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MRI correlation of anterior cruciate ligament injuries with Femoral Intercondylar Notch, Posterior Tibial Slopes and Medial Tibial Plateau Depth

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Abstract--Background: Knee joint is one of the largest joints in the body which solely is responsible for supporting the foremost weight of the body. Anterior Cruciate Ligament plays a primary role in stabilizing the knee joints, which also increases its chances of risk. Therefore, in comparison to other ligaments Anterior Cruciate Ligament injury can more commonly lead to knee instability. Aims & Objectives. To study and correlate femoral intercondylar notch width and shape on Magnetic Resonance Imaging in Anterior Cruciate Ligament injuries. Further, to study relationship of posterior tibial

slopes of medial and lateral plateaus and depth of the medial tibial plateau with Anterior Cruciate Ligament injury on Magnetic Resonance Imaging. **Materials & Methods:** Patients with clinical suspicion of Anterior Cruciate Ligament injury undergoing Magnetic Resonance Imaging knee at M.S. Ramaiah hospitals, Bengaluru in the period of November 2019 to June 2021. Medial and Lateral Tibial Plateau Slope, Medial Tibial Plateau Depth, Notch Width Index were recorded along with other data such as age, gender, etiology, Lachman test, presence or absence of tears, shape of notch and other relevant data. All the qualitative or categorized variables like gender, age group, presence or absence of tears, shape of notch were presented using frequency and percentage. **Results:** Mean age of the patients in cases and controls in our study was found to be 34.03 ± 13.91 and 39.26 ± 13.79 years with male predominance. Mean value of medial tibial plateau depth in cases and controls was found to be 2.41 ± 0.316 and 2.58 ± 0.36 respectively and the mean value of tibial plateau slope in cases and controls was found to be 8.55 ± 1.07 and 8.03 ± 0.88 and the mean value of tibial condyle angle lateral in cases and controls was found to be 6.77 ± 1.22 and 6.19 ± 0.85 respectively. 25 cases were positive for LACHMAN TEST with mean value of Notch Width Index in cases and controls was found to be 0.28 ± 0 and 0.3 ± 0 respectively with the shape of ICN in the form of A, U & OMEGA was found to be seen in 11, 7 and 17 cases respectively. **Conclusion:** A clear male predilection with instability and valgus involvement was observed in majority of the patients. We also found that there was narrowing of the notch width index which was statistically significant in comparison with the control group. Patients with Anterior Cruciate Ligament injury, had decreased notch width index and medial tibial plateau depth whereas there was an increase in the tibial condyle angle medially as well as laterally.

Keywords--Knee, Trauma, Tear, Instability, Angle, Pain, Tibia.

Introduction

Knee joint is one of the largest joints in the body and supports the major weight of the body. It comprises of the Tibia, femur, and patella bone stabilized by the medial as well as the lateral collateral ligament and posterior as well as the anterior cruciate ligament (ACL). It is further made of medial and lateral menisci that act as shock absorbers, by distributing weight consistently with every movement in a uniform form.^{1,2,3}

The annual incidence of ACL injury accounts for 200,000 cases with 100,000 of restructured knees.^{4,5,6} Non-contact mechanisms contribute 70% of ACL injuries while direct contact injuries contribute to the remaining 30% of ACL injuries, especially during field or court sport.^{3,4,5,6}

Traditionally arthroscopy has been used as the gold standard in diagnosing ACL damage due to its high sensitivity.⁷ Of late; magnetic resonance imaging (MRI)

examination for the diagnosis of ACL injury has become popular, as it's noninvasive.^{8,9} Oblique orientation of ACL poses slight difficulty in imaging and subsequent image interpretation, dedicated imaging protocols help in almost accurate conclusion of its pathologies. MRI characterizes the spectrum of morphologic and signal intensity changes in ACL tears.^{7,10,11}

The ACL discontinuity, assessed in different planes and failure of ACL fascicles to parallel Blumensaat's line are considered primary and accurate signs of a ligament tear. Discontinuity of the ACL in one plane, disruption of fascicles, bone contusions on the weight-bearing surface of the lateral femoral condyle and posterolateral tibial plateau, buckling of the posterior cruciate ligament (PCL), a positive PCL sign and a positive posterior femoral line signs are the other indicators evaluated in MRI.^{7,10,11}

The patients with a narrow notch width index (A ratio of intercondylar notch width to femoral condyle width) should also be screened contra-laterally to prevent ACL injuries on the other knee, as there are increased chances of ACL injury. It can be prevented by planning specialized training programs.¹² An increase in the lateral PTS ($\geq 4.5^\circ$) may be an anatomical risk factor for ACL ruptures.¹³ Shallow medial tibial plateau depth along with steep medial tibial slope (MTS) and lateral tibial slope (LTS) has also been recognized as a risk factor for ACL injury.¹⁴

This study was undertaken to assess all the 4 factors i.e., femoral intercondylar notch width and shape, posterior tibial slopes of medial and lateral plateaus and depth of the medial tibial plateau (MTPD) in MRI of suspected ACL patients.

Aims & Objectives

- To study and correlate femoral intercondylar notch width and shape on MRI in ACL injuries.
- To study relationship of posterior tibial slopes of medial and lateral plateaus and depth of the medial tibial plateau with ACL injury on MRI.

Materials and Methods

The study was a hospital based prospective analytical observational study carried out in 62 patients with clinical suspicion of ACL injury undergoing MRI knee at M.S. Ramaiah hospitals, Bengaluru from the time period of Study November 2019 to June 2021.

Inclusion Criteria

All patients aged 18 years and above with clinical suspicion of ACL injury and in whom MRI knee was performed.

Exclusion Criteria

- Patients with previous knee injury.
- Patients with old or new tibial plateau fractures
- Patients with pathologies like osteoarthritis which alter the morphology of intercondylar notch and tibial plateau

Method of collection of data for standardization

The parameters assessed were as follows

MRI technique & measurement

Knee MRI was performed using 1.5 T Siemens Avanto Magnetom dedicated 18 channel scanner with commercially available IPACX OsiriX IMAGING SOFTWARE. [Figures 1,2,3,4]

Notch width index

- NWI was calculated by dividing the Notch width at the level of popliteal groove with Bi-condylar width at the same level.
- Shape of Intercondylar Notch (ICN) was assessed by comparing the Notch Width at the levels of Popliteal Groove (NWP) and Joint Line (NWJ).
- Three shapes of intercondylar notch were defined on the coronal sequence.
- Inverted U shaped - $NWP = NWJ$
- A shaped - $NWP < NWJ$
- Omega (Ω) shaped notch

Tibial Measurements

Posterior Tibial slopes were calculated stepwise on a sagittal reconstructed image of a Proton density 3D SPACE coronal sequence (TE: 51 ms, TR: 1300 ms, slice thickness 0.7 mm, Matrix: 320 x160, FOV: 160 mm).

Tibial Longitudinal Axis

- Identification of midline sagittal image of the tibial attachment of the Posterior Cruciate Ligament (PCL), the intercondylar eminence and concave shaped anterior and posterior tibial plateau was done.
- Further, on the mid sagittal section of tibia, the midpoint of the anterior to posterior diameter of the tibia at two points situated approximately 4-5 cm apart was marked, as caudally as possible.
- These two midpoints when connected represented the longitudinal axis of tibia.
- This axis was positioned as an overlay and remained in a fixed position on the sagittal image series

MTPS and LTPS Measurement

- This longitudinal axis was then reproduced in the middle of the mediolateral centre of the medial tibial plateau in sagittal plane.
- On this image a tangent was drawn to the tibial plateau connecting the peak anterior and posterior cortical edges.
- The slope of the line (angle subtended) extending through these two points represented the MTPS, and it was measured with respect to the axis perpendicular to the longitudinal axis of the tibia.

- Similarly, the LTPS was obtained.

MTPD Measurement

A line connecting the peak anterior as well as the posterior points of the medial plateau to a line drawn tangential to the deepest point of the medial plateau with measurement of the maximum vertical distance between the two parallel lines depicted the MTPD.

Statistical Analysis

All the quantitative variables like age, MTPS, LTPS, NWI, etc were analyzed using descriptive statistics such as mean and standard deviation. All the qualitative or categorized variables like gender, age group, presence or absence of tears, shape of notch were presented using frequency and percentage. The mean values of notch width index were compared between the 2 groups using Student “t” test.

Results

Mean age of the patients in cases and controls in our study was found to be 34.03 ± 13.91 and 39.26 ± 13.79 years with male predominance [Table 1,2]. Most of the patients reported instability and pain [Table 3,4] and valgus mode of injury [Table 5]. 25 cases in the study group reported positive results for LACHMAN TEST out of 35 patients [Table 6]. The mean value of NWI in cases and controls was found to be 0.28 ± 0 and 0.3 ± 0 respectively with the shape of ICN in the form of A, U & OMEGA was found to be seen in 11, 7 and 17 cases respectively, which clearly showed that there was a decrease in the notch width index of the study group [Table 7,8]. Mean value of medial tibial plateau depth in cases and controls was found to be 2.41 ± 0.316 and 2.58 ± 0.36 respectively; the mean value of tibial plateau slope in cases and controls was found to be 8.55 ± 1.07 and 8.03 ± 0.88 and the mean value of tibial condyle angle lateral in cases and controls was found to be 6.77 ± 1.22 and 6.19 ± 0.85 respectively [Table 9,10,11].

Discussion

Knee is the largest joint with the most complex anatomy.³ The complexity of the knee structure is such that any trauma to it may make its diagnosis as well as its repair a cumbersome process. It is important to understand that the damage to the structure may not involve only a single part and may involve multiple parts. Damage to such structures may not only limit the range of motion but also cause instability and also impact the other functional outcome that is normally rendered by the structure of the human body. The damage to the knee and its structures as per their causative factors are rupture of the knee ligaments (12%), Muscle tears (14%), and Meniscus and Cartilage injuries (6.3%).¹⁵

Out of all the ligaments which work in synchronization for the functioning of the knee, it is the anterior cruciate ligament which is the key stabilizing structure of the knee, which is depicted by the instability that is seen when there is injury to the anterior cruciate ligament.³ The mean age of the patients in cases and controls was found to be 34.03 ± 13.91 and 39.26 ± 13.79 years respectively. In a

study done by Stijak et al, they found the average age of the patients was 30 ± 10 years (range, 15–48 years) in the study group, and 30 ± 11 years (range, 15–48 years) in the control group.¹⁶ Another study done by Shen Lei et al, found the mean age of 30.8 ± 10.0 vs. 32.4 ± 9.7 years in ACL vs control group,¹⁷ whereas Gormeli et al., reported a mean age of 29.9 ± 9.3 and 31.02 ± 7.9 in injured non-injured group respectively.¹²

Our study consisted of 24 males and 11 females with ACL tear in our study group. The predominance of the type of injury and its correlation with the gender is dependent on many factors like the activity involved, the angle of impact/trauma and many more as the external factors. Other factors includes ACL injury incidence, knee joint laxity, knee joint kinematics, or knee joint kinetics.^{13,18,19,20,21}

However, females usually project a greater degree of knee joint laxity; smaller flexion angles along with more internal rotation, and more knee valgus for jumping and cutting manoeuvres which are responsible for the greater incidence of ACL injury in women. Apart from these, other factors include GRFs, knee extension moments, internal rotation moments and knee valgus moments which are comparatively greater in females.^{20,22}

In agreement with our study, Stijak et al, the study had 21 male and 12 female patients who suffered injuries.¹⁶ Another study done by Shen Lei et al., males were more commonly affected than females in the injured group.¹⁷ Similarly, a study done by Ashwini et al., had 35 males & 15 female patients in their study.²³ Controlled laboratory studies have determined that different movement and muscle activation patterns exist between males and females; however, it is unclear how these differences are related to the risk of suffering ACL injury.²⁴ Compression of the medial and superior aspects of the knee followed by the tapping the lateral aspect with a fluid wave reveals presence of subtle effusion. Further on palpation of the patella, a spongy feel can be felt which is also suggestive of effusion.¹ In our study, 30 cases in the study group and 22 cases in the control group reported pain and further 30 cases in the study group and 6 cases in the control group reported instability.

The presence of pain as well as the limitation in the range of motion could be caused due to hemarthrosis which causes increased intraarticular volume. The other reasons for the limitation in the range of motion could be attributed to the all-embracing guarding effect and the spasm of the hamstring muscle group. When there is a reduced hyper-extensibility, we should suspect ACL disruption. The compression of the ACL stump amid the tibia and the femur post rupture accompanied by joint effusion causes a limitation in the movement and hinders the full extension capability. Also a locked displaced meniscal tear should be suspected.²⁵

1 case in the study and 21 cases in the control group showed knee varus involvement while 34 cases in the study and 10 cases in the control group showed knee valgus involvement. NWI represents a ratio of the intercondylar notch width to the femoral condyle width.^{6,26} It has been suggested that a narrow intercondylar notch may increase the risk of ACL injury. The patients with a

narrow notch width index (NWI) (A ratio of intercondylar notch width to femoral condyle width) should also be screened contralaterally to prevent ACL injuries on the other knee. So, specialized training programs for the people with narrow NWI can be prepared for preventing ACL injuries.¹²

The mean value of NWI in cases and controls was found to be 0.28 ± 0 and 0.3 ± 0 respectively. Gormeli CA et al., reported a NWI of 0.22 ± 0.008 in bilateral injured knees and 0.24 ± 0.01 in unilateral injured knee which indicated that the NWI was significantly narrowed in patients with bilateral and unilateral ACL tears compared with the healthy controls suggest that a narrow NWI is associated with an increased risk of ACL injury.¹²

A study calculated NWI from measurements taken from x-ray films in a unilateral ACL deficient sample found that NWI is typically smaller in the injured knee compared to the non-injured knee.⁶ Another study calculated NWI using magnetic resonance imaging (MRI) but found no relationship between NWI. The study concluded that elongation of the ACL when the knee was moved through kinematics is believed to injure the ligament.²⁷

Another study done by Shen Lei et al., showed smaller notch width index (0.247 ± 0.032 vs. 0.273 ± 0.024 , $t = -7.360$, $P < 0.001$), smaller α angle (46.70 ± 7.04 vs. 50.73 ± 7.76 , $t = -4.293$, $P < 0.001$), larger β angle (41.48 ± 2.22 vs. 38.30 ± 3.16 , $t = 9.199$, $P < 0.001$), larger medial tibial slope (6.85 ± 2.59 vs. 5.61 ± 1.76 , $t = 4.424$, $P < 0.001$), and larger lateral tibial slope (8.04 ± 3.32 vs. 5.34 ± 1.83 , $t = 7.953$, $P < 0.001$) in ACL-injured group compared to the controls.¹⁷

In the study group, the shape of ICN in the form of A, U & OMEGA was found to be seen in 11, 7 and 17 cases respectively with variation seen only in U & OMEGA form seen in 12 and 8 cases respectively. In a study done by Ashwini et al, they found that the omega shape as in comparison to A and inverted U had 7.2 and 3.9 times more predilection for ACL injury respectively and concluded that MTPD of less than 2.1mm was 4.1 times more indicative of ACL injury.²³ Hirtler et al., from their study revealed that the distal femur is prone to age-dependent remodeling and that there is a significant increase in the width and contour changes, which would appear as an elephant's foot appearance, specifically of the medial condyle.²⁸

Intercondylar notch is subject to change throughout life, narrowing more distally and widening more proximally. Its width ranges from 16.23 ± 2.71 mm before the age of 11 years to 19.38 ± 2.90 mm in middle age and then decreases to 18.6 ± 2.36 mm after the age of 60 years. The shape of the intercondylar notch changes from A shape in young individuals to Ω -shape later on.²⁸

A retrospective study which analyzed 110 MRI of knees to compare the significance of the tibio-femoral morphological variables (notch width index, notch shape index, intercondylar notch angle, medial and lateral tibial slopes) in predicting non-contact ACL (anterior cruciate ligament) injuries and to compare these factors between genders in South Asian population, reported that ACL tears were associated with type A notch, decreased notch width index, intercondylar notch angle and increased lateral posterior tibial slope.²⁹

We found the mean value of medial tibial plateau depth in cases and controls was found to be 2.41 ± 0.316 and 2.58 ± 0.36 respectively. Similarly, a study done by Ashwini et al., reported the medial tibial plateau depth amongst the patients without tear and with tear in males was found to be 2.45 ± 0.69 & 2.4 ± 0.7 respectively. The medial tibial plateau depth amongst the patients without tear and with tear in females was found to be 2.4 ± 0.5 & 2.25 ± 0.65 respectively.²³ Shallow medial tibial plateau depth along with steep medial tibial slope (MTS) and lateral tibial slope (LTS) has also been recognized as a risk factor for ACL injury.^{13,14} MRI helps in measuring the MTS and LTS separately.

In our study, the mean value of tibial condyle angle medial in cases and controls was found to be 8.55 ± 1.07 and 8.03 ± 0.88 respectively. Further, the mean value of tibial condyle angle lateral in cases and controls was found to be 6.77 ± 1.22 and 6.19 ± 0.85 respectively. Shen Lei et al, reported the medial tibial slope to be 6.85 ± 2.59 & 5.61 ± 1.76 respectively and the lateral tibial slope was found to be 8.04 ± 3.32 & 5.34 ± 1.83 respectively.¹⁷

Papagelopoulos PJ, found the mean MTPS of uninjured and injured pooled population was $7.73 \pm 3.20^\circ$ and $8.73 \pm 2.26^\circ$ respectively.³⁰ A study done by Ashwini et al., MTPS of controls and injured ACL was $7.2 \pm 3.78^\circ$ and $9.3 \pm 3.07^\circ$ respectively.²³ The medial tibial slope amongst the patients without tear and with tear in males was found to be 6.7 ± 4.2 & 8.7 ± 2.68 respectively. The medial tibial slope amongst the patients without tear and with tear in females was found to be 8.3 ± 2.2 & 11.3 ± 3.5 respectively. Shallow medial tibial plateau depth has also been recognized as a risk factor for ACL injury.⁶

Application of the compressive load in combination with the anterior force vector displaces the femur which is relative to the tibia where the lateral femoral condyle swings posteriorly and the tibia translates anteriorly and rotates within, leading to rupture of the ACL. After the ACL is torn, the primary restraint to anterior translation of the tibia is gone which causes the medial femoral condyle also to be displaced posteriorly, resulting in external rotation of the tibia. After ACL injury, there was a decrease in the notch width index and medial tibial plateau depth whereas there was an increase in the tibial condyle angle medially as well as laterally. Further, they also justify the limitation of movement and the instability in the study group. Hence, indicating the importance of ACL in knee movement.

Conclusion

We found a clear male predilection with instability and valgus involvement in majority of the patients with narrowing of the notch width index, which was statistically significant in comparison with the control group. Also, in patients with ACL injury, there was a decline in the notch width index as well as the medial tibial plateau depth whereas there was an upsurge in the tibial condyle angle medially as well as laterally.

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TABLES

TABLE 1: MEAN VALUES OF AGE

AGE	CASES	CONTROL
MEAN	34.03	39.26
S.D	13.91	13.79
P	0.065	

Statistical significance $P < .05^*$

TABLE 2: FREQUENCY DISTRIBUTION OF GENDER

GENDER	CASES		CONTROL	
	No	Percentage	No	Percentage
MALE	24	68.57	13	41.94
FEMALE	11	31.42	18	58.06
TOTAL	35	100	31	100

TABLE 3: FREQUENCY DISTRIBUTION OF PAIN

PAIN	CASES		CONTROL	
	No	Percentage	No	Percentage
YES	30	85.72	22	70.97
NO	5	14.28	9	29.03
TOTAL	35	100	31	100

TABLE 4: FREQUENCY DISTRIBUTION OF INSTABILITY

INSTABILITY	CASES		CONTROL	
	No	Percentage	No	Percentage
YES	30	100	6	29.03
NO	5	0	25	70.97
TOTAL	35	100	31	100

TABLE 5: FREQUENCY DISTRIBUTION OF MOI

MOI	CASES		CONTROL	
	No	Percentage	No	Percentage
VARUS	1	2.86	21	67.74
VALGUS	34	97.14	10	32.26
TOTAL	35	100	31	100

TABLE 6: FREQUENCY DISTRIBUTION OF LACHMAN TEST

LACHMAN TEST	CASES		CONTROL	
	No	Percentage	No	Percentage
POSITIVE	33	94.28	3	9.7
NEGATIVE	2	5.72	28	90.3

TOTAL	35	100	31	100
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TABLE 7: MEAN VALUE OF NWI

NWI	CASES	CONTROL
MEAN	0.28	0.3
S.D	0	0
MANN WHITNEY - U VALUE - 309		
P	.0028*	

Statistical significance $P < .05$

TABLE 8: FREQUENCY DISTRIBUTION OF SHAPE OF ICN

ICN	CASES		CONTROL	
	No	Percentage	No	Percentage
A	11	31.43	11	35.48
U	7	20	12	38.71
OMEGA	17	48.57	8	25.81
TOTAL	35	100	31	100

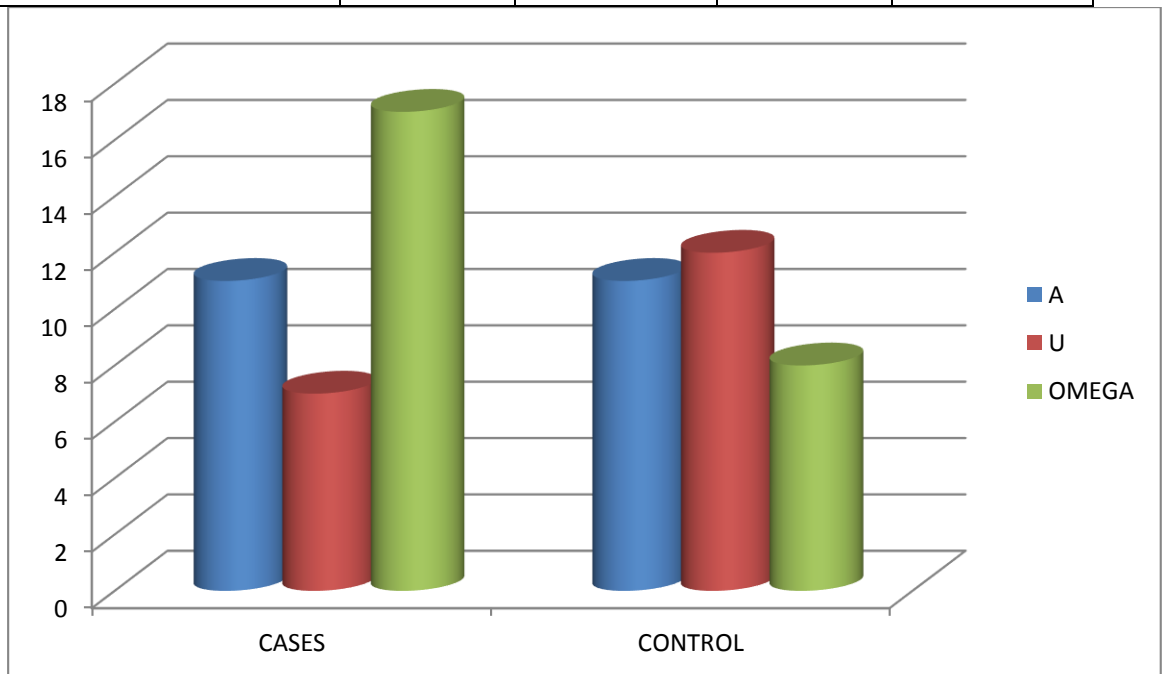


TABLE 9: MEAN VALUE OF MEDIAL TIBIAL PLATEAU DEPTH

MTPD	CASES	CONTROL
Mean	2.41	2.58
S.D	0.316	0.36
P	0.019*	

Statistical significance $P < .05$

TABLE 10: MEAN VALUE OF TIBIAL CONDYLE ANGLE MEDIAL

TIBIAL CONDYLE ANGLE MEDIAL	CASES	CONTROL
MEAN	8.55	8.03
S.D	1.07	0.877
P	0.018*	

Statistical significance $P < .05^*$

TABLE 11: MEAN VALUE OF TIBIAL CONDYLE ANGLE LATERAL

TIBIAL CONDYLE ANGLE LATERAL	CASES	CONTROL
MEAN	6.77	6.19
S.D	1.22	0.85
P	0.015*	

Statistical significance $P < .05^*$

PICTURES WITH LEGENDS

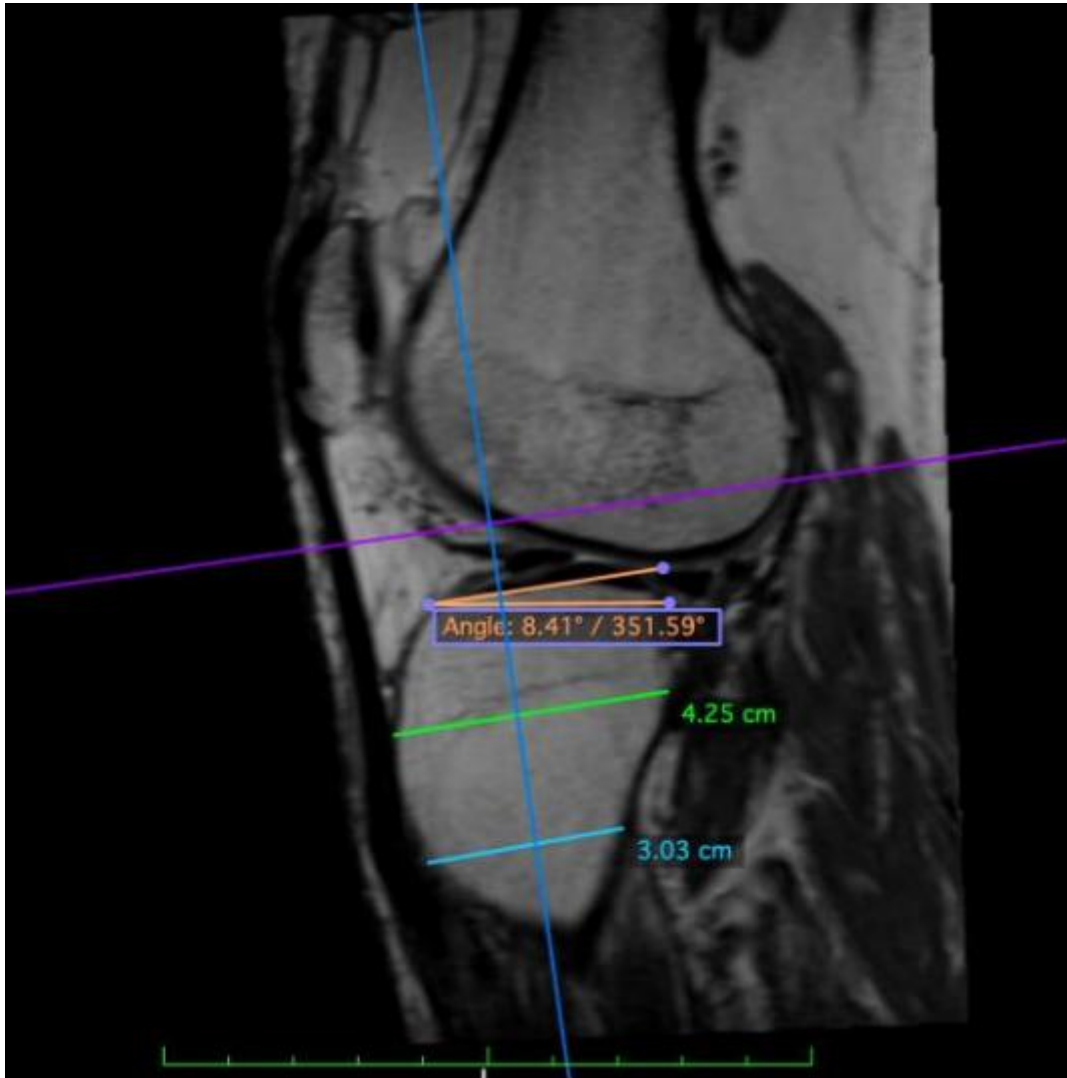


Figure 1: Shows Lateral tibial plateau slope.

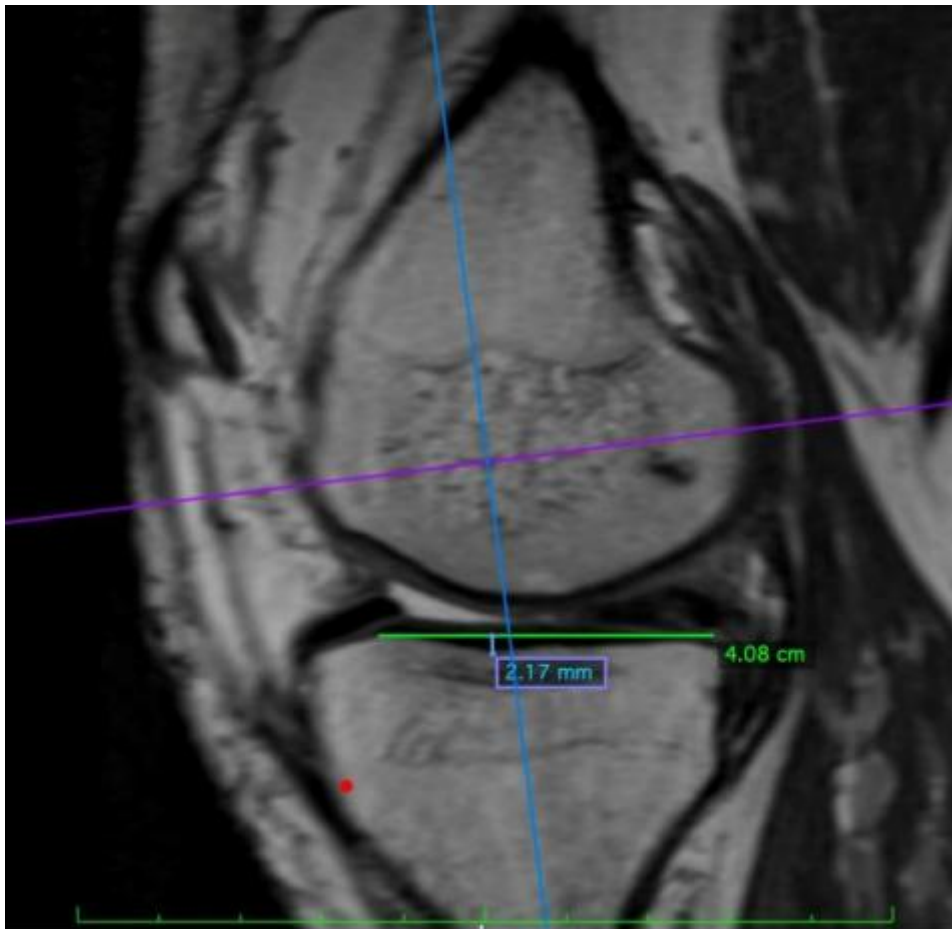


Figure 2: Shows Medial tibial plateau depth.

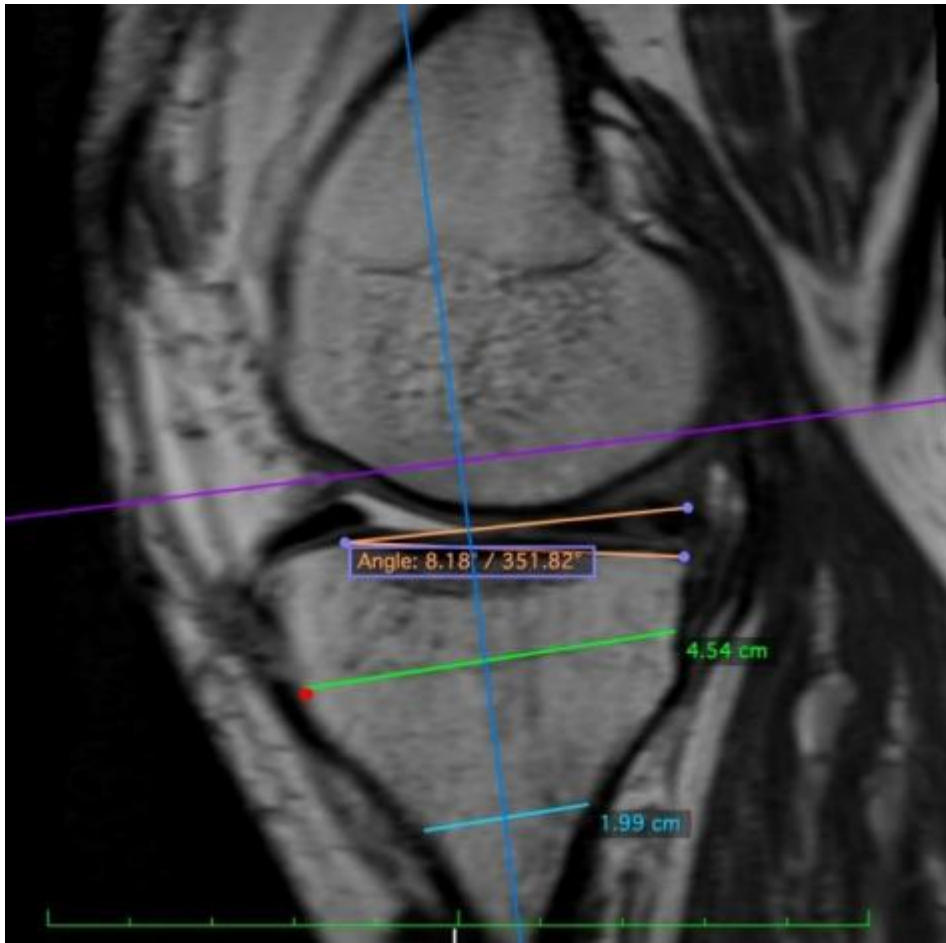


Figure 3: Shows Medial tibial plateau slope

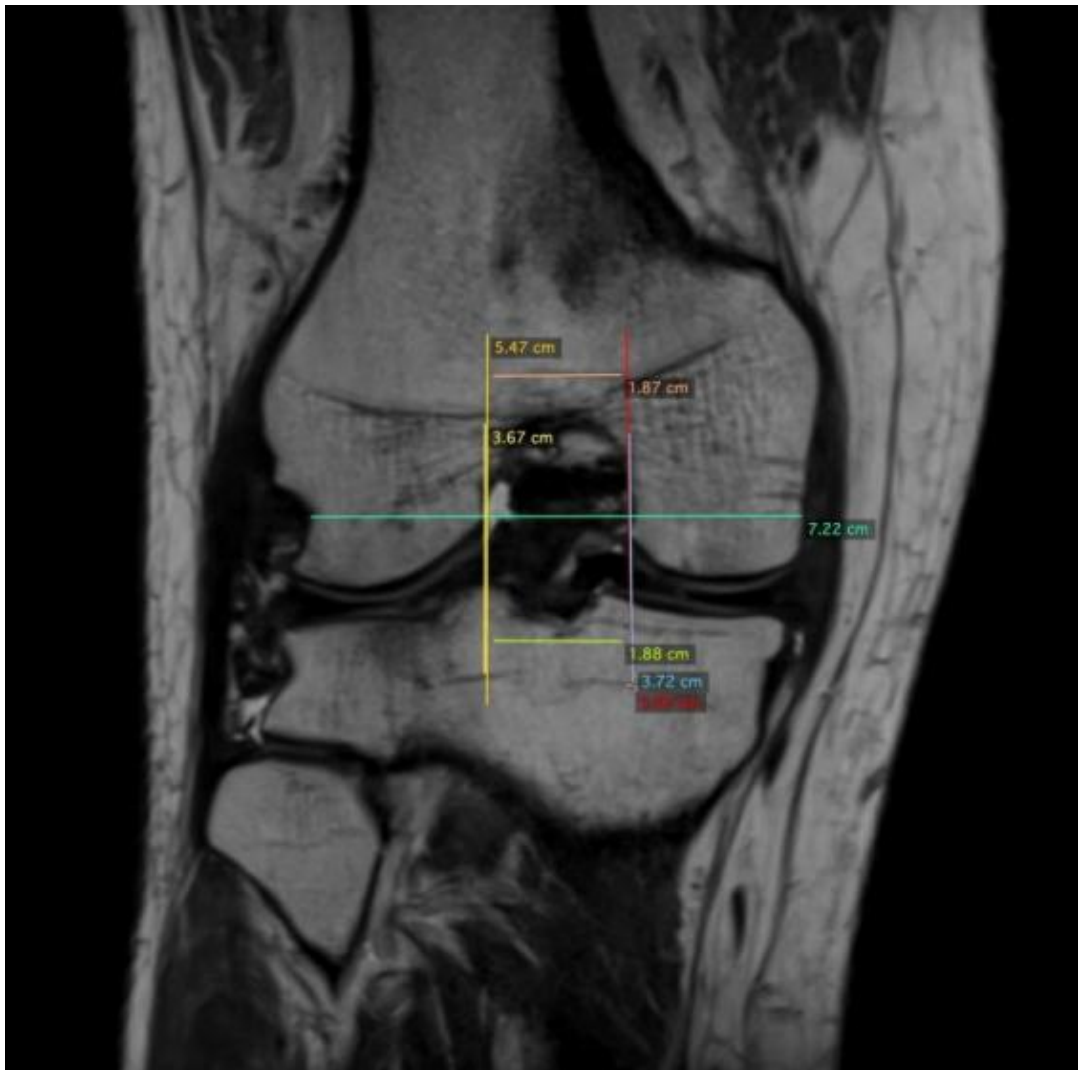


Figure 4: Shows Notch width index of 0.25 and U-shaped notch.