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Original Research Article

AN ASSESSMENT OF THE ROLE OF DIAGNOSTIC ULTRASOUND IN ANTERIOR CRUCIATE LIGAMENT TEAR AND ITS CORRELATION WITH MRI FINDINGS

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ABSTRACT

Background: The anterior cruciate ligament (ACL) is crucial for knee stability, and its injury can lead to further joint damage if undiagnosed. While MRI is the gold standard, it is expensive and not always accessible. Ultrasound offers a rapid, cost-effective alternative for dynamic assessment of ACL tears. This study aims to evaluate the role of ultrasound in diagnosing ACL injuries and correlate its findings with MRI. **Aims:** To assess the role of ultrasound in diagnosing anterior cruciate ligament injury and correlate its findings with MRI findings. **Materials and Methods:** The present study was a Hospital-based cross-sectional study. This Study was conducted from 1st January 2023 to 30th June 2024 at Department of Radiodiagnosis, Nilratan Sircar Medical College & Hospital, and Kolkata. Involving 70 patients with anterior cruciate ligament (ACL) tear. Positive USG signs are – significant anterior tibial translation, femoral notch sign, wavelike PCL sign and capsular protrusion sign. **Results:** Out of 70 patients, 75.7% showed positive anterior tibial translation, with significantly higher mean translation in injured knees (3.9 ± 1.8 mm) than uninjured (0.9 ± 0.45 mm; $p < 0.0001$). The side-to-side difference was greater in MRI-confirmed ACL tears (2.26 ± 0.98 mm vs. 0.81 ± 0.21 mm; $p < 0.0001$). The femoral notch sign had high sensitivity (91.1%) and PPV (92.7%). The wavelike PCL sign showed moderate sensitivity and specificity (71.4%), with high PPV (90.9%) but low NPV. Anterior tibial translation had a sensitivity of 94.6% and specificity of 71.4%. Clinical signs were more evident in early presentations (<6 weeks). Overall, anterior tibial translation using ultrasonography were the most sensitive diagnostic tools. **Conclusion:** Anterior tibial translation by ultrasonography proved to be the most sensitive diagnostic tools for detecting ACL tears, with sensitivities of 94.6% and 96.4%, respectively. The femoral notch sign and wavelike PCL sign also demonstrated good diagnostic value, particularly in early presentations. Clinical and imaging findings strongly correlated with MRI-confirmed ACL injuries, highlighting the usefulness of combined diagnostic approaches in early and accurate ACL tear detection.

INTRODUCTION

The knee is among the most vulnerable joints in the human body, with anterior cruciate ligament (ACL) injuries being one of the most common ligamentous pathologies requiring surgical reconstruction.[1,2] The ACL, along with the posterior cruciate ligament (PCL), medial collateral ligament (MCL), and lateral collateral ligament (LCL), provides static stability to the knee, enabling it to function as a complex hinge joint.[3] The ACL specifically acts as the primary restraint to anterior tibial translation and a secondary restraint to internal rotation [4]. Failure to recognize acute ACL tears may lead to further intra-articular damage, particularly to the medial meniscus and articular cartilage.[5]

Diagnosis: According to the American Academy of Orthopaedic Surgeons (AAOS), accurate diagnosis requires a thorough history, physical examination, and magnetic resonance imaging (MRI).[6] While patients often report a "pop" sensation, rapid swelling, and instability following an ACL injury,

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physical exams in the acute setting are limited due to pain and hemarthrosis.[7] MRI remains the gold standard for ACL tear diagnosis but is expensive and not always readily available.[8]

Role of Ultrasound: Dynamic high-resolution ultrasound (USG) has emerged as a promising alternative, offering several advantages over MRI: it is cost-effective, accessible, quick to perform, and suitable for dynamic assessment of knee structures.[9] USG can detect complete ACL tears and associated intra-articular pathologies such as meniscal tears with good accuracy. Indirect signs—like femoral notch sign, capsular protrusion, and wave-like PCL—further support diagnosis. Moreover, USG allows real-time, point-of-care interpretation, enhancing clinical decision-making.[10] Early and accurate diagnosis of ACL tears is essential to prevent secondary complications and ensure timely surgical management. Although MRI remains the reference standard, musculoskeletal USG is a valuable, accessible, and cost-effective diagnostic tool, especially beneficial in resource-limited settings or in patients contraindicated for MRI.[11] To assess the role of ultrasound in diagnosing anterior cruciate ligament injury and correlate its findings with MRI findings.

MATERIALS AND METHODS

Study design/ Experimental design: Hospital-based cross- sectional study.

Place of study: Department of Radiodiagnosis, Nilratan Sircar Medical College & Hospital, Kolkata.

Period of study: 1st January 2023 to 30th June 2024.

Study population: Adult patients of age group 18yrs to 50 yrs having symptoms of an ACL tear, referred from Department of Orthopedic Surgery, Nil Ratan Sircar Medical College & Hospital to Department of Radiodiagnosis, Nil Ratan Sircar Medical College & Hospital for undergoing USG and MRI study of knee.

Inclusion Criteria: OPD and IPD patients who sustain trauma to knee joint with a suspicion of having ACL injury.

Exclusion Criteria

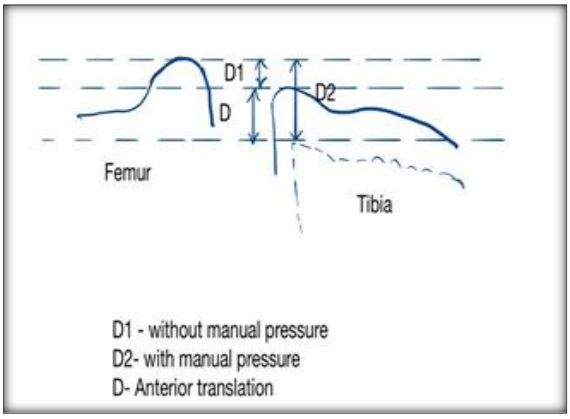
i. Critically ill patients
ii. Having bleeding diathesis
iii. Any fracture in the distal femur and proximal tibia.
iv. Any infections of knee joint.
v. Having degenerative changes
vi. Contraindications for MRI.
vii. Skin infections making difficulty in doing ultrasound.

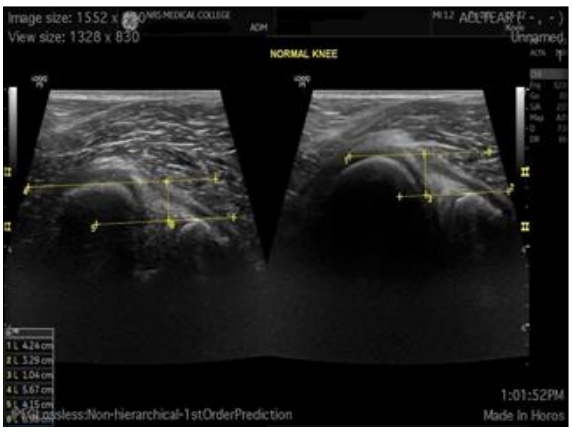
Sample design: Purposive sampling.

Sample size: 70 USG and MRI patients.

Anterior Tibial Translation

Anterior Tibial Translation refers to the forward movement of the tibia (shin bone) relative to the femur (thigh bone) and is a key indicator of anterior cruciate ligament (ACL) injury. A GE Logiq P9 ultrasound machine with a high-resolution linear probe was used to assess anterior tibial translation in patients positioned prone with knees flexed at 20° using a rolled towel under the lower legs. The probe was placed sagittally in the popliteal fossa to align the medial femoral and tibial condyles. Reference lines were drawn tangential to the femoral condyle and posterior tibia to measure distance D1. With maximal anterior pressure applied to the tibia, the resulting forward displacement was measured as distance D2. The same method was applied to both injured and uninjured knees. An ACL rupture was suspected if the side-to-side difference in tibial translation—calculated as [(D2injured – D1injured) – (D2uninjured – D1uninjured)]—exceeded 1 mm.





Indirect Signs

For three indirect signs of ACL tear, namely the femoral notch sign, wavelike PCL signs, and posterior capsule protrusion sign.

The US examination was conducted over the posterior portion of the knee while the patient was positioned prone with the knee extended. Particular attention was paid to the three indirect US indicators of an ACL rupture. The knee was first inspected in a transverse plane to see whether the hypoechoic intercondylar "notch sign" was present at the femoral insertion of the ACL. A round or oval hypoechoic collection at the ACL's femoral connection was indicative of a positive sign. The hematoma that results from an ACL being torn from its proximal attachment on the femur was shown by this hypoechoic collection. Next, a longitudinal

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examination of the knee was performed to determine whether the posterior joint capsule and PCL displayed the wavelike PCL sign and posterior capsule protrusion sign. The posterior capsule was shown on US imaging as a slightly curved echogenic line, while the PCL was seen as a hypoechoic wedge between the posterior capsule and the tibia's bony outline. The posterior capsule protrudes posteriorly and the PCL may seem thicker and wavelike in cases of total ACL ruptures. Both a thickened PCL and a wave-like PCL were seen as pathogenic and favourable indicators. Examined above the PCL, the posterior joint capsule usually had a flat or convex appearance. Capsular protrusion was seen as a convex capsular appearance.

All procedures were performed by experienced Radiologists. The Sonologists were blinded to clinical findings and MRI findings. The patient who did not have an MRI scan was asked to undergo an MRI scan, and the findings were noted. Those who already had an MRI, their findings were recorded.

Statistical Analysis

For statistical analysis, data were initially entered into a Microsoft Excel spreadsheet and then analyzed using SPSS (version 27.0; SPSS Inc., Chicago, IL, USA) and GraphPad Prism (version 5). Numerical variables were summarized using means and standard deviations, while Data were entered into Excel and analyzed using SPSS and GraphPad Prism. Numerical variables were summarized using means and standard deviations, while categorical variables were described with counts and percentages. Two-sample t-tests were used to compare independent groups, while paired t-tests accounted for correlations in paired data. Chi-square tests (including Fisher's exact test for small sample sizes) were used for categorical data comparisons. P-values ≤ 0.05 were considered statistically significant.

RESULTS

Table 1: Distribution of Anterior tibial translation findings in USG (N=70)

Anterior tibial translation	N	%
Negative	17	24.30%
Positive	53	75.70%
Total	70	100.00%

Table 2: Distribution of Anterior tibial translation findings in USG in injured vs. uninjured knee (N=70)

	Mean	Standard Deviation	P value
Anterior tibial translation in injured knee in mm	3.9	1.8	<0.0001
Anterior tibial translation in uninjured knee in mm	0.9	0.45	

Table 3: Distribution of Side to side difference in mm anterior tibial translation test of both normal and abnormal knee (N=70)

Parameter	MRI findings of ACL tear	Mean	SD	P value
Side to side difference	Positive	2.26	0.98	<0.0001
	Negative	0.81	0.21	

Table 4: Sensitivity analysis of Femoral notch sign (N=70)

Parameters		MRI		Total	Chi- square statistic	P value
		Negative	Positive			
Femoral notch sign	Positive	4	51	55	25.98	< 0.00001
	Negative	10	5	15		
Total		14	56	70		
Sensitivity Analysis						
Sensitivity		91.10%				
Specificity		71.40%				
Positive predictive value		92.70%				
Negative predictive value		66.60%				

Table 5: Sensitivity analysis of Posterior capsular protrusion (N=70)

Parameters		MRI		Total	Chi- square statistic	P value
		Negative	Positive			
Posterior capsular protrusion	Positive	4	44	48	12.99	0.0003
	Negative	10	12	22		
Total		14	56	70		
Sensitivity Analysis						
Sensitivity		78.50%				
Specificity		71.40%				
Positive predictive value		91.60%				
Negative predictive value		45.40%				

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Table 6: Sensitivity analysis of Wavelike PCL sign (N=70)

Parameters		MRI		Total
		Negative	Positive	
Wavelike PCL sign	Positive	4	40	44
	Negative	10	16	26
Total		14	56	70
Sensitivity Analysis				
Sensitivity		71.40%		
Specificity		71.40%		
Positive predictive value		90.90%		
Negative predictive value		38.40%		

Table 7: Sensitivity analysis of Anterior tibial translation (N=70)

Parameters		MRI		Total
		Negative	Positive	
Anterior tibial translation	Positive	4	53	57
	Negative	10	3	13
Total		14	56	70
Sensitivity Analysis				
Sensitivity		0.946		
Specificity		0.714		
Positive predictive value		0.929		
Negative predictive value		0.769		

Table 8: Distribution of femoral notch sign on USG according to duration of complaints (N=70)

Parameters		Femoral notch sign		Total	Chi- square statistic	P value
		Negative	Positive			
Duration of complaints	6 weeks	4	42	46	10.71	0.001
	6 weeks	10	14	24		
Total		14	56	70		

Table 9: Distribution of wavelike PCL sign on USG according to duration of complaints (N=70)

Parameters		Wavelike PCL sign		Total	Chi- square statistic	P value
		Negative	Positive			
Duration of complaints	<6 weeks	5	41	46	39.66	<0.0001
	>6 weeks	21	3	24		
Total		26	44	70		

Table 10: Distribution of anterior tibial translation on USG according to duration of complaints (N=70)

Parameters		Anterior tibial translation		Total	Chi- square statistic	P value
		Negative	Positive			
Duration of complaints	<6 weeks	7	39	46	1.91	0.166
	>6 weeks	7	17	24		
Total		14	56	70		

Table 12: Sensitivity analysis of USG (taking any of the positive signs of USG as positive findings for ACL tear) (N=70)

Parameters		MRI		Total
		Negative	Positive	
USG	Positive	3	54	57
	Negative	11	2	13
Total		14	56	70
Sensitivity Analysis				
Sensitivity		96.40%		
Specificity		78.50%		
Positive predictive value		94.70%		
Negative predictive value		84.60%		

Table 12: Sensitivity of different methods (N=70)

Methods	Sensitivity
Wavelike PCL sign	71.40%
Posterior capsular protrusion	78.50%
Pivot shift test	84.90%
Lachman test	87.50%
Anterior drawer test	89.20%
Femoral notch sign	91.10%
Anterior tibial translation	94.60%
USG(minimum one of the four USG signs is positive)	96.40%

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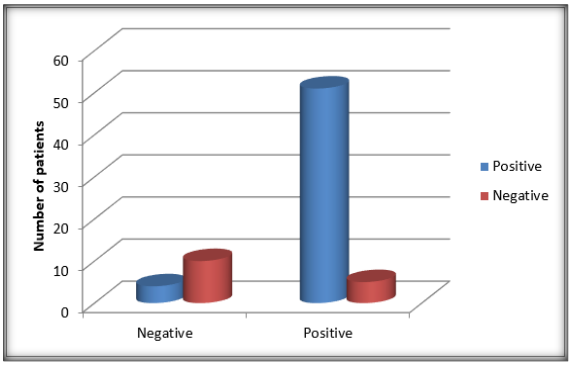


Figure 1: Sensitivity analysis of Femoral notch sign (N=70)

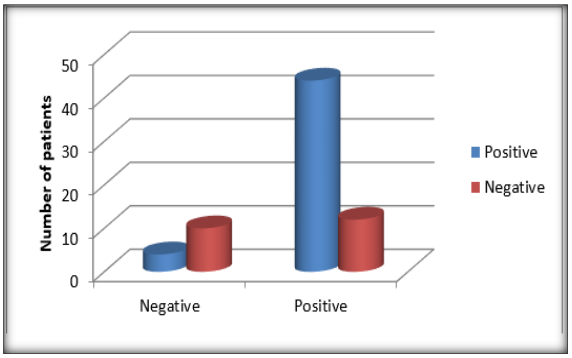


Figure 2: Sensitivity analysis of Posterior capsular protrusion (N=70)

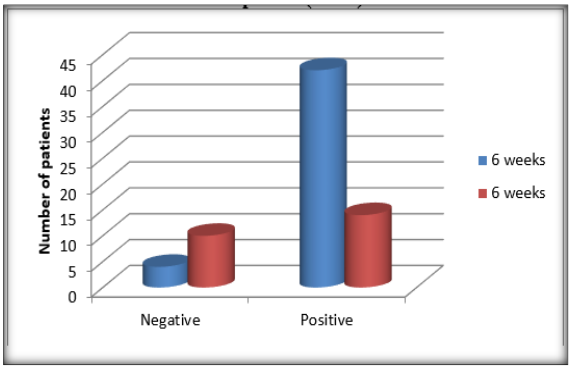


Figure 3: Distribution of femoral notch sign on USG according to duration of complaints (N=70)

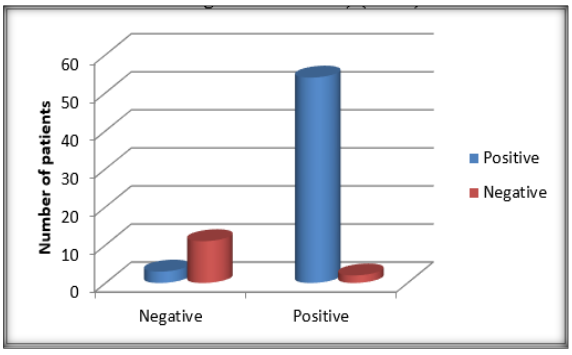
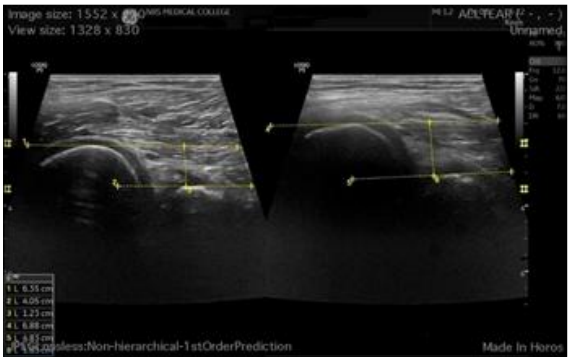


Figure 4: Sensitivity analysis of USG (taking any of the positive signs of USG as positive findings for ACL tear) (N=70)

Out of a total of 70 patients assessed for anterior tibial translation, 53 patients (75.7%) exhibited a positive anterior tibial translation, indicating potential ligamentous laxity or injury, while only 17 patients (24.3%) demonstrated a negative anterior tibial translation.

The mean anterior tibial translation in the injured knee was 3.9 ± 1.8 mm, whereas in the uninjured knee it was significantly lower, at 0.9 ± 0.45 mm. The difference between the two groups was statistically significant with a p-value < 0.0001, indicating a highly significant increase in anterior tibial translation in injured knees.



Anterior tibial translation of 4.0 mm in injured knee making side to side difference of 3.4 mm (left – without pressure, right- with pressure).

The mean side-to-side difference in anterior tibial translation among patients with MRI-confirmed ACL tear was 2.26 ± 0.98 mm, while in those without ACL tear, it was significantly lower at 0.81 ± 0.21 mm. This difference was statistically significant with a p-value < 0.0001, indicating a strong association between increased side-to-side difference and the presence of an ACL tear on MRI.

Out of the total 70 patients, the femoral notch sign was positive in 51 out of 56 (91.1%) patients with MRI-confirmed ACL tears and in 4 out of 14 (28.6%) patients without ACL tears. The association between a positive femoral notch sign and MRI-confirmed ACL tear was statistically significant ($\chi^2 = 25.98$, $p < 0.00001$). Sensitivity of the femoral notch sign for detecting ACL tears was 91.1%, specificity was 71.4%, positive predictive value (PPV) was 92.7%, and negative predictive value (NPV) was 66.6%. These findings suggest that the femoral notch sign is a highly sensitive and fairly specific indicator for ACL injury.

Among the 70 patients, the clinical parameter under evaluation was positive in 44 out of 56 (78.5%) patients with MRI-confirmed ACL tears, and in 4 out of 14 (28.6%) patients without ACL tears. The association between a positive test and MRI-confirmed ACL tear was statistically significant ($\chi^2 = 12.99$, $p = 0.0003$). The sensitivity and specificity of the test were 78.5% and 71.4%, respectively. The positive predictive value (PPV) was 91.6%, while the negative predictive value (NPV) was 45.4%. These findings indicate that the test has good sensitivity and PPV, making it a useful screening tool for ACL injury, though its NPV is relatively low.

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The wavelike PCL sign was observed in 40 out of 56 (71.4%) patients with MRI-confirmed ACL tears and in 4 out of 14 (28.6%) patients without ACL tears. The overall sensitivity and specificity of the wavelike PCL sign were both 71.4%. The positive predictive value (PPV) was 90.9%, indicating a high likelihood of ACL tear when the sign is present. However, the negative predictive value (NPV) was relatively low at 38.4%, suggesting limited reliability in ruling out ACL tears when the sign is absent.

Anterior tibial translation was positive in 53 out of 56 (94.6%) patients with MRI-confirmed ACL tears and in 4 out of 14 (28.6%) patients without ACL tears. This yielded a sensitivity of 94.6% and a specificity of 71.4%. The positive predictive value (PPV) was 92.9%, and the negative predictive value (NPV) was 76.9%.

Among the 70 patients, those with symptom duration ≤6 weeks showed a positive femoral notch sign in 42 out of 46 cases (91.3%), whereas among those with symptom duration >6 weeks, only 14 out of 24 cases (58.3%) had a positive sign. This association between the duration of complaints and the presence of the femoral notch sign was statistically significant (χ^2 = 10.71, p = 0.001).

Among the 70 patients, the wavelike PCL sign was positive in 41 out of 46 patients (89.1%) with symptom duration <6 weeks, whereas only 3 out of 24 patients (12.5%) with symptoms >6 weeks demonstrated a positive sign. This association was highly statistically significant (χ^2 = 39.66, p < 0.0001).

In patients with symptom duration <6 weeks, anterior tibial translation was positive in 39 out of 46 cases (84.8%), while in those with symptoms >6 weeks, it was positive in 17 out of 24 cases (70.8%). Although there was a higher frequency of positive anterior tibial translation in the early presentation group, the association was not statistically significant (χ^2 = 1.91, p = 0.166).

Ultrasound (USG) as a whole using any of the methods was positive in 54 out of 56 patients (96.4%) with MRI-confirmed ACL tears and in 3 out of 14 patients (21.4%) without ACL tears. This yielded a sensitivity of 96.4% and specificity of 78.5%. The positive predictive value (PPV) was 94.7%, and the negative predictive value (NPV) was 84.6%.

The sensitivity of various diagnostic methods for detecting ACL tears varied across clinical, radiological, and ultrasound parameters. Among clinical tests, the anterior tibial translation test showed the highest sensitivity at 94.6%, followed by the femoral notch sign (91.1%), anterior drawer test (89.2%), Lachman test (87.5%), and pivot shift test (84.9%). Radiological indicators such as posterior capsular protrusion and wavelike PCL sign showed sensitivities of 78.5% and 71.4%, respectively. Notably, ultrasonography (USG) demonstrated the highest sensitivity at 96.4% when at least one of the four USG signs was positive.

DISCUSSION

The findings of the present study, particularly regarding the diagnostic performance of clinical and imaging modalities in detecting ACL tears, are consistent with and further supported by existing literature. In this study, anterior tibial translation exhibited a sensitivity of 94.6% and specificity of 71.4%, underscoring its high diagnostic value. Similarly, Sonin et al. (1994) reported that anterior tibial translation measured by stress radiography provided accurate quantification of ACL deficiency, correlating well with clinical findings.[12] The femoral notch sign showed a sensitivity of 91.1%, consistent with findings by McCauley et al. (1994), who found that femoral notch effacement on MRI was a reliable secondary sign of ACL rupture.[13] The current study's finding of 96.4% sensitivity for ultrasound, when at least one USG sign was present, aligns with research by Safran et al. (2001), who demonstrated that sonography could detect ACL tears with high sensitivity and specificity when performed by experienced clinicians.[14]

The mean anterior tibial translation in injured knees (3.9 mm) compared to uninjured knees (0.9 mm) showed a highly significant difference (p < 0.0001), reflecting similar observations by Daniel et al. (1985), who used the KT-1000 arthrometer to objectively measure increased anterior laxity in ACL-deficient knees.[15] Likewise, the side-to-side difference in anterior tibial translation was significantly higher in MRI-confirmed ACL tear cases (2.26 mm), echoing the results of Papannagari et al. (2006), who demonstrated increased anterior translation in biomechanical simulations of ACL-deficient knees.[16]

The diagnostic utility of the wavelike PCL sign (sensitivity 71.4%) was corroborated by the work of Umans et al. (1995), who described the buckled PCL appearance on MRI as a supportive sign of ACL rupture.[17] Regarding clinical tests, the Lachman test and anterior drawer test demonstrated sensitivities of 87.5% and 89.2%, respectively, findings that agree with a meta-analysis by Benjaminse et al. (2006), which confirmed that the Lachman test remains the most reliable clinical test for ACL rupture, with pooled sensitivity >80% [18]. The pivot shift test showed a sensitivity of 84.9%, similar to results reported by Scholten et al. (2003), who highlighted its value in detecting dynamic instability due to ACL insufficiency.[19]

Importantly, the role of symptom duration was also highlighted in the current study, with both the femoral notch sign and wavelike PCL sign significantly more frequent in patients with symptom duration <6 weeks (p = 0.001 and p <0.0001, respectively). This temporal association is in line with observations by Van Dyck et al. (2012), who reported that secondary signs of ACL tear such as PCL buckling and notch effacement are more

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prominent in acute phases due to joint effusion and hemarthrosis.[20]

Finally, the superior sensitivity of ultrasonography (96.4%) was notable when at least one of the four USG signs was positive. This supports research by Chiavaras et al. (2013), who demonstrated that point-of-care ultrasound (POCUS) can accurately detect ACL tears when combined with dynamic assessment, showing excellent agreement with MRI findings.[21] Overall, these findings collectively reinforce that a multimodal approach—incorporating clinical tests, MRI, and increasingly, ultrasonography—enhances diagnostic accuracy in ACL injury assessment.

CONCLUSION

We conclude that anterior tibial translation and the femoral notch sign using ultrasonography are valuable tools in the diagnosis of ACL tears. Among the various clinical and radiological parameters assessed, anterior tibial translation using ultrasonography emerged as the most sensitive methods. The femoral notch sign also demonstrated high diagnostic value, especially in patients with shorter symptom duration. While some tests like the wavelike PCL sign and posterior capsular protrusion showed moderate sensitivity, their predictive value was enhanced when interpreted alongside other findings. Overall, combining clinical examination with imaging modalities, particularly ultrasonography and MRI, significantly improves the accuracy of ACL tear diagnosis

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