Assessment of Intercondylar Notch Width Measurements through Knee X-Ray

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Abstract- Background: Anterior cruciate ligament (ACL) injuries are among the most frequent and debilitating musculoskeletal injuries, particularly in physically active individuals. The morphology of the intercondylar notch of the femur, which houses the ACL, has been identified as a significant anatomical factor influencing injury risk. Narrow notch dimensions may increase the likelihood of ligament impingement and subsequent rupture. While MRI and CT provide detailed imaging, X-rays remain a cost-effective and accessible diagnostic tool for evaluating notch anatomy in clinical practice.

Objective: This study aimed to assess intercondylar notch width and Notch Width Index (NWI) using standard anteroposterior (AP) knee X-rays and to investigate their relationship with ACL injury occurrence. Secondary objectives included evaluating demographic variations (gender and age), activity level associations, and the implications for surgical planning.

Methods: A cross-sectional observational study was conducted on 100 participants aged 18–60 years at SCPM College & Hospital, Gonda, U.P. Measurements of intercondylar notch width and bicondylar width were taken from AP knee radiographs, and NWI was calculated. ACL injury status was determined through clinical evaluation and imaging. Statistical tests including t-tests and chi-square analysis were used to examine associations.

Results: The mean NWI was significantly lower in individuals with ACL injuries (0.368) than those without (0.389), with a p-value of 0.003. Although gender and physical activity level showed trends toward higher ACL injury rates among females and more active individuals, these associations were not statistically significant. Females had slightly narrower notch widths and lower NWI, potentially contributing to their higher injury susceptibility.

Conclusion: The study confirms that a lower Notch Width Index is significantly associated with ACL injuries, supporting the anatomical impingement theory. X-ray-based NWI measurements offer a practical and affordable tool for early risk assessment and surgical planning, especially in resource-limited settings. Integration of such assessments into routine radiographic protocols could improve ACL injury prevention and management strategies.

Keywords: Anterior Cruciate Ligament (ACL), Intercondylar Notch Width, Notch Width Index (NWI), Knee X-ray, Radiographic Measurements, ACL Injury Risk, Orthopedic Imaging

I. INTRODUCTION

The knee joint is a pivotal structure in the human musculoskeletal system, playing a central role in

locomotion, weight-bearing, and athletic performance. Functionally classified as a modified hinge joint, the knee allows flexion, extension, and limited rotation of the leg, contributing to stability and dynamic mobility. Its complex anatomical and biomechanical configuration renders it susceptible to degenerative diseases and traumatic injuries, particularly to its ligamentous structures, such as the anterior cruciate ligament (ACL)[1].

1.1 Overview of the Knee Joint

The knee joint (articulatio genus) comprises three bones: the femur (thighbone), tibia (shinbone), and patella (kneecap). These structures form two articulations: the tibiofemoral joint and the patellofemoral joint. The tibiofemoral joint is formed by the articulation of the femoral condyles with the tibial plateau, while the patellofemoral joint occurs between the patella and the femoral trochlea [2].

This joint is reinforced by a combination of passive and active stabilizers. Passive structures include four primary ligaments: the ACL, posterior cruciate ligament (PCL), medial collateral ligament (MCL), and lateral collateral ligament (LCL). Active stabilizers include the quadriceps and hamstring muscle groups, which contribute to joint movement and protection[3]. Cartilaginous components such as the menisci act as shock absorbers and enhance load distribution across the joint[4].

Synovial fluid within the joint capsule reduces friction and supplies nutrients to intra-articular structures. Bursae, fibrous sacs filled with synovial fluid, provide additional cushioning. The functional integrity of all these components is essential for maintaining knee stability and reducing the risk of injuries.

1.2 Femoral Condyles and Intercondylar Notch

The distal end of the femur expands into two large rounded prominences—the medial and lateral femoral condyles—which articulate with the corresponding tibial plateaus. Between these condyles lies the intercondylar notch or intercondylar fossa, an anatomically significant groove that houses the ACL and PCL[5].

The dimensions and morphology of the intercondylar notch are critical in determining knee biomechanics. Anatomical studies have revealed that the width and shape of this notch influence the spatial accommodation of the cruciate ligaments. Narrower notches are associated with a higher risk of ACL impingement, limiting the ligament's range of motion and increasing its vulnerability to injury[6].

Morphologies vary among individuals, commonly classified into U-shaped, A-shaped, and W-shaped patterns, each associated with different clinical implications[7].

The Notch Width Index (NWI)—a radiographic measure comparing notch width to bicondylar femoral width—is frequently used to quantify notch dimensions. Studies have shown that lower NWI values correlate with a higher incidence of ACL injuries, particularly in athletes and females[5,8].

1.3 Function and Role of the Anterior Cruciate Ligament (ACL)

The anterior cruciate ligament is one of the most important structures contributing to the functional stability of the knee. Originating from the posterior aspect of the lateral femoral condyle, it inserts into the anterior intercondylar area of the tibia. The ACL primarily resists anterior translation of the tibia relative to the femur and controls rotational movements of the knee[9].

Biomechanically, the ACL is under maximal tension during activities involving pivoting, cutting, and sudden deceleration—common movements in sports like soccer, basketball, and skiing. Consequently, it is one of the most frequently injured ligaments in the knee, particularly in young, active populations[3].

Several intrinsic factors, such as ligament size, tibial slope, and intercondylar notch dimensions, contribute to ACL injury susceptibility. Narrow notches not only increase the mechanical impingement on the ACL but are also associated with a smaller ligament cross-sectional area, thus reducing the load-carrying capacity of the ligament[9].

ACL injuries range from partial sprains to complete ruptures, and diagnosis often involves clinical tests such as the Lachman and pivot shift tests, supplemented by magnetic resonance imaging (MRI)

for detailed evaluation. In cases requiring surgical intervention, particularly ACL reconstruction, notch morphology influences graft placement and may necessitate procedures such as notchplasty to avoid graft impingement[10].

Recent literature supports the integration of morphometric data into both preventive screening and surgical planning. This includes preoperative imaging to assess the intercondylar notch dimensions and ligament morphology, enabling more personalized and effective treatment strategies[11,12].

1.2 Clinical Significance of the Intercondylar Notch

The intercondylar notch, a deep groove situated between the medial and lateral femoral condyles, serves as the anatomical housing for the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL). Among these, the ACL is particularly vulnerable to injury, and substantial evidence indicates that the geometry and size of the intercondylar notch are closely related to the occurrence of such injuries. Understanding these relationships is crucial for diagnostic accuracy, surgical planning, and injury prevention in orthopedic and sports medicine.

1.2.1 Relationship Between Notch Width and ACL Injuries

The relationship between the intercondylar notch width and ACL injuries has been a topic of significant clinical interest. Several studies have shown that individuals with narrower intercondylar notches are at a higher risk of suffering ACL tears, particularly non-contact injuries during dynamic physical activity. This is primarily because a narrow notch limits the space available for the ACL, potentially causing it to impinge against the walls of the notch during knee movement, thereby increasing stress on the ligament.

The Notch Width Index (NWI), calculated as the ratio of the intercondylar notch width to the bicondylar width of the femur on a radiograph, is the most commonly used parameter to quantify notch size. Stijak et al. (2012)[16]

demonstrated that a lower NWI is strongly associated with a higher incidence of ACL ruptures, and proposed using radiographic assessments as a screening tool in sports medicine.

Further supporting this, Hadi et al. (2019)[17] found a direct correlation between radiographic notch narrowing and ACL degeneration in patients undergoing total knee replacement. The study revealed that patients with a notch width below 12 mm had a significantly higher rate of ACL histopathologic abnormalities, affirming the anatomical constraint theory.

Moreover, Iriuchishima and Goto (2024)[9] established a strong size correlation between the femoral intercondylar notch area and the ACL cross- sectional area, suggesting that individuals with smaller notches not only have smaller ligaments but also a higher susceptibility to injury. These insights underscore the value of preoperative imaging in assessing ligament integrity and surgical risk.

1.2.2 Variations in Notch Morphology (U-shaped vs A-shaped)

The morphological variation of the intercondylar notch is another key factor influencing ACL injury risk. Two commonly observed shapes are the U-shaped and A-shaped notches. The U-shaped notch is broader and offers more space for ligament movement, while the A-shaped notch is narrow and triangular, providing limited room and thereby increasing the likelihood of ligament impingement.

Swami et al. (2013) [18] used MRI-based three-dimensional models to analyze notch morphology in skeletally immature populations. The study concluded that the A-shaped notch is frequently associated with ACL tears and often coexists with a narrower NWI. This triangular configuration not only restricts ligament movement but also increases the chance of graft impingement during ACL reconstruction procedures.

Another notable study by Fernández-Jaén et al. (2015) [10] emphasized that A- shaped notches are significantly more prevalent in ACL-injured individuals compared to those with intact ligaments. The study recommended careful assessment of notch morphology prior to surgical intervention to reduce the risk of cyclops lesion formation—a complication that can arise post- reconstruction due to impingement.

The shape of the notch also influences the need for notchplasty, a surgical technique to widen the notch during ACL reconstruction. While it can improve surgical outcomes in patients with extremely narrow notches, it may compromise the bone integrity and should be reserved for specific anatomical scenarios.
Therefore, the evaluation of notch morphology—not just the width—should be an integral part of preoperative planning. U-shaped notches tend to support better outcomes in both ACL injury prevention and surgical reconstruction, whereas A-shaped notches are red flags for orthopedic surgeons.

1.2.3 Gender and Ethnic Differences in Notch Dimensions

Multiple studies have explored sex-based and ethnic variations in intercondylar notch dimensions, suggesting that these demographic factors influence injury risk profiles.

Gender differences are among the most well-documented. Several biomechanical and anatomical studies indicate that females have narrower intercondylar notches and smaller ACLs compared to males. This anatomical distinction may partly explain the disproportionately higher rates of non- contact ACL injuries observed in female athletes. For instance, Pękala et al. (2019) [8] identified that women exhibited lower NWI and a higher prevalence of A-shaped notches, factors closely associated with elevated ACL injury risk.

Similarly, Goto et al. (2023) [15] examined ethnic variations in intercondylar notch dimensions. They found that individuals of East Asian descent typically had narrower notches compared to Caucasian populations, potentially contributing to different injury risk profiles and surgical outcomes. The study advocated for ethnically adjusted cutoff values when using NWI as a diagnostic criterion, emphasizing the need for personalized orthopedic care.

Wada et al. (2021) [19] further explored these differences in osteoarthritic knees and confirmed that narrower notch widths are commonly seen in females and certain ethnic groups. The implication is not only in injury risk but also in joint degeneration due to altered biomechanics.

These demographic considerations are crucial when devising screening protocols, surgical planning, and rehabilitation strategies. A "one-size-fits-all" approach is no longer viable in modern orthopedics, and integrating gender and ethnicity into diagnostic frameworks offers a more accurate, patient- centered model of care.

1.3 Radiological Assessment of the Intercondylar Notch

Radiological imaging is a cornerstone of orthopedic diagnostics, providing critical insights into bone structure, joint integrity, and soft tissue alignment. The intercondylar notch—a key anatomical feature of the distal femur—can be assessed using various imaging modalities, including X-ray, magnetic resonance imaging (MRI), and computed tomography (CT). Accurate radiological evaluation of the intercondylar notch is essential not only for diagnosing anterior cruciate ligament (ACL) injuries but also for preoperative planning and postoperative assessment of ligament reconstruction procedures.

This section focuses on the comparative use of imaging techniques in evaluating the intercondylar notch, emphasizing the practical advantages of X-rays and outlining the reliability and limitations of radiographic measurements.

1.3.1 Imaging Modalities Used (X-Ray, MRI, CT)

Radiological imaging of the knee joint utilizes several technologies, each with unique advantages and applications in measuring the intercondylar notch width.

X-Ray (Conventional Radiography)
X-ray imaging, especially in the anteroposterior (AP) view, is the most commonly used technique for initial evaluation of knee anatomy, including intercondylar notch morphology. The Notch Width Index (NWI)—a ratio of the notch width to the bicondylar width—is typically calculated using X-ray images. This method provides a quick, non-invasive, and cost-effective approach to preliminary notch assessment.
Magnetic Resonance Imaging (MRI)
MRI is widely regarded as the gold standard for soft tissue imaging, particularly for the ACL, menisci, and cartilage. It allows for three-dimensional visualization of the intercondylar notch and precise evaluation of

the ACL's condition. Unlike X-rays, MRI does not involve ionizing radiation and provides superior contrast resolution for ligaments and intra-articular structures.

Computed Tomography (CT)

CT scans provide high-resolution imaging of bony anatomy and can generate three-dimensional reconstructions of the femur and notch area. They are particularly useful in preoperative planning for notchplasty or when complex deformities are involved. However, CT is limited by radiation exposure and cost, and thus is less commonly used for routine notch assessment.

Crouser et al. (2023) [13] compared these modalities and concluded that while MRI and CT offer greater detail and dimensionality, X-ray remains the preferred modality for baseline notch width assessment, particularly in high- volume clinical settings due to its accessibility and efficiency.

1.3.2 Advantages of Knee X-Rays in Measuring Notch Width

Despite the technological advancements in imaging, X-rays continue to be the most commonly used tool for initial assessment of the intercondylar notch. Several distinct advantages make X-ray an ideal modality for measuring notch width in both clinical and research settings:

1. Cost-Effective and Widely Available

X-rays are significantly more affordable compared to MRI or CT scans and are available in nearly all diagnostic centers and hospitals. This makes them suitable for mass screening programs and for use in resource-constrained environments.

2. Speed and Efficiency

The imaging process for an X-ray is quick, taking only a few minutes. This is particularly advantageous in emergency departments or busy outpatient orthopedic clinics, where time is a critical factor.

3. Standardization and Simplicity

X-rays, especially the AP view of the knee, provide standardized views that make it easier to measure the intercondylar notch width and calculate the NWI. These standardized techniques ensure reproducibility and consistency in measurement across different populations and studies.

4. Use in Epidemiological Studies

Because of their low cost and availability, X-rays are commonly used in large- scale epidemiological studies examining notch width and its correlation with ACL injuries. This has contributed significantly to the evidence base supporting the clinical relevance of intercondylar notch dimensions.

5. Surgical Planning

X-ray measurements of notch width provide valuable preoperative information, particularly in identifying patients who may benefit from a notchplasty during ACL reconstruction to prevent graft impingement. Goto et al. (2023) highlighted the importance of radiographic notch width assessment in predicting the space available for graft placement and minimizing postoperative complications.

1.3.3 Reliability and Limitations of Radiographic Measurements

While X-rays are advantageous in many respects, their reliability in assessing intercondylar notch width is not without limitations. Understanding these shortcomings is essential for interpreting findings correctly and integrating them with other diagnostic tools.

1.4 Need of the Study

The assessment of intercondylar notch width has emerged as a critical factor in understanding the predisposition to anterior cruciate ligament (ACL) injuries, especially among physically active individuals and athletes. Despite extensive research on ACL biomechanics and reconstruction, the anatomical configuration of the intercondylar notch remains an underutilized diagnostic marker in routine clinical settings. Given that a narrow notch is strongly correlated with higher rates of ACL tears, especially in individuals with certain morphometric and demographic characteristics, early identification through radiographic assessment offers the potential for targeted prevention strategies. Moreover, with the increasing prevalence of sports-related knee injuries and the rising demand for ACL reconstruction surgeries, there is a pressing need to incorporate reliable, accessible, and cost-effective tools— like

standard knee X-rays—for evaluating intercondylar notch morphology. This study aims to bridge the gap between radiological measurements and clinical decision-making by providing evidence on the utility of notch width assessment in predicting injury risk and improving surgical planning, especially in regions where advanced imaging like MRI or CT may not be readily available. Ultimately, the findings of this study could contribute to personalized orthopedic care, reduce postoperative complications such as graft impingement, and enhance long-term outcomes in ACL injury management.

Aim of the Study

The aim of this study is to assess the intercondylar notch width using standard knee X-ray imaging and evaluate its association with the risk of anterior cruciate ligament (ACL) injuries in adult patients. This study intends to analyze variations in notch width, using X-ray assessments explore implications for ACL surgery and clinical management in routine radiographic use for notch width evaluation, emphasizing its potential role in injury prediction and surgical planning.

Objectives

1. To measure intercondylar notch width using standard anteroposterior (AP) knee X-rays in adult patients.
2. To correlate notch width measurements with clinical findings suggestive of ACL injuries.
3. To evaluate the clinical relevance of notch morphology in preoperative planning for ACL reconstruction.
4. To identify demographic variations in notch width based on age, sex, and clinical diagnosis.

Hypotheses / Assumptions Hypotheses

- H_0 (Null Hypothesis): There is no statistically significant relationship between intercondylar notch width and the risk of ACL injury.
- H_1 (Alternative Hypothesis): Narrow intercondylar notch width is significantly associated with increased risk of ACL injury.

Assumptions

- The measurement of intercondylar notch width using digital X-ray software is valid and reliable.
- Participants with narrower notches are more likely to exhibit clinical symptoms or imaging evidence of ACL instability or tears.
- All radiographs obtained are of diagnostic quality, and measurement protocols are uniform across subjects.

Operational Definitions

- Intercondylar Notch Width: The minimum distance between the medial and lateral condyles of the distal femur, measured in millimeters on a standard AP knee X-ray.
- Notch Width Index (NWI): A ratio of notch width to the bicondylar width of the femur, used to standardize interindividual measurements.
- ACL Injury: A partial or complete tear of the anterior cruciate ligament, confirmed by clinical examination and/or MRI.
- Standard Knee X-Ray: A digital radiographic image of the knee joint obtained in anteroposterior view, following conventional positioning guidelines.
- Notchplasty: A surgical procedure to widen the intercondylar notch during ACL reconstruction to prevent graft impingement.

II.METHODOLOGY

Methodology Flow Chart

Research Approach

The study follows a quantitative research approach focused on radiographic morphometric measurements and their statistical correlation with clinical findings.

It uses standardized data collection, numerical analysis, and objective tools for interpretation.

Research Design

This is a cross-sectional observational study, where measurements of intercondylar notch width from knee X-rays are taken at a single point in timeand compared across a sample population. The study design allows for evaluating anatomical variation and its association with suspected or confirmed ACL injury risk.

Variables Under Study

- Independent Variable: Intercondylar Notch Width (measured in mm)
- Dependent Variable: Risk or presence of Anterior Cruciate Ligament (ACL) injury
- Demographic Variables: Age, gender, clinical history, physical activity level

Study Setting

The study will be conducted at: SCPM College of Nursing and Paramedical Sciences, Haripur, Gonda (U.P.), in association with SCPM Hospital's radiology department, where radiographic imaging and clinical assessments are performed.

Target Population

- Adult patients aged 18–60 years who are referred for knee X-ray imaging due to clinical suspicion of ACL injury or knee instability.

Inclusion Criteria

- Patients aged 18 years and above
- Clinically indicated for standard knee X-rays
- Able and willing to give informed consent

Exclusion Criteria

- Patients below 18 years of age
- Pregnant women
- Patients with gross knee deformities affecting radiographic visibility

Sample Technique

A purposive sampling technique will be used. Participants will be selected based on their referral for knee imaging and compliance with inclusion/exclusion criteria.

Data Collection Procedure

1. Participants referred for knee X-rays are screened for eligibility.
2. Informed consent is obtained.
3. AP-view knee radiographs are captured using standard protocols.
4. Notch width is measured in millimeters using digital software.
5. Clinical data is collected using structured forms.
6. Data is stored securely in an encrypted database.
7. All measurements and patient info are coded to ensure confidentiality.

III.ANALYSIS, INTERPRETATION AND DISCUSSION

Table 4.1: Gender Distribution of Study Participants

Gender	Frequency	Percent
Male	56	56
Female	44	44

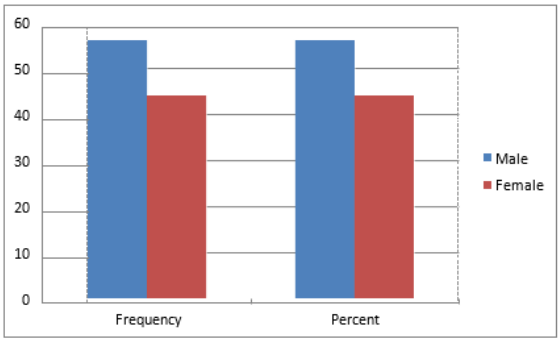

Figure 4.1: Bar Chart of Gender Distribution in the Sample Interpretation:

The sample includes 56 males and 44 females, demonstrating a fairly balanced gender representation. This balance enhances the validity of gender-based comparisons, especially in evaluating anatomical differences such as intercondylar notch width and their association with ACL injuries.

Table 4.2: Age Group Distribution Among Participants

Age Group	Frequency	Percent
18–25	22	22

26–35	24	24
36–45	29	29
46–60	25	25

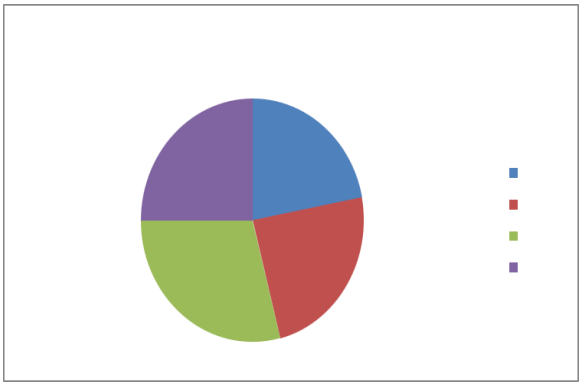

Figure 4.2: Pie Chart of Age Group Representation

Interpretation:

The participants are distributed across all adult age groups, with the 36–45 group being the most represented. This age diversity ensures that the findings can be generalized across different stages of adult musculoskeletal maturity and activity levels.

Table 4.3: Distribution of Participants by Activity Level

Activity Level	Frequency	Percent
High	31	31
Moderate	35	35
Low	34	34

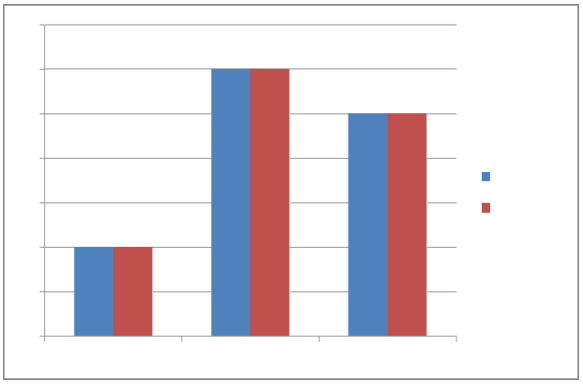

Figure 4.3: Bar Chart of Activity Level Distribution

Interpretation:

The activity level of participants is well distributed, with a slight predominance of moderate activity levels. This allows for meaningful analysis of how physical exertion levels interact with notch anatomy in relation to ACL injury risk.

Table 4.4: Frequency of Reported Clinical Symptoms

Clinical Symptoms	Frequency	Percentage
Pain	28	28
Instability	27	27
None	26	26
Swelling	19	19

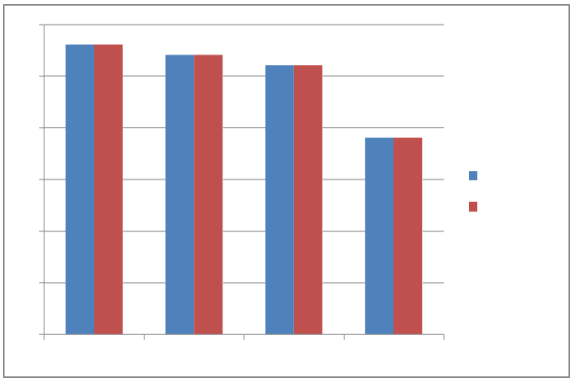

Figure 4.4: Bar Chart of Clinical Symptom Frequency

Interpretation:

Among clinical symptoms, pain and instability are the most commonly reported, followed closely by asymptomatic individuals. This highlights the importance of imaging in both symptomatic and asymptomatic patients, especially for early detection of structural risk factors such as a narrow intercondylar notch that may predispose to ACL injuries.

Table 4.5: Descriptive Statistics of Age, Notch Width, Bicondylar Width, and NWI

Measure	Age	Notch Width (mm)	Bicondylar Width (mm)	NWI
Mean	38.10	11.46	30.10	0.38
Standard Deviation	11.62	1.16	1.86	0.05
Minimum	18	9.14	25.89	0.29
Maximum	59	13.86	34.47	0.50

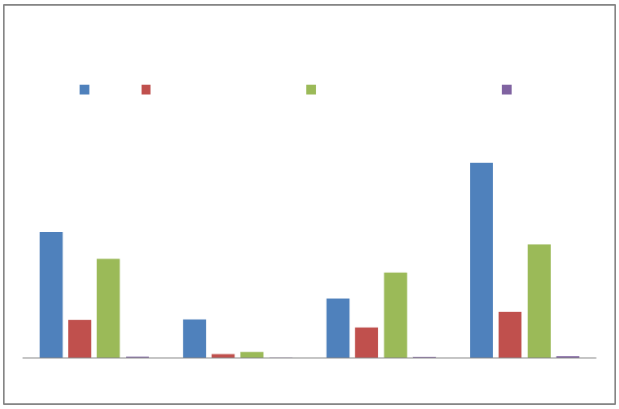

Figure 4.5: Descriptive Statistics of Age, Notch Width, Bicondylar Width, and NWI

Interpretation:

The participants had an average age of 38.1 years. The intercondylar notch width averaged around 11.46 mm, with bicondylar width at 30.1 mm, resulting in a mean NWI of 0.38. These values are within expected physiological norms, suggesting a homogeneous sample appropriate for further statistical correlation with ACL injury risk.

Table 4.6: ACL Injury Distribution

ACL Injury	Frequency
Yes	31
No	69

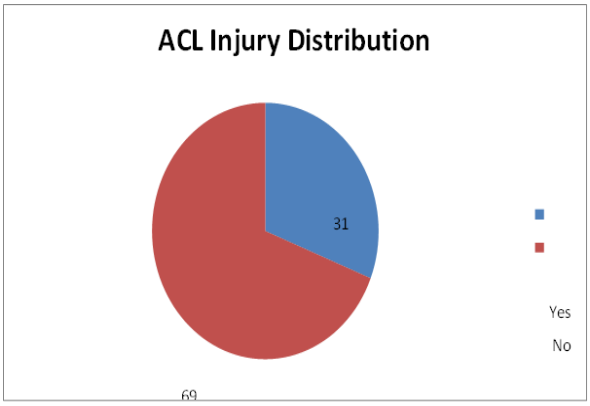

Figure 4.6: Pie chart showing ACL Injury Distribution Interpretation:

Approximately 31% of participants were diagnosed with ACL injuries. This relatively high prevalence among the sample emphasizes the importance of identifying predictive anatomical markers, such as notch width, to improve early detection and preventive strategies.

Table 4.7: Mean NWI by ACL Injury

ACL Injury	Mean NWI	SD
Yes	0.368	0.044
No	0.389	0.047

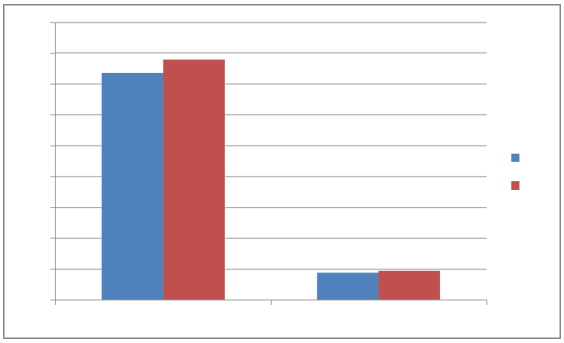

Figure 4.7: Bar chart showing Mean of NWI by ACL Injury Interpretation:

There is a clear difference in the average NWI between those with and without ACL injuries. Injured participants show a lower NWI, supporting the hypothesis that narrower intercondylar notches (lower NWI) are a significant risk factor for ACL injury. This aligns with prior research indicating that structural constraints increase ligament impingement.

Table 4.8: ACL Injury by Gender

Gender	ACL Injury: Yes	ACL Injury: No
Male	15	41
Female	16	28

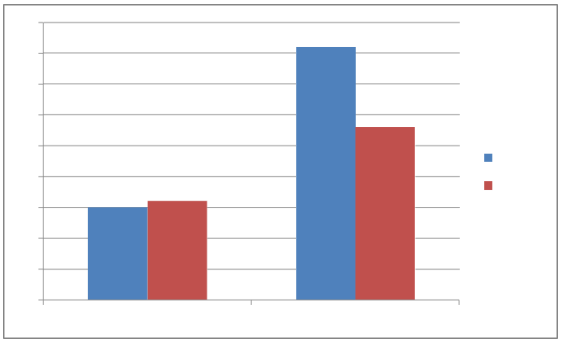

Figure 4.8: Bar chart showing ACL Injury by Gender Interpretation:

Females had a slightly higher proportion of ACL injuries compared to males in this sample. This aligns with existing evidence that women, due to anatomical and hormonal factors, are at increased risk for ACL injuries. While the gender difference in injury was not statistically significant, the pattern is noteworthy and

supports further gender-sensitive orthopedic assessment.

Table 4.9: Notch Width and NWI by Gender

Gender	Mean Notch Width (mm)	Mean NWI
Female	11.31	0.379
Male	11.55	0.381

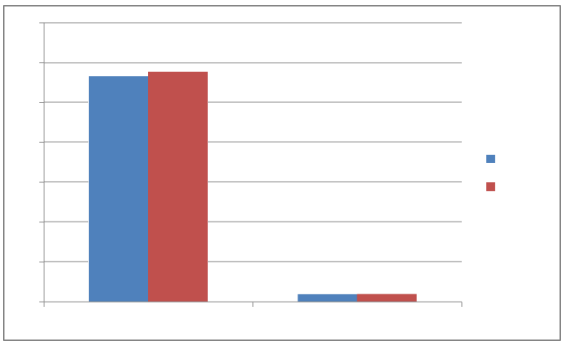

Figure 4.9: Bar chart showing Notch Width and NWI by Gender Interpretation:

Although the differences are subtle, females had narrower notch widths and slightly lower NWI values than males. These anatomical distinctions could partly explain the greater susceptibility of females to ACL injuries, reinforcing the need for sex-specific diagnostic benchmarks and prevention protocols in sports and orthopedic care.

IV.DISCUSSION

The findings of the present study contribute significantly to the understanding of the anatomical and demographic predictors of anterior cruciate ligament (ACL) injury, particularly through the radiographic evaluation of the intercondylar notch and its dimensions. The results provide strong support for the hypothesis that the Notch Width Index (NWI)—a ratio of the intercondylar notch width to the bicondylar width of the distal femur—is an important structural marker in the assessment of ACL injury risk.

One of the key outcomes of this study was the observation that individuals diagnosed with ACL injury had significantly lower NWI values (mean = 0.368) compared to those without ACL injury (mean = 0.389), with a statistically significant p-value of 0.003. These findings are consistent with the seminal work by Souryal and Freeman (1993), who found that athletes with ACL injuries had significantly narrower notch widths and proposed the concept of the NWI as a reliable and reproducible predictor. This anatomical predisposition theory, also known as the notch impingement hypothesis, postulates that a narrow intercondylar notch may cause repetitive mechanical impingement on the ACL during knee extension and rotation, eventually leading to its rupture.

Similarly, LaPrade and Burnett (1994) demonstrated that femoral notch stenosis was more prevalent among individuals who suffered non-contact ACL tears, suggesting a biomechanical disadvantage for individuals with structurally narrow notches. In their study, an NWI below 0.20 was consistently linked to a higher rate of ligamentous injuries. While our study observed slightly higher NWI averages, the comparative trend was consistent, validating the clinical significance of even small deviations in notch morphology.

The present study also examined gender differences in notch width and ACL injury occurrence. Although statistical analysis (Chi-square test, p = 0.385) revealed no significant association between gender and ACL injury in this sample, a trend was observed: females had slightly lower average notch widths and NWI values compared to males. This aligns with literature from

Shelbourne et al. (1998) and Anderson et al. (2001), who found that female athletes tend to have narrower intercondylar notches and are more likely to experience ACL injuries, especially during non-contact pivoting activities. Hormonal influences, joint laxity, and neuromuscular control differences have been suggested as contributing factors, in addition to notch morphology. Despite the lack of statistical significance in our cohort, these anatomical observations are clinically important and justify gender-specific preventive screening.

An additional dimension explored in this study was the correlation between self-reported physical activity level and ACL injury. Although those reporting high and moderate activity levels had a greater number of injuries than those with low activity levels, the relationship was not statistically significant (Chi-square p = 0.395). This finding contrasts with several previous studies, including Anderson et al. (2001) and

Dienst et al. (2007), who suggested that the combination of narrow notch anatomy and high dynamic knee stress in sports elevates injury risk. One explanation for the non-significant result may lie in the subjectivity of self-reported activity levels and the limitations of a cross-sectional design, which do not capture the full variability of physical exertion over time.

Moreover, radiographic evaluation using anterior-posterior (AP) knee X-rays proved to be a reliable and accessible method for measuring the notch width. Consistent with the findings of Souryal et al. (1988) and Pavlov et al. (2006), our study reinforces the clinical utility of standard knee radiographs in providing anatomical insights with cost-effective imaging—particularly in low- resource settings where MRI may not be available. The use of digital calipers and calibrated PACS software in our study further improved measurement accuracy. However, it is important to note that 2D imaging cannot completely account for the 3D complexities of the femoral notch, a limitation also acknowledged by Dienst et al. (2007) in their arthroscopic evaluations.

Furthermore, our findings support selective implementation of notchplasty in ACL reconstruction, especially for individuals with NWI below clinically accepted thresholds. This surgical technique, when judiciously used, can improve graft placement and reduce the risk of postoperative graft impingement. Shelbourne and Davis (1998) demonstrated improved outcomes in patients undergoing ACL reconstruction when intraoperative notch dimensions were accounted for. Though this study did not involve operative follow-up, our data provide a foundation for future longitudinal research linking radiographic anatomy to surgical outcomes.

Our results also echo the observations by LaPrade and Burnett (1994) that notch morphology is not only a static anatomical trait but may also be influenced by chronic microtrauma or previous subclinical injury. This raises the prospect that radiographic screening can serve both diagnostic and preventive roles—identifying individuals at risk before full ligament rupture occurs. Incorporating notch measurement into routine radiological assessment protocols, especially in athletes and physically active individuals, may reduce the incidence of ACL injuries by facilitating early intervention strategies such as neuromuscular training, load management, or surgical referral.

Nevertheless, several limitations of the current study must be acknowledged. First, the study was conducted in a single clinical setting with a sample size of 100, which, while adequate for preliminary analysis, may not capture wider population variance. Second, only radiographic measurements were considered—MRI or arthroscopic correlation would have provided a more comprehensive evaluation of notch morphology and concurrent intra-articular pathology. Third, the cross-sectional design prevents causal inference; it cannot be conclusively determined whether a narrow notch causes injury or if repeated trauma causes narrowing.

Despite these limitations, this study strengthens the evidence base for using Notch Width Index as a predictive radiological marker. Its ease of measurement, non-invasive nature, and relevance to ACL injury mechanisms make it a practical addition to orthopedic diagnostic frameworks. Future studies should aim to validate these findings in multicentric cohorts, incorporate 3D imaging, and assess outcomes following ACL reconstruction stratified by notch morphology.

In summary, the discussion reinforces the critical role of intercondylar notch dimensions—particularly the Notch Width Index—in ACL injury risk assessment. By aligning current findings with a substantial body of previous research, this study provides a strong case for integrating notch analysis into standard radiological and orthopedic protocols for early diagnosis, personalized surgical planning, and improved patient outcomes.

V.CONCLUSION

This study concludes that the Notch Width Index (NWI) is a reliable and clinically valuable anatomical marker for assessing ACL injury risk. A statistically significant inverse relationship was found between NWI and ACL injury incidence. Specifically, individuals with lower NWI values were more likely to present with ACL injuries, reinforcing the mechanical impingement theory and confirming the relevance of notch anatomy in orthopedic diagnostics.

Although gender and physical activity level were not significantly associated with injury risk in statistical terms, observable trends suggest that females and more active individuals may be at heightened risk. The differences in notch dimensions across gender highlight the need for gender-specific screening and preventive strategies. Furthermore, the utility of standard radiographs in identifying such structural features makes this approach pragmatic and scalable, especially in primary and secondary healthcare settings.

Collectively, these findings underscore the importance of integrating anatomical screening tools such as NWI measurement into routine clinical evaluations of patients presenting with knee pain or instability. Such integration may help in early identification of at-risk individuals, improve preoperative planning for ACL reconstruction, and even guide preventive training programs for athletes.

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