Demonstration of Knee Hyaline Cartilage with 3d_Watsc/T1a Ge Technique, Comparison with Standart MRI, Correlation with Arthroscopy

Diz Hiyalin Kıkırdağın 3d_Watsc/T1a Ge Tekniği ile Gösterilmesi, Standart MRG ile Karşılaştırılması ve Artroskopi ile Korelasyonu

İbrahim Atasoy[1], Ali Murat Koç[2], Özgür Sipahi Esen[2], Semiha Canverenler[3], Ahmet Kurtulmuş[4], Zehra Hilal Adıbelli[2]

[1]Clinic of Radiology, Şanlıurfa Balıklıgöl State Hospital, Şanlıurfa, Turkey
[2]Department of Radiology, University of Health Sciences, İzmir Bozyaka Training and Research Hospital, İzmir, Turkey
[3]Clinic of Radiology, Medical Park Uşak Private Hospital, Uşak, Turkey
[4]Department of Orthopedics and Traumatology, University of Health Sciences, İzmir Bozyaka Training and Research Hospital, İzmir, Turkey

Cite this article as: Atasoy İ, Koç AM, Esen ÖS, Canverenler S, Kurtulmuş A, Adıbelli ZH. Demonstration of Knee Hyaline Cartilage with 3d_Watsc/T1a Ge Technique, Comparison with Standart MRI, Correlation with Arthroscopy. Clin Exp Health Sci 2018; 8: 103-11.

Abstract

Objective: The primary aim of this prospective study was to compare fat-suppressed three-dimensional water selective cartilage scan (3D_WATSc) magnetic resonance (MR) imaging with standard MR imaging for the detection of defects in the hyaline cartilage of the knee, using arthroscopy as the reference standard.
Methods: Overall, 40 patients who were referred for knee MRI by orthopedic surgeons before arthroscopy were included in the study. Chondromalacia was diagnosed in 19 patients by arthroscopy and built the mainframe of the study. Hyaline cartilage damage was imaged using 3D_WATSc sequence with the appropriate parameters. Standard MRI imaging of the knee consisted of two-dimensional coronal T1-weighted spin-echo, coronal, and sagittal T2-weighted spin-echo, and sagittal and axial superior pericardial recess sequences. With arthroscopy as the gold standard, sensitivity, and specificity of 3D_WATSc and standard MR imaging for detecting cartilage damage were determined in six articular surfaces (patellar facets, trochlear facets, medial and lateral femoral condyles, and medial and lateral tibial plateaus).
Results: In total, 240 cartilage surfaces in 40 patients were evaluated by arthroscopy, and 28 of them had shown to have chondromalacia. 3D_WATSc had higher sensitivity and specificity (92% and 96%, respectively) than standard MR images (60% and 95%, $p<0.05$) and was also more successful in the detection of early-stage (stage 1–2) cartilage defects than standard MR images and arthroscopy ($p<0.05$).
Conclusion: 3D_WATSc MRI sequence is more sensitive than standard MR imaging for the detection of abnormalities of the hyaline cartilage in the knee. Routine use of this low-cost technique in addition to standard imaging strengthens the role of non-invasive MR imaging in the evaluation of cartilage damages.
Keywords: Knee, cartilage, chondromalacia, MRI, arthroscopy

Öz

Amaç: Bu prospektif çalışmada diz hiyalin kıkırdak hasarı tespitinde yağ-baskılı (FS) 3D_WATSc MR sekansın, standart MRG görüntüleri ile karşılaştırılması ve artroskopi ile korelasyonunu değerlendirilmiştir.
Yöntemler: Ortopedi ve travmatoloji uzmanı tarafından artroskopi planlanan ve diz MRG çekilmesi için refere edilen 40 hasta çalışmaya dahil edildi. Bunların 19'da artroskopide kondromalazi saptanmış olup, çalışmanın temelini oluşturmaktadır. Hiyalin kıkırdak hasarı yağ-baskılı (FS) 3D_WATSc MR sekansı ile uygun parametrede görüntülendi. Standart olarak uygulanan diz MRG görüntülemede iki boyutlu koronal T1 ağırlıklı spin eko, koronal ve sagital T2 agırlıklı spin eko, sagital ve aksial SPIR multıplanar sekanslar kullanıldı. Artroskopi altın standart alınarak, altı yüzde (patella, troklea, femoral kondiller ve tibial platolar) kıkırdak hasarı değerlendirildi, yağ-baskılı (FS) 3D_WATSc MR sekansı ve standart MRG'de duyarlılık ve özgüllük değerleri hesaplandı.
Bulgular: 40 hastada, 240 kıkırdak yüzü artroskopide değerlendirildi ve 28'inde kondromalazi saptandı. Yağ-baskılı (FS) 3D_WATSc MR sekansının kondromalazi saptamada duyarlılık ve özgüllüğü (%92, %96), standart MRG'ye (%60, %95) göre belirgin yüksektir ($p<0.05$). Yağ baskılı (FS) 3D_WATSc MR sekansının, artroskopi ve standart MRG de Evre 1-2 olarak belirtilen erken evre kıkırdak hasarı tespitinde daha başarılı olduğu görülmektedir ($p<0.05$).
Sonuç: Yağ baskılı üç boyutlu su seçici kıkırdak tarama (3D_WATSc) MR sekansı diz kıkırdak anormalliklerin tespiti için Standart MRG incelemeden daha duyarlıdır. Düşük maliyetli bu tekniğin standart incelemeye ek olarak rutin kullanımı diz kıkırdak hasarı tespitinde non-invaziv MR görüntülemenin rolünü güçlendirir.
Anahtar kelimeler: Diz, kıkırdak, kondromalazi, MRG, artroskopi

INTRODUCTION

Many methods from direct radiography to state-of-the-art cross-sectional diagnosis methods have been used historically either alone or in combination for imaging articular cartilage. Cartilage imaging has gained substantial significance in recent years in terms of treatment of the damage occurring in the cartilage and monitoring the result of treatment. A diagnosis method is necessary that can provide di-

Correspondence Author/Sorumlu Yazar: Ali Murat Koç /E-mail/E-posta: alimuratkoc@gmail.com
Received/Geliş Tarihi: 20.05.2017 **Accepted/Kabul Tarihi:** 23.08.2017 **DOI:** 10.5152/clinexphealthsci.2017.519

rect and accurate information in the evaluation of articular cartilage in pre- and postoperative period, making correct diagnosis in suspected cases of cartilage pathologies and determining the numbers, localizations, and sizes of existing lesions.

Although direct radiography, the main imaging method for imaging the skeletal system, arthrography, computerized tomography (CT), and CT arthrography are the methods used in cartilage imaging, none of these techniques can show the cartilage directly. The purpose of cartilage imaging is to evaluate the surface integrity of the cartilage, thickness and volume of the cartilage matrix, and its relationship with the subchondral bone (1). However, physiological and morphological changes in the cartilage itself cannot be evaluated through these methods owing to indirect imaging. Magnetic resonance imaging (MRI) is the gold standard non-invasive imaging method in the evaluation of osseous, ligamentous, and meniscal structures with the possibility of high-resolution power, soft tissue resolution, and multiplanar evaluation. Use of suitable MRI sequences for the determination of the type of cartilage damage, existence, and degree of accompanying pathology in the subchondral bone will decrease diagnosis mistakes (1).

The basic MRI sequence in the evaluation of cartilage pathologies is spin echo (SE). However, conventional T1-weighted (T1W) and T2-weighted (T2W) SE images may not be sufficient. In conventional T1W images, the limit between cartilage and subchondral bone can be distinguished, but adequate contrast cannot be provided between synovial fluid, cartilage, and adipose tissues (1, 2). In T2W images, the contrast between cartilage and synovial fluid is higher, but signal/noise ratio is insufficient to support spatial resolution (1, 3). Therefore, the boundary between cartilage and subchondral bone gets blurred, and cartilage thickness may not be measured correctly (1, 4, 5). Hence, fast/turbo SE (FSE/TSE) gradient echo (GE) and proton density (PD) sequences are incorporated in routine MRI examinations in joint imaging (1, 6, 7). Fat-suppressed FSE (FS-FSE) and 3-dimension GE (3D-GE) MR imaging techniques have been reported in many studies as sequences that evaluate joint cartilage lesions with the highest accuracy and can be used routinely (8, 9). However, accuracy of routine MRI sequences in detecting cartilage lesions has become a matter of debate owing to the newly developed methods (8).

Morphological features of articular cartilage can be evaluated accurately through MRI sequences specific to the cartilage. There is a need for several special sequences, helixes, and devices with high gradient power to evaluate in all joints the anatomy and pathology of articular cartilage that can be imaged directly, particularly knee joint, in a clearer and quicker manner (1, 2, 10). Cartilage-specific 3D-GE technique is an MR sequence that allows to conduct the examinations in a short time, and it is used in cartilage imaging with different parameters. It has the types of T1 GE (DESS-3D-WE, SPGR, FLASH-3D-T1-WE, and WATSc) that suppresses the synovial fluid and T2 GE (DESS, SSFP, FLASH T2*-MEDIC, FFE T2*, and WATSf) that does not suppress. Contrast/noise between cartilage-synovial fluid and cartilage-subchondral bone is significantly high in three-dimensional water selective cartilage scan (3D_WATSc) sequence using the frequency selective fat suppression; articular cartilage is observed with this technique as a high-signal band. Thanks to fat suppression, the only high-signal structure in the joint is cartilage tissue, and the synovial fluid and subchondral bone have lower signal (1, 11). Homogeneous hyperintense view of the normal cartilage is divided into two with a hypointense line passing through the middle section. By this way, this view of the cartilage having a three-layered structure is a result of MR technique and termed as "truncation artifact" and does not reflect histological view (1, 4, 5) (Figure 1). Owing to the volumetric feature of 3D_WATSc technique, higher resolution and signal/noise ratio are obtained compared with two-dimensional imaging

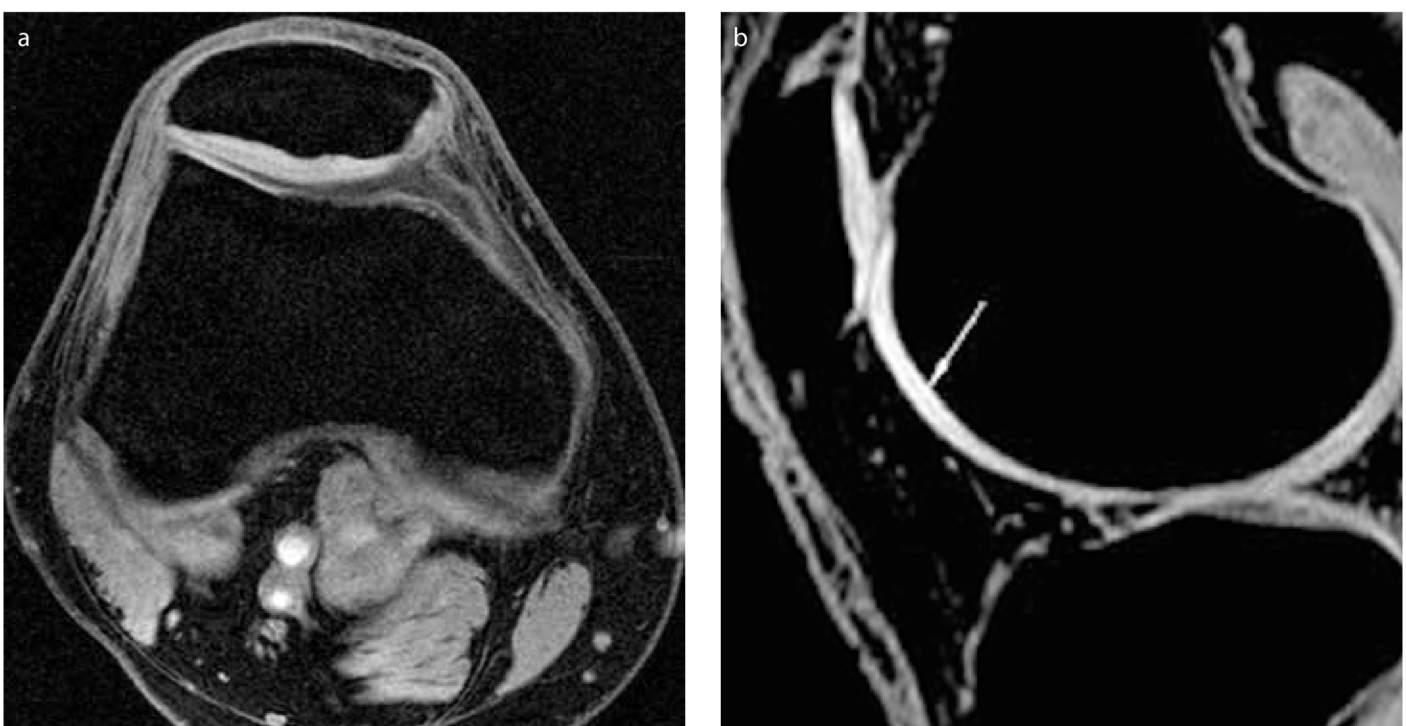

Figure 1. a, b. Truncation artifact in 3D_WATSc sequence. Hypointense lines depending on normal hyperintense cartilage and truncation artifact therein are observed on the patellar cartilage on the axial (a) and sagittal (b) planes (ok)

Table 1. Bauer-Jackson, Outerbridge arthroscopic classifications, and modified MRI classification cartilage lesions (1, 19, 20).

Bauer-Jackson		Outerbridge		MRI	
Stage		**Stage**		**Stage**	
1	Isolated, linear	0	Normal	0	Normal
2	Stellate	1	Malacia on surface	1	Edema/focal signal change
3	Flap	2	<50% irregular surface defect	2	<50% fissure formation/focal defect
4	Crater formation	3	>50% defect reaching subchondral bone	3	>50% fissure formation/focal defect
5	Fibrillation	4	Cartilage defect where subchondral bone is exposed	4	Full-thickness cartilage loss, signal increase in subchondral bone
6	Cartilage disintegration				

techniques. With multiplanar reconstruction (MPR) images formed at 1 mm thin sections, it is possible to evaluate the patellar and trochlear cartilage tissues arranged perpendicularly to the joint, especially where the articular surface is curved (1, 5). FS 3D_WATSc is an easy-to-apply and widely accepted sequence that does not require new data, know-how, and skills for post-processing in contrast with other cartilage imaging methods such as magnetization transfer imaging and does not contain matching errors such as "misregistration" (1, 5).

MR arthrography is used in selected cases in cartilage imaging. A contrast agent containing gadolinium is directly administered into the joint in this technique. However, it is not necessary to be used routinely owing to the invasiveness of the method, developing technology of MR devices, and increased gradient power.

Chondromalacia patella is a disease of the deep layers of the cartilage holding external layers only in the late period. Its surface is smooth and intact. It is associated with a decrease in sulfated mucopolysaccharides in the core ingredient (12, 13).

Cartilage defects are defined in four stages pathologically (12, 13) (Figure 2). In the grading system developed by Shahriaree, chondral damage is evaluated together with its both traumatic and non-traumatic types, and it was shown in the studies conducted that it is useful in associating MRI findings and arthroscopic findings (14, 15).

Arthroscopy

Arthroscopic examinations are the most successful invasive diagnosis method in the evaluation of pathologies pertaining to knee articular cartilage. Some of the advantages of arthroscopy are lowness of complication and morbidity rates, intact proprioceptive senses, possibility of simultaneous treatment, and short hospital stay. Some of the disadvantages of arthroscopy are relative length of the intervention depending on experience, requirement of advanced surgical technique knowledge, probability of intra-articular injury, and expensiveness of arthroscopic devices (16).

Bauer-Jackson classified isolated and traumatic cartilage injuries of the knee joint into six groups in terms of form and severity of lesion in arthroscopic examination (Table 1). The stage defined by Outerbridge is the most commonly preferred chondromalacia classification at present as it is more current and easily applicable (17, 19) (Table 1).

Magnetic resonance imaging

Cartilage injuries may be traumatic or degenerative. The response in articular cartilage in cases of traumatic injuries is related with how far the damage extends up to the subchondral bone. Cartilage defect is typically big and sharply circumscribed in traumatic injury. Usually, there is a defect causing full-thickness damage and reaching to the subchondral bone. In this case, a signal increase in the subchondral bone is observed in MRI examination, and this is a stimulating finding in terms of cartilage damage. In degenerative osteoarthritis, lesions are high in number and are accompanied by diffuse cartilage thinning. The size and depth of defects vary. The edges of cartilage defect are blunt and obtuse angled (1, 4).

A modified staging system based on Outerbridge's arthroscopic staging system is used in the evaluation of cartilage damage in MRI (1, 2, 19) (Table 1). Normal cartilage is accepted as stage 0. Earliest joint cartilage changes where hyperintense signal change focuses without any contour irregularity or edema appearance is observed in the cartilage are classified as stage 1. Fragmentation or fissure formation in cartilage or focal defects smaller than 50% of cartilage thickness are classified as stage 2; fissures bigger than 50%, fragmentation, or focal defects are classified as stage 3; ulcer in joint cartilage, signal increase in the subchondral bone occurring upon exposure of the subchondral bone, or full-thickness cartilage loss is classified as stage 4.

Defects in articular cartilage are shown as focal signal decrease in 3D_WATSc sequence. The changes in cartilage thickness can also be considered as quantitative. Edema occurring in the subchondral bone in 83% of the cases with full-thickness defect in the cartilage can be evaluated using fat-suppressed FSE/TSE PD sequences (1).

In this prospective study, six cartilage sites of the knee joint (patella, trochlea, medial and lateral femoral condyles, and medial and lateral tibial plateaus) were evaluated in terms of routine MRI, FS 3D_WATSc/T1A MRI sequence, or cartilage damage by arthroscopy, the reference diagnosis method.

METHODS

Overall, 40 female and male patients, who applied to the Orthopedics and Traumatology Polyclinic of our hospital with a complaint of knee pain, who were thought to have joint cartilage damage or other knee pathologies in their examination, and for whom arthroscopic examination was planned, and preoperative MRI imaging of whom were conducted between March 2013 and March 2014, were included in the study. Written informed consent was obtained from the patients before MRI.

MRI examination was carried out in a radiology clinic with a 1.5T MR device (Philips Achieva, Philips Medical System). Patients were laid in a supine position, and a knee coil was placed while the knee was at a slight flexion (at 20°-30°). Routine knee MRI examination was performed at sagittal (TR/TE/FA: 800/6.6/90, NEX: 1, and ST: 4.5 mm), coronal (TR/TE/FA: 680/6.6/90, NEX: 1, and ST: 4.5 mm), axial (TR/TE/FA: 680/6.6/90, NEX: 1, and ST: 5.5 mm), and fat-suppressed PD and sagittal T2A (TR/TE/FA: 3800/100/90, NEX: 1, and ST: 4.4 mm) and coronal T1A (TR/TE/FA: 780/32/90, NEX: 1, and ST: 4.3 mm) sequences. Then, imaging was performed with FS 3D_WATSc T1A sequence, and MPR images were formed at axial, coronal, and sagittal planes (TR/TE/FA: 20/50/25, NEX: 2, and ST: 1 mm). Duration of 3D_WATSs sequence was 2.5 min, and total filming time was approximately 8.5 min.

All MRI images obtained were evaluated by two radiologists (with clinical experience of 4 years and 20 years) and an orthopedist (with clinical experience of 16 years) before arthroscopy. MRI images assessed by two radiologists and an orthopedist were not evaluated in terms of interobserver consistency.

Six cartilage sites (patella, trochlea, medial and lateral femoral condyles, and medial and lateral tibial plateaus) were examined in each patient. Cartilage signal changes, contour defects, and cartilage loss were recorded. Modified MRI staging was used for cartilage damage.

Arthroscopic examination was conducted on patients by orthopedics and traumatology physicians on day 1 to 15 following MRI examination. Lesions such as malacia in articular cartilage, blister fissure, or eburnation were evaluated during arthroscopy visually or by means of a probe and staged according to Outerbridge's classification.

The conventional MRI findings obtained were compared with the findings of 3D_WATSc sequence and correlated with the findings of arthroscopy. Arthroscopy reference diagnostic procedure was adopted, and MRI methods were compared through McNemar test. A p-value <0.05 was considered as statistically significant. Sensitivity, specificity, and positive and negative predictive values were calculated for MRI methods. SPSS software was used for statistical analysis (IBM SPSS Statistics for Windows, version 20.0; IBM Corp., Armonk, NY, USA).

The Izmir Bozyaka Training and Research Hospital Ethical Committee approved the study.

RESULTS

A total of 240 cartilage sites in 40 patients were evaluated in this prospective study of cartilage imaging during 1 year. Table 2 shows the distribution of the lesions detected in arthroscopy, conventional MRI, and 3D_WATSc sequences by stages. Figure 1 shows the number of patients with lesions.

Overall, 25.7% (n=9) of patients included in the study were females, and 74.3% (n=31) were males. Patients were in the age range of 13-57 years with a mean age of 31.68 years (26.77 for females and 33.38 for males). The patient group comprised young and middle-aged indi-

Table 2. Numbers of cartilage lesions by stages of arthroscopy, conventional MRI, and 3D_WATSc sequences.

	No.		
Stage	**Arthroscopy**	**MRI**	**3D_WATSc**
0	212	214	206
1	4	7	9
2	14	8	15
3	6	6	6
4	4	5	4
Total		240	

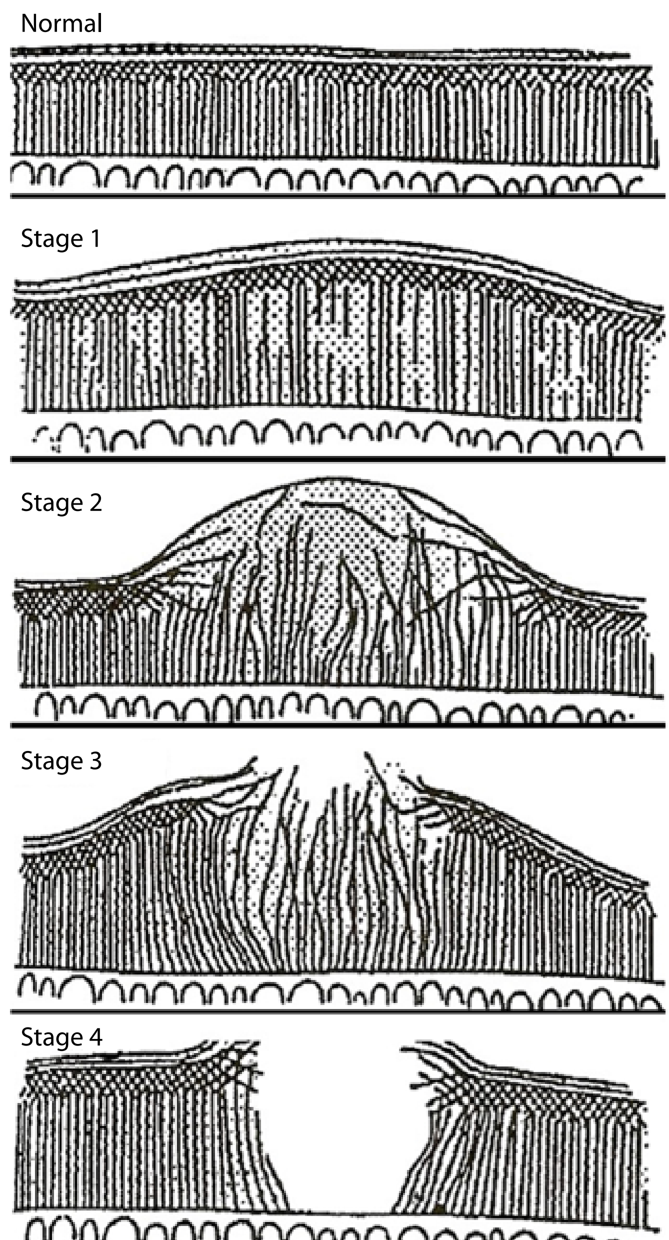

Figure 2. Pathological stages of cartilage defects. Malacia in the cartilage is observed in stage 1, blister formation in stage 2, ulceration in stage 3, and crater formation and eburnation in stage 4

viduals who had active daily lives and did sports, and 92.5% (n=37) of whom used their right knees dominantly. When cartilage lesions were evaluated in detail by all three methods, it was determined that the most commonly affected articular surface was the medial femoral condyle, and that the tibial medial plateau had the second highest incidence. The least cartilage damage was detected in the trochlear facet articular surface.

Chondromalacia was detected in 47% (n=19) of patients in arthroscopic examination. It was also detected in 55% (n=22) of patients in 3D_WATSc sequence and 42% (n=17) of patients in conventional MRI. 3D_WATSc sequence could detect chondromalacia in more patients than conventional MRI (Figure 3).

Chondromalacia was detected in 34 cartilage sites by 3D_WATSc sequence, 26 sites by conventional MRI, and 28 sites by arthroscopy (Table 2). When cartilage lesions were divided as per their stages, it was observed that the number of stage 1 lesions detected in arthroscopy (n=4) was less than that detected in conventional MRI (n=7) and 3D_WATSc sequence (n=9). Furthermore, early-stage chondromalacia lesions (stages 1 and 2) were observed to be predominant in the entire patient group (most common: stage 2 and rarest: stage 4). It was observed that all methods were similarly successful in the detection of late-stage chondromalacia lesions (stages 3 and 4). No cartilage damage was observed in 204 out of a total of 240 cartilage sites in both arthroscopy and 3D_WATSc sequence (Table 3) and in 205 in both arthroscopy and conventional MRI (Table 4) (stage 0, true negative). Figure 4 shows the normal cartilage structures in 3D_WATSc sequence.

When stage 1 chondromalacia lesions were examined, damage in three cartilage sites was observed in both arthroscopy and 3D_WATSc sequence. No lesion was detected in arthroscopy in six cartilage sites, where stage 1 damage was observed by 3D_WATSc sequence (false positive); and stage 1 chondromalacia was detected in one cartilage site in arthroscopy, but no lesions could be shown by 3D_WATSc sequence (false negative). Figure 5 shows the stage 1 cartilage damage in 3D_WATSc sequence.

When stage 2 chondromalacia lesions were examined, damage was observed in 13 cartilage sites in both arthroscopy and 3D_WATSc sequence. No lesion was detected by arthroscopy in two cartilage sites, which were shown to have stage 2 damage by 3D_WATSc sequence (false positive); and stage 2 chondromalacia was detected in arthroscopy in one cartilage site, but no lesion could be shown by 3D_WATSc sequence (false negative). Figure 6 shows the stage 2 cartilage damage in 3D_WATSc sequence.

Advanced stage chondromalacia lesions could be shown in arthroscopy and 3D_WATSc sequence with identical sensitivity, and stage 3 chondromalacia was detected in six cartilage sites and stage 4 chondromalacia in four cartilage sites. Figures 6 and 7 show the stage 3 and 4 cartilage damages in 3D_WATSc sequence.

Table 3 shows the comparative results of arthroscopy and 3D_WATSc and the numbers of lesions by stages. Table 4 shows the comparative results of arthroscopy and conventional MRI and the numbers of lesions by stages. Table 5 shows the success of conventional MRI and 3D_WATSc sequences in detecting lesions compared with arthroscopy results.

Table 3. Numbers of cartilage lesions by stages of arthroscopy and 3D_WATSc sequences.

	Arthroscopic stage					
3D_WATSc stage	**0**	**1**	**2**	**3**	**4**	**Total**
0	204	1	1	0	0	206
1	6	3	0	0	0	9
2	2	0	13	0	0	15
3	0	0	0	6	0	6
4	0	0	0	0	4	4
Total	212	4	14	6	4	240

Table 4. Numbers of cartilage lesions by stages of arthroscopy and conventional MRI.

	Arthroscopic stage					
MRI stage	**0**	**1**	**2**	**3**	**4**	**Total**
0	205	2	7	0	0	214
1	5	2	0	0	0	7
2	1	0	6	1	0	8
3	1	0	0	5	0	6
4	0	0	1	0	4	5
Total	212	4	14	6	4	240

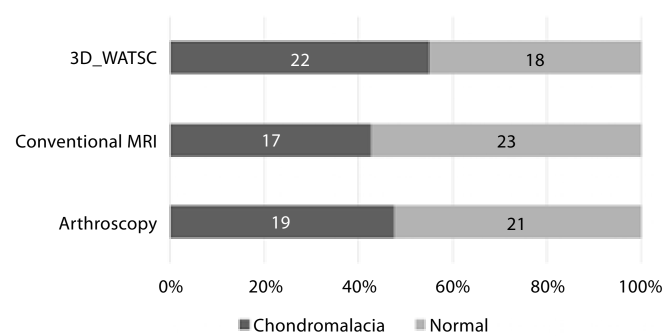

Figure 3. Sensitivity and specificity rates of conventional MRI and 3D_WATSc sequences; positive and negative predictive values

When sensitivities of MRI examinations regarding the detection of cartilage damage were compared, it was remarkable that both sensitivity and specificity of 3D_WATSc sequence were higher than those of conventional MRI. Furthermore, it was determined that positive and negative predictive values of conventional MRI examination were lower than those of 3D_WATSc sequence (Figure 8).

Incidence of early-stage chondromalacia in both MRI methods (stages 1 and 2) was found to be higher than that of advanced stage (stages 3 and 4). Lesion detection rates in early-stage and all chondromalacia cases by different techniques were analyzed,

Table 5. Success of conventional MRI and 3D_WATSc sequences in detecting lesions by stages of arthroscopy compared with gold standard arthroscopic diagnosis.

3D_WATSc stage	TP (%)	FP (%)	TN (%)	FN (%)	A (%)
1	3 (1.25)	6 (2.5)	204 (85)	1 (0.5)	92
2	13 (5.4)	2 (1)		1 (0.5)	
3	6 (2.5)	0		0	89
4	4 (1.7)	0		0	
Total	26 (10.8)	8 (3.3)		2 (1)	96
Conventional MRI stage					
1	2 (1)	5 (2.1)	205 (86)	2 (1)	89
2	6 (2.5)	2 (1)		7 (3)	
3	5 (2.1)	1 (0.5)		1 (0.5)	89
4	4 (1.7)	1 (0.5)		0	
Total	17 (7.3)	9 (4.1)		10 (4.2)	92

TP: true positive; FP: false positive; TN: true negative; FN: false negative; A: accuracy/observed consistency.

Figure 4. a-c. Normal cartilage views in 3D_WATSc sequence. Femoral condyle and tibial plateau (a) on the coronal plane; trochlear cartilage (b) and normal MRI views of the patellar cartilage (c) not including pathology are observed on the axial plane

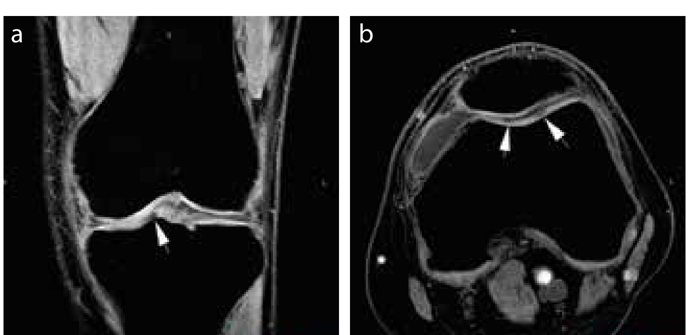

Figure 5. a, b. Stage 1 cartilage damage in 3D_WATSc sequence. Focal hypointense signal change fields are observed without contour irregularity in the tibial medial condyle (a) on the axial view and in the trochlear cartilage (b) on the coronal view

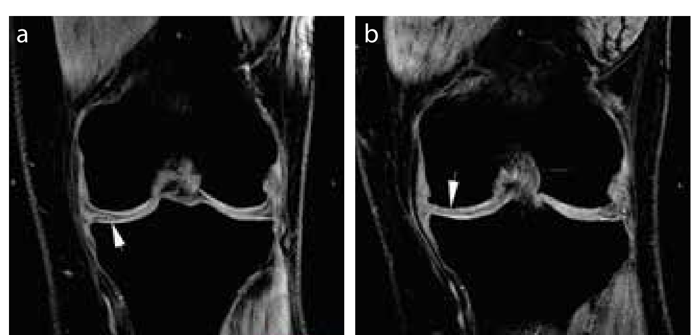

Figure 6. a, b. In 3D_WATSc sequence, stage 2 and 3 cartilage damages. <50% focal defect matching stage 2 cartilage damage in the tibial medial plateau (a) on the coronal view and >50% focal defect matching stage 3 cartilage damage in the femur medial condyle (b)

and a statistically significant difference was detected between 3D_WATSc sequence (96% and 92%, respectively) and conventional MRI examination (89% and 92.5%, respectively) ($p<0.05$). No statistically significant difference was found between both MRI techniques for advanced stage chondromalacia cases (89% and 89%, respectively).

Figure 7. In 3D_WATSc sequence, stage 4 cartilage damage. Focal full-thickness defect and medullary bone marrow edema on the subchondral area, matching stage 4 cartilage damage is observed in the femur medial condyle on coronal views

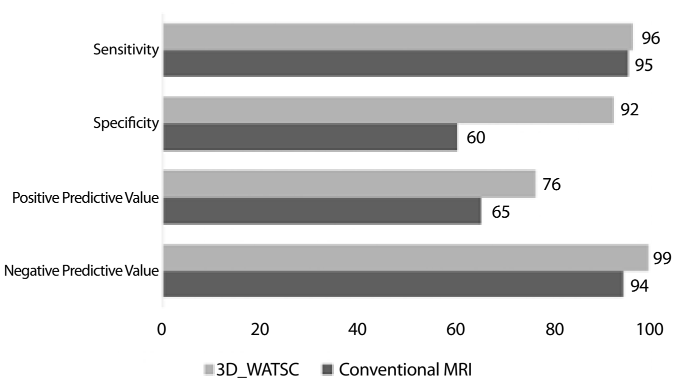

Figure 8. Numbers and rates of patients found to have chondromalacia in their arthroscopy, conventional MRI, and 3D_WATSc sequences

DISCUSSION

The purpose of cartilage imaging was to evaluate the integrity of the cartilage, thickness and volume of the cartilage matrix, and its relationship with the subchondral bone. Although the cartilage tissue covering the articular surface has a big area, it is indeed relatively thin. The knee joint has the thickest cartilage layer of the body. The thickest cartilage in the knee is 6-7 mm in the patella, and the thinnest cartilage is 2 mm in the tibial plateau (8, 20).

Imaging of the cartilage, treatment of the damage occurring in the cartilage, and follow-up of the outcomes of treatment have gained significant importance in recent years. There is a need for a diagnosis method that can provide direct and accurate information in the evaluation of articular cartilage in pre- and postoperative period, making correct diagnosis in suspected cases of cartilage pathologies and determining the numbers, localizations, and sizes of existing lesions. For these reasons, MRI is now the main diagnosis method in the examination of the cartilage. Although there are a multitude of studies in the literature related to MRI, no agreement could be reached on normal cartilage MRI techniques and detection of cartilage lesions. While TSE/FSE PD sequence added to SE-based T1 and T2W sequences is the most valuable sequence in cartilage evaluation in routine examinations, artifacts develop because of slice thickness and the "magic angle phenomenon" on curved surfaces. This decreases the sensitivity of the examination. Owing to volumetric examinations with thin slices that are fat-suppressed and some of which are liquid-suppressed, cartilage-specific 3D-GE sequences of which are performed, these artifacts are prevented, and very small-sized cartilage defects and signal changes can be detected by reconstructive multiplanar images (1, 4, 11, 21).

Cartilage pathologies are observed in the form of contour irregularities rather than signal changes in 3D-GE sequence. However, sensitivity is low and insufficient in the recognition of superficial lesions as adequate contrast resolution cannot be achieved between cartilage and synovial fluid, both of which are high-signaled in this sequence. Accuracy, sensitivity, and specificity rates were reported as 91%, 87%, and 97%, respectively, for this sequence in the literature (1, 5). While the highest accuracy was achieved in patellofemoral articular cartilage evaluation as in other cartilage imaging sequences, the accuracy rate increases in high-degree cartilage defects. The greatest disadvantage of the sequence is long examination time that may exceed 5 min and its insensitivity to extra cartilage and bone marrow pathology. Faster and more powerful gradient systems are needed to reduce the examination time (1, 11).

In our study, 3D_WATSc/T1A sequence is the equivalent of FS 3D T1A-GE sequence in Philips MR systems. Added to routine knee MRI examinations, this sequence was used as a low-cost and non-invasive tool to diagnose cartilage lesions of the knee joint earlier. Existence and degree of chondromalacia could be determined using this technique with higher sensitivity and specificity than conventional MRI images. The most successful values in similar studies in the literature were published by Recht et al. (5) and Disler et al. (22). Sensitivity and specificity degrees were found as 81% and 97%, respectively, in the study by Recht et al. (5) and as 93% and 94%, respectively, in the study by Disler et al. (22), both of which used 3D, fat-suppressed GE sequences. In our study, sensitivity and specificity ratios were very similar to these results at 92% and 96%, respectively. In addition, focal defects in hyaline cartilage could be shown better in our study compared with conventional MRI examination by 3D_WATSc/T1A sequence.

As there are no apparent surface changes in early-stage (stages 1 and 2) chondromalacia cases yet, minor changes that cannot be detected even in conventional MRI and arthroscopy, the reference diagnostic method, could be successfully shown by 3D_WATSc/T1A sequence. When detection rates of early-stage lesions were compared, a statistically significant difference was detected between 3D_WATSc/T1A sequence and other methods ($p<0.05$). This result showed that it is more difficult to detect internal structure and superficial malacia of the cartilage in arthroscopy than in 3D_WATSc sequence, which is superior than other techniques in detecting early-stage lesions.

In advanced stage (stages 3 and 4) chondromalacia cases, it was remarkable that 3D_WATSc/T1A sequence is more successful than conventional MRI in terms of sensitivity and specificity and shows total harmony with arthroscopy.

MRI and arthroscopy results were compared with other studies on the subject matter in the literature. Rose et al. (23) detected 94% sensitivity rate in early-stage chondromalacia and 98% sensitivity rate in advanced stage chondromalacia. Sang Hoon Lee et al. (24) detected sensitivity and specificity values in MRI examination that they conducted using inversion recovery-fast SE technique as 75% and 94%, respectively, in early-stage chondromalacia cases and as 80% and 99%, respectively, in advanced stage chondromalacia cases. These results are similar to the findings identified by our study.

Arthroscopic evaluation is a semi-quantitative technique depending on the observation of the practitioner and remains insufficient in terms of diagnosis in early-stage chondromalacia cases termed as "closed chondromalacia," where surface changes are not apparent, when evaluated together with the difficulties in probe use. For that reason, suspicions have emerged recently as to whether arthroscopy is the gold standard in evaluating early-stage cartilage disorders. Assessing arthroscopy as negative and MRI as false positive in showing lesions in cartilage degenerations not having surface irregularities poses high risk in rating chondromalacia. Therefore, MRI examination has a crucial role especially in the diagnosis and monitoring of symptomatic patients. Invasive procedures requiring anesthesia, such as arthroscopy or arthrography, which will be conducted in these patients for diagnosis, will decrease, and new approaches will emerge with conservative treatment methods. However, it will be indispensable to perform arthroscopic examination in case treatments to be conducted result in failures

A total of eight cartilage sites that were shown in MRI by 3D_WATSc/T1A sequence, but where arthroscopy was negative, were detected in our study. However, it is required to monitor both clinical and MRI findings of these patients in the long term for the purpose of verifying MRI results conclusively. Not including long term follow-ups of patients leads to a relative limitation in our study.

Gradually increasing the number of studies on the physiological changes of articular cartilage started to be conducted with widespread use of 3 Tesla MRI devices. Both physiological and morphological changes in the cartilage can be displayed simultaneously by the increased magnetic field power, and substantial increases can be observed in contrast resolution owing to the increased signal/noise ratio (1). It was shown in a limited number of studies that information close to histology is obtained with the use of contrast substance in 3 T devices with delayed gadolinium-enhanced MRI of cartilage technique, showing biochemical structure of the cartilage. However, comprehensive studies are still in progress.

CONCLUSION

Cartilage-specific, fat-suppressed 3D_WATSc/T1A MR sequence is more successful than conventional MRI in the determination of knee joint cartilage pathologies. Signal of articular cartilage is higher than other surrounding tissues; thus, high-contrast resolution is achieved, and cartilage lesions are detected more easily. Particularly, it can be even more successful than arthroscopy in the detection of early-stage cartilage damage. Through the decrease in artifacts, optimum evaluation of especially curved surfaces and of patellar and trochlear cartilages arranged perpendicularly to the joint is possible with high-resolution two-dimensional multiplanar reconstruction views acquired from 1 mm three-dimensional images. Despite the increase in the examination time, absence of the need for formation of image after examination allows use of this sequence routinely. 3D_WATSc/T1A is a low-cost, non-invasive, and repeatable tool that can be added to a conventional knee MRI examination adjunctly and can show hyaline cartilage lesions beginning from early-stage.

Ethics Committee Approval: Ethical committee approval of the study was obtained from Izmir Bozyaka Training and Research Hospital Ethical Committee, March 2013, Izmir.

Informed Consent: Written informed consent was obtained.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - İ.A., Ö.E, Z.A.; Design - İ.A., Ö.E., Z.A.; Supervision - İA., S.C., Ö.E, Z.A.; Resource - İ.A., A.K., Z.A.; Materials - İ.A., S.C., A.K.; Data Collection and/or Processing - İ.A., A.M.K, S.C., A.K.; Analysis and/or Interpretation - İ.A., A.M.K., Ö.E.,A.K.; Literature Search - İ.A., S.C., A.K.; Writing - İ.A., A.M.K.; Critical Reviews - A.M.K.., Ö.E.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Arkun R. Imaging of articular cartilage. Acta Orthop Traumatol Turc 2007; 41 Suppl 2: 32-42.
2. Hayes CW, Conway WF. Evaluation of articular cartilage: radiographic and cross-sectional imaging techniques. Radiographics 1992;12: 409-28. [CrossRef]
3. Imhof H, Nobauer-Huhmann IM, Krestan C, Gahleitner A, Sulzbacher I, Marlovits S, et al. MRI of the cartilage. Eur Radiol 2002; 12: 2781-93.
4. McCauley TR, Kier R, Lynch KJ, Jokl P. Chondromalacia patellae: diagnosis with MR imaging. AJR Am J Roentgenol 1992; 158: 101-5. [CrossRef]
5. Recht MP, Kramer J, Marcelis S, Pathria MN, Trudell D, Haghighi P, et al. Abnormalities of articular cartilage in the knee: analysis of available MR techniques. Radiology 1993; 187: 473-8. [CrossRef]
6. Yao L, Gentili A, Thomas A. Incidental magnetization transfer contrast in fast spin-echo imaging of cartilage. J Magn Reson Imaging 1996; 6: 180-4. [CrossRef]
7. Bredella MA, Tirman PF, Peterfy CG, Zarlingo M, Feller JF, Bost FW et al. Accuracy of T2-weighted fast spin-echo MR imaging with fat saturation in detecting cartilage defects in the knee: comparison with arthroscopy in 130 patients. AJR Am J Roentgenol 1999; 172: 1073-80. [CrossRef]
8. Kneeland JB, MR Imaging of Articular Cartilage and of Cartilage Degeneration. In: Stoller DW, eds. Magnetic Resonance Imaging in Orthopaedics Sports and Medicine. 2nd Edition, Philadelphia; Lippincott-Raven Publishers, 1997; 83-91.
9. Kneeland BJ. Principles of MR Imaging of Cartilage. In Erden İ. eds. Kas-İskelet Manyetik Rezonans. Pozitif Matbacılık Ltd. Ankara 2004; 15-16.
10. Disler DG, Recht MP, McCauley TR. MR imaging of articular cartilage. Skeletal Radiol 2000; 29: 367-77. [CrossRef]
11. Imaging of articular cartilage Prof. Dr. K. Verstraete Ghent Universty. Available from: URL: http://www.vvsport.be/userfiles/Powerpoint%20Verstraete%20Koenraad.pdf Accessed at: 19.05.17
12. Gür E, Baydar ML. Patellar kondromalazinin artroskopik tanı ve tedavisi. Acta Othop Traumatol Turc 1995; 29: 385-90.
13. Bullogh P, Cawston T. Pathology and biochemistry of osteoarthritis. Osteoarthritis 1994; 29-58.

14. Hayes CW, Sawyer RW, Conway WF. Patellar Cartilage Lesions: In Vitro Detection and Staging with MR Imaging and Pathologic Correlation. Radiology 1990; 176: 479-83. [CrossRef]
15. Şahin G. MR Artrografi. In: Erden I, eds. Kas-İskelet Manyetik Rezonans. Pozitif Matbacılık Ltd. Ankara 2004; 6-14.
16. Aydın TA, Özenci M. Artroskopinin Avantaj ve Dezavantajları, Artroskopi Tekniği Anatomisi ve Komplikasyonları. In Ege R eds. Diz Sorunları. Ankara: Bizim Büro Basımevi, 1998.
17. Bauer and Jackson: Chondral lesion of femoral condyles: A system of arthroscopic clasification. Arthroscopy 1988; 4: 97-102. [CrossRef]
18. Insall J. Current Concepts Review: patellar pain. J Bone Joint Surg Am 1982; 64: 147-52. [CrossRef]
19. Outerbridge RE. The etiology of chondromalacia patellae. J Bone Joint Surg Br 1961; 43: 752-7. [CrossRef]
20. Suh JS, Lee SH, Jeong EK, Kim DJ. Magnetic resonance imaging of articular cartilage. Eur Radiol 2001; 11: 2015-25. [CrossRef]
21. Mc Cauley RT, Recht MP, Disler DG. Clinical imaging of articular cartilage in the knee. Semin Musculoskelet Radiol 2001; 5: 293-304. [CrossRef]
22. Disler DG, McCauley TR, Wirth CR, Fuchs MD. Detection of knee hyaline cartilage defects using fat-suppressed three-dimensional spoiled gradient-echo MR imagining and corelation with arthroscopy. AJR Am J Roentgenol 1995; 165: 377-82. [CrossRef]
23. Rose PM, Demlow TA, Szumowski J, Quinn SF. Chondromalacia patellae: fat-suppressed MR imaging. Radiology 1994; 193: 437-40. [CrossRef]
24. Lee SH, Suh JS, Cho J, Kim JS, Kim JS. Evaluation of chondromalacia of the patella with axial inversion recovery fast spin-echo imaging. J Magn Reson Imaging 2001; 13: 412-6. [CrossRef]