Evaluation of anatomic risk factors using magnetic resonance imaging in non-contact anterior cruciate ligament injury

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ABSTRACT

Background: The purpose of our study was to compare the significance of the tibio-femoral morphological variables (notch width index, notch shape index, intercondylar notch angle, medial and lateral tibial slopes) in predicting non-contact ACL (anterior cruciate ligament) injuries and to compare these factors between genders in South Asian population. The author hopes to provide a comprehensive analysis on the risk factors which would help in betterment of the patients at danger for anterior cruciate ligament injury.

Materials and methods: A total of 110 MRI knees of patients with 55 subjects of noncontact ACL injury and 55 age and sex matched controls were included in a retrospective study. Notch width index, notch shape index, intercondylar notch angle were assessed in axial and coronal MR imaging along with medial and lateral posterior tibial slopes. Morphology of the notch was also assessed.

Results: ACL injured group were found to have a statistically significant narrow notch width index and decreased intercondylar notch angle with increased lateral posterior tibial slope. Type-A notches were found to have increased risk of having ACL injuries. Gender comparative results showed no statistically significant differences.

Conclusion: ACL tears are associated with decreased notch width index, intercondylar notch angle and increased lateral posterior tibial slope. Type-A notches are seen to have increased risk for ACL injuries.

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1. Introduction

Anterior cruciate ligament (ACL) tears account for the most reported ligament injuries in literature. Increased involvement in sports activities has led to a recent surge in the incidence of ligament injuries in and around knee joint over the recent decades. Non-contact anterior cruciate ligament injuries occur without physical contact.^{1–3} The mechanism of varus and internal rotation force on the tibia during knee hyperextension is often implicated in these injuries. The ligament being vital in knee stability produces anterior and rotational instability in cases of deficiency.⁷

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Anatomic variations within individuals may predispose to ligament rupture. ACL injuries and its association with variations in bony anatomy around the knee are studied in literature.^{4–6,12–29} Understanding of the femoral and tibial bony anatomy fosters an increased awareness regarding the predisposition for these injuries. The intercondylar notch width and its morphology on the femoral side and the posterior tibial slope in the tibial part all have been reported as risk factors for ACL injuries. Currently, literature exist supporting the role these morphological parameters^{13–17,27} and those which don't.^{4–6} Most of the present studies focus on notch width index and the posterior tibial slope. The role of the intercondylar notch angle, Notch shape index and morphology of the same are poorly understood in association with the risk of ACL injuries.

Over the decades though there has been significant leaps in the field of ligament reconstruction but it still causes significant health impairment and has high economic repercussion.^{8,9} With these elements are taken into account, the identification of the possible predictive risk factors in ACL injuries gains significance.¹⁰ The

literature currently available describe the anatomical variations in the Caucasian population. Furthermore, they lack clarity in analysing the intercondylar notch morphology and its anthropometry. The aim of our study was to evaluate the association between ACL injuries with tibial and femoral morphologic parameters using magnetic resonance imaging in South Asian population. The author hopes to provide a comprehensive analysis on the risk factors which would help in betterment of the patients at danger for anterior cruciate ligament injury.

2. Materials and methods

The study included a total of 110 subjects. The test group included 55 patients with noncontact unilateral ACL injuries from August 2017 to August 2018. The control group of 55 subjects was selected retrospectively from MR (magnetic resonance) imaging examination with intact cruciate ligaments. Control group included patients being evaluated with MRI for knee injuries and found to have normal anatomy in the MRI report. The test and control groups were age and sex matched as variations in the injury patterns and prevalence with respect to the above variables have been recorded in previously published literature.^{35,36}

Measurements in MRI: MR imaging was performed using 1.5 T scanner with proton density fat suppression, coronal plane, 4 mm slice thickness, 0.5 mm space, matrix of 352×224 , 13.6 ms echo time and repetition time of 1700–2000 ms. Sagittal and axial images, thickness of 3.5 mm, space of 0.5 mm, matrix of 352×224 , echo time of 86 ms, repetition time of 4200 ms with the knees in near normal extension. Axial, sagittal and coronal images were obtained for all examined knee MR images.

The medial and lateral posterior tibial slopes were measured in sagittal MR slices. Axial and coronal cuts were used to assess the

intercondylar notch. The MR axial T2 weighted image slice with the popliteal groove is selected.¹¹ Posterior condylar reference line is drawn tangent to the lowermost points of medial and lateral condyles. The intercondylar depth is defined as the perpendicular distance from the reference line to the top of the notch. The notch width is measured at the lowermost part of the notch that corresponds to the narrowest distance.¹⁸ The sum of the notch width, the medial and the lateral condylar width at the same level provided the bicondylar width. The notch angle is formed between the most inferior aspect of the notch at the medial and lateral condyles and the top of the intercondylar notch¹¹ (Fig. 1). The coronal image chosen in every knee was the cut in which the ACL and PCL (posterior cruciate ligament) cross one another as close as possible to the mid-substance of the anterior cruciate ligament.¹² The technique used in axial cuts is again employed in the coronal slices to get the values.

The posterior tibial slope is measured in the sagittal MR images employing the method described by Hashemi et al.¹³ The central slice containing the tibial attachment of the PCL, intercondylar eminence and with the anterior and posterior cortices appearing as concave shape was selected first. The sagittal longitudinal axis was determined by joining the midpoints of two separate lines in diaphysis. It's then overlapped in the slices containing the medial and lateral plateau. The angle between the perpendicular to the tibial longitudinal axis and the line joining the top points on the anterior and posterior cortices of either plateau gives the medial/lateral PTS (posterior tibial slope). T1 weighted cuts were used to evaluate the tibial slope (Fig. 2). The morphology of the notch was assessed in axial image^{14,15}. The knees in the study were classified as A, U, and W types (Fig. 3).

2.1. Statistical analysis

Statistical analysis was performed with XLSTAT® Windows

Fig. 1. Measurement of intercondylar notch parameters. Notch width is the distance between points B and C in the axial (a) and coronal (b) slices along the line drawn at the lowest point of the notch parallel to the posterior condylar reference line. AD represents the intercondylar width. Intercondylar notch angle is formed between the most inferior aspect of the notch at the medial and lateral condyles and the apex of the intercondylar notch. (c) and (d) depicts the axial and coronal notch angles.

Fig. 2. Posterior tibial slope. The angle between the perpendicular to the tibial longitudinal axis and the line joining the top points on the anterior and posterior cortices of either plateau gives the medial/lateral PTS (posterior tibial slope). (a) Depict medial posterior tibial slope and (b) depicts lateral posterior tibial slope.

Fig. 3. Notch morphology. Depicts the Type-A notch which is narrowed in all dimensions and (b) depicts the U type notch with notch dimensions.

software. MR images acquired were analysed using tools for measuring distances in millimetres and angles, with Radiant Dicom software. Two orthopaedicians independently measured the parameters. These were completely deidentified and presented in random order. With this data, we evaluated the Interobserver, and intraobserver agreement. For comparing intraobserver and Interobserver agreement, we used the intra-class correlation coefficient as described by Shrout and Fleiss.³⁴ These consensus measures were used in all the analyses. We calculated the mean values, standard deviation of all the values using one-way analysis of variance, and Pearson's correlation methods. Normality of the test and control variables was assessed with Shapiro-Wilk test. The means of the variables were expressed as mean $\pm$ standard deviation. Mann Whitney U test (non-parametric variables) and Student's t test were used to evaluate the statistical significance ($p < 0.05$). Chi-square test was used when percentages were used in the study.

3. Results

The test group ($n = 55$) had a mean age of 29 and consisted of 33

males and 22 females. The control consisted of 55 patients including 33 males, 22 females with average age of 31 (Table 1). The mean axial notch width index was found to be 0.272 ± 0.026 in the ACL injured patients and 0.285 ± 0.036 in the control group. The mean coronal notch width index was 0.263 ± 0.029 and 0.274 ± 0.032 respectively. Mean NWI in both the views was found to be significantly lower in patients with injured ACL in comparison with the control (Table 2). A significant difference was found in the notch angle measurements of the test group and the control group. The mean angle was found to be 49.30 ± 5.40 in axial and 57.6 ± 8.05 in coronal images of test patients. Mean control group notch angles were 52.78 ± 5.82 and 61.71 ± 6.84 axial and coronal slices respectively. The shape index averaged 0.661 ± 0.108 in axial and 0.709 ± 0.124 in coronal in patients with intact ACL and 0.624 ± 0.078 and 0.700 ± 0.114 in injured. The mean angle of the posterior tibial slope on the medial plateau in the ACL injured and in the control was $7.37 \pm 2.83^\circ$ and $6.72 \pm 2.28^\circ$. P value of >0.05 suggested there was no statistical significance. The mean lateral posterior tibial slope in ACL injured patients and in the control were $7.87 \pm 3.34^\circ$ and $5.97 \pm 2.40^\circ$ respectively with a p value of suggesting statistical significance (Table 2). Gender comparison

Table-1

Age and sex distribution.

Parameter	Cases (n = 55)	Control (n = 55)	p value
Sex,			
Male	33	33	>0.05
Female	22	22	
Age,*			
Male	32.27	31.72	0.60
Female	36.95	35.81	0.78
Total	34.14	33.36	0.68

*Mean values are showed, P value < 0.05 is significant.

Table-2

Comparison between ACL-Injured and Non ACL-Injured Individuals ACL; anterior cruciate ligament, PTS; posterior tibial slope Statistical significance p < 0.05.

Variables	Value		P value
	ACL-Injured group	Non injured group	
Coronal,			
Notch width index	0.263 ± 0.029 Min:0.202 Max:0.339	0.274 ± 0.032 Min:0.214 Max:0.353	<0.05
Notch shape index	0.70 ± 0.114 Min:0.476 Max:1.00	0.709 ± 0.124 Min:0.511 Max:0.705	>0.05
Notch angle ^e	57.6 ± 8.05 Min:40.14 Max:74.54	61.71 ± 6.84 Min:46.25 Max:78.39	<0.01
Axial,			
Notch width index	0.272 ± 0.026 Min:0.221 Max:0.337	0.285 ± 0.036 Min:0.232 Max:0.389	<0.05
Notch shape index	0.624 ± 0.078 Min:0.464 Max:0.833	0.661 ± 0.108 Min:0.473 Max:0.933	>0.05
Notch angle ^e	49.30 ± 5.40 Min:39.47 Max:62.1	52.78 ± 5.82 Min:40.81 Max:65.77	<0.01
Sagittal,			
Medial PTS	7.37 ± 2.83 Min:1.6 Max:17	6.72 ± 2.28 Min:2.39 Max: 10.9	>0.05
Lateral PTS	7.87 ± 3.34 Min:2.25 Max:20.71	5.97 ± 2.40 Min:0.85 Max:10.75	<0.05

revealed no statistical significant difference in the above parameters (Table 3).

Type –A notch was seen in 81.8% and of the test and 60% of control group. The percentage of the type-U notch was 18.2% and 40% respectively. Of the 78 subjects with type-A intercondylar notch and 32 with type-U notch 57.6% and 31.2% had ACL tears respectively (Table 4).

4. Discussion

The significant findings of this study were (1) Type-A intercondylar notches were seen to be associated with increased risk of ACL injuries; (2) Intercondylar notch angle and NWI were significantly lower in ACL injured group; (3) Increased lateral posterior tibial slope may be associated with an increased risk of ACL injuries. Intercondylar notch angle and notch morphology appears to have a more considerable clinical relevance as a risk factor for anterior cruciate ligament injuries.

The femoral intercondylar notch dimensions are often commented while exploring the anatomic risk factors of non-contact ACL tears. In literature it's often assessed with NWI. Little has been studied about the NSI and the intercondylar notch angle^{11,14,16} and the morphology.^{14,15,17} On top of that there is a lack of clarity in these literature where they assess the variables in a single plane (axial or coronal) and compare an axial value with coronal or vice versa.¹⁷ In this study we have assessed the intercondylar notch in both axial and coronal planes to reveal the subtle changes present.

Our study results regarding the NWI appear to be in accordance with previous studies.^{14,18–20,33} The NWI was assessed in two

Table-3

Gender wise comparison PTS; posterior tibial slope, NWI; notch width index, NSI; notch shape index, N; number, Statistical significance p < 0.05.

Variable	N	Mean	Standard deviation	Test value	P Value
Medial PTS					
Male	33	7.154	2.792	T = 0.692	0.492
Female	22	7.696	2.937		
Lateral PTS					
Male	33	8.225	3.588	T = –0.955	0.344
Female	22	7.347	3.022		
Axial Notch angle					
Male	33	49.47	5.68	T = –0.280	0.781
Female	22	49.05	5.07		
Coronal Notch angle					
Male	33	57.90	8.47	T = –0.333	0.740
Female	22	57.16	7.08		
Axial NWI					
Male	33	0.276	0.027	T = –1.404	0.166
Female	22	0.266	0.022		
Coronal NWI					
Male	33	0.264	0.031	T = –0.240	0.811
Female	22	0.262	0.028		
Axial NSI					
Male	33	0.634	0.079	T = –1.143	0.258
Female	22	0.609	0.076		
Coronal NSI					
Male	33	0.708	0.122	T = –0.651	0.518
Female	22	0.688	0.102		

Table 4

Notch morphology.

ACL Status				
Notch type	Tear	Intact	Total	P value
Type A	45	33	78	0.041
Type-U	10	21	31	
Type-W ^a		1	1	
Total	55	55	110	

P value: <0.05(χ² test).^a W type notch included in type U for calculations.

separate planes axial and coronal. NWI was found to be significantly decreased in ACL injured group (Table 2). Hoteya et al. recommended a cut off of 0.25 for coronal NWI wherein he reviewed patients with bilateral ACL injuries.¹⁸ Our study dealt with unilateral ACL injuries and they may possibly explain the differences. Female subjects were seen to have a narrow NWI in comparison to males (Table 3) but, were not statistically significant.

Palmer et al. recognized the association of narrow intercondylar notch width and ACL injuries¹⁹. Anderson et al. found statistically significant decrease in NWI and notch opening angle in ACL injured subjects using computed tomography. The morphology of the notch was first documented by him.¹⁴ Souryal et al. described the measurement of intercondylar notch width and NWI on plane tunnel view radiographs and revealed correlation between decreased notch width and ACL injuries.²⁰ Herzog et al. revealed that the cadaveric and MRI notch measurements were similar, whereas that of the radiographic measurement was significantly different.⁴ Though there are studies that associate the influence of notch width on ACL tears, there are some which doesn't.^{4,6,21–23} Furthermore, some consider absolute notch width rather than notch width index as a risk factor for ACL injuries. Intercondylar notch angle is a poorly investigated anatomic risk factor in ACL related literature. A cut off of 50° was suggested by Anderson et al. who associated decreased angle with increased risk of having ACL injuries.¹⁴ Alentorn et al. documented notch angle and its association with risk of having ACL tears.¹⁶ Stein et al. studied same in osteoarthritic knees accepting the cut off by Anderson et al. and observed no significant difference between test and control

Fig. 4. (a) Represents the distribution of the notch angle (NA) and notch width index (NWI) in Type-A notch and (b) depicts the same in Type-U notch. Type-A notches are seen to have narrower NWI and notch angles.

groups.¹¹ Shape of the notch and intercondylar notch angle are interlinked. Our study revealed the angle to be significantly less in ACL injured group (Table 2). Type A notch is seen to have narrower angle in both axial and coronal images in comparison to the U type. Gender comparison revealed no significant differences between the sexes (Table 3). Our study didn't detect a significant difference in notch shape index between the two groups.

Notch morphology was commented initially by Anderson et al.¹⁴ Later, Van eck intra-operatively assessed the notch morphology and suggested that three types are seen clinically.¹⁵ Type-A was defined as a narrow notch (narrowed in all dimensions) in comparison to Type-U and W. Al-Saeed et al. reported association of Type-A notch with ACL injuries and found no correlation between a low NWI and presence of ACL tears.¹⁷ Bouras et al. showed that Type A stenotic femoral notch can be a valuable predictive factor for ACL injury.³⁷ Our study found that the Type-A notches were associated with increased risk of ACL injuries which is in union with previous study (Table-4). Also NWI was significantly lower in ACL injured group. The Type-A notches were seen to have a smaller notch opening angle and a smaller NWI when compared with U types. The scatter diagram depicts the variations between the two types (Fig-4). The prevalence of Type-A notch was 81.8% and 60% in ACL injured and non-injured group respectively.

In our study the lateral PTS was significantly larger in the ACL injured group (Table 2). The mean medial posterior tibial slope though was slightly higher in patients with ACL injuries was not statistically significant. This study agrees with Stijak et al.²⁴ and other studies which noted an increase in lateral PTS as an anatomic risk factor for anterior cruciate ligament injuries.^{13,25} Association of the posterior tibial slope as a risk factor for sustaining non-contact ACL injuries are documented in literature. Brandon et al. found higher posterior tibial slope in patients with ACL injury.²⁶ Zeng et al. also similarly appreciated a significant relation between medial and lateral posterior tibial slope and risk for ACL injuries.²⁷ Hashemi et al. recorded an increase in both medial and lateral posterior tibial slope ACL deficiency group.¹³ Hudek et al. observed no statistical difference between the injured and non-injured groups in respect with increased PTS.²⁸ The posterior tibial slope and knee kinematics are often interlinked. Dejour et al. in his study on ACL injured patients noted an increase in 6 mm of anterior tibial translation and 3 mm in lachmans with 10° increase in posterior tibial slope.²⁹ Marounane et al. found an increase in forces across the anterior cruciate ligament from 181 to 317 N and to 460 N when the posterior tibial slope was increased by 5° and 10° respectively.³⁰

Shelbourne et al. appreciated a linear relationship between the posterior tibial slope and forces across the cruciate ligaments and anterior tibial translation.³¹ Griffin et al. documented a 3.6 mm anterior than usual tibial resting position in subjects with increased posterior tibial slope.³²

In clinical practice, the findings of the present study would help in identifying people at risk and provide appropriate prophylactic measures. People with unilateral ACL rupture should be investigated and identification of Type-A notch in them should prompt proper care.

Limitations of present study: Our study was done on Indian population. Though ethnicity affects the geometry of knee and the distal femoral intercondylar notch morphology, the same variables should apply to them. Apart from the anatomic risk factors there are other several variables like as hormonal, cognitive function, genetic, gender, weight and activity status. These factors were not ruled out in this study. One of the limitations of our study is the small sample size. Further analysis of these parameters with a larger sample size is needed to validate our findings.

5. Conclusion

The present study aimed to compare the tibial and femoral morphologic variables between ACL deficient group and subjects with intact ACL. ACL tears are associated with decreased notch width index, intercondylar notch angle and increased lateral posterior tibial slope. Type-A notches are seen to have increased risk for ACL injuries. We would recommend cut off values of 0.270 and 0.278 for coronal and axial NWI and 52.04° for axial and 58.7° for coronal intercondylar notch angle. This would help in identification of people at risk for ACL injuries.

Conflicts of interest

No conflicts of interest.

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