

Femoral Notch Morphology and Its Association with Anterior Cruciate Ligament Injury: An MRI Study

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ABSTRACT

Introduction: The anterior cruciate ligament is a critical stabilizer of the knee joint, and its injury is associated with significant morbidity. This study evaluated the association between the femoral intercondylar notch morphology and anterior cruciate ligament injury on MRI of the knee joint.

Methods: This retrospective case-control quantitative study included 112 patients, comprising 56 cases with complete anterior cruciate ligament injuries and 56 controls with normal anterior cruciate ligaments. Measurements of femoral notch shape, notch width, notch width index, notch angle, and alpha angle were done on MRI images, and their association with anterior cruciate ligament injury was analyzed. Statistical analysis included chi-square and independent sample t-tests, and a p-value of < 0.05 was considered significant.

Results: Type A notches were significantly associated with anterior cruciate ligament injuries, with 67.5% of type A notch shapes having injury compared to 40.2% in non-A notch shapes ($p = 0.006$). Anterior cruciate ligament-injured patients had narrower mean notch widths (2.01 ± 0.20 cm vs. 2.14 ± 0.22 cm, $p = 0.001$) and lower notch width indexes (0.27 ± 0.02 vs. 0.29 ± 0.02 , $p=0.000$) when compared to normal anterior cruciate ligaments. Anterior cruciate ligament injury was seen in 73% of patients with notch stenosis. The mean notch angle was significantly lower in anterior cruciate ligament-injured individuals ($52.03^\circ \pm 6.05^\circ$ vs. $54.72^\circ \pm 6.69^\circ$, $p=0.028$), while the alpha angle showed no significant differences.

Conclusions: Narrow notch width, lower notch width index, and notch angle, and type A notch shape are associated with ACL injuries.

Keywords: *Alpha Angle; Anterior Cruciate Ligament; Notch Angle; Notch Shape; Notch Width*

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INTRODUCTION

The anterior cruciate ligament (ACL) is one of the main stabilizers of the knee joint and one of the most commonly injured structures in the knee. An ACL tear often leads to knee instability, increasing the risk of damage to other structures such as the menisci, which can eventually result in secondary osteoarthritis. The femoral intercondylar notch, where the ACL is located, has been studied in many ways to understand whether its morphometric variations are associated with ACL injuries. Some of the morphometric variables include notch width, notch width index, notch area, notch shape, outlet dimensions, notch angle, and alpha angle.¹

Understanding the variations in femoral notch morphology can help in identifying anatomical risk factors for ACL injuries. Stature may also influence femoral notch morphology. So countries like Nepal, with populations of shorter stature, are more prone to ACL injuries. Additionally, factors such as a high number of road traffic accidents and an increasing number of youths involved in contact sports contribute to the increasing prevalence of ACL injuries in Nepal. Despite this, limited research has been done in Nepal to study the association between femoral notch morphology and ACL injuries, highlighting the need for such studies to develop targeted prevention strategies and tailored rehabilitation and treatment protocols for the Nepalese population.²

The general objective of this study is to evaluate the association between the femoral intercondylar notch morphology (notch width, notch width index, notch angle, and alpha angle) and ACL injury on MRI of the knee joint.

METHODS

This study was a retrospective case-control quantitative study. Ethical clearance was obtained from the Institutional Review Committee, TUTH, and IOM. The study population consisted of patients who had presented for knee MRI to the Department of Radiology and Imaging at Tribhuvan University Teaching Hospital (TUTH),

Maharajgunj, Kathmandu. Patient data was collected from the MRI images stored in the Picture Archiving and Communication System (PACS) of the department. All the MRI knee scans were performed using a 1.5 Tesla Magnetom Amira Siemens MRI scanner. A non-probability sampling method was used, and a total of 112 patients were selected, which consisted of 56 cases with complete ACL injury and 56 controls with normal ACL. Individuals with incomplete MRI data or non-standard imaging quality and prior ACL surgery or any other significant knee pathologies that could affect the femoral notch were excluded from the study.

Femoral notch shape, notch width (NW), notch width index (NWI), and notch angle (NA) were assessed on proton density weighted fat suppressed (PDFS) axial images at the level of the popliteal groove. The alpha angle was assessed on the PDFS sagittal image. Femoral notch shape was classified according to Van Eck et al. into type A, U, or W (Figure 1). Type A is the stenotic notch and is narrow from the middle to the apex. Type U has a wider contour at its apex than type A, and type W has two apices. NW and NWI were measured as described by Domzalski et al.⁴ NWI was calculated as a ratio between the notch width and bicondylar width. Femoral notch with NWI of < 0.27 was considered to be stenotic as per Domzalski et al. NA was assessed following the Akgun et al. method and was defined as the angle between the two tangential lines of the entrance of the medial and lateral femoral condyles upto the apex of the intercondylar notch. The alpha angle was measured according to Fernandez et al. as the angle between the longitudinal femoral axis and Blumensaat line.^{3,4,5,6}

Statistical analysis was done using Statistical Package for Social Sciences (SPSS) version 26. Mean, standard deviation, minimum and maximum values were used to present descriptive analyses. Chi-square test and Independent Sample T-test were used for the inferential analysis and p-value of < 0.05 was considered statistically significant.

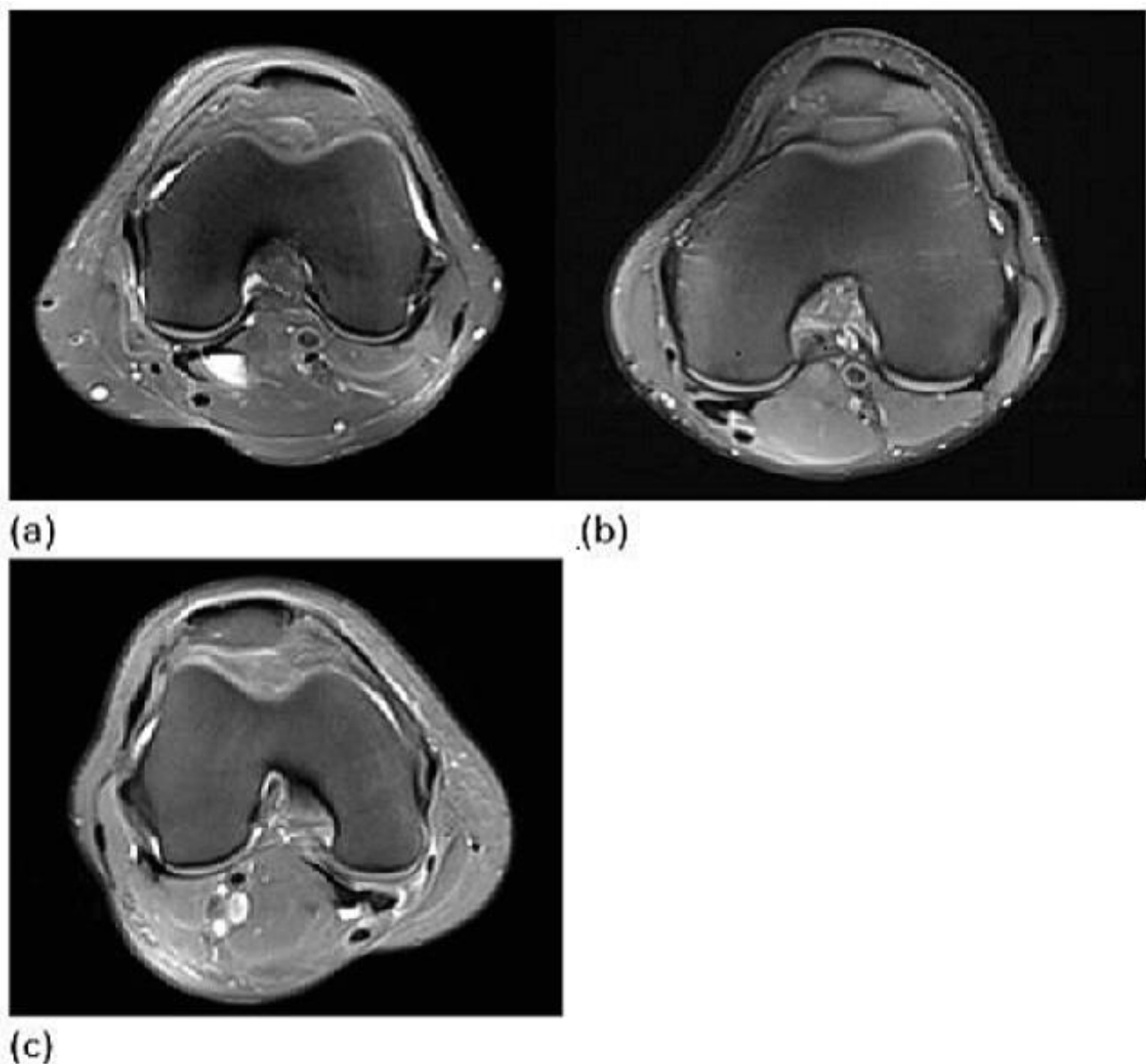


Figure 1: PDFS axial images showing different femoral notch shapes:
(a) U type, (b) A type, (c) W type

RESULTS

A total of 112 participants were included in this study, which consisted of 56 cases with complete ACL injury and 56 controls with a normal ACL. The age of the patients ranged from 16 to 69 years, with a mean of 35.61 ± 11.41 years. Out of the total 112 patients, 68 (60.7%) were males, and 44 (39.3%) were females.

The most common femoral notch shape was the U shape, observed in 70 individuals (62.5%). The A shape was present in 40 participants (35.7%), while the W shape was the least common, found

in only 2 participants (1.8%). The relationship

between femoral notch shape and ACL status was analyzed (Table 1). Among patients with a U-shaped notch, 28 individuals (40.0%) had ACL injuries, while 42 (60.0%) had normal ACL. In contrast, participants with an A-shaped notch included 27 individuals (67.5%) with ACL injuries and 13 (32.5%) with normal ACL. Among patients with ACL injury, an A-shaped notch was present in 48.2% and in 23.2% of those among patients with normal ACL. A W-shaped notch was found 1 in each category, contributing 1.8% to both ACL status groups. Since the W shape was only

present in two individuals, for the simplicity of inferential analysis, it was grouped together with the U shape, as they are morphologically similar.

Significant association was found between the femoral notch shapes and ACL injury status using the Chi-square test ($p = 0.006$).

Table 1: Association between femoral notch shapes and ACL status

		ACL status		Total	P-value
		Injured	Normal		
Femoral Notch Shape	U	29	43	72	0.006
	A	27	13	40	
Total		56	56		

The mean femoral notch width was 2.08 ± 0.22 cm (range from 1.55 cm to 2.79 cm). The mean femoral notch width was narrower in participants with ACL injuries (2.01 ± 0.20 cm) compared to those with normal ACL (2.14 ± 0.22 cm) (Table 2). This mean difference was statistically significant ($p=0.001$). The mean notch width index was 0.28 ± 0.27 (range 0.22 to 0.34). The mean notch width index was 0.27 ± 0.02 for ACL-injured participants and 0.29 ± 0.02 for those with normal ACL (Table 2). This difference in mean was also statistically significant ($p = 0.000$). The U-shaped notch had a greater mean notch width (2.12 ± 0.23 cm) compared to the A-shaped notch (2.00 ± 0.19 cm, $p=0.004$), and a higher mean notch width index (0.29 ± 0.02 vs. 0.27 ± 0.02 , $p=0.003$) (Table 2).

The relationship between femoral notch shape and the presence of a stenotic notch was analyzed (Table 3). In our study, there were 37 (33%) patients with notch stenosis and 75 (66%) patients without notch stenosis. Among participants with a U-shaped notch, 20.8% patients had a stenotic notch. In contrast, patients with an A-shaped notch showed a higher prevalence of stenotic notches, with 55% having a stenotic notch. The chi-square test revealed a significant association between femoral notch shape and the presence of a stenotic notch. A shaped femoral notch was more commonly associated with stenotic notches compared to

the U-shaped notch and had 4.65 times higher odds of having a stenotic notch. Among patients with notch stenosis, 73.0% had ACL injuries in contrast to 38.7% in patients without notch stenosis (Table 4).

The mean femoral notch angle was $53.37 \pm 6.49^\circ$ (range 40.75° to 69.99°). Femoral notch angle was also compared with the ACL status, and the mean NA was $52.03 \pm 6.05^\circ$ for individuals with ACL injury, in contrast to $54.72 \pm 6.69^\circ$ for individuals with normal ACL (Table 2). The difference in mean was found to be statistically significant ($p=0.028$). The mean alpha angle was $29.76 \pm 5.14^\circ$ (range 19.63° to 43.36°). It was slightly higher in ACL-injured participants ($30.68 \pm 5.21^\circ$) than in those with normal ACL ($28.84 \pm 4.95^\circ$) but was not statistically significant ($p=0.058$) (Table 2). The notch angle was slightly larger for the U-shaped notch ($54.13 \pm 7.09^\circ$) compared to the A-shaped notch ($52.01 \pm 5.04^\circ$), though this difference was not statistically significant ($p=0.099$) (Table 2). The alpha angle was nearly identical between the two shapes, with means of $29.75 \pm 5.06^\circ$ for the U-shaped notch and $29.77 \pm 5.36^\circ$ for the A-shaped notch ($p=0.989$) (Table 2). These findings suggest that notch width and notch width index differ significantly between U and A-shaped notches, while notch angle and alpha angle do not.

Table 2: Comparison of means of femoral notch measurements between ACL status and notch shapes

		Notch width	Notch width index	Notch angle	Alpha angle
ACL status	Injured	2.01 ± 0.20 cm	0.27 ± 0.02	52.03 ± 6.05	30.68 ± 5.21
	Normal	2.14 ± 0.22 cm	0.29 ± 0.02	54.72 ± 6.69	28.84 ± 4.95
P-value		0.001	0.000	0.028	0.058
Notch shape	U	2.12 ± 0.23 cm	0.29 ± 0.02	54.13 ± 7.09	29.75 ± 5.06
	A	2.00 ± 0.19 cm	0.27 ± 0.02	52.01 ± 5.04	29.77 ± 5.36
P-value		0.004	0.003	0.099	0.989

Table 3: Association between femoral notch shapes and notch stenosis

		Notch Stenosis		Total	P-value
		Yes	No		
Femoral Notch Shape	U	15	57	72	0.000
	A	22	18	40	
Total		37	75	112	

Table 4: Association between notch stenosis and ACL status

		ACL status		Total	P-value
		Injured	Normal		
Notch Stenosis	Yes	27	10	37	0.001
	No	29	46	75	
Total		56	56	112	

DISCUSSION

The ACL is a crucial stabilizer of the knee joint, and its injury can lead to significant morbidity for the patient. Previous studies have shown that variations in the morphometry of the femoral notch can influence the likelihood of ACL injuries. The association between a narrow intercondylar notch and ACL injury was first recognized by Palmer in 1938. Various notch parameters, such as notch shape, notch shape index, notch width index, notch area, and notch area index, have since been identified as risk factors for ACL injury. By studying this relationship, anatomical risk factors that predispose to ACL tears can be identified, and prevention strategies can be implemented in high-risk individuals like athletes. This study studied the differences in femoral notch morphology between individuals with ACL injury and those with normal ACL.^{7,8}

Van Eck et al. arthroscopically evaluated the femoral notch in patients with ACL injury and classified the femoral notch shape into three types (A, U & W). In their study, Type A notch had the narrowest width and was present in the largest number of patients (54%). In a study by Al-Saeed et al. 73% of patients with type A notch shape had ACL tears and had a statistically significant correlation. Basukala et al. also concluded that type A notch is a risk factor for ACL tear. Type A notch rate was also significantly higher in the ACL-damaged group in a study done by Akgun et al. Our study also showed that there was a significant association between the notch shape and ACL injury. Among the patients with type A notch shape, 67% had ACL injury, in contrast to 40% of patients in other notch types.^{3,5,9,10}

Many previous studies have shown that a narrow notch width and notch width index are associated

with a higher incidence of ACL injury. LaPrade et al. demonstrated that there was a significant correlation between intercondylar notch stenosis and ACL injuries. Souryal et al. hypothesized that a narrow femoral notch impinges on the ACL more than a normal notch, making the ligament more prone to injury. In their study, they found that athletes sustaining noncontact ACL injuries had statistically significant intercondylar notch stenosis. Many other studies by Akgun et al., Fernandez et al., Fahim et al., and Huang et al. also found NWI to be significantly lower in patients with ACL injury.^{5,6,11,12,13,14}

There is no clear-cut off value given in the literature to determine notch stenosis. Different authors have used different NWI cut-off values in their studies to assess the relation between notch stenosis and ACL injuries. LaPrade et al., Souryal et al., and Domzalski et al. have determined the cut-off values as 0.19, 0.2, and 0.27, respectively. Basukala et al. considered the femoral notch with NWI of < 0.27 as stenosed. In their study, 40.67% of patients with ACL injury had a stenotic notch as compared to 22 % of patients without ACL injury. Akgun et al. found 73% of their participants with a stenotic notch (NWI < 0.26) had type A notch shape, which was statistically significant. Our study also showed a significant association between ACL injury and a stenotic notch. However, Al Saeed et al. did not find any such significant association. Only 17% of the patients with ACL injury had low NWI.^{4,5,9,10,11,12}

We also studied the association of femoral notch shape and notch stenosis, which was statistically significant. In our study, patients with type A notch shape had a higher prevalence of notch stenosis (55%) in comparison to type U notch shape (20.8%). Type A notches were also more prevalent (73%) among stenotic notches in a study by Akgun et al.⁵. A study by Basukala et al. shows 42.59% of type A notches had a narrow notch compared to 21.87% of non-A types.¹⁰

The relationship between ACL injury and femoral notch angle has been infrequently studied in the literature. Herzog et al. reported a femoral notch angle of $45.7^\circ \pm 10.9^\circ$ in the patient group

compared to $49.8^\circ \pm 7.2^\circ$ in the control group. According to Herzog, the lack of a significant difference between the groups could be attributed to the small sample size in their study. In contrast, Anderson AF et al., using CT scans, and Cha JH et al., and Alentorn-Geli E. et al., using MRI, found that a femoral notch angle of less than 50° increased the risk of ACL injury. However, Stein et al. did not observe any association between $NA < 50^\circ$ and ACL injury. Huang et al. found a significant difference in mean notch angle between the injured ACL and normal ACL, and it was less in the ACL-injured knee. Akgun et al. also found significantly lower values of notch angle in the ACL-damaged group than in the control group. In our study, the overall mean notch angle was $53.37 \pm 6.49^\circ$. Among the ACL-injured and normal ACL patients, it was $52.03 \pm 6.05^\circ$ and $54.72 \pm 6.69^\circ$, respectively. Notch angle was less in patients with ACL injury in comparison with those having a normal ACL. This difference was found to be statistically significant. There was no significant association between notch angle and notch shape.^{5,14,15,16,17,18,19}

Fernandez et al. concluded that ACL tears were associated with a high alpha angle. They believed that an increase in the alpha angle positions the ACL in a relatively horizontal orientation, making it more prone to rupture during extension due to impingement against the anterior intercondylar notch. Shen et al. also supported this finding and found increased alpha angle to be the most crucial component for ACL injury. In contrast, Akgun et al. did not find any statistically significant difference between the injured ACL and normal ACL in terms of alpha angle. Our study also did not find any significant difference in the mean between the cases and controls or between the notch shapes.^{5,6,20}

There are several limitations of the study. Firstly, the retrospective nature of the study fails to establish causality. There are several other factors affecting ACL injury beyond femoral notch morphology. Since the images were extracted from the PACS, we could not get information about the history and physical examination of

the patient, and could not select patients who had a similar mechanism of injury.

CONCLUSION

This study highlights the significant association between femoral notch morphology and ACL injuries. Narrow femoral notch width, low notch width index, and type A notch shape were strongly associated with an increased risk of ACL injury. Additionally, notch stenosis was more prevalent among participants with ACL injuries, particularly in those with an A-shaped notch. While the femoral notch angle showed a statistically significant difference between injured and normal ACL groups, no such association was observed for the alpha angle.

CONFLICT OF INTEREST

None

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None

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