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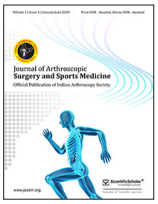

Original Article

Triangular notch morphology in young males linked to increased risk of non-contact anterior cruciate ligament tears

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ABSTRACT

Objectives: The knee joint, critical for human mobility, faces a heightened risk of injuries, with non-contact anterior cruciate ligament (ACL) tears occurring at a notable rate. This study aims to investigate the relationship between femoral intercondylar notch (ICN) morphometry, assessed through magnetic resonance imaging (MRI), and non-contact ACL tears. Given the anatomical intricacies of the femoral ICN, understanding its morphometry becomes imperative. The study also considers sex-based differences, the influence of individual height, and various notch shapes, including triangular, "U," and omega configurations.

Materials and Methods: A cross-sectional study involving 100 patients undergoing knee MRI examinations was conducted. Inclusion criteria encompassed patients over 18 years with a history of trauma and clinical evidence of knee joint instability. Measurements of femoral ICN were made using a 3 Tesla MRI scanner, with parameters such as notch depth, width, ICN width index (ICNWI), notch angle, and alpha angle (AA) being evaluated in axial and coronal planes.

Results: Among 100 cases of non-contact ACL injuries, MRI examination revealed distinct ICN shapes: 24% triangular, 34% omega-shaped, and 42% U shaped. Triangular notches were more prevalent in young adults, with a mean age of approximately 25 years. Analysis of femoral ICN dimensions showed no significant associations for notch depth, width, ICNWI, notch angle, and AA. However, a significant difference in age was noted for the triangular-shaped ICN.

Conclusion: Our study suggests a notable association between a triangular-shaped ICN, young age, and male individuals with a higher prevalence of non-contact ACL tears.

Keywords: Anterior cruciate ligament, Femoral intercondylar notch, Instability, Knee, Non-contact

INTRODUCTION

The knee joint, integral to human mobility, is particularly vulnerable to injuries, with ligamentous tears occurring at an alarming rate of 15%.[1] Among these, the anterior cruciate ligament (ACL) is especially critical, accounting for up to 56% of all knee ligament injuries. The vulnerability of the ACL has been closely associated with the anatomical characteristics of the femoral intercondylar notch (ICN).[2] Given its significance, a detailed investigation of the femoral ICN's morphometry is essential to understanding its role in ACL injuries.

Magnetic resonance imaging (MRI), known for its precision in soft tissue imaging, serves as an invaluable tool in this study to explore the relationship between femoral ICN measurements and non-contact ACL tears. MRI's high-resolution imaging allows for an in-depth examination of the knee joint's intricate structures, making it a cornerstone in clinical diagnostics and research.[3]

The shape and dimensions of the ICN have been previously linked to ACL injury risk. Studies have demonstrated that narrower and more constricted ICNs, as well as specific notch shapes, such as the triangular notch, are associated with a higher incidence of ACL tears.[4] Furthermore, sex-based differences in ICN morphology and the influence of an individual's height on notch dimensions add complexity to this relationship. Notch shapes, including triangular, "U," and omega configurations, have been identified, with triangular notches being particularly implicated in ACL injuries.[5]

The ACL, although an intracapsular ligament, is not impervious to injury. Its unique biomechanical characteristics, which include the division into anteromedial and posterolateral bundles, contribute to its susceptibility to sprains and tears during knee movement. The ACL's poor vascularity, especially in its mid-substance, complicates the healing process following injury.[6]

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Mechanisms of ACL sprains and tears are multifactorial, involving both contact and non-contact scenarios. While contact mechanisms, such as valgus-abduction injuries and hyperextension from direct blows, are well documented, non-contact mechanisms predominate, particularly in athletes. These include the pivot shift mechanism and hyperextension injuries, which are more common in females.[7] However, the role of femoral ICN morphology in predisposing individuals to these non-contact ACL injuries remains a critical area of exploration.

This study hypothesizes that specific femoral ICN morphologies, particularly the triangular notch shape, are associated with a higher prevalence of non-contact ACL tears. By analyzing parameters such as the alpha angle (AA), femoral ICN width (ICNW), notch angle, notch width index (NWI), notch shape, and depth, we aim to uncover correlations that could provide valuable insights into the biomechanical factors predisposing individuals to ACL injuries.

This study seeks to contribute to the existing body of knowledge by examining how these anatomical variations may influence the risk of ACL injury, potentially informing improved diagnostic and preventive strategies.

MATERIALS AND METHODS

This study was a prospectively designed cross-sectional study of 50 patients. Participants were recruited from the outpatient and inpatient departments undergoing MRI knee examinations in the radiodiagnosis department. The study was conducted after obtaining ethical approval from the Institutional Review Board (IRB). All participants provided written informed consent prior to enrollment in the study.

Patient selection

Patients were selected based on the specific inclusion and exclusion criteria to minimize bias. Inclusion criteria focused on patients over 18 years with a history of trauma and clinical evidence of knee joint instability who were willing to undergo radiographic and MRI examination before surgery. Exclusion criteria included patients under 18 years, those with significant joint degeneration, arthritic disorders, congenital deformities of the knee joint, and those with a history of previous knee surgeries or known ligament injuries.

Mechanism of injury and non-contact ACL tears

Detailed patient history was obtained to document the mechanism of injury, ensuring that only those with non-contact ACL injuries were included. The mechanism was verified through clinical interviews, focusing on the absence of direct trauma or contact during the injury event, which was crucial to distinguish non-contact ACL tears. Gender differences in injury mechanisms were considered to account for potential biases.

MRI evaluation

After obtaining informed consent and a detailed clinical history, patients underwent knee MRI evaluation. Intercondylar measurements were performed in standard planes using a 3 Tesla MRI scanner (Siemens Magnetom Spectra, Germany) with a dedicated knee joint coil. Patients were positioned supine with a slight knee flexion of 5–10°.

MRI sequence and parameters

Various measurements were planned on axial T2-weighted, proton density–fat-saturated (PD-FS), sagittal T2-weighted, T1, PD-FS, and coronal T2-weighted sequences. Parameters included a field of view of 16 × 16 cm, 256 × 256 matrix size, 3 mm slice thickness, and a flip angle of 25–40°.

Femoral morphologic parameters

Measurements were taken in axial and coronal planes, as described by Stein *et al*.,[7] at sections showing the popliteal groove. This included the dorsal condylar reference line and femoral ICN measurements. In both axial and coronal planes, femoral morphological parameters were measured at the level of the popliteal groove. In the axial plane, a posterior bicondylar line was drawn, and a perpendicular line was extended from the apex of the ICN. The intercondylar height (line B) was defined as the distance from the apex of the ICN to the bicondylar line (line A) [Figure 1a]. The intercondylar width (line C) was measured at the anterior third of the intercondylar height (line B) within the axial plane [Figure 1a]. At the same level, the widths of the lateral and medial condyles (lines D and E) were recorded [Figure 1b]. The total condylar width was calculated as the sum of the intercondylar width, medial condylar width, and lateral condylar width. This methodology was similarly applied to obtain measurements in the coronal plane [Figure 1c and d]. The NWI was then calculated as the ratio of the ICNW to the total condylar width.

Statistical analysis

Descriptive statistics (mean and standard deviation) were calculated for quantitative data, while frequency and percentage were used for categorical data. Inferential methods, including the Chi-square test and Student's unpaired *t*-test, were employed, with a significance level set at $P < 0.05$. Data analysis was performed using the Statistical Package for the Social Sciences 2.0 version.

RESULTS

Our investigation enrolled 100 patients with clinically and radiologically confirmed non-contact ACL injuries. Participants' ages ranged from 17 to 48 years, with a mean age of 31 ± 9.04 years. The study showed a male predominance, with 52 males and 48 females.

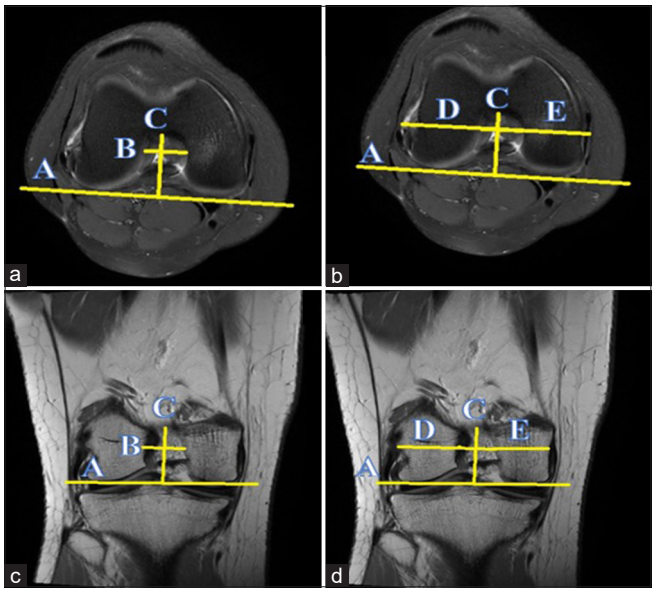

Figure 1: Magnetic resonance images depicting the method used to obtain the femoral measurements in the axial plane. (a) The intercondylar height (line B) was the distance from the top of the intercondylar notch to the bicondylar line (line A). The intercondylar width (line C) was obtained at the anterior third of the intercondylar height (line B). (b) At the same level, the width of the lateral and medial condyles (line D, E) was obtained. (c and d) The same method was used to collect these measurements in the coronal plane.

Notch morphometry

Upon MRI examination, femoral ICN shapes were categorized as follows: 24 cases with a triangular notch, 34 with an omega-shaped notch, and 42 with a U-shaped notch. Triangular notches were more frequently observed in younger adults, with a mean age of approximately 25 years [Table 1].

Notch dimensions

The analysis of femoral ICN dimensions provided the following results:

1. The mean notch depth was 3.42 ± 0.35 cm, with a range of 2.6–4.12 cm. Despite these measurements, no significant correlations or associations with other variables were found.
2. The mean notch width was 2.30 ± 0.33 cm, ranging from 1.48 to 3.2 cm. Similarly, this parameter showed no significant associations, suggesting that variations in notch width may not play a crucial role in non-contact ACL injuries.
3. The mean ICNW index (ICNWI) was 0.32 ± 0.04, and no statistically significant association was observed with other parameters or outcomes.
4. The mean notch angle was 48.53 ± 7.57°, with a range from 35.4 to 65.6°. This variable also lacked significant associations, indicating that the notch angle alone may not be a decisive factor in ACL injury risk.
5. The mean AA was 47.92 ± 3.79°, ranging from 35.3 to 54.6°, with no significant correlations identified.

Table 1: Intercondylar notch shapes among the participants.

Notch shape	Number	Percentage
Triangular	24	24
Omega	34	34
U	42	42
Total	100	100

Chi-square testing revealed a non-significant $P = 0.6369$, suggesting no association between gender and ICN shapes. Further analysis using the Student's unpaired *t*-test indicated a significant difference in age concerning the triangular-shaped ICN. Specifically, this notch shape was more prevalent in younger adults, with a mean age of 25 years. For other morphometric parameters, no significant differences were observed, highlighting the complexity of factors contributing to non-contact ACL injuries [Table 2].

DISCUSSION

The primary finding of our study is the significant association between a triangular-shaped femoral ICN and non-contact ACL injuries in young male patients. This result aligns with existing literature, suggesting that specific notch morphologies may predispose individuals to ACL injuries.[8] However, other measured parameters, such as ICNW, ICN angle (ICNA), AA, and ICNWI, did not show significant correlations with ACL injury risk.

Previous research has extensively explored the relationship between femoral ICN morphology and ACL injuries, albeit with varying conclusions. Palmer,[9] in their seminal 1938 study, first proposed that a stenotic ICN is associated with an increased risk of ACL tears and sprains. This early observation laid the groundwork for subsequent studies, which largely supported this association. Anderson *et al.*,[10] Ireland *et al.*,[11] Shelbourne *et al.*,[12] Lund-Hanssen *et al.*,[13] and Souryal and Freeman[14] all found that femoral notch stenosis was a significant risk factor for ACL injuries, independent of gender. Al-Saeed *et al.*[15] further investigated notch morphology and width index, concluding that while a stenotic notch was indeed a risk factor, a reduced NWI did not have a significant impact on ACL injury risk.

Our findings regarding the triangular notch shape align with the general consensus of these studies, highlighting the importance of notch morphology in ACL injury predisposition. The prevalence of this specific notch shape in younger patients suggests that developmental or age-related factors may influence notch morphology, thereby affecting ACL vulnerability. However, the lack of significant

Table 2: Comparison between triangular notch and other shapes.

	Triangular shape				Other shapes				*P*-value	Inference
	Mean	SD	Min	Max	Mean	SD	Min	Max		
Age	25.42	8.44	17	43	32.76	8.58	17	48	0.0125	S
ND (cm)	3.45	0.37	3.01	4.22	3.55	0.38	2.6	4.23	0.4468	NS
NW (cm)	2.39	0.30	1.9	2.98	2.37	0.32	1.48	3.2	0.8134	NS
NWI	0.33	0.04	0.2639	0.3835	0.32	0.04	0.2349	0.4360	0.3099	NS
NA (degrees)	52.57	7.08	37.8	58	48.43	6.83	35.4	65.6	0.0757	NS
Alpha angle (degrees)	47.53	3.93	43.7	54.6	48.05	3.79	35.3	53.1	0.6864	NS

SD: Standard deviation, Min: Minimum, Max: Maximum, ND: Notch distance, NW: Notch width, NA: Notch angle, NWI: Notch width index, NS: Not significant, S: Significant

associations with other morphometric parameters in our study contrasts with earlier findings, particularly those that emphasized the role of notch width and angle.

Contradictory results have also been reported in the literature. Herzog *et al*.,[16] using radiographic and MRI measurements, did not find significant differences in notch dimensions among athletes with chronic ACL tears, challenging the notion that notch morphology is a consistent predictor of ACL injury. Similarly, Stijak *et al*.[17] found no significant differences in NWI or notch shape between injured and control groups, suggesting that other factors, possibly biomechanical or genetic, may play a more critical role in ACL injury risk.

Our study adds to this ongoing debate by suggesting that while notch shape, particularly the triangular configuration, maybe a relevant factor, other traditionally measured parameters such as ICNW, ICNA, and ICNWI might not be as influential as previously thought. The age-specific association observed in our study further complicates the picture, indicating that younger individuals with certain notch shapes might be more susceptible to ACL injuries, potentially due to differences in bone and ligament development.

Despite these insights, our study has several limitations. The relatively small sample size, dictated by time constraints, limits the generalizability of our findings. In addition, the absence of robust gender-based analysis due to the small number of female participants restricts our ability to draw definitive conclusions about sex-specific differences in notch morphology. Furthermore, the lack of established reference values for the parameters we measured complicates the interpretation of our results. The scarcity of studies focusing on the Indian population also highlights the need for further research to validate these findings within this demographic.

In conclusion, our study underscores the significance of triangular notch morphology in the context of non-contact ACL injuries, particularly in young males. However, it also raises important questions about the role of other morphometric parameters, suggesting that ACL injury risk may be influenced by a complex interplay of anatomical, developmental, and possibly genetic factors. Future research with larger, more diverse populations and standardized reference values is essential to further elucidate these relationships and enhance our understanding of ACL injury mechanisms.

CONCLUSION

Our study identifies a significant association between triangular femoral ICN morphology and non-contact ACL injuries, particularly in young male patients. While this finding aligns with previous research emphasizing notch shape as a risk factor, other measured parameters like notch width, angle, and width index did not show significant correlations. These results suggest that ACL injury risk may be more closely linked to specific notch shapes rather than general morphometric dimensions.

Author contributions: AMR, VUK, CD, and RD: Concepts, design, definition of intellectual content, literature search, clinical studies, experimental studies, data acquisition, data analysis, statistical analysis, manuscript preparation, manuscript editing, review, and final approval.

Ethical approval: The research/study approved by the Institutional Review Board at Jawaharlal Nehru Medical College Institutional Ethics Committee on Human Subjects Research, Jawaharlal Nehru Medical College, Belagavi, number MDC/DOME/243, dated December 24, 2019.

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