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Role of T2 Mapping Sequences using MR Imaging in Evaluation of Knee Joint Articular Cartilage

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: Cartilage mapping using Magnetic Resonance Imaging T2 is a functional scanning procedure without invasion delivering cartography of the cartilage T2 relaxation time without using of any contrast. It is tissue anisotropy sensitive, and compositional data on the collagen network of cartilage, content of water and concentration of proteoglycans are provided by it. This study used MR scanning technique to assess the T2 mapping sequence role in diagnosis of articular cartilage lesions of knee joint.
Patients and Methods: This prospective trial was done to utilize sagittal T2 mapping sequence for assessment of articular cartilage of knee joint on 1.5 T MR. The material of this study included thirty (30) patients. The study included 24/30 cases presented by knee pain, 6/30 cases presented by knee pain following trauma, 10/30 cases presented by limitation of movement and 7/30 cases presented by knee swelling. As each patient had a single conventional MRI examination of the knee followed by a single sagittal T2 maps, 30 MRI examinations and 30 corresponding T2 maps were analyzed.
Results: The addition of sagittal T2 maps to standard views improved accuracy in diagnosing cartilage affection in early osteoarthritis. there are 69 (57.5%) lesions diagnosed as grade 0 by MRI

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only VS 24 (20%) lesions diagnosed as grade 0 by MRI with T2 mapping sequence and 34 (28.3%) lesions diagnosed as grade 1 by MRI only VS 77 (64.2%) lesions diagnosed as grade 1 by MRI with T2 mapping sequence. there is 46 (38.3%) lesions diagnosed as grade 1a by MRI with T2 mapping sequence which diagnosed grade 0 by MRI only.

Conclusions: This imaging plane seems to provide a useful addition to standard MR imaging when osteoarthritis is suspected specially among the young population.

Keywords: T2 mapping sequences using MR imaging; knee joint articular cartilage.

1. INTRODUCTION

Alterations within glycosaminoglycan, collagen type two and water contents are the characteristic criteria of the breakdown of matrix of the cartilage [1]. Even with using of plain radiography or conventional MRI, the determination of these alterations in the matrix of the cartilage remains difficult [2]. In symptomatic cases undergoing knee joint MR scanning as a routine, it is an important issue to detect early degeneration of the cartilage [3].

This assessment is achieved by utilizing sequence that checks morphological criteria of the cartilage [4]. Their detection skill of early degenerative alterations of the cartilage is relatively low and it is considered the most important limitation of scanning sequences of morphological criteria of the cartilage [5].

Nowadays, many techniques of MRI are documented to be sensitive to biochemical modifications of the cartilage. Delayed gadolinium enhanced MRI of cartilage (dGEMRIC) technique that is sensitive to charge density of the cartilage contributed by the cartilaginous (GAG) content [6], T2/T2* mapping sensitive to water and collagen fiber network contents [7], and others is one of them. These MRI procedures that are "biochemically sensitive" have the ability of adding compelling diagnostic markers for disease onset and coarse of progression with different sensitivity and specificity levels, so they are considered effective tools for assessment for abnormalities of the cartilage diagnosis and follow-up [8]. In comparison with other MRI techniques that are biochemically sensitive [9] mapping with T2 sequence has special characteristics including fast scanning, clear image, and the capability to evaluate isotropic three-dimensional (3D) cartilage. Likewise, on MRI clinical systems, it can be implemented easily, as sequences of pulse and software of inline processing to generate maps of quantitative T2. Furthermore, contrast media management or special hardware are not required [10].

For a given tissue, T2 is constant at a given intensity of MR Field strength. [11]. Alterations in relaxation times of T2 in cartilage are dependent upon the water quantity and the proteoglycan–collagen matrix decency [12].

Early destruction to the collagen network causes an influx of water. This increased permeability produces stress throughout the matrix and subsequent atrophy and loss of cartilage tissue. These physiological alterations are characterized by an increase in signal of T2. Sectors of higher or lower water content (which usually correlates with torn cartilage) can be recognized by assessing the T2- relaxation times of distribution pattern across articular cartilage [12].

Technology is very important in these trials. Broadly speaking, by using a multi-echo spin echoes (SE), the scan time was reduced and signal limits are adapted to one or even more decaying exponentials, based on whether over one T2 dispersion is expected in the tissue. Inexact actually focusing pulses can, however, distort T2 measurements, leading to regional variation. An image of T2—relaxation times is developed with either a color or grayscale map even after regional evaluation [12].

An optimal cartilage MRI evaluation would evaluate thickness, volume and integrity, provide data on cartilage morphology and underlying bone, and evaluate cartilage biochemistry and physiology, which include collagen and proteoglycan matrix [13].

2. PATIENTS AND METHODS

The study was prospectively carried on 30 patients with knee pain, their age ranged from 22 to 70 years old with mean age of (39.4 ± 15. 7) years old, which referred from Orthopedic Department to Radio- Diagnosis and Medical

Imaging Department at Tanta University for MRI knee with T2 mapping sequence to evaluate articular cartilage.

2.1 Inclusion Criteria

- Patients complaining of knee pain (N.B. referred pain excluded from the study.).

2.2 Exclusion Criteria

- Patients contraindicated for MRI e.g. cardiac pacemaker, Aneurysmal clips, bone growth stimulators, electrically programmed infusion pump, bullets and shrapnel, orthopedic implants and devices, intravascular stents, coils and filters.
- Overweight, more than 150 kg (cannot fit in the MRI machine).
- Patients suffering from claustrophobia.

2.3 All Patients were Submitted to the Following

- Demographic and clinical data collection.
- Clinical provisional diagnosis.
- Imaging procedure.

Firstly, the standard imaging planes of the knee were evaluated with focusing on its articular cartilage at different imaging sequences, and then sagittal T2 maps were generated using a special software technique. Thereafter, these standard planes were evaluated together with sagittal T2 maps for the same regions medial femoral condyle (MFC), lateral femoral condyle (LFC), medial tibia condyle (MTC) and lateral tibia condyle (LTC) and articular cartilage was evaluated using color scale from red to blue.

Intact articular cartilage was defined by the normal signal intensity in different pulse sequences with uniform thickness, while in T2 maps normal knee articular cartilage at different sites generally below 50 milliseconds which corresponds to the green zone on the color scale in our study.

Agreement between MRI only VS MRI with T2 mapping sequence had done.there is moderate significant agreement between MRI only VS MRI with T2 mapping sequence.

2.4 Statistical Analysis

The data was fed to the computer and analyzed using version 20.0.0 of the IBM SPSS software package. Qualitative data was described using number and percentage (Armonk, NY: IBM Corp).

3. RESULTS

The study was conducted on thirty patients with knee pain, their mean age was (39.4 ± 15. 7) years ranged from 22 to 70 years old (19 (63.3%) males and 11 (39.4%) females). All patients of our study underwent MRI of knee and T2 mapping as illustrated in Table 1.

In this study, the most affected age group was (20-30ys) and (>30-40ys) each of them included 10 patients (33.3%), followed by age group (>40-50) which included 4 patients (13.3%), followed by age group (>50-60) which included 3 patients (10%) and (>60- 70) which included 3 patients (10%) as illustrated in the Table 2.

As shown in the Table 2 majority of cases was males 19 (63.3%), while 11(37.7%) were females Fig. 1 and Table 2.

Twenty four patients in our study were presented clinically by knee pain, six patients were presented by knee pain that follow trauma to knee, ten patients were presented by limitation of movement and seven patients were presented by knee edema. As illustrated in Table 3.

Table 1. Distribution of the studied cases according to socio demographic data

Characteristics	Study sample (n = 30)
Age, (years)	
Mean± SD	39.4± 15.7
Range	22 -70
Gender	
Male (%)	19 (63.3%)
Female (%)	11(36.7%)

Table 2. Distribution of the studied cases according to age and sex groups

Age group (years)	Sex		No	X
	Male	Female		
20-30 ys	6	4	10	33.3%
>30-40 ys	9	1	10	33.3%
>40-50ys	3	1	4	13.3%
>50-60ys	1	2	3	10%
>60-70 ys	0	3	3	10%
Total no.	19	11	30	100%

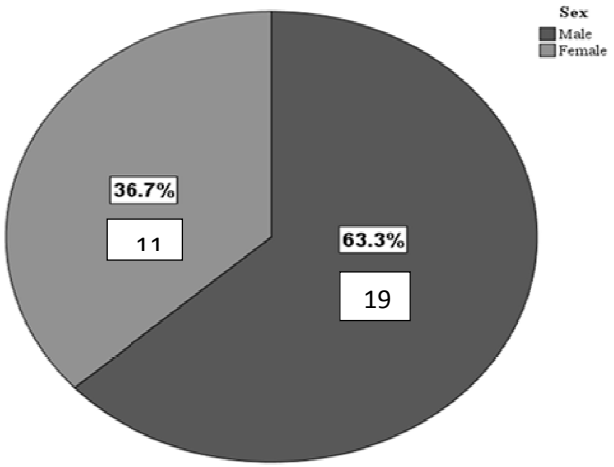

Fig. 1. Distribution of the studied cases according to sex

Table 3. Distribution of the studied cases according to clinical complain

Complain	No.
Knee pain	24
Knee pain(post trauma)	6
Limitation of movement	10
Knee edema	7

As regard MRI using T2 mapping sequence at the total four knee compartment (MFC, LFC, MTC and LTC) most of cases were diagnosed as grade 1 (64.2%).

MRI only & T2 mapping sequence using MRI recorded agreement as they agreed in diagnosis of 23 cases as a Grade 0, 27cases as grade 1, 7case as grade 2A and 1case as grade 3..as illustrated in (Table 4).

(57.5) 69 cases diagnosed as grade 0 by MRI vs 24 cases (20%) diagnosed by T2 mapping sequence using MRI. (28.3%)34 cases diagnosed as grade 1 by MRI vs 77 cases (64.2%) diagnosed by T2 mapping sequence using MRI. (12.5%)15cases diagnosed as grade 2A osteoarthritis by MRI vs12 cases (10%) diagnosed by T2 mapping sequence using MRI. (0.8%) 1 cases diagnosed as grade 2B osteoarthritis by MRI vs 4 cases (3.3%) diagnosed by T2 mapping sequence using MRI. (0.8%) 1 cases diagnosed as grade 3 osteoarthritis by MRI vs 3 cases (2.5%) diagnosed by T2 mapping sequence using MRI as illustrated in Table 4.

In the total four knee compartment (MFC, LFC, MTC and LTC) 46 (38.3%) lesions diagnosed as grade 1a by MRI with T2 mapping sequence and diagnosed grade 0 by MRI only.

Total Agreement between MRI only VS MRI with T2 mapping sequence in diagnosis of knee joint articular cartilage lesions: Using weighted Kappa, there is moderate significant agreement between MRI only VS MRI with T2 mapping sequence as (K (95% CI) =.622(0.502 to 0.743), P=.001).

Table 4. Total agreement between MRI only VS MRI with T2 mapping sequence in diagnosis of knee joint articular cartilage lesions

MRI	MRI										
	Grad 0		Grad 1		Grad 2A		Grad 2B		Grad 3		Total
	No	%	No	%	No	%	No	%	No	%	No (%)
Grad 0	23	19.2	46	38.3	0	0	0	0	0	0	69(57.5)
Grad 1	1	0.8	27	22.5	5	4.2	1	0.8	0	0	34(28.3)
Grad 2A	0	0	4	3.3	7	5.8	3	2.5	1	0.8	15(12.5)
Grad 2B	0	0	0	0	0	0	0	0	1	0.8	1(0.8)
Grad 3	0	0	0	0	0	0	0	0	1	0.8	1(0.8)
Total	24	20	77	64.2	12	10	4	3.3	3	2.5	120(100)

Table 5. Distribution of study sample according to arthroscopy

	No.	%
Arthroscopy		
Not done	25	83.3
Normal	4	13.3
Abnormal	1	3.3

In our study only 5 cases had performed arthroscopy, 4 cases were normal only one case was abnormal. This case had ulcer at the medial femoral condyle as illustrated in Table 5.

An example of male patient aged 31 years old, presented with RT sided knee pain after trauma, knee edema and limitation of movement. It was finally diagnosed as grade III osteoarthritis at the medial femoral condyle and lateral tibial condyle, grade II osteoarthritis at the medial tibial and lateral femoral condyles and knee joint synovial effusion (Fig. 2).

4. DISCUSSION

In about 25 percent of adults, frequent knee pain affects. As the most common cause of knee pain in people 50 years of age or older, osteoarthritis leads to impaired function and mobility, and impaired quality of life. Knee pain is a significant reason for knee replacement among people with knee osteoarthritis [14]. Osteoarthritis is an extremely worrying musculoskeletal disorder expressed by synovial inflammation and cartilage lesion progression. Osteoarthritis' main pathophysiological process contributes to the growth of cartilage lesions or cartilage destruction; new radiological imaging studies therefore concentrate on the mapping of cartilage [15].

It is clinically important to identify initial cartilage degeneration in symptomatic patients undergoing a regular knee joint MRI [16]. MRI, including T2 mapping, can be used to evaluate articular cartilage qualitatively and quantitatively.

MRI relaxation mapping with T2 can assist in monitoring and analyze the water content of cartilage quantitatively [17]. This study was therefore intended to examine the importance of the T2 mapping sequence in the detection of knee joint articular cartilage malformation by MR imaging.

This prospective study enrolled 30 patients; most of them were male 19 patients and their age ranged from 22 to 70 years old with mean age of (39.4) years old which is similar to Dautry et al in their study which enrolled 23 patients; most of them were male 16 and their age ranged from 20 to 50 years old with mean age were (36.5) years old [18].

Most of the patients presented with knee pain which is similar to Dautry et al. [18].

All patients were submitted to the standard knee MRI protocol in addition to complementary sagittal or axial T2 maps. The grade of their hyaline cartilage was determined according to Noys classification system in each anatomical compartment.

Kappa coefficient was calculated for assessment of agreement between the two imaging techniques in the four anatomical compartments (medial and lateral condyles of femur and medial and lateral condyles of tibia). The results of our

study showed that there was a significant agreement between MRI only and MRI with T2 mapping sequence in classifying knee cartilage at the different anatomical parts.

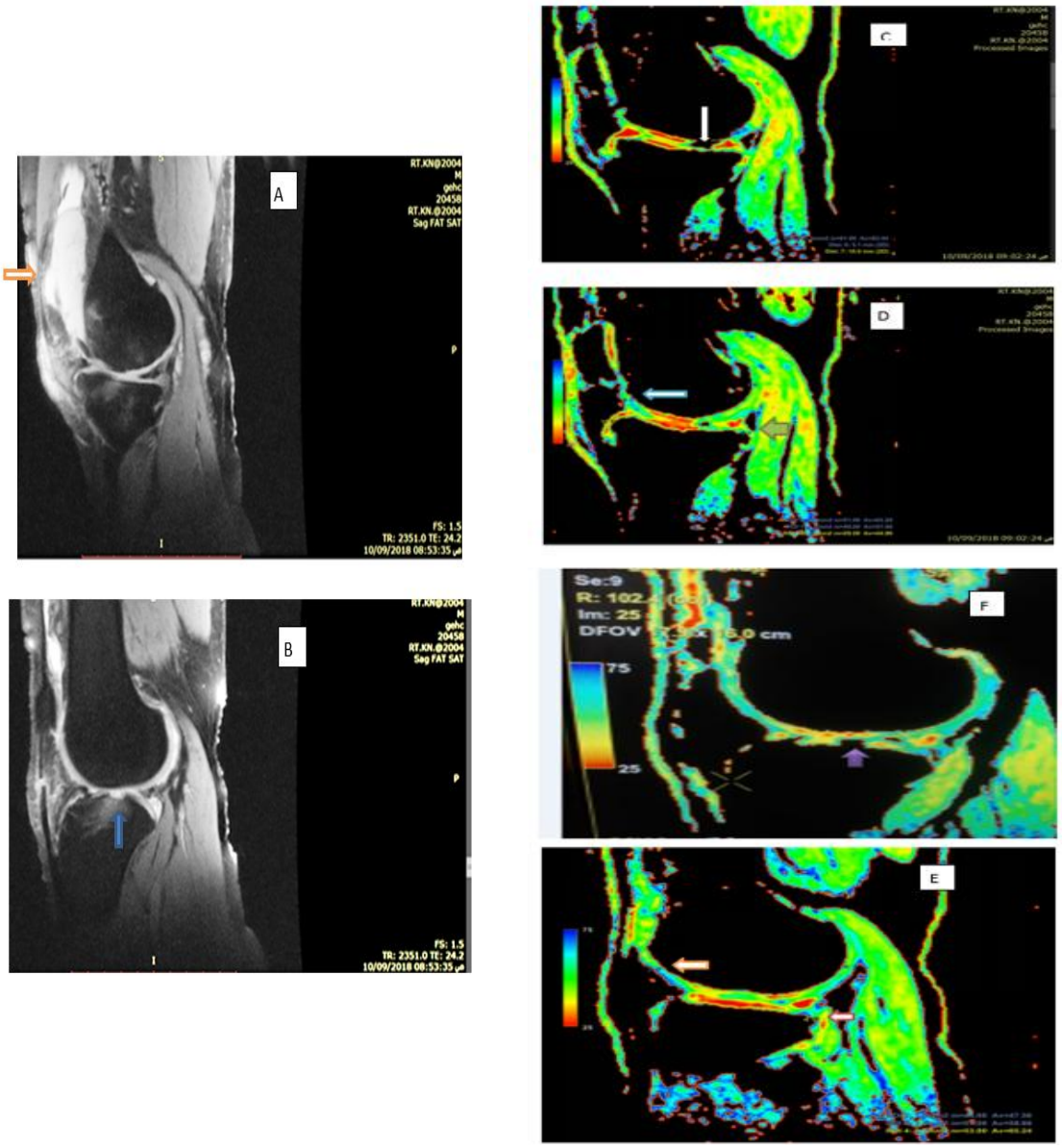

Fig. 2. (A,B) Conventional MRI, sagittal fat sat at medial (A) and lateral (B) tibiofemoral condyles :Show increased signal intensity of cartilage covering the medial tibiofemoral condyle with decreased cartilage thickness and irregularity at the cartilage.fullthickness cartilage lesion at the lateral tibial condyle "cartilage ulcer" (blue arrow). Knee joint synovial effusion with supra pateller plica (orange arrow). (C,D,E,F) sagittal T2 mapping at medial (C,D) and lateral (E,F) tibiofemoral condyles: Show elevated color coded values of cartilage at media tibio femoral condyle . Elevated color coded values of cartilage at lateral tibio femoral condyle. Full thickness cartilage lesion at the medial femoral condyle "cartilage ulcer" measure (10mm)(white arrow) this ulcer appear also by arthroscopy.Full thickness cartilage lesion at the lateral tibial condyle "cartilage ulcer" (purple arrow)this ulcer appear also by Conventional MRI, sagittal fat sat sequence

Similarly, Dunn et al. [19] defined cartilage areas obtained with spoiled gradients and fat suppression with manual segmentation of an MR image. The segmentation was implemented to a T2 relaxation time map and evaluated in four compartments of knee cartilage (i.e., the medial and lateral tibia and femur) that correlate with our study which analyzed in the four anatomical compartments (medial femoral condyle, lateral femoral condyle, medial tibial condyle and lateral tibilal condyle).

In young adults with normal standard knee MRI, Dautry et al. [18] assess the correlation of T2 mapping abnormalities to the location of knee pain, and this is similar to our study.

Dautry et al. [18] analyzed in each anatomical compartment (medial and lateral femoro-tibial) and they added the anterior patello- femoral joint to their study that differs from our study which analyzed in (medial and lateral femoro-tibial compartments) only.

In our study there is 46 out 120 lesions diagnosed as grade 1a by MRI with T2 mapping sequence which diagnosed grade 0 (normal) by MRI only. An this is similar to Dautry et al. (2014) [18] who diagnosed focal abnormalities by T2 mapping in 18 out 23 patients with normal standard knee MRI.

Kijowski et al. [16] assessed the sensitivity and specificity of MR imaging to detect 351 cartilage lesions in patients undergoing knee joint arthroscopy. Their findings demonstrated that the inclusion of a T2 mapping sequence at 3.0 T to the routine MR protocol improved the sensitivity of 24 areas of cartilage softening (grade 1 osteoarthritis) detection (from 4.2 percent to 62 percent). In our study there is 46 (38.3%) lesions diagnosed as grade 1a by MRI with T2 mapping sequence which diagnosed grade 0 by MRI only.

Our study correlates with Joseph et al. [20], in showing relationship between heterogeneity of cartilage T2 mapping and morphologic joint degeneration in the cartilage, meniscus and bone marrow).

Regarding the assessment quantitative T2 mapping for knee joint cartilage, Soellner et al. [21] compared T2 knee cartilage relaxation times with intraoperative results for the evaluation of early osteoarthritis in 21 patients and found significantly increased mean T2 relaxation times with rising morphological cartilage defect grade, varying from 38.97±6.78 ms in areas with 0 to 97.16±14.88 ms ICRS score in regions with 3 lesions modified ICRS score. This findings correlate with our study in which there is increasing T2 relaxation times with increasing morphological cartilage defect grade, grade 0 with Noys classification less than 50 ms and reach more than 60ms in grade 3.

Our study concludes that addition of T2 mapping to standard MR imaging when osteoarthritis is suspected (especially among the young population) is useful. And this is matched with (Soellner et al, 2017) [21] who concluded also T2 mapping is a diagnostic tool for knee joint cartilage damage evaluation and considered a non-invasive differentiation between ICRS grades.

Li et al. [22] also assessed T2 mapping of articular cartilage in knee osteoarthritis and showed that, compared with healthy controls, T2 cartilage values were significantly higher in OA patients. In addition, significant increase with more severe MR grades of cartilage degeneration was reported. This is typical for our study in which T2 cartilage values were significantly increased in patients with OA.

In our study, a moderate significant agreement between MRI only vs MRI with T2 mapping sequence was detected. However, T2 mapping sequence was able to classify 46 lesions as grade 1a that diagnosed as grade 0 by MRI only. Similarly T2 mapping sequence graded 4 lesions as 2b that diagnosed as grade 2a by MRI only. In the same point of view, Apprich et al. (2010) evaluated 43 patients and discovered that with an increased grade of cartilage defect, the T2 values of the cartilage layers significantly increased. Furthermore, their results revealed that 3 patients who were at first classified as healthy on morphological MRI and were subsequently found to have higher T2 values. That is why they reported that a potential mark may be quantitative T2 mapping [23].

It is evident according to the above results that the addition of a T2 mapping sequence to a regular MR scanning protocol can enhance the identification of cartilage lesions inside the knee joint, with the greatest improvement in the detection of early degenerative changes taking place. Kijowski et al. [16] and Dautry et al. [18] are in agreement with this finding.

Dautry et al. [18] mentioned that T2 mapping is an impressive MRI sequence for the study of young patients with a standard protocol for knee pain in the case of normal MRI, with a good correlation between the location of pain and focal prolongation of the T2 cartilage relaxation time [18].

Normal or decreased T2 relaxation time within degenerative cartilage was relatively uncommon in Kijowski et al. [16]. However, the fact that some surgically declared cartilage lesions did not show increased T2 relaxation time suggests that T2 mapping sequences should not be used alone in clinical practice to evaluate articular cartilage or osteoarthritis research studies; this differs from our study because only five patients (13.3 percent) who did arthroscopy lack patients who did arthroscopy.

Standard MRI can actually visualize morphological alterations in articular cartilage, such as decreased volume of cartilage, irregularities in the cartilage contour, fissures, and thinning of cartilage. On the other hand, the interaction of water and the extracellular matrix is reflected by T2 relaxation time mapping. T2 relaxation time mapping can visualize changes in hydration as well as collagen anisotropy, reported to be early indicators of cartilage deterioration.

At the molecular level, the quantitative T2 values (ms) of cartilage reflect the interaction of water and the extracellular matrix. The orientation of the collagen fiber defines the layers of articular cartilage that are most important for the imaging of articular cartilage and cartilage tissue repair or degenerated cartilage [24,25].

However, this study has some limitations which consist of a small cohort of patients in addition to absence of arthroscopic confirmation of chondral lesion in all patients as most of them 25 (83.3%) patients did not do arthroscopy and from five patients (13.3%) who did arthroscopy only 1 patient (3.3%) showed abnormal finding.

5. CONCLUSION

This imaging plane seems to provide a useful addition to standard MR imaging when osteoarthritis is suspected specially among the young population.

CONSENT AND ETHICAL APPROVAL

This prospective study was conducted in accordance with recommendations of local ethics committee of Tanta University that approved it. Written informed consent was signed by all included patients.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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