Original Article

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Anterior Translation of the Tibia at MR Imaging as a Predictor of Degree of Anterior Cruciate Ligament Tear

Radiology Section

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ABSTRACT

Introduction: The ACL is the most common ligament of the knee to be injured. Numerous mechanisms of ACL injuries have been described.

Aim: To determine whether the degree of anterior translation of tibia correlates with the degree of anterior cruciate ligament tear.

Materials and Methods: It was a retrospective study done on 108 patients with intact ACL, 39 patients with partial ACL tears and 66 patients with complete ACL tears at MR imaging. Mid sagittal plane of the lateral femoral condyle was used to measure the anterior tibial translation with regard to a plane parallel to the cephalocaudal axis of the image. The degree of anterior tibial translation was then analysed in different groups using SPSS statistical software.

Results: The mean anterior translation in patients with complete tear was 5.95±0.81. In patients with partial tears it was 3.92±1.29 and in those with intact ACL it was 2.79±0.54. Anterior translation of 5 mm or more had 56% sensitivity, 80% specificity for a complete ACL tear. Unpaired-t test analysis showed highly significant statistical difference ($p<0.0001$) between the degree of anterior tibial translation in patients with complete ACL tear and those with intact ACL.There was no statistically significant difference between the anterior translation in patients with intact ACL and in those with partial tears ($p=0.36$).

Conclusion: Anterior translation of the tibia serves as a secondary sign to identify complete ACL tears only when the ACL is not visualised in its entirety in a single sagittal section. This sign is not specific for partial ACL tears and is significant only in complete ACL tears. The degree of anterior translation of tibia at MR imaging correlates with the degree of anterior cruciate ligament tear and hence can be used as a predictor of the degree of tear.

Keywords: Complete tear, Partial tear, Posterior cruciate ligament, Proton-density

INTRODUCTION

The anterior tibial translocation sign is seen on sagittal Magnetic Resonance (MR) images of the lateral femoral condyle [1]. This sign occurs when there is 7 mm or greater anterior translocation of the tibia relative to the femur [2, 3]

The ACL attaches to the inner aspect of the lateral femoral condyle proximally and fans out to attach to the anterior aspect of the intercondylar eminence of the tibia distally. It runs from the femur to the tibia anteriorly, medially, and distally within the intercondylar notch. It is intra-articular and extra synovial throughout its course. The primary role of the ACL is to provide stability to the knee joint. It resists anterior translocation and internal rotation of the tibia over the femur. The ACL also limits hyperextension and both valgus and varus forces on the knee [4].

ACL injury is associated with anterolateral instability of the knee. Deficiency of the ACL allows the tibia to undergo anterior subluxation relative to the femur, thus producing the anterior tibial translation sign. The degree of anterior subluxation of the tibia can be measured directly at MR imaging. This is analogous to the anterior drawer test [5] elicited during physical examination, in which the tibia moves anteriorly as the leg is pulled forward.

The ACL is the most common ligament of the knee to be injured. Numerous mechanisms of ACL injuries have been described. The pivot shift is a common mechanism of injury, which consists of a valgus stress and internal rotation of the tibia or external rotation of the femur applied to a flexed knee. This twisting injury frequently occurs with rapid simultaneous deceleration and directional movements, such as in skiing and soccer. Other mechanisms include hyperextension of the knee and valgus injury that results from a direct lateral blow to the partially flexed knee [6]. The ACL is the most commonly reconstructed knee ligament [7]. MRI is reserved for those cases where the clinical examination of ACL laxity is equivocal or if a significant associated injury is suspected (e.g. a locked knee with a possible prolapsed meniscal tear) [8]. On axial MR images, the ACL has an elliptical homogeneous low signal intensity through the proximal intercondylar notch with a heterogeneous appearance more distally through the notch where the anteromedial bundle and posterolateral bundle can be distinguished. These two bundles are also distinct functionally. The anteromedial bundle is maximally taut in flexion and restricts anterior tibial translation during flexion. The posterolateral bundle is maximally taut in extension, restricting anterior tibial translation in extension as well as tibial rotation. On sagittal MR images with extended knee, the ACL fibres are taut and almost parallel to the roof of the intercondylar notch (Blumensaat line) [9].

Physiologic strain on the ACL is primarily due to proximal tibial anterior shear force, which is exerted through the quadriceps mechanism. This force increases as the knee flexion angle decreases. Combination of varus and valgus forces with anterior tibial translation accentuates the forces on the ACL. As mentioned earlier, the pivot shift injury is composed of valgus force, quadriceps loading, and a planted foot with relative internal rotation of the tibia in relation to the femur seen in sports such as soccer, in which there are abrupt changes in direction [10]. The O'Donoghue triad (also called the unhappy medial triad) was described in 1964 as the combination of ACL, MCL, and medial meniscal tears [11].

MRI has been established as an excellent modality for identifying anterior cruciate ligament tears. Most often the anterior cruciate ligament is not included in its entirety in a single sagittal section due to its obliquity, in such situation it becomes difficult to assess the integrity of the ACL. Such cases depend on identification of secondary signs of ACL tear in supporting the presumptive diagnosis of an ACL tear. There has not been enough data relating the magnitude of anterior translation of tibia and various grades of ACL tear. The purpose of this study is to quantitatively analyse the degree of anterior translation of tibia and to determine whether the degree of anterior translation of tibia correlates with the degree of anterior cruciate ligament tear.

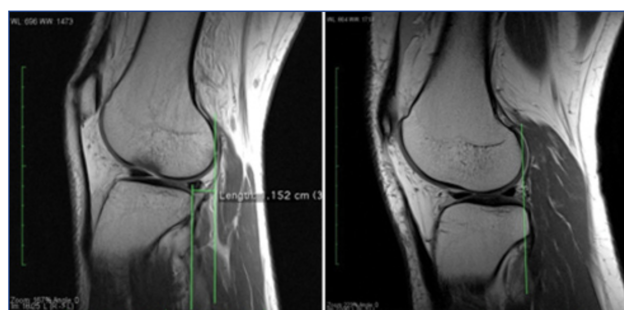
MATERIALS AND METHODS

This was a retrospective analytical study on patients who underwent MRI knee in the Department of Radiodiagnosis, M.S. Ramaiah Medical College and Hospitals, Bengaluru from July 2015 to March 2017. Since, this was a retrospective study ethical clearance was not done.

The subjects were divided into 3 groups, viz; Intact ACL, Partial ACL tears and Complete ACL tears. A blinded retrospective analysis was done on 108 patients with intact ACL, 39 patients with partial ACL tears and 66 patients with complete ACL tears at MR imaging. All patients undergoing MRI knee in the hospital were included in the study. Those with prior surgery of the knee, surgical implants, infection/tumours affecting the knee and fractures in the knee causing significant anatomical derangement were excluded from the study.

MR examinations were performed with a 1.5 T MRI (Magnetom, Siemens, Erlangen, Germany). The routine sequences used consisted of a localising T1- weighted axial sequence followed by sagittal T1-weighted, sagittal and coronal proton-density-weighted, sagittal and coronal T2-fat suppressed, axial proton-density fat suppressed and T2-SPACE sequences. A 12-14 cm field of view was used with a 256 x 256 matrix. A 5 mm section thickness was used with no gaps. The knee was examined in 10^{o}-15^{o} of external rotation to optimise visualisation of ACL. Appropriate support was given to the knee to minimise patient motion and discomfort.

Anterior tibial translation was measured using sagittal proton-density-weighted sequence at the midsagittal plane of the lateral femoral condyle with regard to a plane parallel to the cephalocaudal axis of the image [Table/Fig-1a]. The mid-sagittal plane of the lateral femoral condyle was determined using the coronal images. In case there was anterior displacement of femur with respect to the tibia [Table/Fig-1b]. the value of anterior translation was considered to be zero. Other parameters including buckling of PCL, empty notch sign, lateral and medial meniscus tear and collateral ligament injuries were also assessed.



[Table/Fig-1a,b]: a) Sagittal PD-weighted sequence in the mid sagittal plane of the lateral femoral condyle.The two parallel lines are drawn from the posterior aspects of the lateral femoral condyle and lateral tibial condyle respectively. Shortest distance between the two parallel lines is considered to be the anterior translation of tibia; **b)** Sagittal PD-weighted sequence in a patient with anterior displacement of the femur with respect to the tibia. In this case the anterior translation of the tibia was considered as zero.

STATISTICAL ANALYSIS

The degree of anterior tibial translation was then analysed in different groups using SPSS statistical software 20.0.

RESULTS

The mean anterior translation in patients with complete tear was 5.95±0.81. In patients with partial tears it was 3.92±1.29 and in those with intact ACL it was 2.79±0.54 [Table/Fig-2]. The maximum value of the anterior translation in the complete

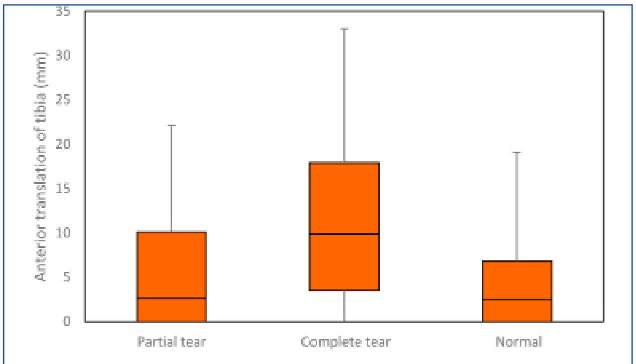
ACL tear group was 15 mm compared to 12 mm in the partial tear group and normal knees [Table/Fig-2]. Anterior translation of 5 mm or more had 56% sensitivity, 80% specificity for a complete ACL tear. Unpaired-t test analysis showed highly significant statistical difference (p<0.0001) between the degree of anterior tibial translation in patients with complete ACL tear and those with intact ACL.There was no statistically significant difference between the anterior translation in patients with intact ACL and in those with partial tears (p=0.36). In patients with complete tear, about 57% (38 of total 66) had empty notch sign, whereas none of the patients with partial tear had empty notch sign [Table/Fig-3]. About 72% patients with complete ACL tear had associated MCL injury compared to only 23% among the partial tear group [Table/Fig-3]. The median and quartiles in the three groups have been illustrated in [Table/Fig-4]; showing higher value of the median in patients with complete ACL tear. The distribution pattern of the values in

Parameters	Intact ACL	Partial ACL Tear	Complete Tear
Mean	2.79	3.92	5.95
Median	2.5	2.6	6.35
Standard Deviation	2.87	3.99	3.36
Lowest Value	0	0	0
Highest Value	12	12	15

[Table/Fig-2]: Parameters in the 3 study groups (in mm).

Total	Buckling of PCL	Empty Notch Sign	Lateral Meniscal Tear	Medial Meniscal Tear	MCL Injury	LCL Injury
Partial ACL Tear (n=39)	6	0	6	18	9	3
Complete Tear (n=66)	29	38	17	32	48	11

[Table/Fig-3]: Associated findings in patients with partial and complete ACL tear.



[Table/Fig-4]: Box and whisker plot depicting the anterior translation of tibia along the vertical axis and its distribution pattern in the three groups.
*AT- Anterior translation of tibia

partial tear group and normal knees is more or less the same showing no significant difference.

DISCUSSION

ACL is the most common ligament of the knee to disrupt. MR imaging is an excellent modality for detecting ACL tears and it readily identifies ACL tears. But with suboptimal rotation of the knee the diagnosis can be difficult as the ACL is not visualised in its entirety in a single sagittal image. Also partial volume averaging of the ligament and pulsation artifacts arising from the popliteal artery can cause diagnostic problems. Due to these potential pitfalls evaluation of secondary signs of ACL tear is indicated. One such secondary sign is the anterior translation of tibia with respect to the femur.

The ACL was considered to be normal when it was seen as a continuous linear band of low signal intensity on T1, PD and T2 weighted images [12]. Direct signs of ACL tear include wavy contour of the ACL, focal or diffuse high signal intensity within the substance of ACL on the T2WI and lack of continuity of the ACL [13]. ACL tears typically occur in the middle portion of the ligament, although they can also occur at the proximal or distal attachments. Avulsion of the tibial attachment may be seen in younger patients. Injuries of the ACL are often caused by external rotational forces of the femur, occurring at abduction and flexion of the knee [14]. The presence of secondary signs of ACL tear increases the confidence of the diagnosis. The absence of secondary signs, however, does not exclude the possibility of ACL tear. Secondary signs can be used to diagnose ACL tear even when the ACL itself cannot be visualized [15]. Both chronic and acute ACL tears may demonstrate the anterior tibial translocation sign [16]. Chan WP et al., showed that anterior tibial subluxation greater than 5 mm served as an adjunctive sign in the diagnosis of complete tear of the ACL [17].

Many secondary indirect signs of ACL tear have been described and evaluated and include the empty notch sign (an indistinct ACL on coronal images through the intercondylar notch) [18], PCL buckling, kissing contusions, uncovered posterior horn of the lateral meniscus, MCL injury etc.

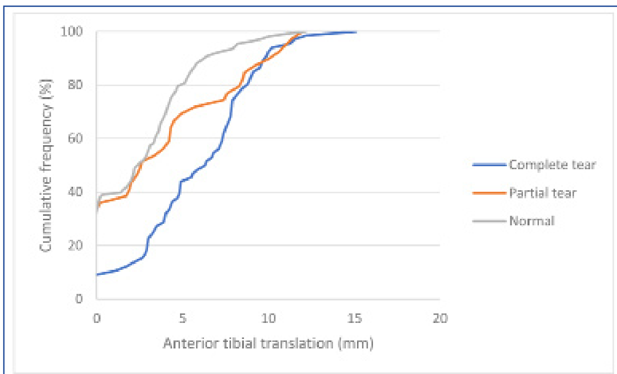
Diagnosis of partial ACL tears is challenging. The clinical examination findings are often subtle and radiographic studies may not reveal significant abnormality. Accurate diagnosis can be made by integrating history, clinical examination findings, imaging studies, and routine follow-up. A residual straight and tight ACL fiber seen on at least one image and a focal increase in ACL signal intensity in the acute setting are suggestive of partial tear [19]. According to Leferve N et al., 3D-FSE Cube MRI had a better diagnostic performance for detection of partial tears than conventional 2D-MRI [20].

Analysis of our data showed that when knees with intact ACL and those with complete ACL tears were compared, there was a statistically significant difference between the anterior tibial translation in the two groups. In a study conducted by Chan WP et al., anterior translation of 5 mm or more was shown to have a sensitivity of 86% and a specificity of 99% for ACL tear [17]. In another study by Vahey TN et al., a subluxation of 5 mm or more had 58% sensitivity and 93% specificity [1]. Our study however showed a sensitivity of 56% and specificity of 80% for anterior translation of 5 mm or more for complete ACL tears. The previous studies did not have a distinction between complete and partial ACL tears. The discrepancy between the sensitivity and specificity compared to other studies could have possibly been due to differences in selection of patients, distinction of the complete and partial tears and also due to possible differences in measurement techniques. According to Vahey TN et al., an anterior tibial translation of 7 mm or more was considered to be 100 % specific for complete ACL tear [1]. Our study showed a specificity of 92% for anterior translation of more than 7 mm for a complete ACL tear. Hence, not all knees with an anterior tibial translation of 7 mm or more had torn ACLs. The possible reason could be ACL laxity which shows a greater anterior translation without defined tear.

According to Oldrini G et al., the sensitivity and specificity of MRI was 91.1% and 82.9% for the detection of abnormal ACLs [21]. According to a study by Numkarunarunrote N et al., in discriminating intact ACL from partial or complete ACL tear, best accuracy was found at the cut off distance of 3.5 mm, with related levels of sensitivity and specificity of 83.1% and 74.1%, respectively [22]. Our study however showed no statistically significant difference (p=0.36) between the anterior translation in patients with intact ACL and in those with partial tears. [Table/Fig-5] compares the sensitivity and specificity for complete ACL tear with anterior translation >5 mm in different studies.

Study	Sensitivity	Specificity
Present study	56%	80%
Vahey TN et al., [1]	58%	93%
Chang WP et al., [17]	86%	99%
Numkarunarunrote N et al., [22]	58-86%	88-99%

[Table/Fig-5]: Comparison of sensitivity and specificity for complete ACL tear with anterior translation >5 mm in various studies.



[Table/Fig-6]: Cumulative frequency chart depicting the distribution of Anterior tibial translation values in the three groups.
*AT- Anterior translation of tibia

[Table/Fig-6] illustrates the cumulative frequency distribution of values of the anterior translation in the three groups, which clearly shows higher proportion of patients with complete tear beyond 5 mm. There is partial overlap of the values among the partial tear group and normal knees below 5 mm.

LIMITATION

We recognise few limitations of the study. Firstly the inadequate sample size in the partial ACL tears group. Secondly, the absence of arthroscopic correlation. Finally, since this was a retrospective study, accurate uniformity in optimal plane used for scanning could not be assessed. However, this could be negligible as uniform protocol is performed for all MRI knee examinations.

CONCLUSION

MRI is an excellent modality for identification of ACL tears. Loss of integrity in the fibres of the ACL and discontinuity serve as accurate indicators of complete ACL tear. Anterior translation of the tibia serves as a secondary sign to identify complete ACL tears only when the ACL is not visualised in its entirety in a single sagittal section. This sign is not specific for partial ACL tears and is significant only in complete ACL tears. The degree of anterior translation of tibia at MR imaging correlates with the degree of anterior cruciate ligament tear and hence can be used as a predictor of the degree of tear.

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