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Predictive Accuracy of Blumensaat Line Angle and Its Apex along with Anterior Cruciate Ligament Inclination Angle for Diagnosis of Anterior Cruciate Ligament Tear with Abundant Remnant

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ABSTRACT

Background: Anterior Cruciate Ligament Blumensaat line angle and Anterior Cruciate Ligament Inclination angle can be measured when Anterior Cruciate Ligament is visualized on Magnetic Resonance Imaging. Both these angles can be helpful to determine the intactness of Anterior Cruciate Ligament. The aim of this study was to evaluate the diagnostic accuracy of Anterior Cruciate Ligament - Blumensaat line angle, apex of Anterior Cruciate Ligament - Blumensaat line angle and Anterior Cruciate Ligament - Inclination angle to determine the status of Anterior Cruciate Ligament in terms of tear or no tear.

Methods: We conducted a prospective observational study with Magnetic Resonance Imagings of knees of 71 patients, who were divided into Anterior Cruciate Ligament tear and Anterior Cruciate Ligament intact groups based on Anterior Cruciate Ligament - Blumensaat line angle ($<15^0$- intact; $\geq 15^0$ – torn Anterior Cruciate Ligament), Anterior Cruciate Ligament - Inclination angle ($>45^0$ – intact ACL; $\leq 45^0$ – Anterior Cruciate Ligament tear) and apex of Anterior Cruciate Ligament - Blumensaat line angle (apex towards femur – Intact Anterior Cruciate Ligament; apex towards tibia or parallel lines– Anterior Cruciate Ligament Tear) measured on MRI study. Diagnostic accuracy was calculated in terms of sensitivity, specificity, positive predictive value and negative predictive value of Anterior Cruciate Ligament - Blumensaat line angle, Anterior Cruciate Ligament - Inclination angle and apex of Anterior Cruciate Ligament - Blumensaat line angle.

Results: The sensitivity and specificity of Anterior Cruciate Ligament - Blumensaat line angle to detect Anterior Cruciate Ligament status was 95.83% and 95.35% respectively. Similarly, the sensitivity of Anterior Cruciate Ligament - Inclination angle was 95.83% and specificity was 95.35%. The sensitivity of Apex Anterior Cruciate Ligament - Blumensaat line angle to detect Anterior Cruciate Ligament tear on MRI was calculated to be 95.74% and a specificity of 87.5%

Conclusions: Anterior Cruciate Ligament - Blumensaat line angle and Anterior Cruciate Ligament - Inclination angle is highly sensitive and specific for the diagnosis of Anterior Cruciate Ligament tear. Apex of Anterior Cruciate Ligament - Blumensaat line angle is also helpful in determination of Anterior Cruciate Ligament tear.

Keywords: Anterior cruciate ligament; magnetic resonance imaging; ACL blumensaat line angle; ACL inclination angle

INTRODUCTION

The Anterior Cruciate Ligament (ACL) injury is common.[1,2] MRI is the preferred investigation modality with high sensitivity and specificity for ACL tears but its efficiency depends on various factors like radiologist expertise and quality of MRI.[3-5] When ACL cannot be visualized, the diagnosis of ACL tear can made with relative ease. However, if the ACL remnant is visible, the diagnosis might be confusing and misinterpretations are common.[6]

ACL Blumensaat line angle (ACL-BLA) and ACL Inclination angle (ACL-IA) can be measured in MRI when remnant is preserved. These angles measure inclination of ACL in relation to femur (ACL-BLA) and tibia (ACL-IA).[7-9] Hence, we presumed that both these angles can be helpful to

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determine the integrity of ACL on MRI.

We aimed to determine the sensitivity and specificity of ACL-BLA and ACL-IA for detection of ACL tear in patients with preserved ACL remnants on MRI. Similarly, we also analyzed the sensitivity and specificity of the direction of apex of ACL-BLA angle for predicting torn or intact ACL.

METHODS

This is a prospective observational study conducted during 6 months duration the period of February, 2018 to July, 2018. After obtaining ethical approval for the study from ethical review committee, informed written consent was taken from all patients who underwent MRI of knee and were planned for arthroscopic procedures. Patients whose ACL were not visualized on MRI, were excluded from the study. Previous history of knee surgery, multiligament injury and patients with generalized ligamentous laxity were also excluded. Among 153 patients, 50 patients were excluded from the study because of various reasons mentioned in Figure 1. Among 103 cases who were eligible for study, ACL was not visualized on MRI in 32 cases, hence the angles could not be measured and were also excluded from the study. Remaining 71 MRIs were eligible for evaluation, where these angles could be measured (Figure 1).

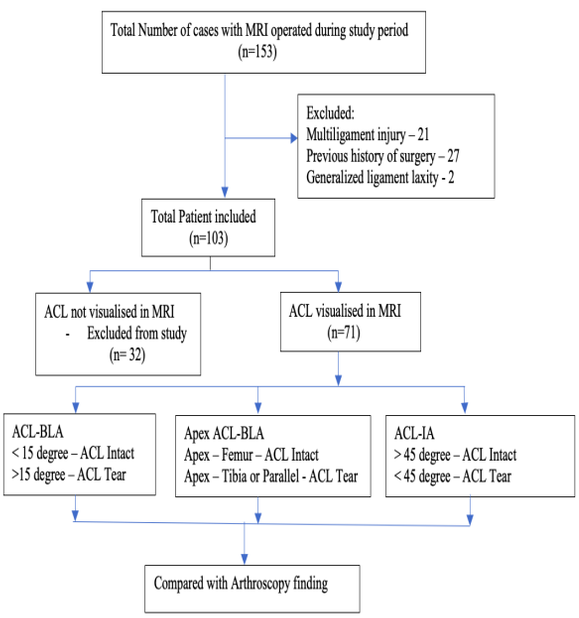

Figure 1. Flow chart of methodology.

The principle author measured ACL-BLA angle as described by Cheng XY[8] and ACL-IA as described by Millado et al[9], and recorded the measurements on a pre-standardized proforma of individual patients. ACL-BLA with measurements less than 15^0 were considered as ACL intact patients and those with more than 15^0 of angle measurements were considered as ACL tear patients. Similarly, ACL- IA with measurements more than 45^0 were considered as ACL intact and those with angle measurements less than 45^0 were considered as ACL tear patients (Table 1). While measuring the ACL-BLA, we noticed that it forms an angle either towards the femur or the tibia and occasionally these lines are parallel to each other. This observation prompted us to use the direction of apex of ACL-BLA as a parameter too, for the determination of the intactness of ACL, and thus we planned to test its sensitivity and specificity as well. We assumed that if the apex of the angle was towards the femur, the ACL was considered as normal, whereas if the apex was towards the tibial foot print or if the lines were parallel to each other, it was considered as torn ACL (Table 1).

Table 1. Normal values used to determine integrity of ACL.

Measurements	ACL Intact	ACL Tear
ACL-BLA	$<15^0$	$>15^0$
Apex of ACL-BLA	Apex of angle towards femur.	Apex of angle towards Tibia or parallel.
ACL-IA	$>45^0$	$<45^0$

Using these criteria's, the principal researcher divided patients into 2 groups (ACL Intact and ACL Tear groups). All these patients underwent arthroscopy for the confirmation of normal ACL or torn ACL. Our study was a double blinded study where the author who evaluated the MRI was unaware of the arthroscopy findings and clinical findings, and the Surgeon who performed arthroscopy was blinded to the measurements of these angles, and only confirmed the ACL status in terms of ACL tear or intact ACL.

A single sagittal proton density image on MRI (1.5-3 Tesla) best showing the ACL fibers was selected. ACL Blumensaat line angle was measured by drawing a line (line a) parallel to the roof of the intercondylar notch of the femur (Blumensaat line) and anterior most fibers of the ACL (line b). The angle was measured and recorded at the intersection of these two lines and was defined as ACL-BLA (Figure 2).

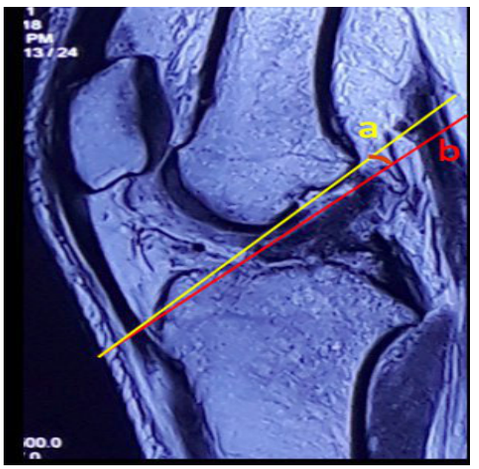

Figure 2. Shows method of measurement of ACL-Blumensaat line angle (ACL-BLA).

After measuring the ACL-BLA as mentioned above, the direction of Apex of the angle was determined if present; towards tibia or towards femur, or whether the above mentioned lines are parallel to each other without forming angle, and the finding was recorded as depicted in Figure 3.

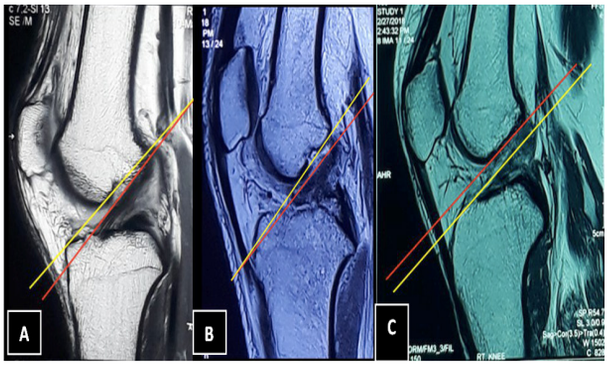

Figure 3. A- Shows ACL-BLA apex towards the femur; B – Shows ACL-BLA apex towards the tibia; C – Shows ACL-BLA lines parallel to each other.

A single sagittal proton density image on MRI (1.5-3Tesla) best showing the ACL fibers was selected. The most distal portion of tibia was identified and a line (line a) parallel to the physeal scar was drawn. Another line was drawn proximally, half the distance of line a (line b). Then the midpoints of both these lines were determined and a longitudinal line joining these points was drawn (line c) which represented the long axis of tibia on sagittal plane. Then the tibial horizontal line (line d) was drawn perpendicular to this line at the most distal portion of the ACL insertion site on tibia. The angle between lines drawn parallel to the anterior most fibers of the ACL (line e) and line d was designated as the ACL inclination angle (Figure 4) similar to the measurement mentioned by Millado et al.[9]

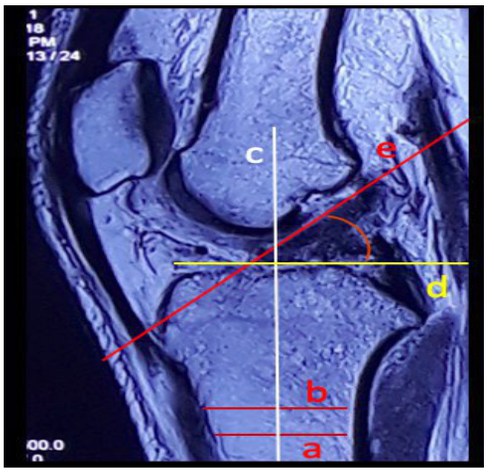

Figure 4. Shows ACL inclination angle (ACL-IA). Angle formed by Line d and Line e is ACL-IA.

In order to determine the accuracy of the diagnosis, we used the following definitions: (1) A true-positive result in which the measurements identified ACL tear on MRI and arthroscopy confirmed the finding; (2) A true-negative result in which the measurements on MRI and arthroscopy both ruled out any ACL tear; (3) A false-positive result when the measurement parameters on MRI identified ACL tear when no tear was present on arthroscopy; and (4) A false-negative result in which the measurement parameters on MRI defined no tear, but ACL tear was present on arthroscopy.

All the obtained data was entered in Microsoft Excel 2016. Sensitivity, Specificity, positive predictive value and negative predictive value of ACL-BLA, apex of ACL-BLA and ACL- IA were calculated.

RESULTS

Among the 71 cases included in the study, 24 had intact ACL on arthroscopy and 47 had torn ACL. The mean ACL-BLA was 18.24 ± 3.26^0in ACL tear group compared to 8.08±2.8 ^{0} in ACL intact Group (Table 2). Similarly, the mean ACL-IA was 38.81±6.03^0 degrees in ACL tear group compared to 52.54±4.55^0in intact ACL group (Table 2).

Table 2. Shows mean values of ACL- BLA and ACL – IA on MRI (n- Number of patients).

Parameter	ACL- BLA Mean Angle (in degrees)	ACL- IA Mean Angle (in degrees)
ACL Intact group (n=24)	8.08±2.8	52.54±4.55
ACL Tear group (n=47)	18.24±3.26	38.81±6.03

ACL- BLA were measured in all 71 patients. Those cases in which ACL and Blumensaat line were parallel to each other, they were considered as having more than 15^0 degree of ACL-BLA and hence considered as tear. Among 71cases, 46 were True Positive (TP), 22 were True Negative (TN), 1 was False Positive (FP) and 2 were False Negative (FN).

The sensitivity of ACL-BLA keeping 15^0 as cut off value, to detect ACL tear on MRI was calculated to be 95.83% and specificity was 95.35%. The positive predictive value was 97.87% and Negative predictive value was 91.66% (Table 3).

Table 3. Shows parameters for sensitivity and specificity of ACL- BLA in detecting ACL status.

	Number of Arthroscopic ACL tear (Disease Positive)	Number of Arthroscopic Intact ACL (Disease Negative)
ACL-BLA, more than 15^0 (ACl Tear)	True Positive 46	False positive 1
ACL-BLA, 0-15^0 (ACl intact)	False Negative 2	True Negative 22

The direction of apex of ACL-BLA were measured in all 71 patients. Those cases in which the lines forming ACL-BLA were parallel to each other were considered as tear. Among 71cases, 45 were True Positive (TP), 21 were True Negative (TN), 3 was False Positive (FP) and 2 were False Negative (FN).

On further analysis, the sensitivity of Apex ACL-BLA to detect ACL tear on MRI was calculated to be 95.74% and specificity was 87.5%. The positive predictive value was 93.75% and negative predictive value was 91.30% (Table 4).

Table 4. Shows findings used to calculate sensitivity and specificity of apex of ACL- BLA for ACL status.

	Arthroscopic ACL tear (Disease Positive)	Arthroscopic Intact ACL (Disease Negative)
Apex ACL-BLA, Inferior or parallel (ACl Tear)	True Positive 45	False positive 3
Apex ACL-BLA, Superior (ACl intact)	False Negative 2	True Negative 21

ACL- IA were measured in all 71 patients. The ACL-IA less than 49^0were considered as tear. Among 71cases, 46 were True Positive (TP), 22 were True Negative (TN), 1 was False Positive (FP) and 2 were False Negative (FN).

On further analysis, the sensitivity of ACL-BLA to detect ACL tear on MRI was calculated to be 95.83% and specificity was 95.35%. The positive predictive value was 97.87% and Negative predictive value was 91.66% (Table 5).

Table 5. Show findings used to calculate sensitivity and specificity of ACL- IA for detection of ACL status.

	Arthroscopic ACL tear (Disease Positive)	Arthroscopic Intact ACL (Disease Negative)
ACL-IA, less than 45^0 (ACl Tear)	True Positive 46	False positive 1
ACL-IA, more than 45^0 (ACl intact)	False Negative 2	True Negative 22

DISCUSSION

Early diagnosis and treatment of ACL tear is important for its timely management and prevention of secondary injuries associated with the delay in diagnosis.[10] Clinical tests are good at expert hands but there is a need for rigorous practice to master the technique which may be a limitation when the patients are attended by orthopedic surgeon other than trained in sports injuries.[6] Although, Lachman's test and anterior drawer tests are shown to have high sensitivity and specificity for ACL tear, MRI is always deemed necessary for confirmation of the diagnosis and identifying concomitant associated injuries.[11] Several studies have claimed MRI to be highly sensitive and specific in detecting ACL tears.[3-5] However, it also needs experienced musculoskeletal-radiologists to interpret the findings accurately which can be considered as one of the major limitations of MRI, especially in developing countries with less skilled manpower and lower quality MRI machines.[5] The MRI diagnosis of ACL tear is precise and often accurate when ACL is not visualised along its length. However, many cases of ACL deficiency are reported as partial tear when the substantial amount of remnant fibers of ACL are visualized on MRI.[12] In order to reduce the diagnostic dilemma in cases with abundant ACL remnant or where there is confusion of diagnosis, several secondary signs have been described to facilitate the diagnosis of ACL tear. To name few, typical bone bruise (sensitivity- 51% and Specificity - 100%), PCL angle (sensitivity - 52% and Specificity- 94%), PCL bowing (sensitivity - 34% and Specificity - 100%), Deep lateral femoral sulcus (sensitivity - 30% and Specificity - 94%) are some of these secondary signs.[7] The major drawback of these secondary signs are that these signs consider structures other than ACL, and most of these are more relevant in

cases of chronic injuries.[13] We too have experienced that the diagnosis is confusing when there is a substantial amount of remnant preserved, and the interpreter is not sure either the visible fibers are intact fibers or remnants of a proximally torn ACL.

When the ACL is intact and attached to the femur, the ACL fibers make certain angle to the femur and tibia.[8,9] Cheng XY measured ACL-BLA and found a specificity of 95.8% for ACL tear on MRI with ACL-BLA $\geq 15^0$.[8] Mellado et al[9] in their 50 patients found that patients with torn ACL had ACL-IA of 45^0 or lesser with resultant specificity of 100%. Although some literature has proposed ACL-BLA and ACL-IA to determine either the visible ACL is intact or it is remnant of a torn ACL, there were very few prospective studies in which the value of these angles were verified by arthroscopic evaluation. We aimed to test the value of ACL-BLA and ACL-IA in terms of its sensitivity and specificity for detection of ACL tear. When we started measuring the ACL-BLA, we noticed the apex of ACL-BLA in three distinct patterns: apex femur, parallel and apex tibia. So, we included the direction of apex as a parameter as well, and calculated its sensitivity and specificity too.

The sensitivity and specificity of ACL-BLA for detection of ACL tear on MRI was found to be 95.83% and 95.35% respectively, with the positive predictive value of 97.87% and negative predictive value of 91.66% in our study. Gentili et al. found the Blumensaat angle to have a sensitivity of 91% and specificity of 86% for detecting ACL tears, using a threshold value of 9°.[14] However, when threshold value of 15° was used, the sensitivity decreased to 89% and the specificity reached 100%.[14] Similarly when threshold value of 9.5° was used by Lee et al[15], this angle had sensitivity of 94% and specificity of 96%. Mellado et al[9] showed that if the threshold value is greater than 0°, the sensitivity of the Blumensaat angle reaches 90% (95% CI: 78.2¤96.7%) and specificity 98% (89.3□99.9%). We they used the threshold value of $0\text{-}15^0$ for intact ACL and more than 15^0 for torn ACL, they found a sensitivity and specificity of more than 95%, which was similar to our findings. Similar to the above-mentioned studies, we too emphasize that ACL-BLA should be used routinely to assess ACL status if abundant ACL remnant is visible on MRI and when there is considerable clinic-radiological mismatch.

We identified a specific pattern of apex of the ACL-BLA during our research (Figure 3). Considering the apex of ACL-BLA towards femur as intact ACL, and apex towards the tibia or ACL and Blumensaat line being parallel to each other as ACL tear, we analyzed the value of this parameter in terms of sensitivity and specificity for ACL tear detection. The sensitivity of apex of ACL-BLA was 95.74%, specificity was 87.5% with a positive predictive value of 93.75% and a negative predictive value of 91.30%. None of the previously published studies have mentioned about this parameter. The relatively lower specificity of this apex of ACL-BLA might be due to some ACL intact cases with ACL Blumensaat lines parallel to each other which were considered as tear in our study. If we remove the cases with parallel lines, and consider sensitivity and specificity of apex femur or tibia only, both sensitivity and specificity are 100%. Based on the above results, we suggest that the apex of this angle can be used as initial assessment parameter as it does not require any further measurements. Cautious measurement and analysis will be required in those cases where these lines are nearly parallel to each other.

Considering 45^0 as the threshold, the sensitivity and specificity of ACL-IA for detection of ACL tear on MRI was found to be 95.83% and 95.35% respectively, with the positive predictive value of 97.87% and negative predictive value of 91.66% in our study. Mellado et al[9] in their study found the sensitivity and specificity of 100% for predicting ACL tears, which was higher than our study. Millado et al, concluded that ACL-IA has better sensitivity and specificity compared to ACL-BLA.[9] In our study, the sensitivity and specificity of both the above mentioned angles (ACL-BLA and ACL-IA) were exactly the same. This may possibly be because of inversely proportionate relationship between ACL-BLA and ACL-IA; if ACL-BLA angle increases then ACL-IA will decrease in ACL tear cases and vice-versa.

In this study, the mean ACL-BLA was 18.24±3.26° in torn ACL, whereas 8.08±2.8° in intact ACL group (Table 2). Our findings were similar to study of Cheng XY et al where they found ACL Blumensaat line angle was $\geq$ 15° when ACL was torn and 0° to 15° when ACL was normal.[8] Gentilli et al, described that when ACL is torn, it assumes a more horizontal orientation.[14] This may be the reason for increase in ACL-BLA angle and decrease in ACL-IA or the ACL Blumensaat line being parallel to each other. The mean ACL-IA was 38.81±6.03° in ACL tear group compared to 52.54±4.55° in intact ACL group, which were comparable to the results of Murao et al[16], where they noted an ACL-IA of 33.9° in ACL tear group compared to 52.3° in ACL normal group. Gentilli et al[14], found ACL-IA of 55.6° in normal ACL and 29.9° if ACL was torn.

Small sample size was one of the major limitations of this study, and a study with larger sample size is recommended. We have not considered the anatomical variations in Blumensaat line, which may have caused

some alteration in the measurement of ACL-BLA. But considering the high sensitivity and specificity of ACL-BLA, it can still be recommended for detection of ACL tears where remnants are preserved, provided there are no preexisting deformities of knee.

CONCLUSIONS

The sensitivity and specificity of ACL-BLA and ACL-AI is more than 95% considering the threshold value of 15^0 and 45^0 respectively. Hence, we recommend the measurements of these angles to determine either the ACL fibers are of an intact or torn ACL. The direction of apex of ACL-BLA is also a sensitive and specific parameter, and should be used as initial assessment tool as it does not require complex measurement process. Moreover, the abovementioned parameters measure direct signs of ACL tear rather than the indirect signs and we believe that these measurements would be more effective.

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