Intercondylar notch morphometrics in Indian population: An anthropometric study with magnetic resonance imaging analysis

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1. Introduction

Knee joint is a complex joint which includes both tibiofemoral joint and patellofemoral joint. The bony geometry of the tibia and femur contributes to the static stability of the knee joint and is responsible for the normal knee kinematics. Of the ligaments in the knee joint, the anterior cruciate ligament (ACL) is the most commonly injured.¹ The variation in morphology of the femur is associated with increased risk for ligament injury. Intercondylar notch dimensions is considered as a significant predictive risk factor for ACL injury.^{2,3,6,7} A thorough understanding of the anatomic relationships of these parameters is of much clinical value.^{4,9}

Significant morphological variations are noted in literature between ethnic groups^{16,17}. The studies in Asian population primarily focus on East Asian population with little literature referencing the South Asian community who are ethnically different. The distal femoral notch dimensions have been repeatedly referred with notch width index but, there is paucity of literature regarding the rest of the parameters in Asian population. In fact no studies have been done in Indian population regarding the notch angle, notch shape index, notch condylar index and blumensaat femoral axis angle. The roof of the intercondylar notch corresponds to the blumensaat line.

Author proposes defining the normal notch dimensions in Indian population using Magnetic Resonance Imaging (MRI). The study aims to provide a future reference to further studies on the risk assessment of morphological parameters in ligament injuries.

2. Materials and methods

A total of 50 knee magnetic resonance imaging series were included in the study after the approval from ethics committee. The MR images were retrospectively collected after determining knee to be normal with no ligament or menisci injury. The study period was June 2017 to May 2018. MR imaging was performed employing 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 m s echo time and repetition time of 1700–2000 m s. Sagittal and axial images, thickness of 3.5 mm, space of 0.5 mm, matrix of 352×224 , echotime of 86 m s, repetition time of 4200 m s with the knees in near normal extension. Axial, sagittal and coronal images were obtained for all examined knee MR images.

The axial and coronal MR image slice that contained the popliteal groove was used to calculate the femoral notch parameters.¹⁵ The posterior condylar reference line is drawn tangent to the lowermost points of medial and lateral condyles first. The intercondylar depth is defined as the distance at right angle from the bicondylar reference line to the top of the intercondylar notch. Intercondylar width is measured at two thirds of the intercondylar depth (Anderson, Herzog). The widths of the medial and lateral condyles are measured at the same level. The sum of the intercondylar width, the medial condylar width, and the lateral condylar width provided the condylar width. The angle between the most inferior aspects of the notch at the medial and lateral condyles and the top of the intercondylar notch was the intercondylar angle. This method has shown adequate reproducibility¹⁵ (Fig. 1). The NWI is defined as the ratio between the intercondylar notch width and the femoral condylar width (Lateral condyle + medial condyle + notch width). The ratio between the notch width and the notch depth gives the NSI (notch shape index). The NDI (notch depth index) is the ratio between the notch depth and the depth of the lateral condyle in axial image. The T2W images were used to calculate the above parameters.

Roof angle is calculated on the sagittal MRI slice where the line is visible (Fig. 2). The femoral axis is obtained by joining the centre of the circles drawn along the shaft. The angle between the blumensaat line and the femoral axis provides the Roof angle. Statistical analysis was done with help of Microsoft excel software.

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Fig. 1. Measurement of the femoral notch dimensions in axial image and coronal image. The notch depth is perpendicular to a line tangent to the posterior condyles. The notch width and the condylar width are parallel to that line at 2/3 of the notch depth. Condylar depth is the maximum depth of lateral condyle in axial image. Notch angle is formed between the apex of the notch and the inferior aspect of the base of notch.

Fig. 2. Sagittal T2W image showing the intercondylar roof angle formed between the Femoral axis and the Bluemensaat line.

3. Results

All the 50 MR image series ($n = 50$, males = 32, females = 18) obtained were analyzed by the same examiner. Parameters were measured in pixels and angles, with IC Measure[®] software. The average age of the subjects was 32 with 20–46 yrs range. In the axial knee images the mean NWI was 0.258 ± 0.025 with no significant difference in males and females (Table 1). NA (notch angle) averaged with $53.08^\circ \pm 5.56$. Females had a smaller notch angle compared to males (p value < 0.05). The mean NSI (notch shape index) was 0.65 ± 0.07 with no significant difference in males and

females (Table 1). The NDI (notch depth index) averaged 0.53 ± 0.04 . In the coronal knee MRI series, the mean values of the NWI, NSI, and NA were 0.254 ± 0.019 , 0.083 ± 0.09 and 63.37 ± 7.54 respectively. Males and females showed no statistical difference (Table 1). The roof angle averaged 36.54 ± 4.3 with no significant difference in males and females.

4. Discussion

Distal femoral geometry performs a key role in maintaining the static stability of the knee joint. Subtle alterations in the bone geometry affect the kinematics of the knee. The rise in incidence of ACL injuries reported over the years has made the understanding of the underlying predictive risk factors significant. Appreciation of the morphologic variations in distal femur and proximal tibia helps in identifying the persons at risk for ligament injuries. Morphological differences in the distal femur intercondylar notch dimensions and the proximal tibia posterior slope have been implicated as cause for the difference in ACL injury rates among men and women.^{13,14,18,19} Numerous radiographic studies have depicted significant differences between control and ACL deficient knees.^{4,20–23} Herzog²¹ et al. in his study revealed that the cadaveric and MRI notch measurements were similar, whereas that of the radiographic measurement was significantly different. We studied the distal femur morphology with help of MR imaging in South Asian population to understand the ethnic variations in femoral anatomy recorded in literature.

Shelbourne et al. noted that females have a narrower notch dimensions compared to males.² The mean notch width index (axial) was found to be 0.258 ± 0.025 with 0.260 ± 0.027 in males and 0.254 ± 0.019 in females respectively. Females have a smaller intercondylar notch dimensions compared to males (Anderson et al.),¹⁰ but he recognized no difference in shape of the notch. Our study revealed females had lesser NWI compared to males. Laprade et al.⁴ proposed value of 0.19 and Uhoroachak et al.²⁴ a value of 0.18 for NWI cut off. Domsalki et al.²⁵ proposed the value of 0.24 as cut off of NWI associated increased risk of ACL tears. Souryal and Freeman²³ stated a NWI value below 0.20 increases the risk of bilateral injury. A cut off of 0.25 was put forward by Hoteya et al.²⁶ in Japanese population. The possible discrepancy between this study and other studies is mostly due to the fact that radiographs were used to calculate NWI in previous studies, whereas in this study MRI was used. Authors believe that radiographic notch measurements are not clearly reproducible.⁵ Variations in projection, variability of technique, magnification and patient positioning can alter the calculations.¹⁰ Narrow notch frequently contains a smaller ACL which is weaker and is more likely to rupture. A normal

Table 1
Comparison of the intercondylar notch parameters in axial, coronal and sagittal images.

VARIABLE	SUBJECT GROUP			
	Mean(n=50)	Male(n=32)	Female(n=18)	P value
Axial,				
Notch width index	0.258 ± 0.025	0.260 ± 0.027	0.254 ± 0.019	$> .05$
Notch shape index	0.65 ± 0.07	0.65 ± 0.08	0.64 ± 0.05	$> .05$
Notch depth index	0.53 ± 0.04	0.53 ± 0.04	0.53 ± 0.02	$> .05$
Notch angle ^a	53.03 ± 5.56	54.16 ± 4.79	51.03 ± 6.3	$< .05$
Coronal,				
Notch width index	0.254 ± 0.019	0.257 ± 0.019	0.249 ± 0.018	$> .05$
Notch shape index	0.80 ± 0.09	0.80 ± 0.08	0.79 ± 0.09	$> .05$
Notch angle ^a	63.37 ± 7.54	63.47 ± 7.4	63.20 ± 7.9	$> .05$
Sagittal,				
Roof angle ^a	36.54 ± 4.3	36.61 ± 4.62	36.42 ± 3.78	$> .05$

Fig. 3. Axial T2W proton density fat sat image showing the morphological types of intercondylar notch seen in the study. Dotted line demonstrates the notch morphology. Notch width appears to be more in Type-U notch compared to the Type –A notch.

sized ACL in a narrow notch surrounding affects the functioning of the ligament. Narrowing leads to impingement which in turn is responsible for ligament damage.⁸ The notch dimensions are usually explained in terms of notch width index. Narrower notch often has a decreased notch width index.⁴ But some studies conflicts this assumption.¹¹

Notch morphology is reflected by the shape of the notch. Anderson et al. revealed 3 morphological types of notches present. Inverted U type, A type and W (wave) type. U shaped notches have normal widths and the narrower ones can be wave shaped or A shaped.¹⁰ Our study revealed 45% of the study population had U shaped notch and the rest 55% had A shaped notch (Figur 3). The mean intercondylar notch angle (axial) was $53.03 \pm 5.3^\circ$ with males having 54.16 ± 4.79 and females 51.03 ± 6.3 respectively. The coronal notch angle value ranged $63.37 \pm 7.54^\circ$. The mean value of 0.083 ± 0.09 was seen with notch shape index with 0.80 ± 0.08 and 0.79 ± 0.09 in males and females respectively. The notch shape index (NSI) were similar in males and females. Females were found to have a narrower notch opening angle compared to the males as suggested by the indices. A narrow roof angle increases the chances of ACL injury because of impingement with anteriorly directed translation force.^{32,33} The notch angle less than 50° (axial) is documented to have increased risk of ACL injury.^{10,34} Anderson et al.¹⁰ and Tillman et al.¹¹ discovered no significant difference in notch shape between males and females. The influence of the notch shape and the ACL injury risk was reported by Al-Saeed et al.¹² who reported that A type notch with narrow notch width was associated with ACL injuries.

Notch depth index calculates the relationship between the notch depths with that of the condylar depth. The mean values of

0.53 ± 0.04 were seen with 0.53 ± 0.04 and 0.53 ± 0.02 in the males and females respectively. NDI is sparingly used to predict the stenosis of notch. Wada et al.²⁷ proposed NDI to be a risk factor for ACL injuries. The NDI obtained in the control group in his study was 0.55.

The roof angle of the intercondylar notch is determining factor regarding impingement of the graft. The graft placement in anterior cruciate ligament reconstruction should be parallel to the roof of the notch so as to prevent impingement. Knees with vertical roof angles require the graft to be placed more posterior in tibia to prevent impingement against the roof.²⁹ Our study revealed mean roof angle of 36.54 ± 4.3 with no significant sex difference. Its less in accordance to the study by scheffel et al.²⁸ who recorded the angle to be $34.7^\circ \pm 5.2^\circ$ and comparable to the range 35–38 in multiple studies.^{30,31} A summary of literature depicting the intercondylar notch morphology is depicted in Table 2.

The discrepancy in measurements of the notch dimensions may be explained by the analysis of diverse ethnic groups. Moreover the points of measurement on the distal femur were not uniform in the literature which makes comparison difficult. The notch width index in our study fell substantially within the 95% confidence interval of previous studies. Author hopes findings of the study be used as a future reference in understanding the notch morphology in Indian population.

5. Conclusion

The author hopes that the findings of the present study serves as a keystone for more sophisticated studies to assess the changes in ACL deficient knees. People with decreased notch dimensions

Table 2

Summary of studies investigating intercondylar notch morphology. The control group values are expressed here. MRI, Magnetic resonance imaging; CT, Computed tomography; NWI, notch width index; NWI-A, notch width index anterior; NWI-P, notch width index posterior.

STUDY	TYPE	VALUE
Notch width index (in control group)		
Souryal and freeman(1993) ²³	Prospective- X-rays	0.231 ± 0.04
Uhorchak et al (2003) ²⁴	Prospective- X-rays	0.26 ± 0.03
Evans et al (2012) ³⁵	Case control- X-rays	0.21 ± 0.03
Hoteya et al (2011) ²⁶	Case control- MRI	0.266 ± 0.03 (NWI-A)
		0.342 ± 0.027 (NWI-P)
Alentron-Geli et al (2015) ³⁶	Case control- MRI	0.25 (axial)
		0.24 (coronal)
Notch angle (in control group)		
Anderson et al (1987) ¹⁰	Case control- CT	54.7
Alentron-Geli et al (2015) ³⁶	Case control- MRI	60.3 (coronal)
		50.1 (axial)
Notch shape index		
Notch depth index (in control group)	nil	nil
Wada et al (1999) ²⁷	Case control- MRI	0.55
Roof angle		
Scheffel et al (2012) ²⁸	Cross-sectional - X-rays	34.7 ± 5.2

should be educated on the increased risk of ACL injuries and be given proper prophylactic precautions.

Conflict of interest

Has no conflict of interest.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.jcot.2018.07.001>.

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