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Magnetic resonance imaging based anthropometric study of knee joint in anterior cruciate ligament insufficient knees

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Abstract
Purpose: The objective of this study was to evaluate multiple morphological features on MR images in patients with ACL insufficient knees.
Methods: Magnetic resonance imaging (MRI) of the knee of 40 anterior cruciate ligament insufficient patients and 20 anterior cruciate ligament intact patients who came to Katuri Medical College and Hospital, Guntur, between May 2017 and April 2018 were reviewed. Their intercondylar notch, femoral condyles dimensions and tibial slopes were measured using MRI.
Results: The ACL insufficient knees and ACL intact knees were comparable in terms of intercondylar notch width. Lateral femoral condyle height and transepicondylar axis are more in ACL insufficient knees. Medial posterior tibial slope is more than Lateral posterior tibial slope in both ACL insufficient knees and ACL intact knees.
Conclusion: The ACL insufficient patients have more Lateral femoral condyle width, intercondylar notch width, intercondylar notch height compared to ACL intact knees. ACL-ruptured patients had statistically significant smaller heights of femur's lateral condyle. MTS is more than LTS in both ACL insufficiency patients and ACL intact patients.

Keywords: Magnetic resonance imaging, anthropometric study, knee joint, anterior cruciate ligament

Introduction
The dimensions of the intercondylar notch are such that there is little space not filled by the cruciate ligaments. It is this intimate relationship between the cruciate ligaments and the notch that may give rise to impingement of these structures following anterior cruciate ligament (ACL) reconstruction. Impingement of the ACL on the inter condylar notch will occur if the notch is steno tic, the ACL is relatively large, or a combination of both. This impingement will jeopardize the surgical repair.
Magnetic resonance imaging (MRI) has been proven as the gold standard method of choice for non-invasive evaluation of the ACL. Multiple studies have been executed in which measurements were taken on MR images to identify the characteristics of the ACL and its surroundings [1, 2]. Furthermore, MRI has been utilized during the evaluation of knee kinematics with and without an ACL rupture [3, 4].
To the best of the authors' knowledge, an assessment of multiple morphological features and their risk for ACL rupture has not been performed. Some studies have investigated the morphological features on the femoral side, while others have studied those on the tibial side. As such, the objective of this study was to evaluate multiple morphological features on both the femoral and tibial sides of the knee on MR imaging in patients with and without ACL rupture. In this way, it is possible to analyze the tibial and femoral morphological features both separately and combined and to evaluate a possible morphological relationship. The hypothesis of this study was that multiple individual and combined morphological features that confer a higher risk of sustaining an ACL rupture could be identified. This complete assessment of multiple morphological features and thereby the identification of predisposing factors for an ACL rupture will identify the potential areas of interest for ACL injury prevention.

Materials and Methods

Magnetic resonance imaging scans from 20 patients with an intact ACL and 40 patients with a ruptured ACL who underwent an ACL reconstruction at Katuri Medical College and Hospital, Guntur, between May 2017 and April 2018 were prospectively studied. MRIs for non-injured knees were taken for knee complaints other than ACL injury. They were interpreted to have either meniscal injury or no identifiable pathology. Patients included in this study are of age 18 years to 60 years. Exclusion criteria for both groups included previous surgical interventions to the knee and patients with knee arthritis. The MR images used for this study were obtained with a 1.5 Tesla MRI with the knee in full extension. Slice thickness was 3 mm. Measurements were made in a standard, open-source image processing software for DICOM images.

In this study, the morphological features measured were the Trans epicondylar axis, lateral femoral condyle width, medial femoral condyle width, medial femoral condyle anteroposterior diameter, lateral femoral condyle anteroposterior diameter, the notch width, intercondylar notch height, medial tibial slope, the lateral tibial slope, medial tibial anterioposterior diameter, lateral tibial anterioposterior diameter.

Transepicondylar axis

The direction of axial slice imaging of the MRI is the slice perpendicular to the femoral mechanical axis in the coronal plane and perpendicular to the long axis of the femur in the sagittal plane. The axial slice on the most prominent part of both femoral condyles was selected for analysis. The transepicondylar axis (TEA) was defined as a line between the most medial and the most lateral prominences of the epicondyles.

Fig 1: Transepicondylar axis

Femoral condyle width, Notch width and Notch height:

It is measured in coronal view of the knee joint MRI. A line is drawn at the most inferior part of the femoral condyles. A line parallel to this line at the level of the popliteal groove is shown, where the notch width (NW), medial condyle width (MCW) and lateral condyle width (LCW) were measured. Femoral condyle anterioposterior diameter are measured at a section of axial slice where maximum anterioposterior diameter of lateral condyle is present. A horizontal line is drawn touching both the posterior surfaces of medial and lateral femoral condyles. Lateral femoral condyle Anterioposterior diameter (LAP) is measured from the anterior most part of the condyle to the previous horizontal line. Medial femoral condyle anterioposterior diameter (MAP) is measured from the anterior most part of the condyle to the previous horizontal line

Fig 2: Lateral femoral condyle width (LFCW), Medial femoral condyle width (MFCW)

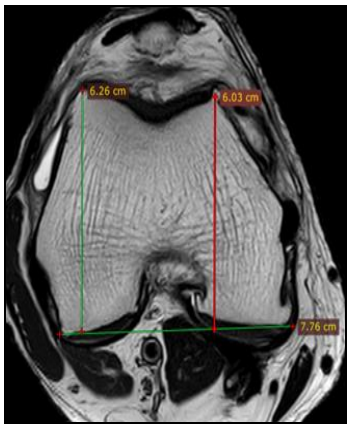

Fig 3: Lateral femoral condyle Anterioposterior diameter (LAP), Medial femoral condyle Anterioposterior diameter (MAP)

Notch width is measured at three different locations in axial section where the popliteal groove appears maximum width. First measurement at the a line through the centre of the popliteal groove (NW-PG), second measurement at the level of two thirds of the notch height (NW-2/3), the third measurement at the level of the articular margins(NW-IAM) of the medial and lateral femoral condyles. The intercondylar notch height (NH) which was the perpendicular distance from the apex of the notch to the horizontal line at the level of the articular margins of the medial and lateral femoral condyles. These measurements are also noted two sections above and two sections below this level.

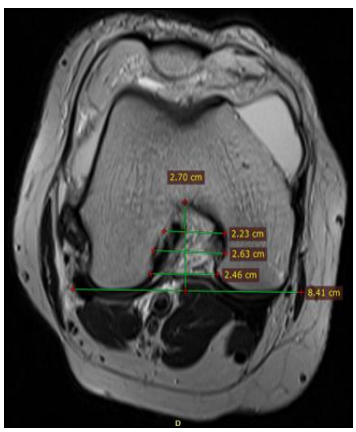

Fig 4: Intercondylar Notch Height (NH), Notch width at level of two thirds of the notch height (NW-2/3), Notch width-popliteal groove (NW-PG), Notch width at the level of the articular margins (NW-IAM)

Lateral femoral condyle height

This is measured on sagittal sections of the MRI at the level of maximum diameter of lateral femoral condyle. Two circles were drawn, one anterior and one posterior, respectively. These matched the rounded anterior and posterior profile of the lateral condyle. A line is drawn at the maximum distance between the two circles touching the anterior and posterior corticals. Twolines parallel to this line were drawn, proximal line touching the posterior circle, distal line touching the anterior circle. The distance between these two lines is the measurement of height of the lateral femoral condyle (LFC-HT).

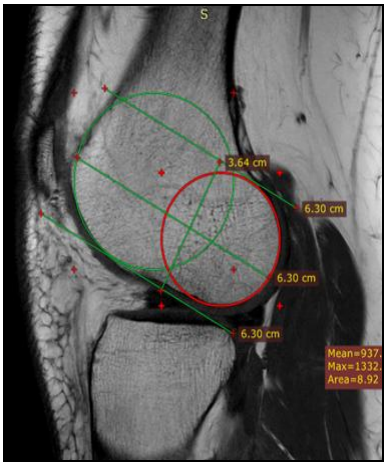

Fig 5: Height of the lateral femoral condyle (LFC-HT).

Tibial plateau slope

Medial tibial plateau slope (MTPS), Lateral tibial plateau slope (LTPS) were measured using the method proposed by Hashemi *et al*. [5]

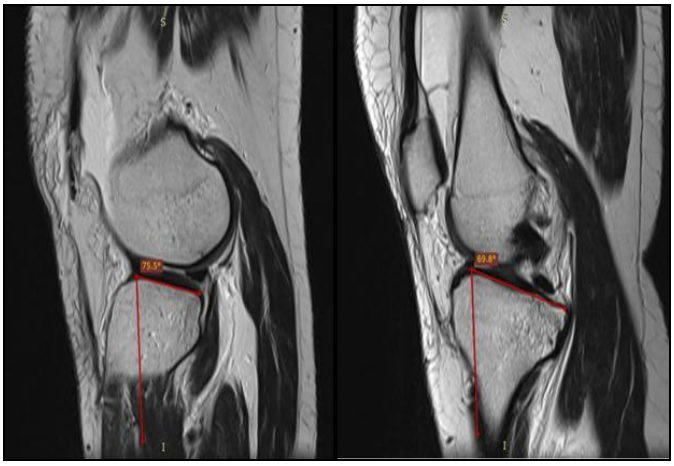

Fig 6: Lateral tibial plateau slope (LTPS), Medial tibial plateau slope (MTPS).

ACL insufficiency and ACL intact groups were compared using the 2-sample t test. A p value of <0.05 was considered statistically significant.

Results

The ACL-injured and ACL-intact groups were comparable in terms of the TEA (7.826 VS 7.6655, P=0.373), LCW (2.885 vs 2.577, p=<0.001), MCW (2.3775vs2.3975, p=0.21), LAP (5.71575vs5.79, p=0.011), MAP (5.4535vs5.616, p=<0.001), At the level of maximum popliteal groove NW -2/3 (2.181 vs1.799, p=<0.001), NW-PG (2.40125vs2.2525, p=<0.001), NW-IAM (2.4745vs2.2165, p=<0.001), NH (2.4955vs2.2075, p=<0.001), 2 levels above NW-2/3 (1.855vs1.779, p=<0.001), NW-PG (2.248vs2.233, p=0.505), NW-IAM (2.168vs2.1415, p=0.161), NH (2.186vs2.523, p=<0.001), 2 levels below NW-2/3 (2.277vs1.896, p=<0.001), NW-PG (2.217vs2.24, p=0.265), NW-IAM (2.444vs2.264, p=<0.001), NH (2.33325vs1.932, p=<0.001), LFC-HT (3.597vs3.666, p=0.07), LTPS (6.988vs2.525, p=<0.001), MTPS (10.208vs3.74, p=<0.001).

Discussion

Knee static stability is enabled by ligaments, menisci, joint capsule, and bony geometry, whereas knee dynamic stability is an integrated function of the neuromuscular system. Injury to the ACL can occur secondary to excessive valgus stress, forced external rotation of the femur on a fixed tibia, andhyperextension. [6-8]. the most important finding of the present study is that there were bony morphological differences between ACL-insufficiency patients and ACL-intact subjects. Therefore, it is important to understand whether MRI measurements of bony morphology can be used reliably to determine a difference between ACL-injured patients and non-injured patients.

Transepicondylar axis is more in ACL Insufficiency patients 7.826cms when compared to ACL intact patients (7.665 cms). Lateral condyle width (LCW) is more in ACL Insufficiency patients (2.885 cms) when compared to ACL intact patients 2.577cms. Medial condyle width (MCW) is similar in both ACL Insufficiency patients 2.377 cms and ACL intact patients 2.397cms.

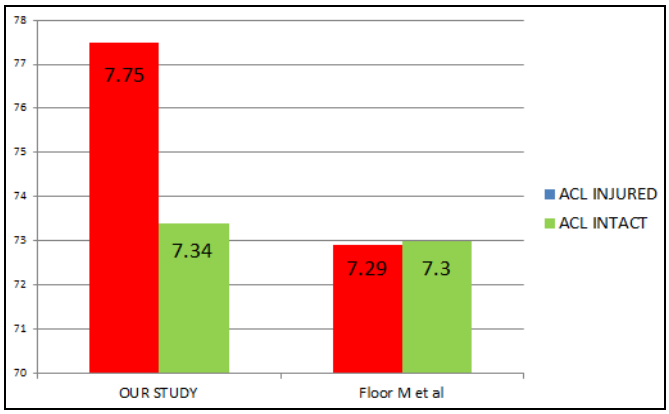

Fig 7: TEA Width is more in ACL Injured knee inour study

Lateral femoral condyle anteroposterior diameter (LAP) is similar in both ACL insufficiency patients and ACL intact patients. Medial femoral condyle anteroposterior diameter (MAP) in ACL insufficiency patients (5.4535 cms) is less than ACL intact patients (5.616cms).

At the level of maximum popliteal groove, Notch width at 2/3rd height (NW-2/3) is 2.181cms in ACL insufficiency knees which is more than ACL intact knees (1.799cms). Which is still more than Kelly klassen study 1.62cms.

Notch width at the maximum popliteal groove level NW-PG is 2.401 cms is more in ACL Insufficient knees when compared to ACL intact knees (2.252 cms) which is even more than Kelly klassen study 2.14cms.

Notch width at the inferior articular margin level NW-IAM is 2.474 cms is more in ACL Insufficient knees when compared to ACL intact knees (2.216 cms) which is even more than Kelly klassen study 1.94cms.

Our study has measured the same parameters two sections above and two sections below the level of maximum popliteal groove. Two sections above the measures are similar to ACL

insufficient knees to ACL intact knees. Two sections below, Notch width at 2/3rd height is more in ACL insufficiency patients and similar at popliteal groove and inferior articular margin.

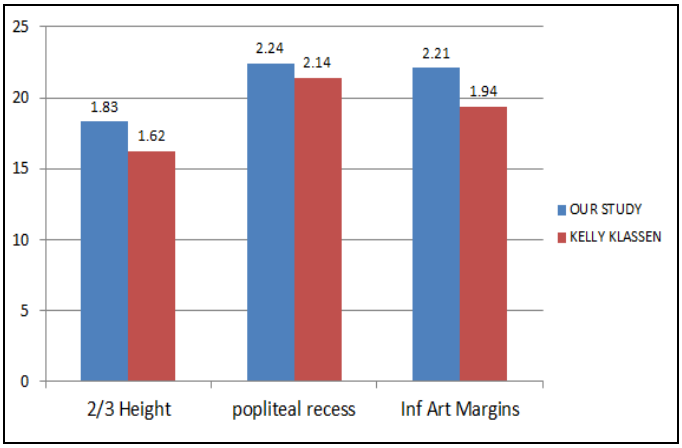

Fig 8: Notch Width (average of ACL insufficient knees and ACL Intact knees) is identical in both the studies.

Many studies have been performed previously to identify potential risk factors for ACL injury, and the femoral notch has been the main topic of interest. The majority of these studies have suggested that a smaller notch width and notch width index can be correlated to an ACL rupture [9-13]. Studies have also shown that women have smaller notch sizes than men. This may lead to the assumption that the smaller notch possibly contributes to a higher frequency of ACL ruptures in women [14-19]. Lombardo *et al.* [20] described that there is no differences between ACL-injured and non-injured basketball players with respect to Notch width. Our study states that notch width is more in ACL insufficiency patients than ACL intact patients.

Notch height at Maximum popliteal grove section is more in ACL insufficiency patients (2.495 cms) when compared to ACL intact patients (2.207 cms), two sections above ACL intact patients (2.523 cms) have more values ACL insufficiency patients (2.186 cms). Two sections below notch height is more in ACL insufficiency patients (2.333cms) when compared to ACL intact patients (1.932cms).

Lateral femoral condyle height is more in ACL intact patients (3.666 cms) when compared to ACL insufficiency patients (3.597 cms). In Margarida *et al.* (2016) also LFC-HT is more in ACL intact patients (4.52 cms) when compared to ACL insufficiency patients (4.125 cms). It was found that ACL-ruptured patients had statistically significant smaller heights of femur's lateral condyle.

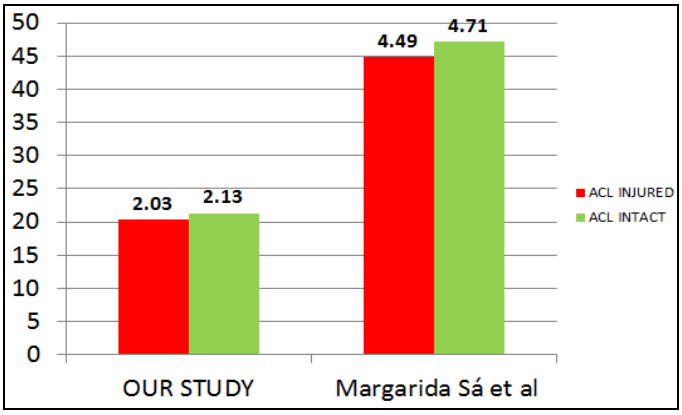

Fig 9: LFC Height is more ACL Intact knees-both studies

Lateral tibial plateau slope is more in ACL insufficient patients (6.988^0) when compared to ACL intact patients (2.525^0). Medial tibial plateau slope is more in ACL insufficient patients (10.208^0) when compared to ACL intact patients (3.74^0).

In our study MTS is more than LTS both in ACL insufficiency patients and ACL intact patients. In lazar *et al.* (2008) study LTS is more in ACL insufficiency patients and MTS is more in ACL intact patients.

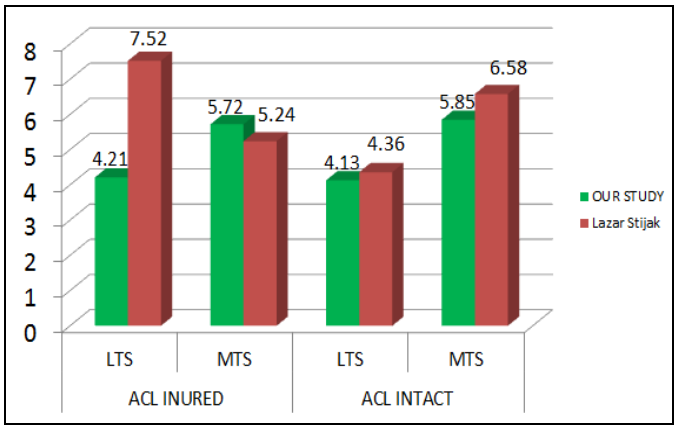

Fig 10: Medial tibial slope is more than Lateral tibial slope in both ACL Insufficient knees and ACL Intact knees.

The geometry of the proximal tibia, in particular the PTS, is considered a factor of ACL injury [21-23]. The PTS directly affects loading of the ACL duringa compressive axial force and contributes to the propensity of the ACL to rupture. For every 10º increase in PTS, there is an associated 6-mm increase in tibial translation, and the Lachman test showsa 3-mm increase for every 10º increase in the tibial slope. 20 In a cadaveric study, a small increase in the tibial slope does not affect anteroposteriortranslation or in situ force in the cruciate ligaments. Nonetheless, increasing slope causes an anterior shift in the tibia resting position that is accentuated under axial loads. Altering the tibial slope may therefore be beneficial for ACL-deficient or posterior cruciate ligament–deficient knees to improve joint congruity [24].

Conclusion

The ACL insufficient patients have more Lateral femoral condyle width, intercondylar notch width, intercondylar notch height compared to ACL intact knees. ACL-ruptured patients had statistically significant smaller heights of femur's lateral condyle. MTS is more than LTS in both ACL insufficiency patients and ACL intact patients.

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