DIAGNOSTIC VALUE OF OBLIQUE CORONAL AND OBLIQUE SAGITTAL MAGNETIC RESONANCE SEQUENCES IN DIAGNOSIS OF ANTERIOR CRUCIATE LIGAMENT (ACL) TEARS

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Background: Anterior Cruciate Ligament (ACL) injuries should be diagnosed and treated as soon as possible to avoid further cartilage deterioration and accelerated traumatic arthritis. The use of magnetic resonance imaging (MRI) of the knee joints can help identify the location and severity of ACL injury.

Objective: The aim of this research study is to evaluate the diagnostic efficacy of oblique sagittal and oblique coronal Magnetic Resonance Imaging (MRI) in diagnosis of ACL tears.

Method: The present study is a cross-sectional study which was carried out in the radiology center at Imam Alhusain Teaching Hospital In Thi-Qar, Iraq. It involves the use of MRI as a diagnostic tool to image internal derangements of the knee in the subjects who were prospectively evaluated for knee injuries. A total of 75 subjects aged between 18 years and 62 years were enrolled in the study. The subjects were subjected to two groups based on the use of MRI on the basis of two diagnostic protocols: standard orthogonal routine images only (protocol A) and standard images with both oblique coronal and oblique sagittal images (protocol B).

Result: The results of this study showed that orthogonal MRI had a sensitivity of 45.5 % and a specificity of 78.19 % in diagnosing ACL damage, while adding oblique sagittal and oblique coronal to the orthogonal MRI for patient analysis yielded a sensitivity of 36.4 % and a Specificity of 84.91 %. Due to the high selectivity in the analysis of ACL damage, addition of oblique sagittal and oblique coronal to the orthogonal MRI was noted to be an efficient method for diagnosis of ACL damage.

Conclusion: Adding oblique sagittal and oblique coronal to the orthogonal MRI for patients with ACL injury improves diagnostic effectiveness. It can be used to diagnose non-invasive ACL damage as a first option.

Keywords: Oblique, Coronal, Sagittal, Anterior cruciate ligament, Magnetic resonance, orthogonal MRI

I. INTRODUCTION:

ACL rupture is the most commonly (20%) diagnosed internal derangement of the knee in sports injuries.[1]The anterior cruciate ligament (ACL) is composed of the anteromedial and posterolateral bundles. Functionally, these two distinct bundles act in a complementary manner to limit excessive femorotibial movement at the end of flexion and extension.[2] ACL is the most frequently injured large ligament in the knee. As injured ACL recovery is very limited long-term consequences are frequent including cartilage loss, secondary meniscal injuries, and degenerative changes.[2] Most ACL tears are complete, with the tear involving all of the anteromedial and posterolateral bundle fibers. Partial ACL tears occur less frequently and should involve both bundles to a variable degree or one bundle completely. Arthroscopic-based studies may reflect an underestimation of true prevalence as patients with complete rather than partial tears are more likely to undergo arthroscopy.[3] An arthroscopic examination allows the diagnosis to be confirmed through direct visualization and probing. Unfortunately, arthroscopies are invasive and require a skilled surgeon. MR imaging has become a popular and practical tool for the evaluation of ACL injuries, with its high degrees of accuracy and sensitivity reported in the literature.[4] Magnetic resonance imaging (MRI) is a proven imaging modality for the detection, evaluation, assessment, staging, and follow-up of disorders of the knee. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment planning and prognostication. Although MRI is a sensitive, noninvasive diagnostic test for detecting anatomic abnormalities of the knee, its findings may be misleading if not closely correlated with clinical history, symptomatology, physical examination, and radiographs.[5] Knee MRI examinations usually include images acquired in appropriate transverse (axial), sagittal, and coronal imaging planes[6][7]. The ACL possesses a unique diagonal course extending from the inner surface of the lateral femoral condyle and attaching to a fossa in front and lateral to the anterior tibial spine[8] Because. of its oblique course, visualization of the complete ACL on a single image would not be expected. To achieve full-length visualization of the ligament on one or more sections, the use of oblique MRI, parallel to the long axis of the ACL has been advocated.[9] therefore, finding a new method or new procedure with high diagnostic value in evaluating ACL injury is needed. Tackling this issue, Kosaka et al. demonstrated that a new method was not needed, as MRI accuracy can be increased by using a different view of knee lesions such as ACL injury. They found that the additional use of oblique MRI improved the accuracy of diagnosis of ACL tear[9] Moreover, In 2018, Ghasem et al. showed that the addition of oblique sagittal to standard images was better than the addition of oblique coronal images in the detection of complete and partial ACL tears[10]. YASSER et al. performed a study that Adding oblique coronal thin slices to the routine MRI protocol provides a better delineation of ACL bundles, improving the diagnostic accuracy of detecting single/double-bundle injury, without adding additional time or cost, hence improving the management of these injuries[11]. In another study performed by Hazem Hamed Soliman**(2020)** he said the addition of oblique sagittal and coronal images improved diagnostic accuracy of detection of complete and partial ACL tears. The concurrent use of sagittal and coronal oblique images enhanced the accuracy, sensitivity, and specificity of diagnosis of partial ACL tears only. Thus, we advise the use of concurrent sagittal and coronal oblique images in cases of partial ACL tear suspicion.[12]

II. MATERIALS AND METHODS

Study population

The study was approved by the hospital ethical committee and all patients agreed to participate in the study. November 2020 to July 2021 we prospectively evaluated 75 patients with MRI examination of the knee in a single-center experience in the Radiology Department of IMAM ALHUSAIN HOSPITAL IN THI-QAR, IRAQ. All Patients presented with painful knee joints due to trauma of knee soft tissue structures. They were 10 females and 65 males, ranging in age from 18 to 62 years. Mean age is 35.5 years.

Patient position: All patients were examined during a supine position with a small external knee rotation. The patient was offered headphones to scale back the repetitive gradient noise.

- **Inclusion criteria:** Inclusion criteria were Patients with painful and instability knee joint, positive history for ACL lesion and/ or positive one or two ACL lesion physical tests (the Lachman test and anterior drawer test) . Cases that performed arthroscopy with less than 1 month from the time of performing the MR examination

- **Exclusion criteria:** Patients with a history of previous knee operation and those with absolute contraindications to MR examination as a cardiac pacemaker, aneurysmal clipping, Obese patients (over 170 kg), Cases that performed arthroscopy with an interval exceeding 1 month from the time of performing the MR examination and claustrophobia were excluded from the study.

MRI Imaging

MR examinations were performed using a 1.5T MRI machine (Achieva, Philips Imaging System, Netherlands) using a phased array knee coil. The patients were placed in the supine position and the knee is extended in external rotation.

MR imaging protocol

Preliminary scout localizers in axial, coronal, and sagittal planes were done. The axial images served as a localizer for prescribing the coronal and sagittal sections. After standard MRI protocol, additional sagittal oblique and coronal oblique techniques were performed in all patients using the same parameters as standard MRI protocol, obtained with the previously applied standard MRI protocol was used as a program for paracoronal oblique sequence that followed the particular course of ACL. **(Fig. 1)**

Obtained paracoronal oblique image was angled depending on the actual anatomy of the patient's knee. **(Fig. 2)** This image, showing the full course of ACL, was used as a program for the oblique-sagittal protocol. **(Fig. 3)**

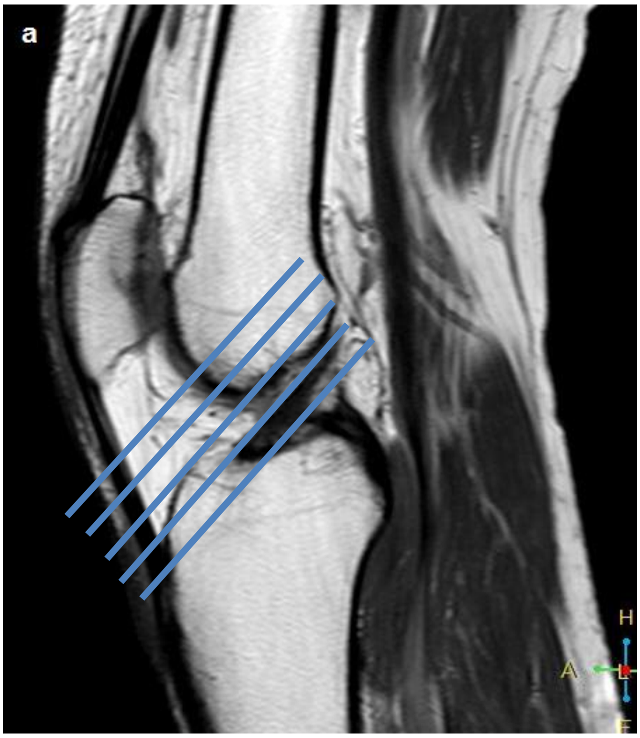

Figure 1: Sagittal image of standard MRI examination as a topogram for planning the para-coronal oblique T2 image

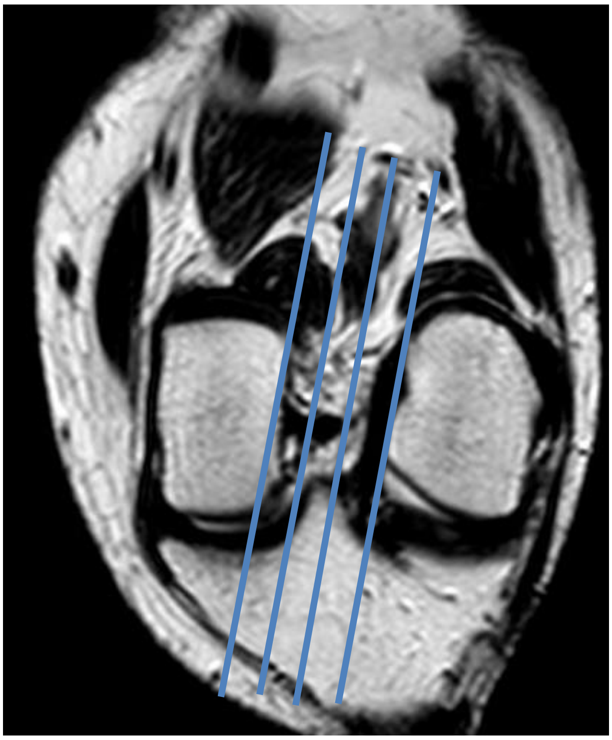

Figure 2 : Anterior cruciate ligament (ACL) paracoronal oblique image

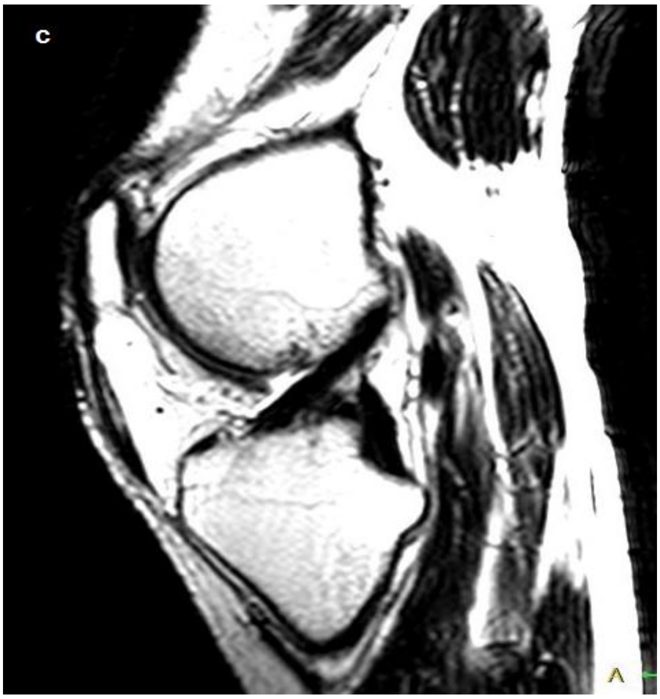

Figure 3: Anterior cruciate ligament (ACL) sagittal-oblique T2 image

The standard knee protocol (sagittal proton density, axial T2 (TSE), sagittal T2(TSE), coronal T1(TSE), and coronal STIR were designated protocol A, while the standard knee protocol plus the sagittal oblique and coronal oblique technique were designated protocol B. Imaging parameters are demonstrated in (Table 1).

Table 1: Imaging parameters for MRI examination

		TR	TE	FOV	SL	Gap	Matrix	NEX
Standard protocol (A)								
Sagittal PD(TSE)		5,000	30	180	4.5	1	512 × 256	3
Axial T2 (TSE)		472	18	160	5	0.4	512 × 256	2
Sagittal T2(TSE)		3.6	100	170	5.5	1.5	256 × 192	2
Coronal T1(TSE)		5.5	30	180	3	0.3	512 × 256	3
Coronal STIR		5,000	30	180	4.5	1	256 × 192	3
Additional sequences protocol (B)								
Coronal-oblique	T2	3.6	100	160	3	0.3	512 × 256	2
Sagittal-oblique	T2	3.6	100	180	3	0.3	512 × 256	3

III. MRI ANALYSIS:

We analysed the diagnostic value of MRI data related to ACL injuries , especially detection of partial and complete ruptures, presentations of the partial ruptures of ACL using standard knee protocol (protocol A) and (protocol B). Firstly, protocol A was evaluated and the ACL was classified as intact, partially torn, or completely torn. Thereafter, protocol B was evaluated and each ACL was again classified as intact, partially torn, or completely torn. An intact ACL was in which all the ACL fibers could be followed on contiguous sections as intact from the tibial to the femoral attachment. A partial ACL tear was defined by a partial discontinuity or disruption of ACL fibers, high signal intensity within the ACL, focal swelling or thinning of the ACL, and/or a wavy course of the ACL with maintained continuity. A complete ACL tear was defined as a complete lack of continuity of the ACL.

In addition, the presentations of the partial ACL tear were assessed in each technique and classified on MRI as direct presentation of partial rupture of ACL (direct visualization of ACL disruption), course of ACL (presented by focal swelling or thinning of the ACL and/or a wavy course of the ACL with maintained continuity) and hyperintense signal (high signal intensity with in the ACL). The position of partial rupture of anterior cruciate ligament (ACL) was also assessed and classified on MRI as upper attachment rupture, middle part rupture, and lower attachment rupture.

Statistical analysis

The obtained data were analyzed and reported only for patients who completed the whole diagnostic protocol. The statistical analysis of data was performed to evaluate the level of agreement. The sensitivity, specificity, positive and negative predictive value and overall accuracy were calculated for all involved methods in evaluating of Anterior Cruciate Ligament (ACL) tears.

Results

The present study is a cross-sectional study and involves the use of MRI as a diagnostic tool to image internal derangements of the knee in the subjects who were prospectively evaluated for knee injuries. A total of 75 subjects were enrolled in the study. The age of the enrolled subjects ranged between 18 years and 62 years (mean age 35.5 years)

Among the studied population, 86.667% were males and 13.333% corresponded to females (Table 2).

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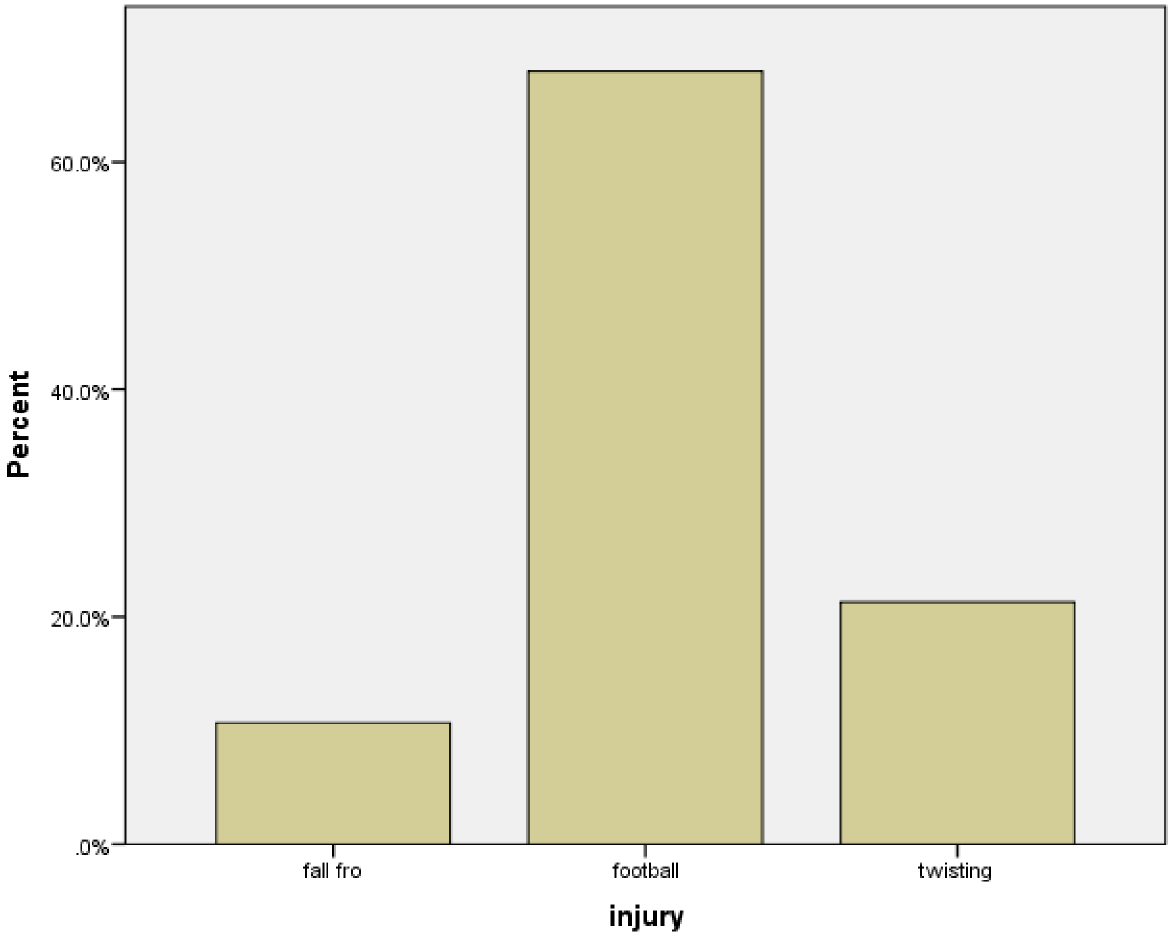
Table 2: Distribution of patients according to sex

Sex	**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
female	10	13.333	13.333	13.333
male	65	86.667	86.667	100.000
Total	75	100.000		

The enrolled patients were evaluated for the type of injury. The observations are presented in (**Table 3)**. The results indicated the fact that the incidence of ACL injury was highest in those playing football. However, other responsible causes were attributed to twisting and falling down from a higher height.

Table 3: Frequencies for Type of injury

Type of injury	**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
fall from high	8	10.667	10.667	10.667
football	51	68.000	68.000	78.667
twisting	16	21.333	21.333	100.000
Total	75	100.000		



Parameters	**Protocol A**	**Protocol B**	**Protocol C**

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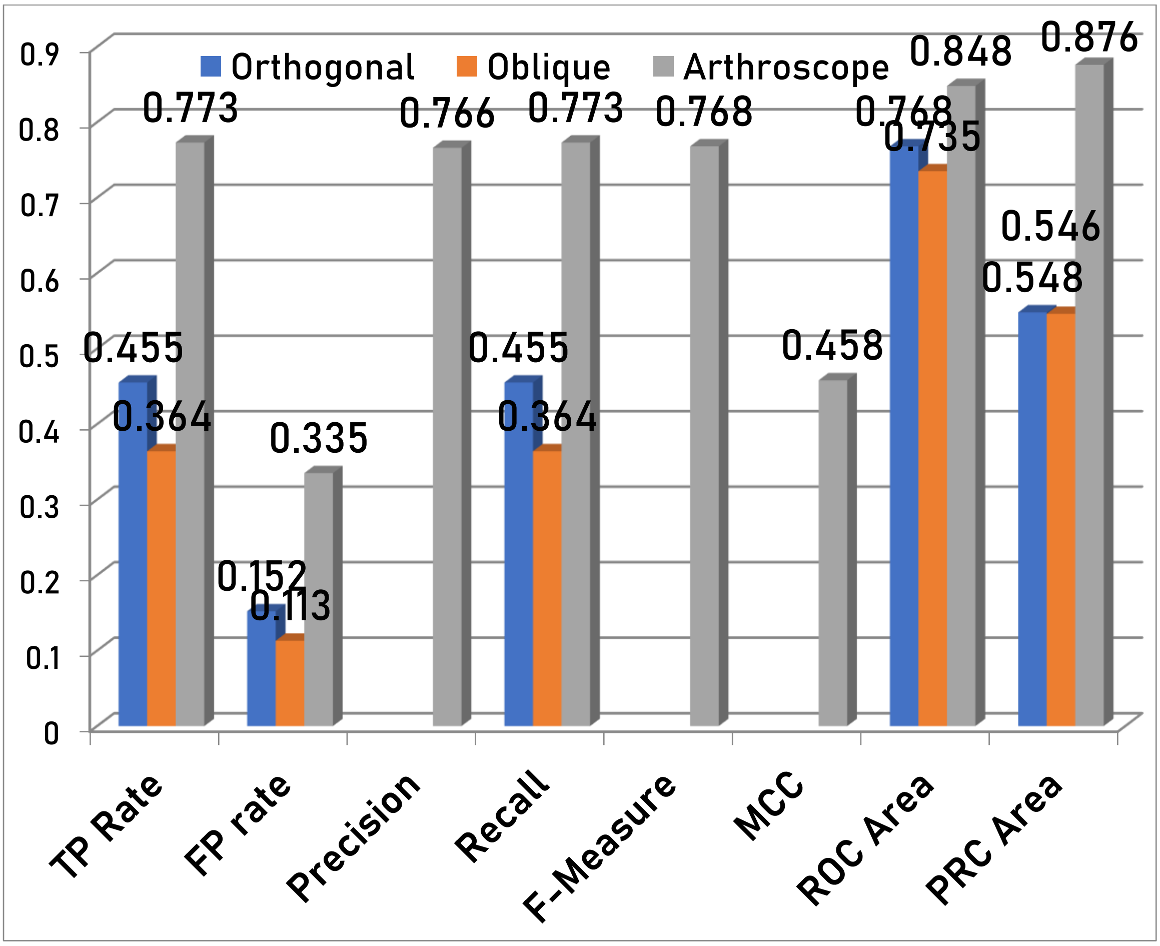
TP Rate(True positive)	0.455	0.364	0.773
FP rate(False Positive)	0.152	0.113	0.335
Precision/Positive Predictive Value(PPV)			0.766
Recall/Sensitivity	0.455	0.364	0.773
F-Measure			0.768
MCC(Matthews correlation coefficient)			0.458
ROC Area(Receiver Operating Characteristic curve)	0.768	0.735	0.848
PRC Area(Precision-Recall (PR) Curve)	0.548	0.546	0.876
Specificity	0.781923	0.849132	0.403914591

Summary of diagnostic ability of ACL tear by each diagnostic approach



Diagnostic ability of ACL tear by each diagnostic approach

Partial tear of ACL of the right knee in a female patient, 43 years old who suffered from knee injury.

Standard MR technique of ACL imaging (Protocol A):

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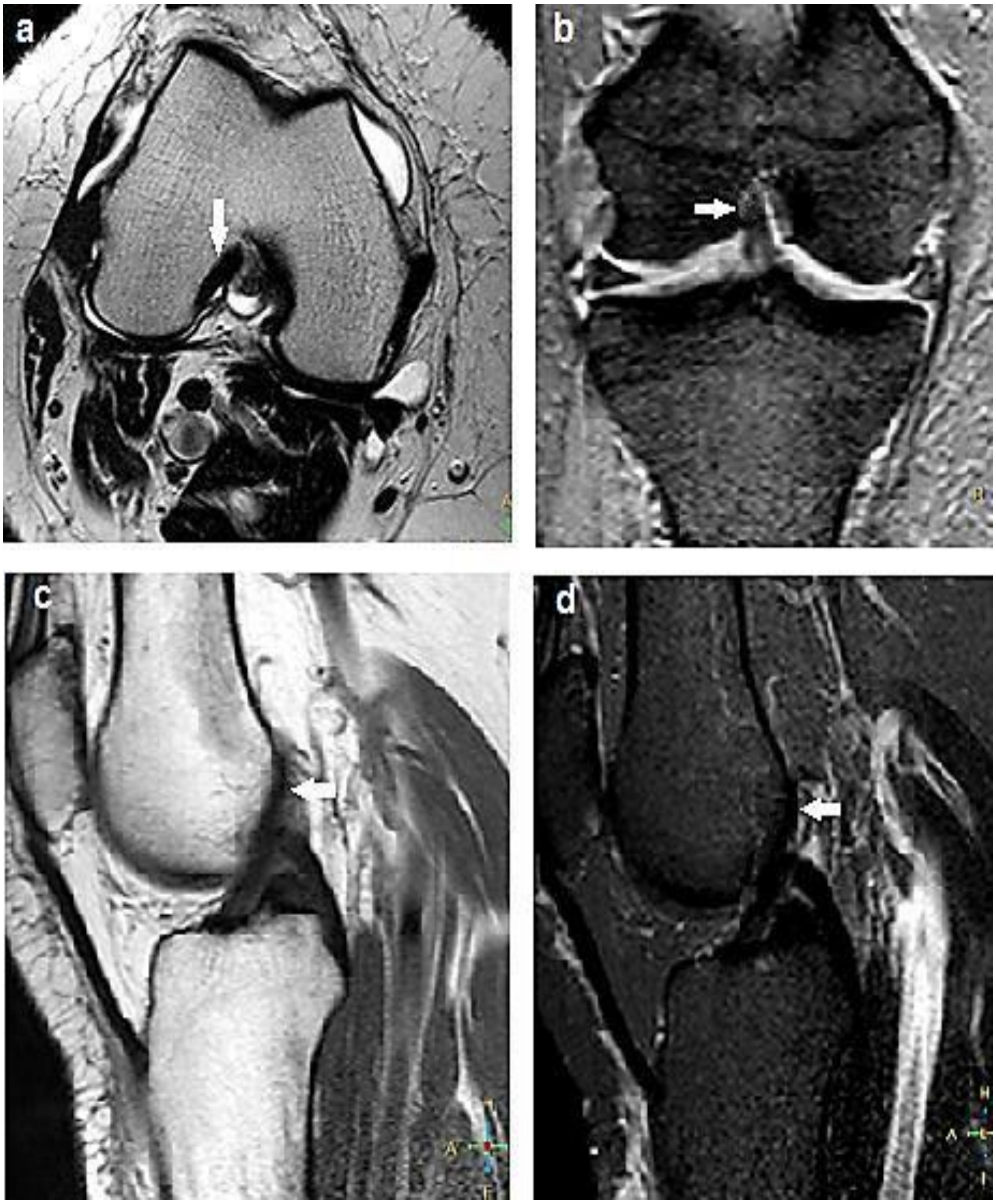

Fig.4 : (a) Axial T2, (b) Coronal T2 fat suppression, (c) Sagittal PD and Sagittal STIR MRI of the right knee, revealed an intact ACL (white arrows).

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Additional oblique coronal and oblique sagittal techniques (Protocol B):

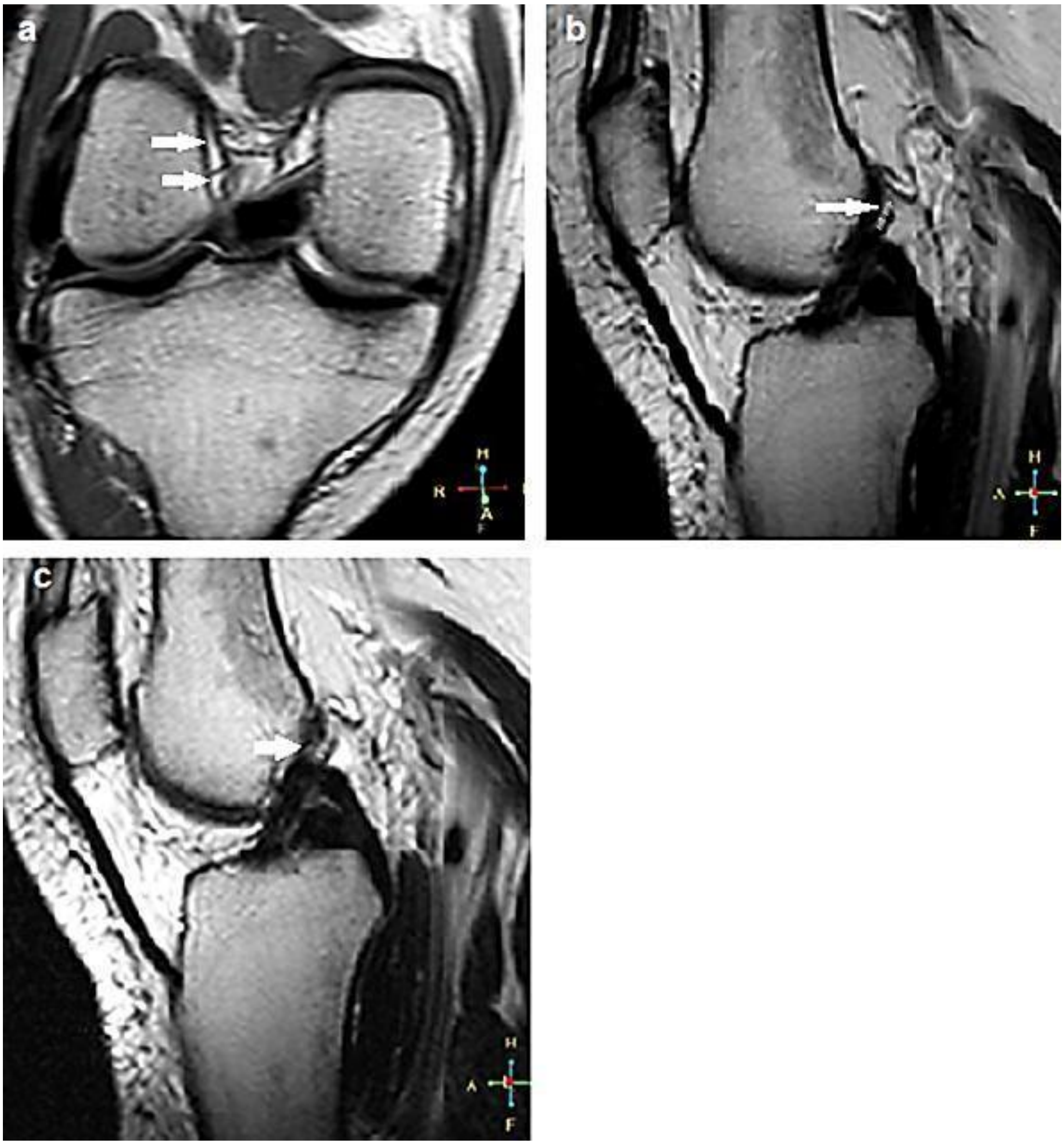

Fig.5 : (a) Oblique coronal PD, (b) Oblique sagittal T2 and (c) Oblique sagittal PD MRI of the same patient. There is an area of increased MRI signal intensity with in proximal substance of the ACL near its femoral insertion (white arrows), but some fibres still intact which is compatible with partial tear of ACL.

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Complete tear of ACL of the left knee in a male patient, 24 years old who suffered from knee injury.

Standard MR technique of ACL imaging (Protocol A):

Fig.6 : (a) Axial T2, (b) Coronal T2 fat suppression, (c) Sagittal PD and Sagittal STIR MRI of left knee of a male patient, 24 years old who suffered from injury of the knee. MR images show fuzzy outline of the ACL with total discontinuity and an area of increased signal intensity extending completely across the ACL in all pulse sequences (white arrows), compatible with complete tear of the ACL.

Additional oblique coronal and oblique sagittal techniques (Protocol B):

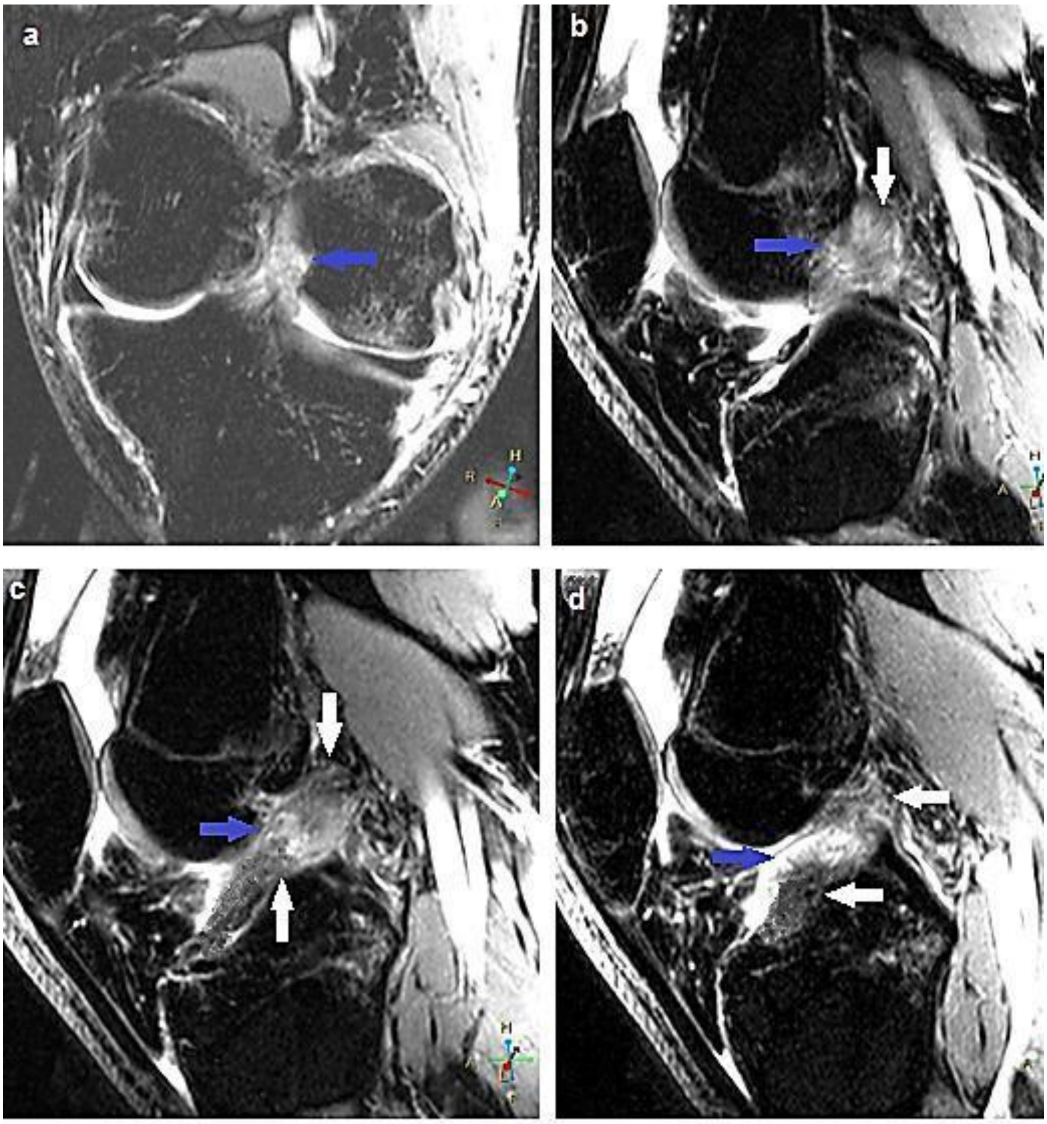

Fig.7 : MR imaging of the ACL of the same patient.(a) Oblique coronal PD with fat suppression, (b,c,d) Oblique sagittal PD with fat suppression MRI, shows a total discontinuity with an area of increased signal intensity extending completely across the mid-substance of ACL (blue arrows), which is compatible with complete tear of ACL. Residual stumps on femoral and tibial sides (white arrows) are thickened and increased in MR signal intensity.

IV. DISCUSSION

The anterior cruciate ligament (ACL) is an important structure in maintaining the normal biomechanics of the knee.[13] ACL injuries occur due to a strong contact or indirect knee trauma, and results in stretching or tearing of non-contractile, elastic soft-tissue articular structures. ACL is the most frequently injured large ligament in the knee. As injured ACL recovery is very limited long-term consequences are frequent including cartilage loss, secondary meniscal injuries and degenerative changes[14] ACL injuries of the knee joint are classed into two groups such as contact or non-contact injuries based on whether or not there was an impact. ACL injury is also been categorized by Sobue et al. as basic ACL injury, ACL with medial structure injury, ACL with lateral structure injury, and ACL with medial and lateral structure injury[15] The injured ACL is most commonly observed at the middle of the ligament, representing for around 70% of all injuries, trailed by the 7 sites of the femoral lateral malleolus (9–20%), and lastly the tibial insertion (10%)[16]. The anatomy of the ACL ligament is complex, reflecting its function of providing sagittal and rotational stabilization of the knee joint.[17] The ACL arises from a semicircular attachment approximately one centimeter in radius on the posteromedial corner of the medial aspect of the lateral femoral condyle, which extends backward along the anteromedial aspect of the intercondylar notch to the attachment on the intercondylar eminence of the tibia.[9] MRI is a type of tomography and also a type of emission tomography; it may be imaged without the use of radioisotopes, which distinguishes it from positron emission tomography (PET) and SPECT (single-photon emission computerized tomography) [18] MRI has a number of advantages, including high spatial resolution and excellent soft tissue resolution, which may effectively reveal the basic structure of the knee joint and allow for clinical observation of the patient's anterior and posterior cruciate ligament injuries[19] In typical ACLs, the hydrogen atoms are locked on the polypeptide net framework and do not interact in MR imaging. As a result, ACLs always generates banded low signals with a width of around 1 cm in each repetition[20] When an injury happens, the most obvious symptom is a shift in ACL signal and the capability to walk The ligament swells with scattered strong signal, acts irregularly, and may rupture, twist, or even disintegrate due to the disruption of the peptide network structure and the buildup of fluids [21] When the ACL is torn, the knee's stability is compromised, and the tibia moves forward, causing irregularities in the form and position of the meniscus and posterior cruciate ligament. These aberrations can be utilized as a secondary indicator of ACL injury [22] The MR imaging assessment has medico-legal ramifications and impacts clinical decision-making. False positive findings may contribute to unwanted surgeries if the surgeon relies exclusively on the report to decide whether or not to proceed with surgery. For restoration of a totally damaged ACL, most orthopaedic surgeons now recommend using an autograft. A knee joint with a partially torn ACL and moderate instability, on the other hand, may operate effectively following well-planned therapy[4] Although. MRI is now frequently used to diagnose intra-articular lesions, the authors of relevant studies have found that false positive results can contribute to over-enthusiastic surgery. Test accuracy is defined statistically as the sum of its true-positive and true-negative rates. As a result, a test with a high true-negative rate but a fair true-positive rate could nonetheless be quite reliable. A high true-positive rate, on the other hand, is crucial for tests that lead to the decision to surgically intervene. The reliability of MRI in identifying internal derangements of the knee has been reported to be high. Between 1983 and 1994, Machenzie et al analyzed 22 related papers and showed good accuracy in identifying ACL lesions, ranging from 72 to 100 percent. There were 498 positive diagnoses out of a total of 2076 individuals, with 90 of these being false-positives[23]. The present study indicated that male participants had a higher incidence of ACL injuries as compared to female participants. Similar observations were reported by Moses and Orchard. Based on heightened exposure to higher risk activities, such as football, Moses and Orchard discovered that male players have a higher frequency of ACL injuries. Professional athletes or sports stars, such as those who participate in sports activities such as football, basketball, soccer, rugby, skiing, handball, volleyball, and dancers, were shown to have a higher prevalence of ACL damage, which the authors believe is due to rising exposure to intense or hard core training and more recurrent competition and competitive activities[24] A study report by Sanders et al., also showed that the incidence of ACL injury in the studied population was higher in males than females[25] The study result portrayed that the subjects playing football had higher rate of injury followed by twisting and falling down from a higher height. Football is the most plausible factor for the incidence of ACL injuries and had the greatest risk of competition-related ACL injuries[26] In a study carried out by Walden et al., the probability of experiencing a new knee injury was significantly higher in the group of football players who had previously sustained an ACL injury, irrespective of whether the player or the knee was employed as the level of observation[27] Given the crippling effects of ACL injuries, particularly in athletes, and the enormous expenses associated with them, prevention is critical. In any case, because the etiology of ACL injury is complicated, there is no way to completely prevent it. Nonetheless, so-called "multi-component programs" appear to be more efficient prevention programs. The priority placed on proper hip, knee, and ankle joint alignment during cutting exercises, shift in direction, and post-jump landing is a constant theme in all of these types of training preventive programs that needs to be taken care of[28] Orthogonal sagittal and coronal MRI scans clearly show the normal structure of the ACL **[Mesgarzadeh et al., 1988].**[29] Furthermore, popliteal artery abnormalities, incomplete volume, osteoarthritis, and post-traumatic fibrous scarring all contribute to the false-positive diagnosis of an ACL tear **[Link et al., 2003].**[30] Detecting an ACL partial tear is critical in the therapy of ACL rupture presently because it enhances the effectiveness of ACL repair. Moreover, the diagnosis partial ACL tears is difficult because of the striated look of a normal ACL, which is exacerbated by the use of fluid-sensitive sequences that imitates the pattern of partial ACL tears **[Borbon et al., 2012]**.[31] Various strategies were used to facilitate identification of the complete course of the ACL in a single slice by parallel imaging all along ACL longitudinal axis to circumvent these anatomical and technical restrictions **[Fuss., 1989].**[32]

The study result inferred that assessment of ACL tears by orthogonal along with oblique sagittal and oblique coronal planes were superior in terms of specificity. The results were similar to another study which reported that when compared to orthogonal views alone in the diagnosis of selective-bundle ACL tears, the oblique coronal view and the conjunction of the orthogonal view and both additional ACL views offered greater diagnostic accuracy with a boost in specificity when evaluated on 3-T MRI. Even though the inclusion of oblique views over orthogonal views did not increase diagnostic performance on 1.5-T imaging, diagnostic performance was noted to be enhanced on 3-T MRI. When comparing evaluation on 1.5-T and 3-T MRI, the diagnostic accuracies for specific imaging planes were not significantly varied **[Park et al., 2014].**[33] In contrast to using either one of the oblique scans (sagittal and coronal), there was no statistical significance in diagnosing a complete ACL tear using a combination of oblique sagittal and coronal images **[Soliman et al., 2020]** .[12] The observed result corroborated with the research result by Kwon et al., who found that adding oblique imaging to the diagnosis of a full ACL tear enhanced the specificity. It also indicated that any oblique imaging method is enough on its own, with no statistical significance seen when both oblique methods were combined **[Kwon et al., 2009].**[34] In the assessment of ACL partial tears, the above stated study reported that there was no statistical significance between the use of a single oblique technique and their concurrent usage with other ones. However the study reported by Soliman et al.[12], indicated that for identification of a partial ACL tear, the accuracy, sensitivity, and specificity of using oblique sagittal and coronal images simultaneously were considerably greater than those of either of the procedures . This is presumably due to the benefits of using both obliques at the same time to detect the complete course and femoral attachment of the ACL on two separate planes, improving the accuracy of ACL thickness, signal intensity, continuity, and contour diagnosis.

V. CONCLUSION

In conclusion, MRI diagnosis of ACL injury is highly accurate and consistent as compared with arthroscopic diagnosis. The present study implies better diagnostic efficacy of adding oblique sagittal and oblique coronal to the orthogonal MRI for patients with an ACL injury. It can be employed as the first choice for non-invasive ACL damage diagnosis and can provide solid recommendations for the selection and formulation of clinical surgery strategies.

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