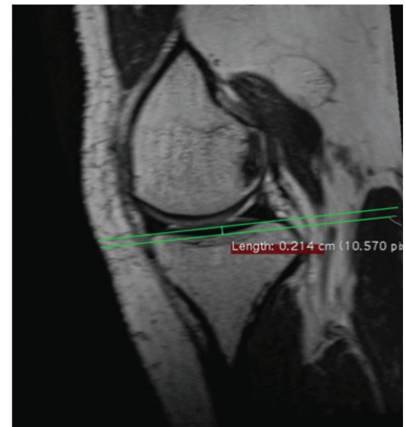




[Table/Fig-4]: A shaped notch- NWP <NWJ.
[Table/Fig-5]: Omega (Ω) shaped notch- NWP >NWJ.







[Table/Fig-6]: Longitudinal tibial axis in the mid sagittal plane; **[Table/Fig-7]:** Measurement of lateral/medial posterior tibial slope; **[Table/Fig-8]:** Measurement of medial tibial plateau depth.

deepest point of the medial plateau with measurement of the maximum vertical distance between the two parallel lines [11] [Table/Fig-8].

STATISTICAL ANALYSIS

The data were analysed using independent sample t-test. Chi square test was used to compare the difference of qualitative/categorical variables in 2 groups and Mann-Whitney U test was used to compare the continuous variables between the 2 groups. Association between age, sex, notch width index, medial and lateral posterior tibial slopes and MTPD without ACL tear (Group A) and with tear (Group B) was tested using Chi-square test and univariate odds ratio were calculated by drawing ROCs.

RESULTS

There were 100 patients in the study. Out of which 50 were in the control group which included 35 males and 15 females and 50 in tear group and consisted of 39 males and 11 females. Low femoral NWI was statistically significant in patients with ACL tear with a value of 0.29 ± 0.02 and a p-value of < 0.014 as opposed to patients without tear where it measured 0.30 ± 0.02. Age interval wise, it was statistically significant only in the age group of 31-45 years where it measured 0.28 ± 0.02 in Group B with a p-value <0.016 [Table/Fig-9]. The NWI was significant in females as compared to males in our study in the tear (0.30 ± 0.01) and without tear, however the value was higher than the overall NWI.

Notch Width Index	18-30 years	31-45 years	46-60 years	60 years and above
Without Tear (Group A)	0.3	0.31	0.3	0.32
With Tear (Group B)	0.291	0.28	0.29	0.3

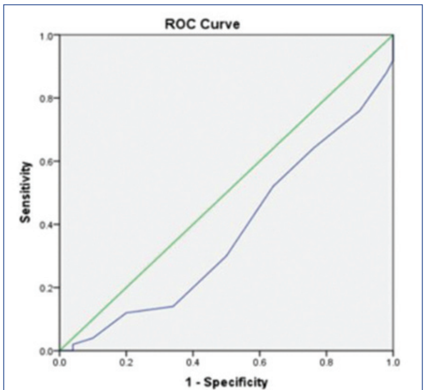
[Table/Fig-9]: Notch width index in different age intervals in patients without and with ACL tear.

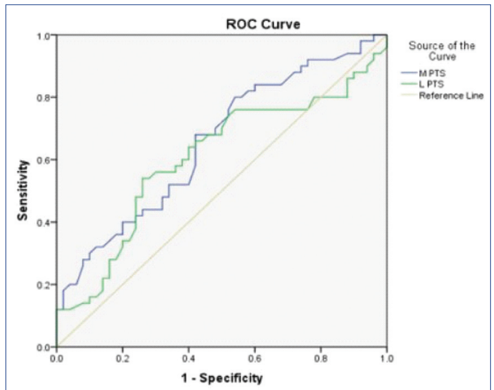
NWI depends on the notch shape (A, Ω, inverted U) which varies with age. In our study Ω shaped notch predisposed to ACL tear and was statistically significant. Twenty out of 50 patients without tear had omega shape (40%) and 36 out of 50 (72%) had tear. The shape of the notch was however not statistically significant in relation to gender. Omega shape showed 7.2 times more predisposition than A shape and 3.9 times to inverted U shape for ACL tear by calculation of odds ratio.

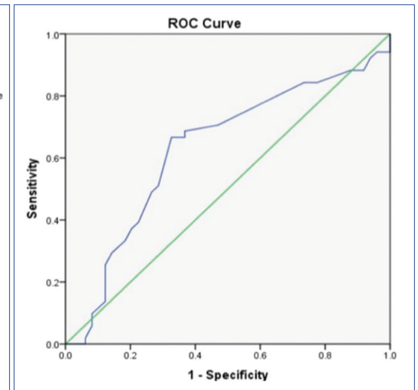
In our patients, increased MTPS was statistically significant with regards to ACL tear with a p-value of 0.008 and measured 9.3 ± 3.0° versus 7.2° in controls. LTPS was not significant for ACL tear and measured 7.0°± 3.4°. According to gender also the MTPS was more significantly associated with ACL tear in females [Table/Fig-10]. Age interval wise, there was no statistically significant difference between controls and the tear group with regards to the tibial slope angles.

Parameters	Group A (without tear)		Group B (with tear)	
MTPS (°)	Mean	SD	Mean	SD
Male	6.7	4.2	8.7	2.68
Female	8.3	2.2	11.3	3.5
Total	7.2	3.78	9.3	3.07
LTPS (°)	Mean	SD	Mean	SD
Male	5.9	2.5	6.3	2.9
Female	5.2	2.3	9.5	4.2
Total	5.7	2.5	7.09	3.47
MTPD (mm)	Mean	SD	Mean	SD
Male	2.45	0.69	2.40	0.7
Female	2.4	0.5	1.89	0.3
Total	2.44	0.65	2.25	0.65

[Table/Fig-10]: Measurements of medial and lateral posterior tibial slopes and medial plateau depth.







[Table/Fig-11]: ROC curve showing sensitivity and specificity related to notch width index; **[Table/Fig-12]:** ROC curve showing sensitivity and specificity related to posterior tibial slope of medial and lateral plateaus; **[Table/Fig-13]:** ROC curve showing sensitivity and specificity related to medial tibial plateau depth.

Decreased MTPD was not significant with p-value of <0.16 and measured 2.25 ± 0.65 mm. Age interval wise, MTPD was not statistically significant for any particular group, however females with shallower MPTD showed statistical significance with p-value of <0.006 and with a mean value of 1.89 ± 0.3 mm and in controls 2.4 ± 0.5 mm.

Univariate odds ratio was also calculated in our study and showed that the males showed 1.5 times more predilection for ACL tear as compared to females, likely due to more number of males in our study. Further increased MTPS was 2.3 times and increased LTPS 2.25 times more associated with tear with p-values of <0.043 and <0.046 and critical angle of 8.57 and 5.5 degrees respectively showing a sensitivity and specificity of 66% and 58% and 60% and 60%respectively. The omega shape as compared to A and inverted U had 7.2 and 3.9 times more predilection for ACL injury respectively. MTPD of less than 2.1mm was 4.1 times more indicative of ACL injury with a p-value of <0.001. According to univariate odds ratio, the NWI as a standalone was not a good predictor of ACL tear with less coverage in ROC [Table/Fig-11-13].

DISCUSSION

The main function of the ACL is to prevent posterior translation of the femur over the tibia during flexion-extension of the knee. It is the most commonly injured ligament in the knee with a common injury mechanism being exertion of varus and internal rotation force on tibia during knee hyperextension [13]. ACL injury occurs when an athlete pivots on the leg [2]. Many risk factors including anatomical, predispose to ACL injury. To our knowledge ours is the only MRI based Indian study which correlates ACL injury with multiple parameters; femoral intercondylar notch width and shape, MTPS, LTPS and MTPD all together in the same set of patients. Many studies have utilised only MRI [8,11,13], some both MRI and radiography [2].

The femoral intercondylar notch contains the intrinsic knee ligaments including ACL and PCL [14]. Various studies have shown relationship between narrow notch width as assessed by NWI and notch shape with ACL injury [15]. The anatomy of the notch is well assessed by MRI in both coronal and axial sequences with respect to various measurements and with calculation of NWI [8]. A study done by Gormeli CA et al., showed NWI of 0.22±0.008 in bilateral injured knees and 0.24±0.01 in unilateral injured knee [13]. In our study too, patients with ACL injury showed lesser NWI (0.29±0.02) as opposed to controls but NWI values were slightly more than the above study. Another study showed NWI at the level of popliteal groove to be 0.25±0.03 [8]. In one of the studies [16] the authors had quoted other studies [17-19] with critical NWI ranging from 0.19 to 0.26. In one study they did not find a relationship between a narrow intercondylar notch width and an ACL tear [20], however in our study there was a relationship between narrow notch width and ACL tear. Many studies have also compared the femoral notch width in males and females and have come to the conclusion that the notch width is less in females as compared to males [21]. Decreased NWI was significant in females as compared to males in our study.

In addition to notch width, the shape of the intercondylar notch has also been studied. The notch shape varies with age, with the A shape more common in childhood and adolescence and the Ω shape beyond the 3^{rd} decade [8]. This occurs due to the varus remodelling and degenerative changes. The type of shape of notch (A, Ω, inverted U in coronal plane) also predisposes to ACL injury, in our study the omega shape showed increased predisposition to ACL tear. In few studies the notch shape and width were measured in the axial plane [12,13,15], the notch shapes in axial plane being A, U and W with the A shaped notch more predisposed to ACL tear [16].

Various tibial parameters also predisposed to ACL injury including the tibial plateau slopes and tibial plateau depth. In an Eastern Indian study the tibial plateau angle varied widely from 6° to 24°, with the mean±standard deviation value 13.6°±3.5° [22].

An Indian study in which they had studied the effects of posterior tibial slope on noncontact ACL injury revealed mean MTPS of uninjured and injured pooled population was 7.73±3.20° and 8.73±2.26° respectively [5]. Similarly, LTPS of uninjured and injured pooled population was 4.68±2.75 and 5.85±2.68° respectively. In our study the MTPS of controls and injured ACL was 7.2±3.78° and 9.3± 3.07° respectively and LTPS was 5.7±2.5°and 7.09±3.47° respectively. Hence, both the plateaus were steeper in the injured population. On the contrary, our MTPS was steeper than LTPS as opposed to other studies [3] which was statistically significant with a p-value of <0.008. The p-value of LTPS was at border line (p<0.07), which was likely due to less no. of patients in our study and with more patients it would too become significant. According to gender, in our study the MTPS was significantly associated with ACL tear in females with a mean value of 11.3±3.5° and a p-value of 0.007. This is similar to one previous study which showed that MTPS was statistically significant in female patients in ACL injury [12]. One latest meta-analysis showed that both plateaus were associated with ACL injury regardless of sex [23].The critical value of MTPS in our study was 8.4° and of LTPS was 5.5°with a sensitivity and specificity of 66%, 58% and 60%and 6% respectively.

Age interval wise, both MTPS and LTPS were steeper in all the ACL injured group intervals but the results were not significant.

MTPD in our study was shallower in patients with tear and measured 2.25±0.65 mm as opposed to patients without tear 2.44±0.65 mm but was not statistically significant. Age interval wise it was also not statistically significant. The critical value below 2.12 mm showed 68% sensitivity and 64% specificity. Odds ratio calculation showed shallower MTPD to be 4.1 times more common in patients with tear. MTPD was also seen to be shallower in other studies in patients with ACL injury [24,25].

LIMITATION

There were few limitations of this study, one the sample volume was small with more numbers of males in the study as compared to the females and also unequal distribution of the subjects in different age intervals. Also, the different parameters were separately assessed for predisposition to ACL injury and were not compared to each other.

CONCLUSION

This study establishes the relationship between narrow femoral intercondylar notch, omega shape of femoral notch, shallow medial tibial plateau and steeper posterior tibial slopes more so the medial plateau with ACL injury in the given population. In our study females have narrower intercondylar notch and steeper and shallower medial tibial plateau as compared to the males. Knowledge of these parameters helps in risk stratification with insights into future non intervention and intervention strategies especially because of increasing interest in various sports activities.

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