The Role of Coronal Oblique Magnetic Resonance Imaging in Detection of Anterior Cruciate Ligament Tears

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ABSTRACT

Background: the anterior cruciate ligament (ACL) is the knee joint ligament that is the most frequently injured and necessitate knee joint MRI secondary to trauma.

Aim of the study: to assess the benefit of adding T2W-coronal oblique sequence to the standard MRI knee protocol in detecting and grading the ACL tears.

Patients and methods: Seventy patients participated in this cross-sectional study between July 2021 to December 2021, 54 were males and 16 were females with an age ranged from 18-45 years (mean age 33.4±8.6). Three well-trained general radiologists interpreted the results; each radiologist assessed all the patients in the standard sequences alone (method A), then randomly re-assessed them using the standard and oblique sequences together (method B).

Results: the results showed a considerable degree of variability in interpretation between the 3 radiologists in method A, while there was a relative decrease in the degree of variability in interpretation between the 3 radiologists in method B. There was a statically significant difference between the results for each radiologist in both methods (P-value 0.0001). The results showed an overall increment in Cohen's Kappa score for radiologists no. 2 and 3 in method B compared to method A, Cohen Kappa for (Radiologist 2: in method A 0.800 became 0.808 in method B) and (Radiologist 3: in method A 0.801 became 0.936 in method B), while for radiologist 1, there was substantial agreement in both methods.

Conclusion: addition of oblique coronal sequence in assessing ACL injury revealed an improved detection and appropriate grading of the ACL tears.

Keywords: coronal oblique sequence, MRI, ACL tears

دور الرنين المغناطيسي باستخدام التصوير المائل الاكليلي في تحديد تمزقات الرباط الصليبي الأمامي

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الخلاصة

الخلفية : الرباط الصليبى الأمامى هو أكثر الأربطة التى تتمزق فى مفصل الركبة وهو أحد الأسباب الأكثر شيوعًا للتصوير بالرنين المغناطيسى لمفصل الركبة بعد الحوادث. يتكون الرباط الصليبى الأمامى من حزمتين من الألياف، الحزمة الأمامية والحزمة الخلفية. انه لمن المهم تحديد درجة إصابة الرباط الصليبى الأمامى، سواء كانت جزئية أو كاملة، لأن طريقة العلاج ستعتمد بشكل كبير على تصنيف الإصابة. ان الرباط الصليبى الامامى له اتجاه مائل على طول مساره؛ وبالتالى، من الضرورى تصوير الرباط على طول اتجاهه التشريحى الطبيعى لتجنب فقدان أى إصابة طفيفة. عادةً ما تكون طرق التصوير بالرنين المغناطيسى القياسية غير قادرة على إظهار الطول الكامل للرباط داخل الحفرة اللقمية بوضوح؛ لذلك، يتم استخدام طرق التصوير المائلة لهذا السبب.

الهدف من الدراسة : ان الهدف من الدراسة هو اختبار فائدة إضافة طريقة التصوير الاكليلى المائل الى الطرق القياسية لغرض فحص تمزقات الرباط الصليبى الامامى ومقارنة النتائج مع الطرق القياسية لوحدها.

طريقة العمل : شارك ٧٠ مريضا فى هذه الدراسة المقطعية، ٥٤ من الذكور و١٦ من الإناث. تتراوح اعمار المرضى من ١٨ - ٤٥ سنة (متوسط العمر ٣٣.٤ ± ٨.٦). تم تحويل جميع المرضى من العيادات الخارجية لشعبة العظام والكسور والذين يتوقع اصابتهم بتمزق للرباط الصليبى الامامى الى قسم الرنين فى مدينتنا الطبية. فسر ثلاثة من أطباء الأشعة المدربين جيدًا النتائج. حيث قام كل اختصاصى أشعة بتقييم جميع المرضى باستخدام الطرق القياسية لوحدها (الطريقة أ)، ثم أعاد تقييمهم عشوائيًا باستخدام الطرق القياسية والاكليلية المائلة معًا (الطريقة ب).

النتائج : تظهر النتائج درجة كبيرة من التباين فى التفسير بين أطباء الأشعة الثلاثة فى الطريقة أ، بينما يوجد انخفاض نسبى فى درجة التباين بين أخصائيى الأشعة الثلاثة فى الطريقة ب. تظهر الدراسة ان هنالك فرق مهم إحصائياً بين النتائج لكل اختصاصى أشعة فى كلتا الطريقتين (قيمة الاحتمال = ٠.٠٠٠١). النتائج النهائية لكل طريقة هى ٢ من ٣ اتفاقيات بين أطباء الأشعة لكل مريض. تم استخدام النتائج النهائية لقياس مستوى التوافق بين أخصائيى الأشعة فى كلتا الطريقتين. هنالك توافق بين الأطباء المقيمين فى الطريقة ب أكثر منها فى الطريقة أ وخصوصا بين الطبيب الثانى والثالث لكن الطبيب الأول بقى فى نفس مستوى الموافقة فى كلتا الطريقتين.

الاستنتاج : ان إضافة طريقة التصوير الاكليلى المائل الى طرق التصوير القياسية أظهرت تحسنا ملحوظا فى الكشف عن إصابات الرباط الصليبى الامامى مقارنة بطرق التصوير القياسية لوحدها.

الكلمات المفتاحية : الرباط الصليبى الامامى ، الرنين المغناطيسى ، التصوير المائل الاكليلى .

INTRODUCTION

The ACL is the knee joint ligament that gets injured most frequently and the pivot shift is the main mechanism of injury, other mechanisms of injury include hyperextension of the knee joint and valgus injury that results from a direct lateral blow to the partially flexed knee [1]. The ACL has the anteromedial (AM) and posterolateral (PL) bundles, named according to their relative tibial insertion sites [2]. The narrowest diameter of the ACL occurs in the mid-substance, while at the tibial side, the fiber bundles of the ACL fan out and form a so-called foot region [3]. The ACL has a unique diagonal course that runs from the medial surface of the lateral femoral condyle to a fossa in front and lateral to the anterior tibial spine.. The ACL should have taut, continuous fibers in all imaging planes with parallel or steeper course to the intercondylar line (Blumensaat's line). The ACL should have low to intermediate SI; the PL bundle has higher SI than AM bundle [4,5].

There are two types of ACL tears: partial and complete (the most common type of ACL tear). It is vital to classify the tear as partial or complete as the management will depend on the grading of the injury [6]. The diagnosis can be confirmed clinically by the combination of "Lachman, pivot shift and anterior drawer tests" [7]. MRI of the knee joint is most frequently ordered for ligamentous injuries namely the menisci and cruciate ligaments [8]. MRI is the primary imaging modality used to assess ACL tears. It can directly visualize the ligament, so any abnormal signal intensity within the ligament can be readily detected; the sequences used to image the knee joint vary from one place to another, the most commonly used sequences to diagnose ACL tears are the 2D fast-spin echo (FSE) with or without fat suppression with different imaging planes, including axial, sagittal and coronal [9]. Generally, fast spin-echo (FSE) sequences, including T2-weighted fat-saturated images and PD-weighted are used in the diagnosis of the internal derangement of the knee joint. Non-fat saturated images are used to delineate the anatomy [10]. Oblique coronal and oblique sagittal sequences were used to further assess the ACL tears. Since the ACL has a diagonal course, the standard sequences usually fail to determine the whole length of the ligament. Hence, the oblique sequences can be oriented parallel along the course of ACL, so they are used to visualize and assess the ACL appropriately along its whole length, including the femoral and tibial attachments [11].

AIM OF THE STUDY

The study aims to evaluate the role of the oblique coronal MRI technique in improving the diagnosis of complete and partial tears of ACL.

PATIENTS AND METHODS

From July 2021 to December 2021, 70 patients (54 male and 16 female) were included in this cross-sectional analytic study performed at the MRI unite of Al-Emamain Al-Kadhmain medical city/ Baghdad/ Iraq. The patient's age ranging from 18-45 years (mean age 33.4±8.6).

Inclusion Criteria: patient with clinical features highly suggestive of ACL tear (painful knee, knee joint instability, locked knee, or history of trauma) with positive Lachman, anterior drawer or pivot shift tests.

Exclusion Criteria: Patients with previous history of ACL or meniscal repair, active intra-articular infectious process, presence of neoplastic or metabolic bone diseases, severe joint degenerative changes or ACL degenerative changes (mucoid degeneration) and general contraindications to MRI examination.

Ethical consideration: the study was approved by the Scientific Committee of the Iraqi Board of Diagnostic Radiology. Verbal informed consent was obtained from all patients included in the study.

MR Protocol: MR imaging was performed using a 1.5T MR system (ACHIEVA, Philips medical system. Netherland) with a phased array knee coil used. The patients were examined in supine position with relaxed knee and slightly externally rotated (about 10-15 degrees); this enables the ACL to be orthogonal to the sagittal plane.

Method A: The standard knee imaging protocol that used to assess the ACL includes: T2W-TSE sagittal (TR/TE: 4794/100, slice thickness: 3mm, interval: 0.3mm, FOV: AP 160mm/ FH. 160mm /RL. 79mm, time: 2.28min), PDW-fat saturation coronal (TR/TE: 3000/30, slice thickness: 3mm, interval: 0.3mm, FOV: AP. 150mm/ FH. 150mm/ RL. 79mm, time: 4.54min), and T2W-fat saturation axial (TR/TE: 4923/60, slice **thickness:** 3mm, interval: 0.3mm, FOV: AP. 150mm /FH. 150mm/RL. 79mm, time: 1.57min).

Method B: T2W-oblique coronal plane-TSE is obtained in a plane parallel to the ACL orientation (parallel to Blumensaat's line or intercondylar roof) in sagittal T2 weighted image (Figure 1), using the same MRI parameters of T2W-TSE in the sagittal plane and as follows (TR/TE: 4794/100, slice thickness: 3mm, interval: 0.3mm, FOV: AP. 160mm /FH. 160mm /RL. 79mm, time: 4-5min).

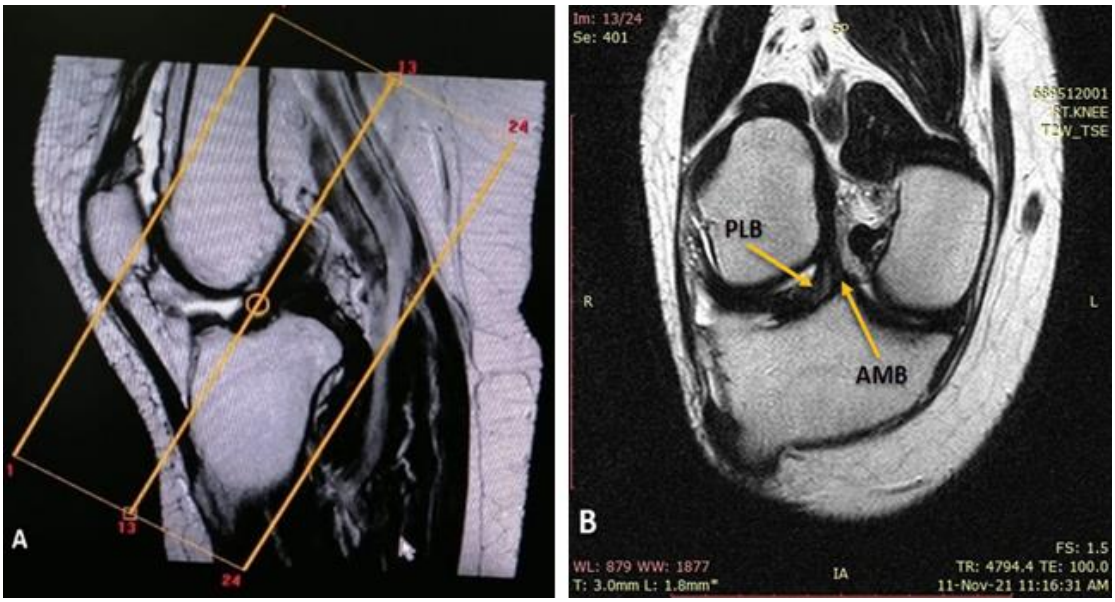

Figure 1: Demonstrating the technique used to obtain T2W- coronal oblique MRI image of normal ACL. A) Sagittal T2 image used to obtain B) T2W- coronal oblique image by superimposing 3 mm slice thickness with 0.3 mm gap interval on it in a plane parallel to the Blumensaat's line "which is the line drawn along the roof of the intercondylar notch of the femur on a sagittal view of the knee" along the course of the ACL with relaxed knee and slightly externally rotated (about 10-15 degrees).

Three impartial, skilled radiologists independently interpreted the MRI images, each of them evaluated the data separately from others. In the beginning, each radiologist evaluated all the patients using the standard sequences alone (method A) and documented the result; then, he re-evaluated all the patients randomly by using the standard and T2W-coronal oblique sequences together (method B).

A grading system of 3 points was used to classify the results of ACL tears: Grade 0: denoting normal ACL, Grade I: denoting partial tear of ACL, Grade II: denoting complete tear of ACL.

Criteria used to categorize the results according to each grade is as the following: **Intact ACL:** if the ligament is presented with well-preserved continuation with taut fibers and low signal intensity. **Partial ACL tear:** considered if there is preserved ACL continuity with focal or diffuse intra-substance abnormal signal intensity, preserved ligament continuity with diffuse or focal thinning/swelling, an undulating contour of the ligament with discernable femoral and tibial attachments, or maintained continuity with direct visualization of partial fibril disruption. **Complete**

ACL tear: considered if there is a lack of continuity, horizontalization of the distal fragment of the ligament, full-thickness abnormal SI, or an edematous mass replacing the whole ligament. Partial ligament tear was defined by either complete or partial tear in one bundle, but not a complete tear of both bundles. Complete ACL tear was defined by a complete tear of both bundles.

Statistical analysis: "data analysis was carried out using the available statistical package of SPSS-27 (Statistical Packages for Social Sciences- version 27). The significance of the difference of different percentages (qualitative data) was tested using the Pearson Chi-square test (χ2-test). Statistical significance was considered whenever the P-value was equal or less than 0.05. Cohen's kappa measures the agreement between two raters, the values <0 indicate no agreement, 0-0.20 as slight, 0.21-0.40 as fair, 0.41-0.60 as moderate, 0.61-0.80 as substantial, and 0.81-1 as almost perfect agreement".

RESULTS

Method A: the results for each radiologist were: Radiologist 1: 21, 25 and 24 for Grade: 0, 1 and 2 respectively. Radiologist 2: 17, 21 and 32 for Grade: 0, 1 and 2 respectively. Radiologist 3: 22, 14 and 34 for Grade: 0,1 and 2 respectively. The final results for each grade were the 2 out of 3 agreements between the radiologists per each patient. Hence, the final results for method A will be as follows: 17, 22 and 31 for Grade: 0, 1 and 2, respectively (Table 1).

Table 1: The number of cases classified under each grade as interpreted by each radiologist using method A.

	Radiologist 1A		**Radiologist 2A**		**Radiologist 3A**		**Final results A**	
	No	%	No	%	No	%	No	%
Grade 0	21	30.0	17	24.3	22	31.4	17	24.3
Grade I	25	35.7	21	30.0	14	20.0	22	31.4
Grade II	24	34.3	32	45.7	34	48.6	31	44.3

There is a considerable degree of variability in interpretation between the 3 radiologists. The Final results column demonstrates that grade II exceeded the others, followed by grade I.

Method B: the results for each radiologist were: Radiologist 1: 25, 29 and 16 for Grade: 0, 1 and 2 respectively. Radiologist 2: 26, 18 and 26 for Grade: 0, 1 and 2 respectively. Radiologist 3: 21, 26 and 23 for Grade: 0, 1 and 2 respectively. The final results for each grade were the 2 out of 3 agreements between the radiologists per each patient. Hence, the final results for method B will be as follows: 23, 25 and 22 for Grade: 0, 1 and 2, respectively (Table 2)

Table 2: The number of cases classified under each grade as interpreted by each radiologist using method B.

	Radiologist 1B		Radiologist 2B		Radiologist 3B		Final results B	
	No	%	No	%	No	%	No	%
Grade 0	25	35.7	26	37.1	21	30.0	23	32.9
Grade I	29	41.4	18	25.7	26	37.1	25	35.7
Grade II	16	22.9	26	37.1	23	32.9	22	31.4

There was a relative decrease in the degree of variability in interpretation between the 3 radiologists. The final results column demonstrates an approximation of the percentages of the three grades with slight grade I predominance.

A substantial level of agreement was seen between each radiologist in method A and method B; this was demonstrated by (Cohen's Kappa) which ranges between (0.639-0.657) for the 3 radiologists, and 0.658 For the final results in the two methods. There was a statically significant difference between the results for each radiologist in both methods (P-value = 0.0001) (Table 3).

Table 3: level of agreement for each radiologist in both methods A & B.

		Grade 0	Grade I	Grade II	Total	Cohen Kappa	P-value
		Radiologist 1B					
Radiologist 1A	Grade 0	20	1	-	21	0.657	0.0001*
	Grade I	5	19	1	25		
	Grade II	-	9	15	24		
	Total	25	29	16	70		
		Radiologist 2B					
Radiologist 2A	Grade 0	17	-	-	17	0.655	0.0001*
	Grade I	8	12	1	21		
	Grade II	1	6	25	32		
	Total	26	18	26	70		
		Radiologist 3B					
Radiologist 3A	Grade 0	19	2	1	22	0.639	0.0001*
	Grade I	2	12	-	14		
	Grade II	-	12	22	34		
	Total	21	26	23	70		
		Final results Method B					
Final results Method A	Grade 0	17	-	-	17	0.658	0.0001*
	Grade I	5	16	1	22		
	Grade II	1	9	21	31		
	Total	23	25	22	70		

*" Significant difference between percentages using Pearson Chi-square test (χ^2-test) at 0.05 level".

By measuring the agreement between each radiologist in each method (A and B) with the corresponding final results of that method, we can notice the significant reduction in the number of cases diagnosed as grade II tear between the two methods (24, 29 and 30 in method A became 15, 21 and 22 in method B), while in grade I tear, the results were (17, 17 and 14 in method A became 19,17 and 24 in method B) and this mean that this part was not so much affected except for radiologist 3. Grade 0, in turn, showed a considerable increment in the number of cases in method B compared to A (16, 15 and 17 in method A became 19, 23 and 21 in method B) (Tables 4 and 5).

Hence, method B decreased the number of cases diagnosed as a complete tear, increased the number of cases diagnosed as normal by the agreement of the 3 radiologists. While grade I was affected to a lesser degree compared to grades 0 and II and this can be attributed to the substantial number of patients added to it from grade II and the considerable number deduced from Grade I to grade 0. There was an overall increment in Cohen Kappa for radiologists 2 and 3 (Radiologist 2: in method A 0.800 became 0.808 in method B) and (Radiologist 3: in method A 0.801 became 0.936 in method B) which was almost perfect as per Cohen Kappa's definition, but this is not the case in radiologist 1 which showed decreased level of agreement between A and B but still within the range of substantial agreement. Radiologist 3 reaches the maximum level of agreement with the final results in the method B. It was worthy to mention that, two cases for radiologist 3 diagnosed initially as grade 0 in method A became grade I in method B (both cases diagnosed as grade I in both A and B by radiologists 1 and 2) and one case for radiologist 2 diagnosed initially as grade I in method A and became grade II in method B (the same case diagnosed by radiologist 1 and 3 as grade II in both method A and B), the fact that may confirm further interpretation agreement in method B compared to method A.

Table 4: agreement between the results of each radiologist (in method A) with the final results of the same method.

Method A		Final results of method A				Cohen Kappa	P-value
		Grade 0 (n=17)	Grade I (n=22)	Grade II (n=31)	Total (n=70)		
Radiologist 1	Grade 0	16	5	-	21	0.720	0.0001*
	Grade I	1	17	7	25		
	Grade II	-	-	24	24		
Radiologist 2	Grade 0	15	2	-	17	0.800	0.0001*
	Grade I	2	17	2	21		
	Grade II	-	3	29	32		
Radiologist 3	Grade 0	17	4	1	22	0.801	0.0001*
	Grade I	-	14	-	14		
	Grade II	-	4	30	34		
*" Significant difference between percentages using Pearson Chi-square test (χ^2-test) at 0.05 level".							

Table 5: agreement between the results of each radiologist (in method B) with the final results of the same method.

Method B		Final results of method B				Cohen Kappa	P-value
		Grade 0 (n=23)	Grade I (n=25)	Grade II (n=22)	Total (n=70)		
Radiologist 1	Grade 0	19	5	1	25	0.634	0.0001*
	Grade I	4	19	6	29		
	Grade II	-	1	15	16		
Radiologist 2	Grade 0	23	3	-	26	0.808	0.0001*
	Grade I	-	17	1	18		
	Grade II	-	5	21	26		
Radiologist 3	Grade 0	21	-	-	21	0.936	0.0001*
	Grade I	2	24	-	26		
	Grade II	-	1	22	23		
*" Significant difference between percentages using Pearson Chi-square test (χ^2-test) at 0.05 level".							

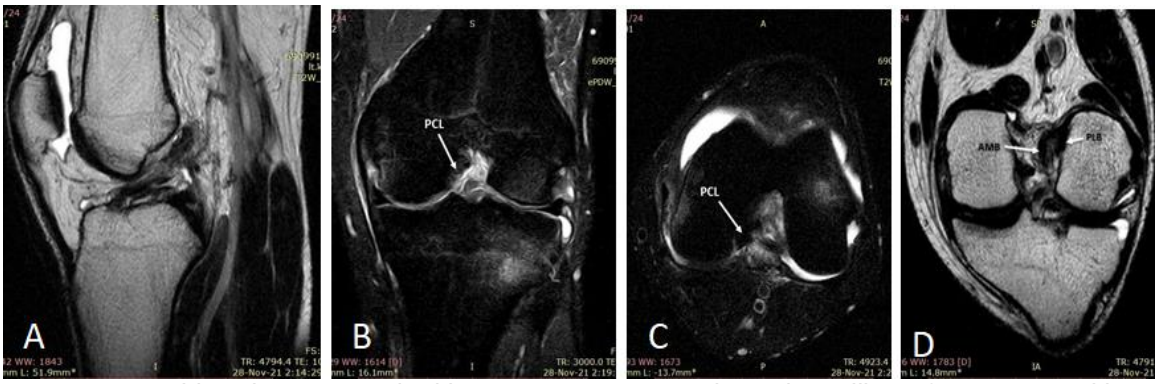

Figure 2: 20years old male presented with severe Lt. Knee pain and swelling after trauma with positive Lachman test. A: Sagittal T2W-TSE shows complete ACL separation with horizontalization of the distal segment. B: Coronal PD-SPAIR and C: Axial T2-SPAIR showing the intercondylar notch with absent ACL (at the presumed level of mid-portion of ACL), only PCL is seen. D: Coronal oblique T2W-TSE clearly demonstrates the torn ACL with discontinuity and retraction of its two fibers (AMB and PLB).

Figure 3: 29 years old male patient presented with popping sensation then severe right knee pain while playing football. A) Two sequential Sagittal T2W-TSE images showing thickening and swelling with abnormal SI involving the mid-portion of ACL with a retracted proximal segment. B) Two sequential coronal oblique T2W-TSE images confirm the abnormal SI that involves the full thickness of mid-portion of ACL in keeping with a complete ACL tear.

DISCUSSION

The AM and PL bundles are the two bundles that make up the ACL. The AM bundle controls anterior tibial movement underneath the femur, while the PL bundle maintains the knee's rotational stability during pivoting, jumping, and twisting [12]. The ACL has an oblique orientation through its course from the posteromedial aspect of the lateral femoral condyle down to its tibial attachment at the anterior tibial plateau. Due to this oblique course, the standard MRI sequences have less efficacy in visualizing the ligament's entire length, including the femoral and tibial insertions. Consequently, the grading of ACL tears (which are very common) is greatly affected by using these sequences alone; hence, many researches were undertaken to overcome this obstacle and finally proposed using the oblique sequences to visualize the ACL fully [13]. Starman et al. [14] assessed the standard sequences for detecting the AM and PL bundles. "The results stated that standard coronal and sagittal views might allow reliable detection of the AM bundle; however, the PL bundle is more challenging to be seen on such sequences, and this is likely due to a partial volume or blurring effect of the low-resolution images of the two adjacent bundles, making them appear as only one structure. So, they recommended using an additional oblique sequence to evaluate the AM and the PL bundles". Staeubli *et al.* [15], "stated that the oblique coronal sequence oriented parallel to the intercondylar roof is an excellent method to visualize the diagonal course of ACL and its relation to the intercondylar notch and the posterior cruciate ligament".

The current study evaluated the efficacy of the T2W-coronal oblique sequence in the determination of ACL tears compared to routine MRI sequences. The T2W-coronal oblique sequence (obtained parallel to the intercondylar roof) does not require flexion of the knee or external rotation. It does not consume much time (the average time consumed in this study is 4-5 minutes). The current study primarily measures the level of agreement between the readings of 3 independent radiologists using the conventional (orthogonal) sequences alone then after the addition of the T2-oblique coronal sequence. The results of each reader were compared with the final results of each method. There was an apparent increase in agreement level in method B compared to method A, especially for radiologists two and three. For the three radiologists, there was a generalized downgrading of the ACL tear from grade II (complete) to grade I (partial) and from grade I (partial) to grade 0 (normal) in method B compared to method A; this can be attributed to the ability of the coronal oblique sequence to visualize both bundles (AM and PL) and the entire length and width of ACL within the intercondylar fossa in addition to the femoral and tibial attachments; as a result, the diagnosis of both complete and partial tears become more accurate in method B compared to method A proved by the agreement of the three radiologists. (The interobserver agreement for method A was in the range of substantial agreement for the three radiologists, but for method B, the agreement was 0.808 and 0.936 for radiologists two and three, respectively, and this is in the range of almost perfect, except for radiologist one, still within the range of substantial agreement).

This study was in agreement with the results of a study conducted by Hong *et al.* [16], which demonstrates that "adding oblique coronal MR imaging improved the accuracy of grading of ACL injury, which can help in the treatment planning". (The interobserver agreement for the Hong et al. study using the oblique coronal sequence is 0.851 and 0.868 for the two readers, respectively). Another study by Kosaka *et al.* [4], "which demonstrated a higher diagnostic performance and

interobserver agreement when using the additional oblique coronal sequence; this is mainly because of the oblique coronal images can clearly delineate the course and femoral attachment of the ACL". (The interobserver agreement for Kosaka *et al.* is 0.812, 0.669 and 0.707 for the three viewers, respectively). The results of this study are also in agreement with Moustafa Abdel Kawi *et al.* [6] study, "which demonstrated that the oblique coronal MRI showed a better agreement with the diagnostic arthroscopy than routine MRI (weighted Kappa; k=0.865 & 0.753 respectively)".

Duc *et al.* [17], conducted a study to evaluate the role of the three standard orthogonal imaging planes plus paracoronal plane in evaluating ACL tears. The study assessed the results of each imaging plane separately, and the results showed that the highest interobserver agreement between the readers was in the paracornal sequence (0.82) that matches the interobserver agreement in the current study. However, Duc *et al.,* recommended using oblique paracoronal sequence as an adjunct in equivocal cases of ACL tears and not as a routine in MRI of knee joint because they found that the paracoronal plane was not significantly more accurate than the routinely used orthogonal planes.

CONCLUSION

The addition of oblique coronal sequence in assessing ACL injury revealed an improved detection and appropriate grading of the ACL tears.

RECOMMENDATION

Based on the results of this study, and since T2W-coronal oblique sequence is easily obtained, requires no particular patient postural modification, and adding no much time to the total time of examination, Hence, adding T2W-coronal oblique sequence to the routine sequences in the assessment of suspected ACL tear is recommended.

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