Correlation between Femoral Intercondylar Notch Width and Anterior Cruciate and Posterior Cruciate Ligament Widths on MRI of Knee Joint

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ABSTRACT

Background

Anatomic variations have been implicated as one of the intrinsic causes of injuries to the cruciate ligaments which can induce a functional deficiency to the knee. Narrow cruciate ligament widths as well as narrow femoral intercondylar notch widths can increase the risk of these ligaments rupturing.

Objective

To correlate the width of the femoral intercondylar notch (ICN) with anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) widths on MRI of the knee joint.

Method

A total of 46 patients who met the inclusion criteria were evaluated. Intercondylar notch was identified on coronal T1W images while anterior cruciate ligament and posterior cruciate ligament were identified on proton density coronal images. All the widths were measured in the same plane at a mid-coronal level where anterior cruciate ligament and posterior cruciate ligament cross each other.

Result

Our result showed a significant correlation between the widths of intercondylar notch and anterior cruciate ligament ($r = 0.68$, $p < 0.001$) and between intercondylar notch width (INW) and posterior cruciate ligament width ($r = 0.65$, $p < 0.001$). Overall, the mean intercondylar notch width measured was 17.5 ±2.5 mm (range 11.8 to 21.8 mm), the mean anterior cruciate ligament width was 5.9 ±1.3 mm (range 3.3 to 8.6 mm), and the mean posterior cruciate ligament width was 8.9 ±1.5 mm (range 5.9 to 11.8 mm). A statistically significant difference was observed between males and females for mean widths of intercondylar notch ($p < 0.001$) and posterior cruciate ligament ($p=0.01$). However, no statistically significant difference was seen for anterior cruciate ligament width ($p=0.07$) between the two genders.

Conclusion

Measurement of the femoral intercondylar notch width can be used as an indicator of anterior cruciate ligament and posterior cruciate ligament widths which can further assist to identify the individuals who are more susceptible to cruciate ligament injuries.

KEY WORDS

Anterior cruciate ligament, Cruciate ligament injury, Intercondylar notch width, MRI, posterior cruciate ligament

INTRODUCTION

Rupture of the anterior cruciate ligament (ACL) is a common injury, mainly affecting young, physically active individuals which can often result in an unstable knee that increases the risk of further damage to the knee, such as secondary osteoarthritis.[1] ACL ruptures are well known to be induced by anatomical, hormonal, genetic, and biomechanical factors.[2] Intrinsic anatomical causes such as narrow intercondylar notch (ICN), stenotic type A notch, and steep tibial slope are frequently reported risk factors for ACL and posterior cruciate ligament (PCL) injury.[3,4]

Palmer was the first investigator to suggest that a narrow intercondylar notch may place the ACL at risk for injury, as the ligament is stretched over the medial edge of the lateral femoral condyle.[5] Since then, several studies have evaluated the role of narrow intercondylar notch as a risk factor for ACL injury with the majority suggesting narrower notch is associated with a higher risk of ACL injuries.

With the increasing trend of sports injuries in the knee, ligament-related injuries are also rising in Nepal. There are inadequate published data regarding the relation of ligament tears with anatomical variations in the knee joints. Thus, the purpose of this study was to observe the correlation between intercondylar notch width (INW) and ACL/PCL widths on magnetic resonance imaging (MRI) of the knee.

METHODS

This was a prospective qualitative study, done in the Department of Radiology, TUTH. We evaluated images of 46 patients who were referred for an MRI knee for various clinical conditions from August 2020 to November 2021. Patients under the age of 12, who had ACL or PCL tear on MR imaging, femoral intercondylar fracture on radiographs, and who had previous history of arthroscopic reconstructive surgery of knees were excluded from the study.

After informed written consent was taken from each patient explaining about the study, participants were scanned on a 1.5T MRI unit (Siemens Magnetom Amira). Standard examination protocol of the department for MRI knee was followed for all the patients which include T1W coronal, T2W sagittal, and proton density (PD) axial, coronal, and sagittal sequences. Patients were kept in a supine position with knees externally rotated by 15-20 degrees. Knee-specific extremity coil was used for the imaging. Measurements were obtained using the OsiriX software of the workstation console in the department.

For measurements, T1W and PD coronal images were used. Intercondylar notch was identified on coronal T1W images (Fig. 1A) while ACL and PCL were identified on PD coronal images (Fig. 1B). All the widths were measured in the same plane at the mid-coronal level where ACL and PCL cross each other. The measurements were recorded in millimeters using electronic calipers at the appropriate positions. The measurement for each structure was performed twice and, if there was a difference in the first and second measurements, it was repeated a third time. In cases with the third measurement, it was recorded only after it matched with one of the previously obtained measurements.

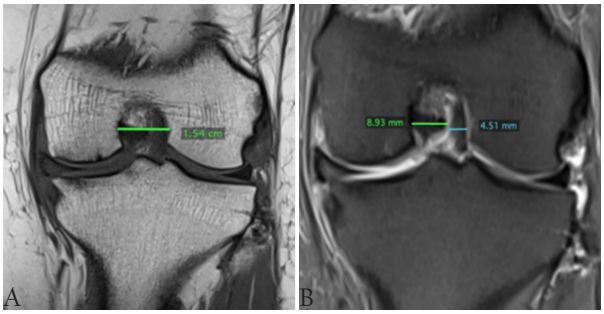

Figure 1. A. Measurement of width of ICN. B. Measurement of widths of ACL and PCL

The demography data of the patients and the relevant measurement data from the MRI knee were entered in a predesigned proforma sheet. Analysis of data was performed using IBM SPSS version 25 and Microsoft Excel software. Statistical analysis was done by linear regression analysis using Pearson's two-tailed test. A two-sample t-test was also done to determine the statistically significant difference between men and women for the calculated measurements. Results were expressed in mean ± SD values and a p-value of < 0.05 was considered as statistically significant.

RESULTS

The age of the study population ranged from 16 to 67 years with a mean of 31.6 ± 11.9 years. Among them, 54% (n = 25) were female and 46% (n = 21) were male. Most of the patients referred for MRI exam had a history of knee pain (n=18) and trauma to the knee (n=18). Other complaints were swelling of the knee (n=4), osteoarthritis (n=3), and miscellaneous causes (n=3) like vascular malformation near the knee joint.

Mean INW was measured to be 17.2 ± 2.5 mm ranging from 11.8 to 21.8 mm. ACL width ranged from 3.3 mm to 8.6 mm with a mean of 5.9 ± 1.3 mm. The mean PCL width was 8.9 ± 1.5 mm and ranged from 5.9 to 11.8 mm (Table 1).

Analysis with Pearson's correlation coefficient (r) was applied to estimate the correlation between widths of ACL and PCL with INW. It showed a correlation of r=0.65 ($p < 0.001$) for INW and ACL width and r=0.68 ($p < 0.001$) for INW and PCL width (Table 2). The linear regression analysis curve also showed a statistically significant positive correlation between them (Fig. 2, 3).

Table 1. Measurement of INW, ACL width and PCL width

		Female	Male	Total
INW	N	25	21	46
	Mean (mm)	15.9	18.6	17.2
	SD (mm)	2.072	2.038	2.5
	Minimum (mm)	11.8	13.3	11.8
	Maximum (mm)	20.1	21.8	21.8
ACL width	Mean (mm)	5.5	6.2	5.9
	SD (mm)	1.233	1.198	1.3
	Minimum (mm)	3.3	4.5	3.3
	Maximum (mm)	7.7	8.6	8.6
PCL width	Mean	8.3	9.4	8.9
	SD	1.373	1.429	1.5
	Minimum	6.4	5.9	5.9
	Maximum	11.5	11.8	11.8

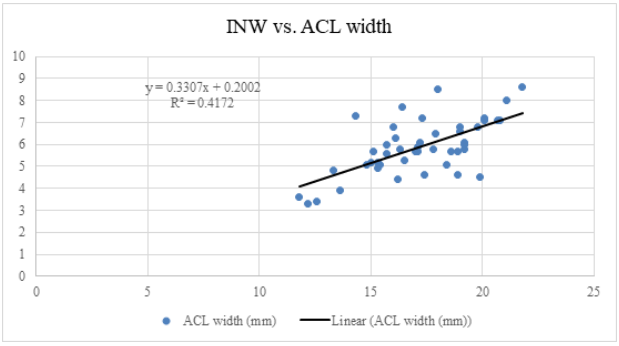

Figure 2. Linear regression analysis curve of INW and ACL width

Using an independent two-sample t-test, a statistically significant difference was noted between males and females with regards to INW ($p < 0.001$) and PCL widths ($p = 0.01$). However, in relation to ACL widths between males and females, no significant difference was observed ($p = 0.07$) (Table 3).

DISCUSSION

MR imaging of the knee is the primary modality to assess the joint including ligaments, menisci, and the surrounding soft tissues. MRI allows extremely accurate measurements of bony and ligamentous structures due to superior soft tissue contrast along with the use of electronic calipers during measurements in the digital image on the screen. A study conducted by Herzog et al. on cadaveric knees compared the absolute measurements on plain radiograph, CT, MRI, and following direct dissection and concluded that the MRI measurements were closest to directly measured values on cadavers.[6]

In our study, the mean INW was 17.2 ± 2.5 mm, the mean ACL width was 5.9 ± 1.3 mm, and the mean PCL width was 8.9 ± 1.5 mm. Davis et al. measured these parameters on MRI knee on 124 patients and found the mean notch width of 17.7 ± 2.6 mm, mean ACL width of 6.4 ± 1.4 mm and

Table 2. Correlation of widths of ACL and PCL with INW

		ACL	PCL
INW	Pearson Correlation	0.65	0.68
	Significance (2- tailed)	< 0.001	< 0.001
	N	46	46

Table 3. Independent t- test of correlation between two gender for mean INW, mean ACL width and mean PCL width

		df	t stat	t critical 2-tail	Sig. (2-tailed)
INW	Equal variances assumed	44.00	4.43	1.68	<0.001
ACL		44.00	1.88	2.02	0.07
PCL		44.00	2.67	2.02	0.01

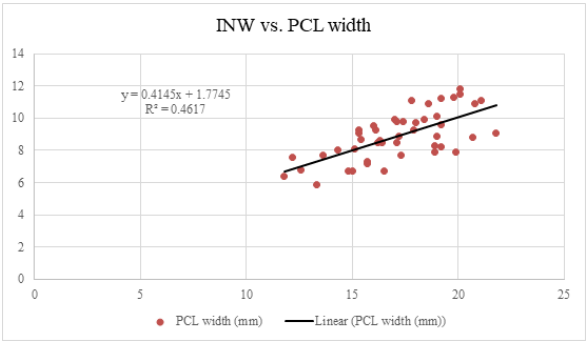

Figure 3. Linear regression analysis curve of INW and PCL width

mean PCL width of 10.2 ± 2.0 mm, which are similar to our findings.[7] However, Girgis et al. and Odensten et al. found higher mean ACL width (11 mm and 10 mm respectively), and higher mean PCL width (13 mm) in dissections of 24 and 33 cadavers respectively, as compared to our findings.[8,9] Both these studies were done with dissections in cadavers, whereas our study was based on MRI findings. One of the reasons for these variations in measurement has also been explained by a study by Harner et al., which states the variance is due to differences in the position of the knee joint at the time of measurement and differences at the site of measurements along the ligament.[10]

In our study, we found a statistically significant linear correlation between INW and ACL and PCL widths with correlation factors of 0.65 and 0.68 respectively. These data concur with the findings of the study by Davis et al. which had a correlation factor of 0.87 between INW and ACL width and 0.75 between INW and PCL width.[7] In addition, they also found a statistically significant difference between males and females regarding the measurement of INW, ACL and PCL widths with males having higher values. The mean notch width was 16.2 ± 2.3 mm in women and 19.0 ± 2.1 mm in men. Similarly, the mean ACL width was 5.7 ± 1.1 mm for women and 7.1 ± 1.2 mm for men, and the mean PCL width was 9.5 ± 1.7 for women and 10.9 ± 2.0 mm for men. Our study also had similar findings with wider intercondylar notches as well as larger ACL and PCL widths in males than females. Our study showed a statistically significant difference between the two genders for widths of ICN and PCL. However, no statistical difference was

observed in ACL width between males and females. Mean INW, ACL, and PCL widths in females in our study were 15.9 ± 2.1 mm, 5.5 ± 1.2 mm, and 8.3 ± 1.4 mm respectively, and among males, they were 18.6 ± 2.0 mm, 6.2 ± 1.2 mm and 9.4 ± 1.4 mm respectively.

Our findings were also similar to the study by Muneta et al. where the data showed that narrower intercondylar notches also contained ACL of smaller widths. They found that the eight cadaveric male specimens had a mean notch width of 19 mm, a mean ACL mid-substance width of 5.5 mm, and a mean mid-substance ACL cross-sectional area of 46.7 mm^2. Their eight female cadaveric specimens had a mean notch width of 17.1 mm, a mean ACL width of 5.3 mm, and a mean mid substance ACL cross-sectional area of 37.0 mm^2. However, they did not correlate the absolute values of INW with ACL instead compared the notch width index (NWI) and ACL widths which was based on the assumption that smaller people have proportionally smaller femurs and narrower intercondylar notch. So, the NWI ratio was then correlated with ACL width and concluded no change in the width of ACL was seen with variation in NWI.[11]

However, Shelbourne et al. challenged the validity of using the NWI ratio as a tool to standardize patients for size.[12] They found no correlation between a patient's INW and the height or weight of the study population. Even though femoral bicondylar width does increase with body size but INW does not. Smaller women did not have narrower notches than larger women. Likewise, small men did not have narrower notch widths than large men. However, women had narrower notch widths in comparison to men of the same size which was similar to the finding seen in our study.[12]

A study by Khodair et al. compared the distal femoral morphology among the ACL injured and non-injured patients.[5] With regard to NW and NWI, they found a statistically significant difference in ACL-injured patients. Similar to the findings in our study, they also observed significant differences in NW between male and female individuals.[5] A study by Stijak et al. divided 33 pairs of patients into two categories as control and study groups.[13] A significant correlation was found to exist between the width of the anterior cruciate ligament and the width and height of the intercondylar notch in the control, but not in the study group. The patients in the control group showed a shorter but wider anterior cruciate ligament in comparison to their matched pairs. The control group showed a correlation between the width of the intercondylar notch and the width of the anterior cruciate ligament similar to our study.[13]

We measured only the width of ACL and PCL and not the anteroposterior dimensions and lengths. Similarly, the notch area or cross-section area and volume of ACL and PCL were also not included in this study.

The mid-coronal plane was chosen for the measurement of ACL and PCL widths. However, there have been debates regarding the best plane and exact site for the accurate measurement of ACL/ PCL widths. Different studies have approached the measurements at different planes which might be the explanation for the difference in measurement values compared to other studies.

We performed the MR exam of the knee in a resting position and not with a ranging degree of flexion or extension which might have effects on ACL and PCL widths.

The study population was heterogeneous with no specific age groups. Patients with degenerative disease were not excluded although the accurate measurement of intercondylar notch width might have been affected.

CONCLUSION

This study aimed to correlate the widths of intercondylar notch with widths of ACL and PCL with the hypothesis that narrower INW tend to have thinner ACL and PCL, consequently, making an individual more prone to ligamentous injury. In such cases, INW can be used to predict the risk of ACL or PCL injury in individuals. Based on the findings of a statistically significant correlation between the INW and widths of ACL and PCL, this study has shown that measurement of the femoral intercondylar NW can be used as an indicator of ACL and PCL width.

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