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# The Influence of Femoral Morphometric Risk Factors on ACL Injury, a Retrospective Case-Control Study – An Indian Perspective.

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***Abstract***
*Background: ACL injuries lead to significant disability among the injured, often requiring surgical reconstruction. Anatomical morphometric analysis helps identify individuals who are more susceptible to incurring an ACL injury, despite activity modifications, thereby improving quality of life and decreasing the economic burden posed by a potential ACL injury. We explore the relation between femoral morphometric variations on MRI associated with an ACL tear to facilitate meaningful insights into ACL injury prevention.*
*Methods: We retrospectively evaluated 269 patients who underwent knee MRI and clinical examination for suspected ACL pathology. Participants were divided into cases (ACL-injured) and controls (ACL-uninjured) based on MRI and clinical findings suggestive of a complete ACL tear. In both groups, NW(notch width), MCW(medial condylar width), LCW(lateral condylar width), BCW(bicondylar width), MLR(medial-lateral condyle width ratio), NWI(notch width index), IHD(Intercondylar notch height depth ratio), ACL Length, ACL mid substance width were calculated.*
*Results: A total of 269 participants were included in the study. The NW, MCW(medial condylar width), LCW, BCW, NWI, IHD, ACL Length, ACL width between the ACL-uninjured and ACL-injured groups were compared, and variations were found to be statistically significant. Scatter plots between NWI vs. ACL mid substance width, NWI vs. IHD, BCW vs. LCW depict a small ACL, a large lateral condyle combined with a stenotic notch are significant risk factors for ACL injuries.*
*Conclusion: The distal femur morphometric variations among cases and controls are in accordance with the existing literature and support the established injury mechanisms leading to ACL injury. It is interesting to note that these remain the same despite the difference in demographic characteristics of the study population.*
***Keywords:*** *ACL injury, notch width, notch width index, MRI, femoral morphometrics*
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## I. Introduction

Over the last few decades, research in ACL injury has shifted from finding unique treatments to injury prevention. A Key part is identifying risk factors and their association with an injury[1][2]. These risk factors are synergistic in causing an injury and include sex, anatomical variations in the knee, mechanism of injury, and pre-co conditioning of an athlete apart, among other factors[3]. The single predictable, stable factor in ACL injury prevention is the anatomical variation of the knee of the individual[4]. Although h this is a widely researched topic, studies have emphasized the notch width and its interpretation associated with tibial slopes[5]. However, their associations with other distal femur morphometrics, ACL anatomical variation, and mechanism of injury have been poorly studied in literature. Analysis of femoral morphometrics was limited only to notch width in view that impingement caused by notch stenosis led to increased chances of ACL injury. We hypothesize that careful biomechanical consideration would imply the need to analyze other femoral morphometric risk factors regarding tibiofemoral contact, a valgus moment of loading, and ACL characteristics regarding the femoral notch to determine any significant association. This study analyzes the anatomical variation in femoral condyles, femoral notch, and ACL anatomical characteristics to correlate them with fundamental biomechanical modes of injury resulting in an ACL injury.

## II. Methodology

This retrospective case-control study was designed by researchers at JIPMER (Jawaharlal Institute of Postgraduate Medical Education & Research). It was approved with the participant's consent waiver by the Institutional Ethics Review Board at JIPMER. The medical records of participants who visited the orthopedic outpatient department (OPD) between January 2017 to December 2019 were reviewed. All participants of either sex, 18 years or above, with no history of prior knee surgeries with chief complaints of persistent pain and instability, coupled with h/o of twisting injury to the knee with MRI and clinical evaluation performed one-month post knee injury were taken as study participants. These participants were then screened for and excluded from the study if any history/MRI findings suggested multi-ligamentous injury, septic arthritis of the knee, hemarthrosis of the knee, Skeletal dysplasia, tumours, ligamentous laxity, and malunited intraarticular fractures of the knee. Thus, the cases (ACL- injured group) represented all Participants meeting the above screening criteria and having positive findings in clinical tests for an ACL tear (a Positive Lachemann's test and Positive Pivot shift), indicating the presence of an ACL tear, accompanied by a complete tear of ACL in MRI. Participants who satisfied the above screening criteria and had knee pain with negative stability tests but required an MRI for further evaluation and MRI showed an intact ACL were included as controls (ACL - uninjured group). Clinical assessment and imaging were taken only after a month of the knee injury to avoid pain during the examination and for hemarthrosis of the injured knee to subside, thereby aiding in more precise clinical and MRI diagnosis. A third separate researcher, a radiologist, measured the various distal femur morphometrics on MRI, ensuring consistency in interpretation and measurement technique. Knee MRI sequences were produced using 1.5 Tesla Magnetom Avanto (Siemens, Germany) with a field of view of 160*160,192*320s, slice thickness 3mm, matrix 256*192 in 3 orthogonal planes. All measurements were performed using the institutional PACS - centricity universal viewer, GE Health care.

The distal femur anatomical variants measured were Notch width, notch width index, medial femoral condyle width, lateral femoral condyle, bicondylar width, ACL length, and mid substance ACL width correlating to distal notch entrance. Notch width, NWI, and femoral condyle morphometrics were measured by using the techniques described by Herzog et al.[6], FIG.1. The ACL morphometrics was measured using the method described by Ng et al.[7], FIG 1.

Data were analyzed using STATA ver.15.1. Categorical and continuous data were presented as percentages (%) and mean with standard deviation. Pearson's chi-squared test and Fisher's exact test evaluated the difference in proportions. A 2-sample t-test was used to determine any significant differences in Distal femur morphometrics (i.e., NW, MCW, LCW, BCW, MLR, NWI, IHD, ACL Length, ACL width) between the cases and control groups without any reference to the participant's gender. Further correlation analyses were done between individual parameters to determine the association.

## III. Results

A total of 269 participants were included in the study, of which 202(75%) participants were male. 154(53%) participants belonged between the age of 25 to 50 years, whereas 99(34%) and 36(12%)participants belonged to age groups <25 years and >50 years, respectively. A total of 126 participants were included as cases ( ACL-injured group), and 143 participants were included in the control arm (ACL-uninjured group).

The distal femur morphometric means of the cases were NW(18.035 ± 0.85), MCW(28.941 ±1.21), LCW(29.329 ±0.92), BCW(76.305 ±2.1), MLR(0.98731 ±0.048), NWI(0.98731 ±0.008), IHD(26.679 ±0.737), ACL Length(30.567 ± 4.19), ACL width(8.350 ±0.51). The distal femur morphometric means of the controls were NW(19.100 ±1.69), MCW(25.685 ±1.19), LCW(30.726 ±1.26), BCW(75.575 ± 2.85), MLR(6.11992 ±65.98), NWI(0.25192 ± 0.016), IHD(26.679 ±1.18), ACL Length(35.258 ± 4.19), ACL width(9.294 ±0.758). Selected summary statistics with the P values based on 2 sample t-tests for NW, MCW, LCW, BCW, MLR, NWI, IHD, ACL Length, ACL width between the ACL-uninjured and ACL-injured groups are provided in Table 1.

To provide meaningful insight into the Distribution of anatomical risk factors between injured and uninjured populations, scatter plots between NWI vs. ACL mid substance width, NWI vs. IHD, BCW vs. LCW were plotted in figure 2.

## IV. Discussion

Our study notes a significant difference in the notch width and NWI among the cases and controls. This is in concordance with other studies such as Domnick et al.[8], Shelbourne et al.[9], Sonnery et al. [10]. Against this finding are studied by Lombardo et al.[11], schickendantz et al.[12], and souryal et al. [13]. However, this finding of significant difference in notch width, NWI adds to the existing literature, which has a divided opinion on the same quoting bias in measurements, the study subjects, and difference in statistical analysis for the same[10][14][13]. The difference found in study participants can be attributed to the difference in demographic characteristics and mode of injury sustained. The participants were not elite sports personalities as in other studies.

This study provides insight into distal morphometric and ACL injuries by correlating distal femur morphometrics and their biomechanical implication. Firstly, The cases have significantly smaller ACL lengths and Mid substance ACL width. When associated with cases having a significantly lower notch width, this finding correlates with the biomechanics of non-contact ACL injury, wherein a taut ACL, when stretched against the lateral condyle in a stenosed canal, is more susceptible to an injury[8]. Secondly, It is interesting to note that bicondylar width and medial condylar width in cases are significantly higher than those in controls. Axial loading and posterior tibial translation have a unique role in the biomechanics of causing ACL injury, wherein the above findings suggest a more uniform loading in cases which is probably countered by the larger surface area of the medial condyle over which the tibia pivots, thereby increasing the stresses in ACL causing injuries. These findings are concordant with the established injury biomechanics of ACL injury[8][15]. Thirdly, Considering the femoral notch as a tunnel through which the ACL passes towards its attachment in the femur, we note that cases have a constricted channel through which ACL passes, i.e., a smaller notch width and a smaller IHD compared to the controls. Thus any pivoting movement would significantly cause a greater stress raiser in the tight ACL ligament leading to its injury[3][16].

The graphic depictions of the Distribution of anatomical risk factors among the study participants between NW vs. IHD, BCW vs. LCW, and NW vs. ACL width are shown in figure 2. we notice that cases are clustered towards a narrower femoral notch compared to controls. Further, participants with a smaller lateral condylar notch associated with greater MC, depicted as a greater BCW, are more prone to an ACL injury, again emphasizing the greater pivoting on the bigger medial condyle base and impingement on the lateral condyle. Finally, in the scatter plot fig 2.3, cases are seen more clustered towards a smaller NWI and smaller ACL mid substance width, suggesting that ACL bulk at the site of impingement also plays a role in injury prevention. These findings are in concordance with the established ACL injury mechanism.

Furthermore, Correlation analysis between the morphometric parameters reveals a direct correlation between ACL width and IHD, suggesting that a greater femoral notch accommodates a thicker ACL, which would decrease the chances of incurring an ACL injury.

The study has many limitations. Firstly, the participants were not matched for other risk factors that would have placed them at a higher risk of suffering an ACL injury. Secondly, participants younger than 18 years were excluded from the study. The reason for exclusion is that bone maturation has yet to occur in these individuals; thus, evaluating anatomical parameters prematurely can lead to bias in predicting the contribution of the risk factor in these participants. Thirdly, we acknowledge that MRI measurements can be subjected to inter-observer inconsistencies. However, with advances in technology from previous studies, with simultaneous visualization in multiple planes at a single time, we could circumvent this problem for the most part.

## V. Conclusions

We note that the distal femur morphometric variations among cases and controls are in accordance with the existing literature. It is interesting to note that these remain the same despite the difference in demographic characteristics of the study population. Further, it is seen that the variations in cases that lead to increased chances of an ACL injury are correlated with the existing ACL injury mechanisms.

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| | Case | Control | p- value |
|---|---|---|---|
| Age | | | [redacted] |
| <25 | 46 | 53 | |
| 25-50 | 80 | 74 | |
| >50 | 7 | 29 | |
| Sex | | | |
| Male | 106 | 110 | |
| Female | 27 | 46 | |
| Notch width | 18.035 ± 0.85 | 19.100 ±1.69 | 0.000 |
| Medial condyle width | 28.941 ±1.21 | 25.685 ±1.19 | 0.000 |
| Lateral condyle width | 29.329 ±0.92 | 30.726 ±1.26 | 0.000 |
| Bicondylar width | 76.305 ±2.1 | 75.575 ± 2.85 | 0.015 |
| Medial / lateral condyle ratio | 0.98731 ±0.048 | 0.611992 ± 0.065 | 0.371 |
| Notch width index | 0.23576 ±0.008 | 0.25192 ± 0.016 | 0.000 |
| Intercondylar notch height / depth | 25.377 ±0.737 | 26.679 ±1.18 | 0.000 |
| ACL length | 30.567 ± 4.19 | 35.258 ± 4.19 | 0.000 |
| ACL width mid substance | 8.350 ±0.51 | 9.294 ±0.758 | 0.000 |

**TABLE: 1** summary statistics for NW, MCW, LCW, BCW, MLR, NWI, IHD, ACL Length, ACL width between the ACL-uninjured and ACL-injured groups.

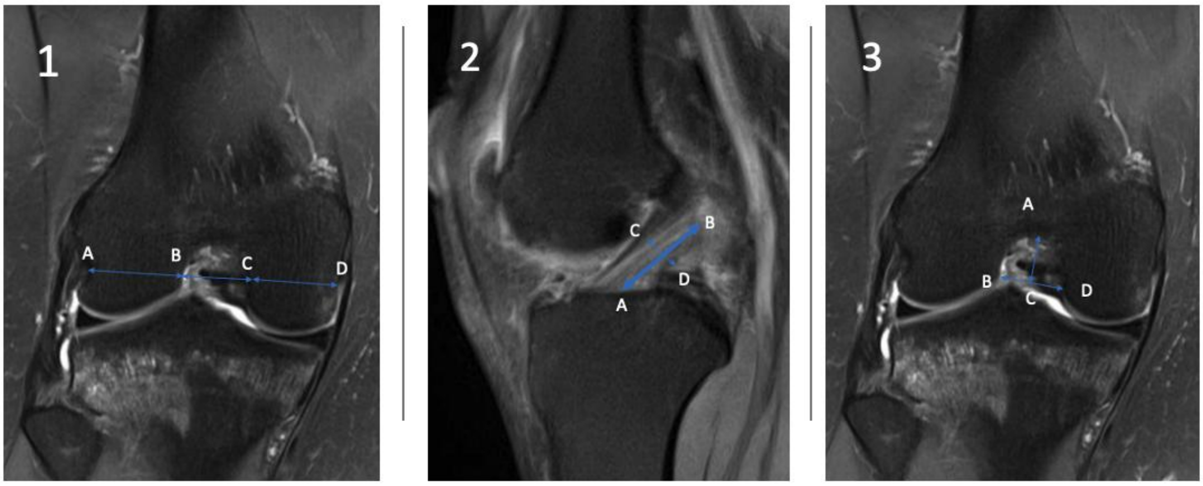


**FIG 1 .** fig 1.1 – AB, BC, CD measure the lateral condylar width, intercondylar notch width, and medial condylar width. Fig 1.2 – AB, CD measure the ACL length and mid ACL width, Fig 1.3 AC, BD measure the intercondylar width and height.

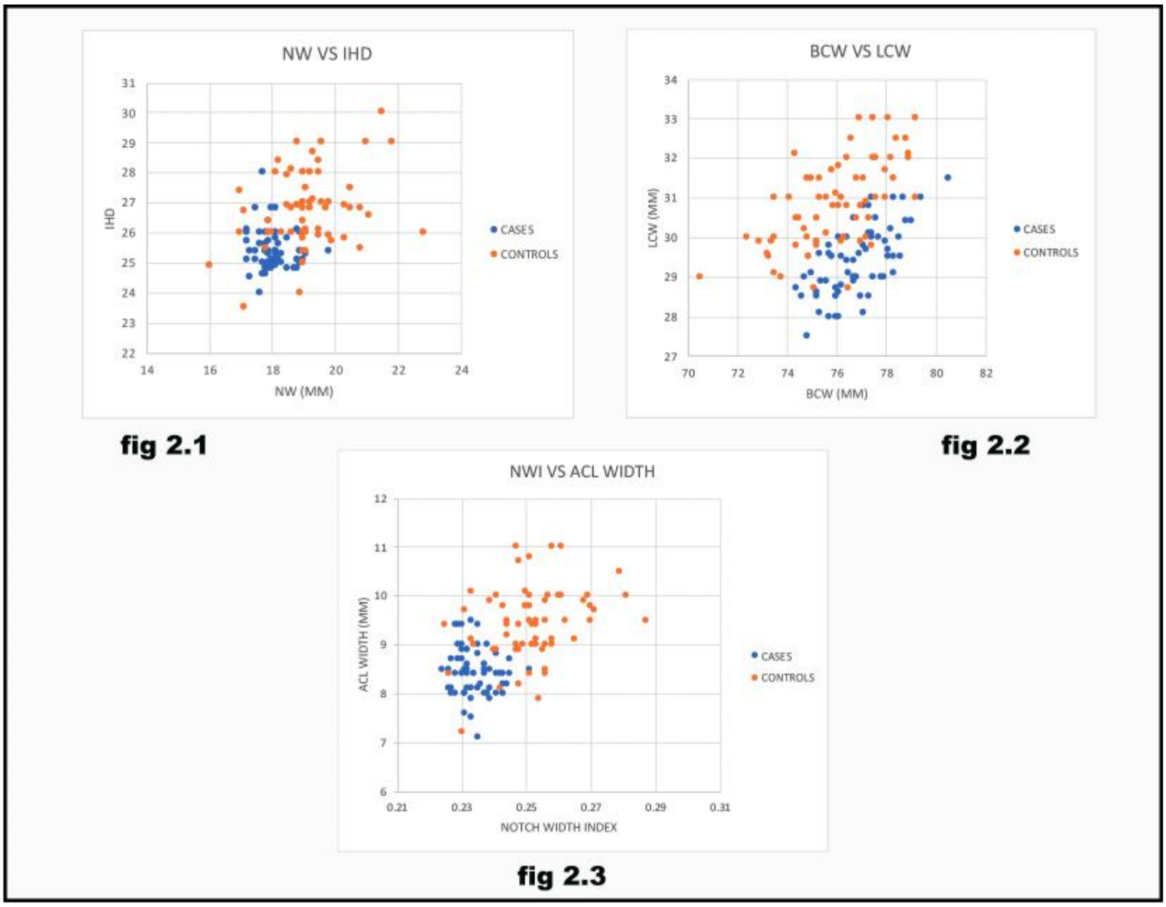


Figure 2: scatter plots comparing different anatomical distal femur morphometric variations.

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