Assessment of Articular Cartilage of Knee Joint by Magnetic Resonance Imaging in Comparison with Arthroscopy of the Knee

*Sinan Urabee Ibrahim**, *Halah Qays Musa***, *Atheer Adnan Fadhil* ***

ABSTRACT:

BACKGROUND:

The use of new and faster MRI techniques with higher resolution, contrast and greater diagnostic accuracy, make the MRI as an excellent method for evaluating articular cartilage disorders.

OBJECTIVE:

To evaluate the sensitivity and specificity of different sequences of MRI in diagnosing and grading damage of articular cartilage of the knee joint.

PATIENTS AND METHODS:

From March 2017 to Feb. 2018 ,40 Patients (50 knees) with age ranging from (34-67 years) MRI evaluation of the knee articular cartilage was performed using a 1.5T MRI scanner . Arthroscopic surgery was done for them after a maximum delay of 2 months from the MRI study, Employing the outer bridge grading system, the MRI grade 0, I, II, III and IV lesions were compared to the arthroscopic results. The sensitivity, specificity and accuracy were evaluated for each sequence.

RESULTS:

Of the 40 patients, 22 (55%) were females and 18 (45%) were males. Of 300 joint surfaces 135(45%) grade 0 ,16(5.3%) grade I , 36(12%) grade II , 85(28%) grade III and 28(9.3%) grade IV by arthroscopy, when comparing to MRI findings, there was good and very good Kappa values (0.759-0.818). Chondral lesions were undergraded by MRI in (13%) and overgraded in (6.6%), the sensitivity of MRI was ranging between (60-92%), the specificity ranging (68.7-88.8%) and the accuracy (70-86%) .Results demonstrated poor sensitivity of MRI in detecting grade I(33.3%) & grade II(35.8%) and better sensitivity in detecting grade III(85.5%) & grade IV(76.4%). IW-FS-FSE sequence showed the highest sensitivity (88%) & accuracy (97%), followed by FS-PD with a sensitivity of (85%) and accuracy (95%).

CONCLUSION:

MRI is an adequately sensitive and specific diagnostic tool for identifying the presence of articular damage, but still not reliably described as Arthroscopy. Among the 2D and 3D GRE images the best diagnostic evaluation of cartilage disorders was obtained by the IW-FS-FSE sequence . The PD sequence can be used to evaluate knee cartilage, the dynamic range and the findings of subchondral bone disorders are increased by fat suppression during imaging techniques so that it is important in cartilage disorders interpretation.

KEYWORDS: MRI, articular cartilage, arthroscope

INTRODUCTION:

Hyaline cartilage covers the articular surface of the knee joint and aids in resistance against compressive and shearing force [1]

* Specialized Surgery Hospital
**Radiology Dept./ Ibn Al Bitar Center for Cardiac Surgery
*** Baghdad Teaching Hospital \ Medical City

Composition of hyaline cartilage

Water makes up approximately (75%) of wet weight, collagen (15%), approximately 95% type II collagen., proteoglycans make up approximately (10%) , and chondrocytes (1%-5%) [2].

- *The superficial zone* comprises the upper (10–20%) densely packed collagen fibers that are oriented parallel to the cartilage surface [3].
- *The transitional zone* (40–60%) consist of randomly arranged spherical cells and fibers [3]
- *The deep or the radial zone* (20-50) characterized by large fibers that form bundles oriented perpendicularly to the articular surface[3].
- *The calcified cartilage zone* a region of the tissue that transitions into the subchondral bone[3]

MR imaging technique

Fat Suppression Techniques It may be used to increase the contrast between lipid and non-lipid surfaces, reduce chemical shift artifacts and add dynamic range,. most commonly used technique is **fat saturation**. [4]. **Short time inversion recovery (or STIR)** imaging is another option for assessing areas that may be affected by magnetic field inhomogeneity[5].**Water excitation imaging** is based on the selective excitation of non–fat-bound protons. A short TR of approximately 18 msec and a small flip angle (15º–40º) are usually used to depict cartilage with high signal intensity and high contrast to surrounding tissue[6].

Two-dimensional SE Imaging most commonly used MRI sequences in the assessment of joint cartilage are 2D or multi section T1-weighted, proton density-weighted, and T2-weighted imaging sequences with or without fat suppression.

T1-weighted images show intra substance anatomic detail of hyaline cartilage [7].

T2-weighted imaging provides good contrast between the cartilage surface and joint effusion[8].

proton density–weighted imaging is capable of detecting abnormalities of internal cartilage composition as well as surface cartilaginous defects, several institutions prefer to use **intermediate-weighted sequences** that combine the contrast advantage of T2 weighting with that of proton density weighting by using a TE of 33–60 msec [9].

Two-dimensional fast or turbo SE imaging provide excellent SNR and clear delineation of lesions in knee cartilage and contrast between tissues , acquisition time is shorter than that with standard SE sequences [6].**Proton density–weighted** and **T2-weighted fast SE imaging** techniques are well used for assessing articular cartilage in addition to menisci and ligamentous structures, with a quality of information comparable to that obtained in surgery[10].

Three-dimensional Fast SE Imaging consisting of isotropic voxels that provides high-spatial-resolution image , in order to increase the accuracy of MR imaging of articular cartilage in the knee but are not perfect for assessing the adjacent subchondral bone [10,11].

SPGR Imaging it offers higher sensitivity than 2D techniques and considered the standard technique for morphologic evaluations of knee cartilage because it provides excellent depiction of cartilaginous defects, comparable to that achieved with arthroscopy [12,13].

1. **DESS Imaging** In 3D dual-echo steady-state (DESS) imaging, two or more gradient echoes are acquired, with each group of two echoes separated by a refocusing pulse and with the data of both echoes joined to give higher T2 weighting for high signal intensity in synovial fluid and cartilage [14].

   bSSFP Imaging Other names for 3D bSSFP imaging is **balanced FFE** (fast field echo) imaging. In 3D bSSFP imaging, as in 3D DESS imaging, cartilage shows high signal intensity, but the parameters vary somewhat from those in DESS imaging. . [15]
2. **DEFT Imaging** Driven equilibrium Fourier transform increases contrast between fluid and cartilage by enhancing the synovial fluid signal while preserving the signal from cartilage, which is based on the active return of magnetization to the z-axis after each excitation. [16]
3. **VIPR Imaging** VIPR-SSFP, (Vastly undersampled Isotropic Projection Reconstruction) permits the acquisition of images with isotropic spatial resolution and T2/T1-weighted contrast, a recently developed technique based on the combination of bSSFP imaging with 3D radial *k*-space acquisition [17].

4. **SPACE Imaging** (Sampling perfection with Application optimized contrast using different flip angle Evolution). in this technique large eligible turbo factors generated by a restore pulse and variable flip angle distribution are used to produce a pseudo steady state ,it is a 3D fast SE technique [18].

Classification of cartilage injuries(Outer bridge scale)[19]

Modified from International Cartilage Repair Society Pathologic change/ MRI findings/arthroscopic findings

- **Grade I**. Superficial lesion/ Normal appearance or increased focal or diffuse signal within the cartilage/chondral softening to Probe .
- **Grade II**. Lesion involving <50% from the cartilage thickness / cartilage defect or Irregularities of the cartilage surface with increased signal intensity <50% thickness / at arthroscopy fissures involving <50% thickness
- **Grade III**. More than 50% of cartilage depth defect but not through subchondral bone / More than 50% of cartilage defect with increased signal intensity /by arthroscopy fissuring in More than 50% of the thickness.
- **Grade IV**. Denudation /fluid like signal intensity in contact with the subchondral bone with complete absence of the cartilage/ exposed subchondral bone at arthroscopy

Pathology

Non-traumatic Cartilage Changes

Osteoarthritis (OA) disease of the joint characterized by degeneration of cartilage, meniscus, subchondral bone, and other tissues with abnormal proliferation of synovium, and bone and cartilage overgrowth due to aging and mechanical load. The tibiofemoral joint of the knee is mostly affected. the medial joint space is more commonly affected than lateral [20].

*On MR Imaging***,** Coronal proton-density (PD) FSE image show high-signal changes with irregularities in the most superficial zone of the cartilage (superficial degeneration), while routine MR sequences unable to show these changes as are earliest features. while the deep layers develop basal degeneration that abnormal matrix-protein substances and edema manifests as areas of focal softening and swelling followed by fibrillation, fragmentation that may ultimately denude areas of subchondral bone [21, 22]. [26] the patellar cartilage *denuded areas of subchondral bone* have lower diagnostic difficulties as its thickness is more and complete loss or thinning is easier to detect.

Traumatic Cartilage Injuries *Cartilage contusions, cartilage fissures, and cartilage fractures*_may affect the superficial or deep layers of the cartilage , or both without involving the subchondral bone. Usually, they are located at the weight- bearing surface.

On MR imaging, an acute cartilage lesion (***contusion or fracture***) is seen on T2-weighted images as a focal area of high signal intensity or as a cartilage defect filled with fluid with abrupt, well-delineated borders in the case of ***fractures***. Subchondral edema may be seen in acute phase but it resolves in time. In chronic lesions, due to healing process the margins are smoother , and over time the defect may be replaced by fibrous tissue. The MR report should include the size ,the location of the lesion, and the depth (<50% of cartilage thickness, >50% of cartilage thickness, full-thickness tear).

Cartilage delamination,[27]. T2-weighted images of the MRI shows increased signal intensity in linear pattern at the junction of the articular cartilage to the underlying bone. As a result of separation of the cartilage from the subchondral bone at the deepest, calcified zone because of the shearing stress. [27].

Osteochondritis dissecans it is an acquired subchondral bone fracture with extention through the articular cartilage. The etiology can be an acute single event or minor repetitive trauma [28]. The size of the lesion may vary from few millimeters to several centimeters, with different grades of stability. MR imaging, shows a curvilinear line that ends on both sides at the cartilage-bone junction. While instability may be indicated by the presence of a rim of fluid-like signal intensity on T2-weighted images. [29]

Options in treating articular cartilage injury

The treatment modality depends on patient selection according to sport and daily activities, aetiology, age, grade and quality of the lesion.

Treatment options can be conservative, arthroscopic or open surgical procedures [30].

AIM OF THE STUDY:

To evaluate the sensitivity and specificity of different sequences of MRI in diagnosing and grading damage of articular cartilage of the knee joint.

PATIENTS AND METHODS:

The study included a total of 40 patients; ten of them had bilateral knee involvement, while the remaining 30 patients had unilateral knee involvement (50 knees), with an age range of (34-67 years). (22) females and (18) males were clinically suspected as knee joint articular cartilage lesion, they were referred from orthopedic department, MRI studies were done for them at the department of radiology (MRI unit) in Baghdad teaching hospital & Ghazi Al-Hariri hospital \ at medical city teaching complex and were then followed up with knee joint arthroscope during the period from march 2017 to Feb. 2018 .Examinations were performed using 1.5 Tesla Achiva Philips MRI, superconductive magnet with dedicated sense coil.

Technique The following technical factors were used when imaging the cartilage:

Coils: a flexible synergy surface coil with 2 coil elements was used for imaging and was placed anteriorly and posteriorly to the knee . Slice thickness: 1.5- 3 mm . FOV: 150 – 180 mm. Plane image : Sagittal-coronal-axial

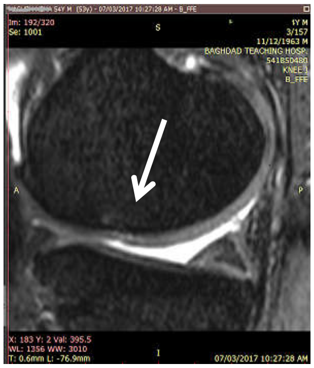
<u>The following sequences were performed:</u>

1. Fat suppressed T2 weighted fast spin echo with intermediate T2 weighting in sagittal plane (IW-FS-FSE) (slice thickness: 3mm, TR: 2500ms, TE: 50ms, AT:1.5min).
2. Proton density-weighted fast spin echo in sagittal planes (PD) (slice thickness: 3mm, TR: 3600ms, TE:30ms, AT:1.42 min).
3. Proton density-weighted TSE with fat suppression in sagittal planes (FS-PD) (slice thickness: 3mm, TR: 3000ms, TE: 30ms, AT:1.5min).
4. 3D T1 fast field echo with water excitation for cartilage in coronal plane (WATS-c) use water selective 1-3-3-1 binominal pulse for optimal fat suppression slice thickness: 1.5 mm, TR: 20ms, TE: 8ms, AT:2.31min).
5. 3D fast field echo with water excitation for fluid in coronal plane (WATS-f) use water selective 1-3-3-1 binominal pulse for optimal fat suppression slice thickness: 1.5 mm, TR: 20ms, TE: 7ms, AT:2.31min).
6. 3D balanced-fast field echo in transverse plane (B-FFE) slice thickness: 1.5mm, TR: 15.3ms, TE: 7.7ms, AT: 3

The articular surface of each knee was divided into six surfaces: medial femoral condyle, medial tibial plateau,patella, trochlea, , lateral femoral condyle and lateral tibial plateau. Each cartilage surface was analyzed as a single entity, so we have 300 articular surfaces in total . we used a classification modified from the Outer bridge grading.

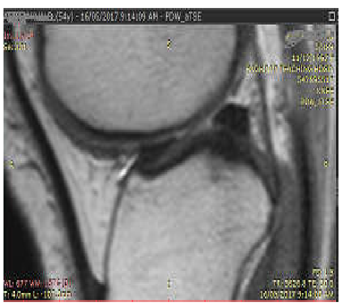
Arthroscopy: After MRI evaluation, knee arthroscopy was done for the patients after a maximum of two months. We used the standard antero-lateral and antero-medial portals; each knee compartment was inspected thoroughly and palpated using a blunt hook. Arthroscopic grading of the findings was done by 2 orthopedic surgeons in grades 0 to 4 according to the modified classification of Outer bridge. We used a standardized documentation sheet to record the findings . Cartilage damage was treated during the same knee arthroscopy.

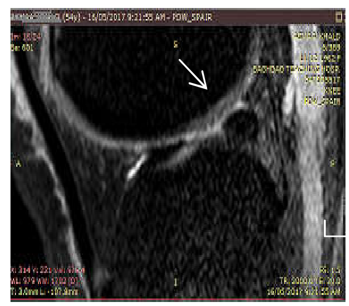
Statistical Analysis: we used SPSS statistical package for Social Sciences (version 20.0 for windows, SPSS, Chicago, IL, USA). Statistically significant P-value was considered <0.05. Agreement between MRI and arthroscopy results was measured by calculating Cohen's Kappa; no agreement if Kappa less than or equal to 0. kappa value < 0.20 = poor, 0.21-0.40 = fair, 0.41-60 = moderate, 0.61-0.80 = good, 0.81-1.0 = very good



A. B.

Fig. (1) 33y. Old male patient complain of knee pain after acute trauma, MRI examination showed grade I chondromalacia (focal high SI) at the medial femoral condyle, more obvious on a. B_FFE sequence. Than other sequences. b. WATS-c sequence.

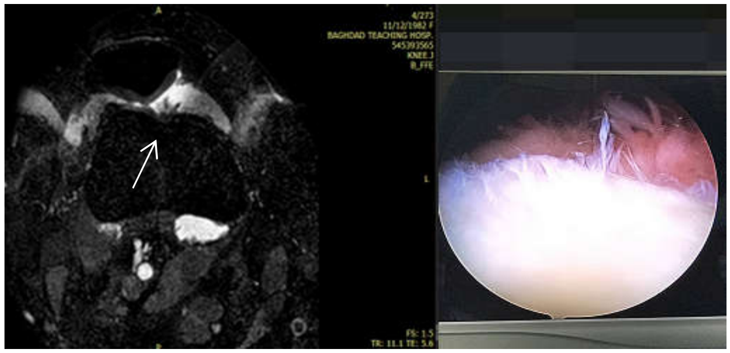




A. B. C.

D. E.

Fig (2): female patient 54 y. old presented with knee pain 1 month ago ,MRI was done for her which reveal grade II chondromalacia at the lateral femoral condyle posteriorly which is more obvious on c. FS-PDW sagittal section, not well seen on other seq. a. PDW sequence, b. WATS-c sequence c. FS-PDW sequence, d. WATS-f sequence e. arthroscopic confirmation.



A. B.

Fig (3) 50 y. female patient presented with Rt. knee pain of 1 month duration, MRI was done for her that revealed grade III chondromalacia at trochlear surface on a. B_FEE seq. axial section, confirmed by b. arthroscope

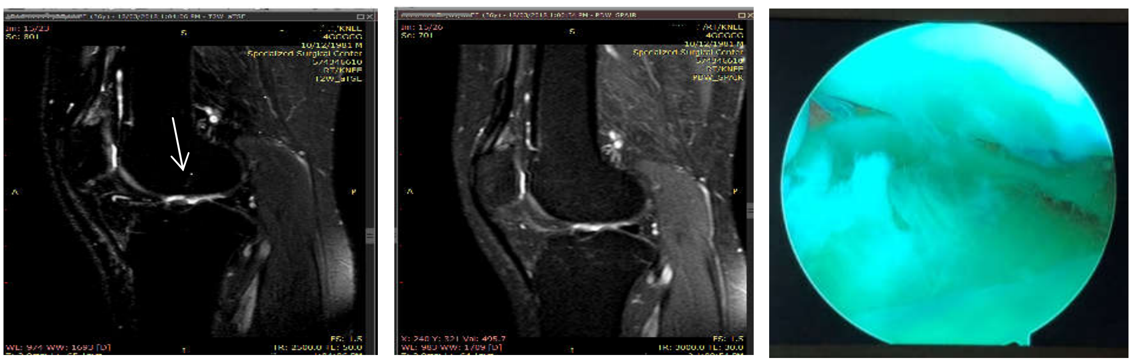
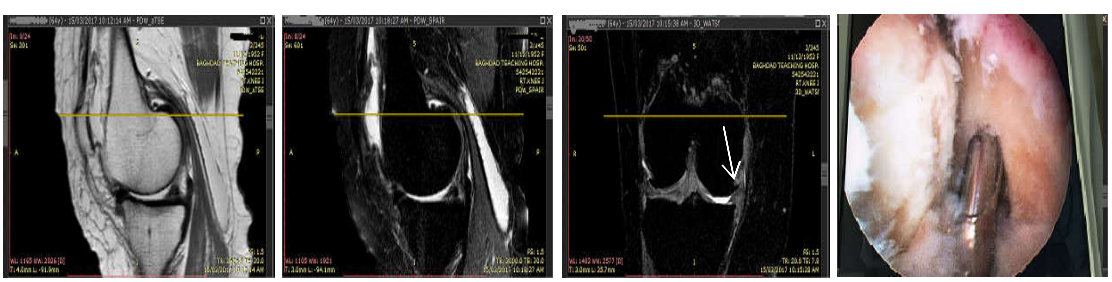


Fig (4) 53 y old male presented with knee pain, MRI was done a. IW-FS imaging and b. PD-SPAIR, demonstrated grade III and grade IV of lateral femoral condyle which were better delinated on a. FS-IW sequence than on b. FS-PDW sequence, c. Arthroscopic view



A. B. C. D.

Fig.(5) 64 y. old female patient presented with chronic Rt. knee pain and limitation of movement, MRI revealed large area at the medial tibio-femoral compartment with complete loss of cartilage which is obvious on all seq. a. PDW sequence b. FS-PDW sequence c. WATS-f sequence and confirmed on d. arthroscope (deudation and exposure of subchondral bone

RESULTS:

Of 300 joint surfaces,135 (45%) were assessed as grade 0, 16(5.3%) as grade I 36 (12 %) as grade II, 85 (28%) as grade III and 28(9.3%) as grade VI lesions during arthroscopy.

Table 1 : Comparing MRI with arthroscopic findings for each articular cartilage.

Joint surface cartilage findings	Grade 0 No. %	Grad I No. %	Grade II No. %	Grade III No. %	Grade IV No. %	Kappa value
Trochlear						0.775 P value =0.0005
MRI	24 48	4 8	3 6	13 26	6 12	
Arthroscope	24 48	2 4	4 8	16 32	4 8	
Patellar						0.816 P value= 0.001
MRI	23 46	4 8	7 14	14 28	2 4	
Arthroscope	23 46	2 4	7 14	16 32	2 4	
Medial tibial						0.818 P value= 0.0005
MRI	17 34	0 0	8 16	11 22	14 28	
Arthroscope	17 34	0 0	4 8	19 38	10 20	
Medial femoral						0.781 P value=0.0005
MRI	20 40	4 8	3 6	15 30	8 16	
Arthroscope	20 40	2 4	3 6	18 36	8 16	
Lateral tibial						0.769 P value= 0.0005
MRI	26 32	4 8	8 16	10 20	2 4	
Arthroscope	22 44	4 8	14 28	8 16	2 4	
Lateral femoral						0.759 P value= 0.0005
MRI	33 66	2 4	7 14	6 12	2 4	
Arthroscope	29 58	6 12	4 8	9 18	2 4	
Total	135 45	16 5.3	36 12	85 28.3	28 9.3	

Results showed that there was an exact agreement between arthroscopic findings and MRI readings in 241 of 300 joint surfaces (80.3%) cartilage lesions were undergraded by MRI grading in 39 of 300(13%) and overgraded in 6.6% (20 of 300) table 2.

Table (2): The validity parameters of MRI findings in diagnosis and grading of knee articular cartilage defects

	True positive	True negative	False negative (undergrading)	False positive (overgrading)
Trochlear	19	24	3	4
Patellar	19	23	6	2
Medial tibial	25	17	4	4
Medial femoral	23	20	5	2
Lateral tibial	14	22	10	4
Lateral femoral	6	29	11	4
Total	106	135	39	20

Our study showed that the lowest sensitivity was for lateral femoral surface (60%) and lateral tibial (77.7%), the highest sensitivity was for medial femoral (92%) and patellar (90%). The lowest specificity was for lateral tibial surface (68.7%) and lateral femoral (72.5%) and the highest specificity was for trochlear (88.8%) and medial tibial (80.9%). Table 3

Table (3): the results of the data analysis; accuracy, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) of MRI for each joint surface

Statistic	Trochlear	Patellar	Medial tibial	Medial femoral	Lateral tibial	Lateral femoral
Sensitivity (95% CI)	82.6% (87.4-100)	90% (85.5-100)	86.2% (88.4-100)	92% (81.5-100)	77.7% (76.8-100)	60% (74.3-100)
Specificity (95% CI)	88.8% (76.8-100)	79% (76.8-100)	80.9% (83.2-100)	80% (89.1-100)	68.7% (75.2-100)	72.5% (76-100)
PPV	86.3%	76%	86.2%	82.1%	58.3 %	35.2 %
NPV	85%	92%	80.9 %	90.9%	84.6%	87.8%
Accuracy	86%	84.8%	84.8%	86%	72%	70%

Table (4): Sensitivity of MR imaging in grading of articular cartilage defects

	Grade I	Grade II	Grade III	Grade IV
Sensitivity	33.3 %	35.8 %	83.5 %	76.4 %

IW-FS-FSE showed slightly highest sensitivity and accuracy among the sequences. The sensitivity varied from 50% (WATS-c) to 88% (IW-FSFSE), the specificity varied from 98% (FS-PD) to 99% (B-FFE and WATS-f) and the accuracy varied from 88% (WATS-c) to 97% (IW-FS-FSE).,.

Table (5): Sensitivity, Specificity and Accuracy for each MRI sequence

	Iw-FS-FSE	FS-PD	PD	WATS-f	B-FFE	WATS-c
Sensitivity	88	85	76	77	71	50
Specificity	98	98	98	99	99	98
Accuracy	97	95	90	93	93	88

DISCUSSION:

In our study, according to table (1), the diagnostic values for MRI assessment of cartilage lesions were relatively high at all grades. When comparing arthroscopic grading to MRI grading , good and very good kappa values (weighted kappa range = 0.759-0.881) were demonstrated .These results show that MRI compares greatly with arthroscopic findings. Our results were similar to the results of Drape et al. who demonstrated very good intra-observer agreements (weighted kappa =0.91) [(23)].

In our study, there was an exact agreement between the MRI readings and the arthroscopic findings in 241 of 300 joint surfaces (80.3%) (table 2), cartilage lesions were undergraded by MRI grading in 39 of 300 (13%) and overgraded in 6.6% (20 of 300) table 2 considered as {true positive+ and true negative}. In further studies (as in our study) degenerative disorders were undergraded more often than overgraded [(24,25)]. This can be explained by the high frequency of advanced cartilage disorders in our sample with higher possibilities for underestimation. The positive predictive values (PPV) are poorer than the NPV, which is a reflection of the predominantly healthy joint surfaces (grade 0).

As noted in table (3), our study showed that MRI has high sensitivity in detecting chondral lesions according to the region, were ranging from (60%-92%) suggests that MRI can be used to rule out the presence of osteochondral damage.

The variability of results between the different joint surfaces suggests that MRI is a more specific test in the patellofemoral (79%, 88.8%) and medial compartments (80%, 80.9%). The high NPV ranging from (80.9-92%) suggests MRI does pick up a high proportion of healthy joint surfaces {high percentage of grade 0 (45%)}.

In our study, MRI was more sensitive in detecting grade III (83.5%) and grade IV (76.4%) and it was relatively less sensitive for grade I (33.3%) and for grade II (35.8%). The accuracy of MRI in detecting chondral lesions affected by the thickness of the hyaline cartilage, which is greater in deeper lesions, especially when there is more than 50% loss of chondral substance, with values in the literature ranging from 73 to 96% [24,25]. Our results are similar to the study done by Bachmann et al. who reported a sensitivity of 14% for grade I, 32% for grade II, 94% for grade III and 100% for grade IV lesions [26].

As noted in table (5), our study showed that IW-FS-FSE had slightly highest accuracy for the evaluation of cartilage pathology-=. Yoshioka et al. [27] reported that FS-PD showed a lower contrast to noise ratio (CNR) between cartilage and fluid and a higher signal to noise (SNR) of articular cartilage, than did the IW-FS-FSE, but the FS-PD and IW-FSFSE images were reported to have the same sensitivity and specificity. We selected a longer echo time (50 ms) for the IW-FS-FSE Than Yoshioka et al. who used a 39 ms echo time for IW-FS-FSE, which probably made our results different. Many institutions tend to use IW-FS-FSE (echo time: 33-60 ms) rather than the PD sequences, as the former provides higher intrinsic contrast and less magic angle effects [28].

Our results showed that WATS-c sequence had the lower sensitivity (50%), specificity (97%) and accuracy (92%) which were similar to recent studies that reported that (WATS-c) has a lower sensitivity and specificity for cartilage disorders than did FS-FSE [29, 27]; this can be attributed to the difficulty in detecting fissures or cartilage fibrillation due to the low contrast between cartilage and synovial fluid, and the internal cartilage abnormality often hidden by the high signal of the WATS-c images [28, 30].

Bauer et al. [29] in their study noted higher diagnostic performance for chondromalacia during IW-FS-FSE sequence than that with SSFP or SPGR sequence; similarly our study showed that (IW-FS-FSE and FS-PD) had a higher sensitivity and accuracy than did Balanced FFE imaging. Schaefer et al. [32] noted that the 3D sequences were an underestimation of grade I cartilage lesions with poor intra substantial contrast between chondromalacia and intact cartilage . Therefore, cartilage lesions were more easily revealed by the IW-FS-FSE sequences . Duc et al. [31] also noted that IW-FSFSE sequence had an advantage for determining chondromalacia over the superior CNR of the 3D water-excitation true FISP sequences .

CONCLUSIONS:

1. MRI is an adequately sensitive and specific diagnostic tool for identifying the presence of articular damage, but is still not as reliable as arthrospoy which shows the detailed evaluation and assessment of cartilage lesions. Therefore, the 1.5-Tesla MRI still not replacing the arthroscopic grading .
2. Among the 2D and 3D GRE images, the best diagnostic evaluation of cartilage disorders was obtained by the IW-FS-FSE sequence that examined with a microscopy coil. Therefore, IW-FS-FSE sequence could be used as the main sequence for articular cartilage evaluation .
3. The PD sequence accuracy was comparable to that of the previously mentioned cartilage-specific sequences and can, therefore, be used to evaluate the knee cartilage .
4. Furthermore, the dynamic range and the findings of the subchondral bone disorders are increased by fat suppression during imaging techniques which is important in cartilage disorders interpretation or else it will be more difficult and less sensitive.

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