Egyptian Journal of Radiology and Nuclear Medicine

RESEARCH

Open Access

Ankylosing spondylitis impact on knee cartilage thickness: correlation with demographic data and clinical characteristics

Omnia R. Adel[1], Shereen R. Kamel[1*], Fatma A. Mohamed[1], Nadia F. El Ameen[2] and Ayman F. Darwish[1]

Abstract

Background Ankylosing spondylitis (AS) is a progressive inflammatory disease involving cartilaginous structures in the spine and peripheral joints**.** However, the number of the studies assessing knee cartilage thickness in AS and its correlations with parameters of disease activity/severity is even less. We aimed to assess the impact of AS on knee cartilage thickness using musculoskeletal ultrasound (MSUS) and magnetic resonance imaging (MRI).

Methods Twenty-five AS patients and 25 healthy individuals (15 served for MSUS assessment, and 10 served for MRI assessment) were included. By employing MRI "using a 1.5-T machine" and MSUS "with a 10–18-MHz linear probe," respectively, the thickness of the femorotibial cartilage and femoral cartilage was assessed.

Results Compared to healthy controls, AS patients showed statistically significantly thinner cartilage thickness ($P < 0.05$) at all femorotibial cartilage subdivisions and the medial femoral condyle and intercondylar area on both sides. Femoral cartilage thickness measurements either assessed by MSUS or MRI were negatively correlated with age, measures of disease activity, and Bath Ankylosing Spondylitis Radiology Index for the spine (BASRI-s) ($P < 0.05$). However, MRI tibial cartilage thickness was negatively correlated with disease duration and measures of spinal mobility, functional limitation, and BASRI-s ($P < 0.05$). MRI total cartilage thickness measurements at the femoral condyle were negatively correlated with Bath Ankylosing Spondylitis Functional Index (BASFI) and Ankylosing Spondylitis Disease Activity Score-*erythrocyte sedimentation rate* (ASDAS ESR) ($P = 0.04$ and $P = 0.03$, respectively). A positive correlation was found between MSUS and MRI total femoral cartilage thickness ($P = 0.02$).

Conclusions The knee cartilage thickness of AS patients was thinner than that of healthy controls. The correlations between cartilage thickness and patient variables demonstrate MSUS and MRI's utility in identifying knee cartilage loss areas in AS patients.

Keywords Ankylosing spondylitis, Femoral cartilage thickness, Tibial cartilage thickness, Magnetic resonance imaging, Musculoskeletal ultrasound

*Correspondence:
Shereen R. Kamel
shereen.refaat@mu.edu.eg
[1] Rheumatology and Rehabilitation Department, Faculty of Medicine, Minia University, Minya 61111, Egypt
[2] Radiology Department, Faculty of Medicine, Minia University, Minya, Egypt

Background

Ankylosing spondylitis (AS) is a persistent, inflammatory condition that influences the axial skeleton over time [1]. Sacroiliitis, enthesitis, and peripheral arthritis are their defining features [2]. AS involved the cartilaginous structures in the spine and peripheral joints [3]. According to a recent study, the immune system's primary target

in spondyloarthropathy may be cartilage [4]. Various approaches have been used to directly measure the thickness of articular cartilage in cadavers; however, these techniques are intrusive and do not allow measurements to be taken in vivo [5, 6].

To be fair, magnetic resonance imaging (MRI) is thought to be the most efficient non-invasive technique for evaluating cartilage. However, there are a number of technological and financial restrictions to using MRI regularly to evaluate cartilage [7].

Musculoskeletal ultrasound (MSUS) is a cheap, non-invasive, secure, and convenient technique [8]. It has been shown to be a reliable method for determining the thickness of the distal femoral cartilage, and tests of the femoral cartilage using ultrasound are known to be highly correlated with histological grading [9, 10].

As far as we are aware, this is the first study measuring knee cartilage thicknesses in patients with AS by MRI and determining correlations with US measurements and different disease parameters.

Methods

Study plan and population

Over the course of 7 months, our analytical cross-sectional study was carried out and included 25 patients [17 males and eight females], who fulfilled the modified 1984 New York criteria for ankylosing spondylitis [11] (mean age 28.4 ± 9.4 years; range 20–37 years). All patients were attending Rheumatology and Rehabilitation Outpatient Clinics. Fifteen healthy individuals (who were healthcare workers at the Main Hospital) were served for MSUS assessment of femoral cartilage thickness, and another 10 healthcare workers at the Obstetrics and Gynecology Hospital were served for MRI assessment "as the MSUS and MRI were not in the same hospital." All controls matched for age and body mass index (BMI). All study participants provided their informed permission. The ethics committee of the Faculty of Medicine gave the study their approval.

Patients who had recently undergone joint or soft tissue surgery, those who had received corticosteroid injections into the knee, those who had congenital or traumatic knee problems, and those who had severe neurological, cardiac, pulmonary, renal, or malignant diseases were all excluded from the study.

Clinical and functional assessment

Bath Ankylosing Spondylitis Disease Activity Index (BASDAI) [12] and Ankylosing Spondylitis Disease Activity Score (ASDAS CRP and ASDAS ESR) were used to assess disease activity [13, 14]. The Bath Ankylosing Spondylitis Metrology Index (BASMI) 3-point answer scale [15] and the Bath Ankylosing Spondylitis Functional Index (BASFI) [16] were used to measure the degree of spinal mobility and functional restriction.

Conventional X-rays radiologic scoring methods

All patients had to undergo a recent X-ray procedure that consisted of taking an anteroposterior and lateral views of the spine and an anteroposterior view of the pelvis. Bath Ankylosing Spondylitis Radiology Index for the spine (BASRI-s) [17] was used to analyze the conventional X-ray findings in all patients.

Musculoskeletal ultrasonographic cartilage measurements

All femoral cartilage evaluations were performed by the same physician who was experienced in the musculoskeletal US (EULAR Certified Trainer MSUS) using a linear array probe (10–18 MHz, Siemens Acuson P300, Germany). When the individuals were comfortably seated on the examination table with their knees in maximum flexion, a physician assessed the thickness of the femoral articular cartilage [9, 18]. Each knee's right lateral condyle (RLC), right intercondylar region (RIA), right medial condyle (RMC), left medial condyle (LMC), left intercondylar area (LIA), and left lateral condyle were measured at the midpoint (LLC). The distance between the thin hyperechoic line at the synovial space/cartilage interface and the sharp hyperechoic line at the cartilage bone interface was used to determine the cartilage thickness [19]. The lateral femoral condyle, medial femoral condyle, and intercondylar area were added together, and the means were calculated, to determine the total femoral cartilage thickness.

MRI examination

The physician assessing the MRI scans was unaware of the US data. Both knees of the patients were first scanned by the US, and then, they were taken for MRI. All patients were examined by MRI using a 1.5-T MR machine (Achieva, Philips medical system, the Netherlands). All patients were imaged using the following protocol in sagittal and coronal STIR (TR: 4080 ms; TE: 30 ms; and slice thickness 4 mm), sagittal PD (TR: 2000 ms; TE: 17 ms; and 4-mm slice thickness), axial and sagittal T2 (TR: 3500 ms; TE: 90 ms; and 4-mm slice thickness). Segmentation was done for the cartilage as follows; (1) distal femoral cartilage and (2) tibial cartilage. The segmented cartilage area is then subdivided into medial and lateral compartments. Three functional regions were defined: the anterior region, the middle region, and the posterior region. The overall maximal medial and lateral cartilage width for each condyle included the central and thickest regions of each condyle, and excluded boundary regions were used to calculate the average cartilage thicknesses [20].

Statistical analysis

The data were analyzed with SPSS 21.0. Additionally, to descriptive statistics by number and percent, there were mean and SD calculations. Comparing qualitative variables was done using the Chi-square (χ^2) [2] test. The difference between the means of the two groups for interval and ordinal variables was compared using the *T*-test or Mann–Whitney *U*-test. There were calculated Pearson correlation coefficients (*r*). $P<0.05$ was used to define the statistical significance level.

Results

Fifty knees from 25 AS patients and 50 knees from 25 healthy people were measured using MRI and US (30 knees were used to test the thickness of the femoral cartilage using the US, and 20 knees were used for MRI).

Clinical characteristics of AS patients

The mean age values of AS patients were 28.4 ± 4.9 years, BMI values were 29.2 ± 2.7 kg/m^2, and mean disease duration was 4.7 ± 2.7 years. Knee pain was found in 17 (68%) patients. The mean visual analog scale for pain (VAS) was 13.6 ± 20.9, the mean ASDAS ESR was 2.59 ± 1.04, the mean ASDAS CRP was 2.48 ± 0.74, the BASDI was 4.21 ± 1.27, the mean BASFI was 6.04 ± 1.88, mean BASMI was 3.84 ± 1.55, and mean BASRI was 5.00 ± 1.09. AS patients were currently under nonsteroidal anti-inflammatory drugs ($N=24$), sulfasalazine ($N=21$), and methotrexate ($N=2$) treatment, but none of them used tumor necrosis factor inhibitors.

MRI measurements

Fifty knees of 25 AS patients and 20 knees of the 10 healthy individuals (six males and four females) were examined. The mean age values of healthy individuals were 28.2 ± 3.5 years, and BMI values were 28.8 ± 2.9 kg/m^2 ($P>0.05$ in comparison with AS patients). Tables 1 and 2 show MRI cartilage thickness values at the subdivisions of femoral and tibial condyles, respectively, for patients and controls. The average cartilage thicknesses for medial and lateral cartilage of femoral and tibials condyle and the total femorotibial cartilage thicknesses were calculated for patients and controls as shown in Table 3. At all measurement sites, AS patients' femoral cartilage was thinner than that of the healthy controls, with statistically significant differences ($P<0.05$).

MRI images of cartilage thickness measurements at femoral and tibial condyles in AS patients are shown in Figs. 1 and 2.

MSUS measurements

Fifty knees of 25 AS patients and 30 knees of the 15 healthy individuals (eight males and seven females) were examined. The mean age values of healthy individuals were 26.9 ± 4.7, and BMI values were 29.8 ± 2.6 kg/m^2 ($P>0.05$ in comparison with AS patients). Table 4 shows the femoral cartilage thickness values for patients and controls. At all measurement sites, femoral cartilage in AS patients was thinner than that in healthy controls; statistically significant differences were found at the medial

Table 1 Comparison of MRI cartilage thickness measurements at subdivision of femoral condyle in AS patients and controls

	Patients ($n=25$)	Controls ($n=10$)	*P*
(a) *Medial compartment*			
R ant (mm)	1.66 ± 0.56 (0.70–2.70)	3.47 ± 0.61 (2.90–4.60)	0.0001*
R middle (mm)	1.63 ± 0.70 (0.50–3.0)	3.08 ± 0.65 (2.10–4.00)	0.0001*
R post (mm)	1.68 ± 0.38 (0.90–2.70)	3.81 ± 0.67 (2.80–4.90)	0.0001*
L ant (mm)	1.60 ± 0.64 (0.40–2.70)	3.25 ± 0.55 (2.70–4.50)	0.0001*
L middle (mm)	1.56 ± 0.57 (0.80–2.70)	2.95 ± 0.60 (2.0–3.90)	0.002*
L post (mm)	2.08 ± 0.61 (1.20–3.20)	3.61 ± 0.61 (2.60–4.70)	0.0001*
(b) *Lateral compartment*			
R ant (mm)	1.56 ± 0.77 (0.40–3.10)	3.19 ± 1.18 (2.40–5.10)	0.0001*
R middle (mm)	1.79 ± 0.71 (0.80–3.50)	2.75 ± 0.97 (1.60–4.80)	0.003*
R post (mm)	1.90 ± 0.67 (0.70–3.50)	3.49 ± 0.85 (2.60–5.40)	0.0001*
L ant (mm)	1.54 ± 0.79 (0.40–3.10)	3.05 ± 1.08 (2.30–5.0)	0.0001*
L middle (mm)	1.78 ± 0.73 (0.60–3.50)	2.81 ± 0.90 (1.50–4.80)	0.001*
L post (mm)	1.96 ± 0.73 (0.70–3.50)	3.29 ± 0.75 (2.40–5.20)	0.0001*

Data were presented as mean ± SD (range)

R, right; ant, anterior; post, posterior; L, left; and mm, millimeter

*Significant ($P<0.05$)

Table 2 Comparison of MRI cartilage thickness measurements at subdivision of tibial condyle in AS patients and controls

	Patients ($n=25$)	Controls ($n=10$)	*P*
(a) *Medial compartment*			
R ant (mm)	1.34 ± 0.43 (0.60–2.00)	3.21 ± 0.59 (2.50–4.10)	0.0001*
R middle (mm)	1.61 ± 0.54 (0.70–3.10)	3.06 ± 0.56 (2.20–3.90)	0.0001*
R post (mm)	1.50 ± 0.37 (1.0–2.10)	3.65 ± 0.82 (1.60–4.10)	0.0001*
L ant (mm)	1.25 ± 0.40 (0.60–2.00)	2.79 ± 0.49 (2.30–4.0)	0.0001*
L middle (mm)	1.59 ± 0.50 (0.70–3.10)	2.86 ± 0.36 (2.00–3.70)	0.0001*
L post (mm)	1.45 ± 0.32 (1.0–2.10)	1.45 ± 0.32 (1.0–2.10)	0.0001*
(b) *Lateral compartment*			
R ant (mm)	1.35 ± 0.37 (0.70–2.20)	3.19 ± 0.48 (2.70–4.0)	0.0001*
R middle (mm)	2.02 ± 0.77 (1.0–3.70)	3.01 ± 0.51 (1.90–3.70)	0.0007*
R post (mm)	1.96 ± 0.73 (0.90–3.50)	3.32 ± 0.47 (2.50–4.10)	0.0001*
L ant (mm)	1.29 ± 0.31 (0.70–2.20)	2.91 ± 0.41 (2.40–3.90)	0.0001*
L middle (mm)	1.91 ± 0.72 (1.0–3.70)	2.95 ± 0.41 (1.70–3.60)	0.0002*
L post (mm)	1.86 ± 0.70 (0.90–3.50)	2.87 ± 0.40 (2.30–4.0)	0.0002*

Data were presented as mean ± SD (range)

R, right; ant, anterior; post, posterior; L, left; and mm, millimeter

*Significant ($P<0.05$)

Table 3 Comparison of MRI femorotibial cartilage thickness measurements in AS patients and controls

	Patients ($n=25$)	Controls ($n=10$)	*P*
Total cartilage thickness at femoral condyle (mm)	1.89 ± 0.23 (1.50–2.70)	2.11 ± 0.32 (1.70–2.90)	0.03*
Total cartilage thickness at tibial condyle (mm)	2.03 ± 0.11 (1.80–2.20)	2.19 ± 0.28 (3.10–5.00)	0.02*
Total femorotibial cartilage thickness (mm)	1.94 ± 0.14 (1.80–2.40)	2.15 ± 0.29 (1.80–2.90)	0.01*

Data presented as mean ± SD (range)

mm, millimeter

*Significant ($P<0.05$)

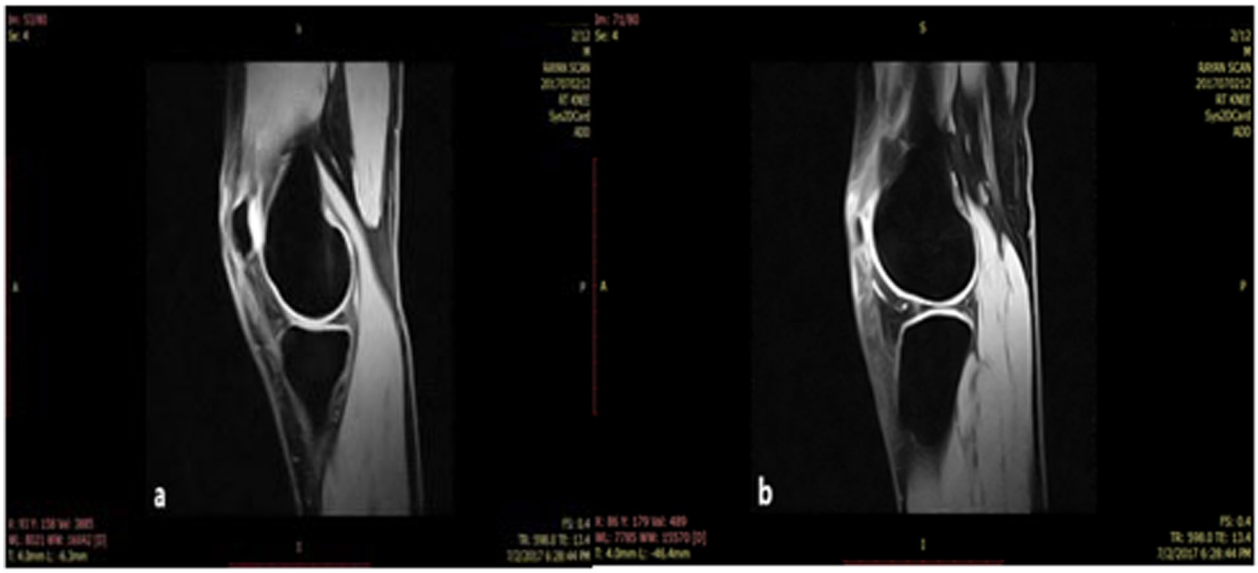

Fig. 1 Sagittal STIR images of male patient aged 30 years show reduced cartilage thickness of the anterior region of the medial compartment of femoral and tibial condyles (**a**) and middle region of the lateral compartment of femoral condyle (**b**)

femoral condyle and intercondylar area in both the right and left knees ($P<0.05$). Figure 3 displays musculoskeletal ultrasonographic images of measurements of femoral cartilage thickness in an AS patient.

Correlation between MRI measurements of femoral/tibial cartilage thickness and demographic information and clinical characteristics

Correlations of MRI measurements at subdivisions of femoral and tibial condyles with demographic data and clinical characteristics are shown in Table 5. MRI total cartilage thickness measurements at the femoral condyle were negatively correlated with BASFI and ASDAS ESR ($r=-0.40$, $P=0.04$ and $r=-0.37$, $P=0.03$ respectively), but the total MRI cartilage thickness measurements at the tibial condyle and the total femorotibial cartilage thickness were not correlated with any of demographic data or clinical characteristics. Taking into consideration, that there was a very strong positive correlation between the femoral and the tibial cartilage thickness ($r=0.9$, $P<0.001$).

Correlation of MSUS femoral cartilage thickness values with demographic data and clinical characteristics

Ultrasonographic femoral cartilage thickness at LIA, LLC, and RMC was negatively correlated with age, BASRI, and ASDAS ESR, respectively ($r=-0.37$, $P=0.04$; $r=-0.31$, $P=0.04$; and $r=-0.38$, $P=0.02$, respectively). Disease duration or BMI had no correlation with cartilage thickness for all regions.

Correlation between MSUS and MRI total femoral cartilage thickness

Musculoskeletal ultrasonographic total femoral cartilage thickness had a positive correlation with MRI total femoral cartilage thickness ($r=0.49$, $P=0.02$) as shown in Fig. 4. No other correlation could be detected between the US and MRI knee cartilage thickness in other regions.

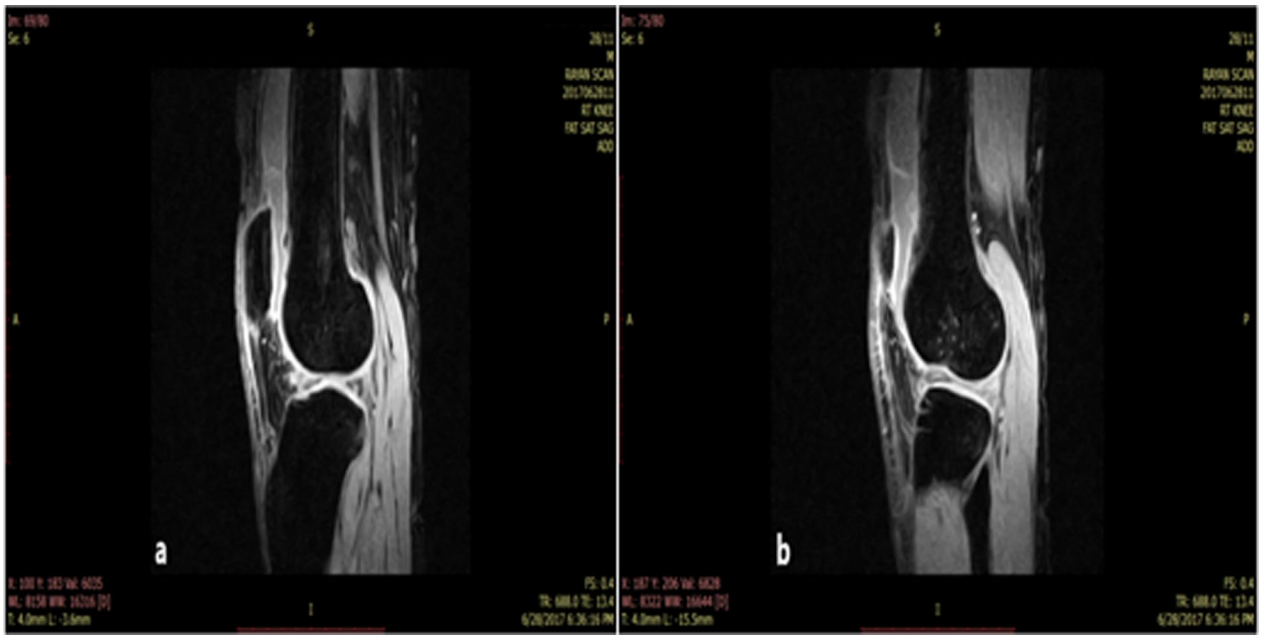

Fig. 2 Sagittal STIR images of male patient aged 34 years show marked reduction in the cartilage thickness of both medial and lateral compartments of femoral (**a**) and tibial condyles (**b**)

Table 4 Comparison of musculoskeletal ultrasonographic femoral cartilage thickness measurements in AS patients and controls

	Patients ($n=25$)	Controls ($n=15$)	*P*
RLC (mm)	2.08 ± 0.43 (1.30–2.9)	2.17 ± 0.41 (1.80–3.10)	0.58
RIA (mm)	2.38 ± 0.34 (1.80–3.0)	2.62 ± 0.31 (2.10–3.10)	0.04*
RMC (mm)	2.03 ± 0.29 2.38 ± 0.34	2.26 ± 0.26 (2.0–2.90)	0.02*
LLC (mm)	2.37 ± 0.29 (1.70–2.80)	2.55 ± 0.47 (1.50–3.10)	0.13
LIA (mm)	2.42 ± 0.34 (2.0–3.40)	2.66 ± 0.32 (2.10–3.20)	0.03*
LMC (mm)	2.15 ± 0.23 (1.60–2.60)	2.32 ± 0.23 (1.90–2.70)	0.02*

Data presented as mean ± SD (range)

RLC, right lateral femoral condyle; RIA, right intercondylar area; RMC, right medial femoral condyle; LLC, left lateral femoral condyle; LIA, left intercondylar area; LMC, left medial femoral condyle; and mm, millimeter

*Significant ($P<0.05$)

Discussion

Knees, hips, or other joints are involved in 25%–70% of AS patients [21]. In comparison with the other joints, the knee joint has separate cartilage compartments that are easily identified on MRI [22] and US [10].

Our results showed that AS patients had thinner knee cartilage thickness measurements than the healthy controls with statistically significant differences.

The structural damage in AS was predicted using a variety of biomarkers. The various types of biomarkers include genetic markers, markers of inflammation, markers of cartilage and bone turnover, and others. Radiographic damage and AS progression both heavily depend on cartilage degradation [23–25]. A study by Kim et al. [3] found elevated C-propeptide of type II collagen (CPII), 846 epitopes, and CPII:C2C ratio in AS patients compared to controls. In individuals with AS, *anti-tumor necrosis factor* (anti-TNF) medications may affect cartilage metabolism by reducing type II collagen breakdown and boosting aggrecan turnover [26].

For evaluating the size of the knee cartilage in vivo, reliable imaging methods include magnetic resonance imaging and ultrasonography [10, 27]. Most earlier research has looked at the peak and mean cartilage thickness of the entire surface to quantify the cartilage thickness distribution. Other studies have separated the femur's two condyles and trochlea into distinct sections [28–30].

Most of our patients have moderate to high activity (according to ASDAS), and 68% of them have knee pain. When compared to healthy controls, AS patients had bilaterally statistically significant ($P<0.05$) thinner knee cartilage thickness at all subdivisions of the femoral and tibial condyles. Moreover, total femoral, total tibial, and total femorotibial cartilage thicknesses were significantly reduced ($P<0.05$).

The present study reported the correlation of MRI knee cartilage thickness values with patients' characteristics. Femoral cartilage thickness was negatively correlated with age which was in agreement with Roberts et al. [31]. Moreover, femoral cartilage thickness was negatively correlated with the measure of spinal mobility (BASMI)

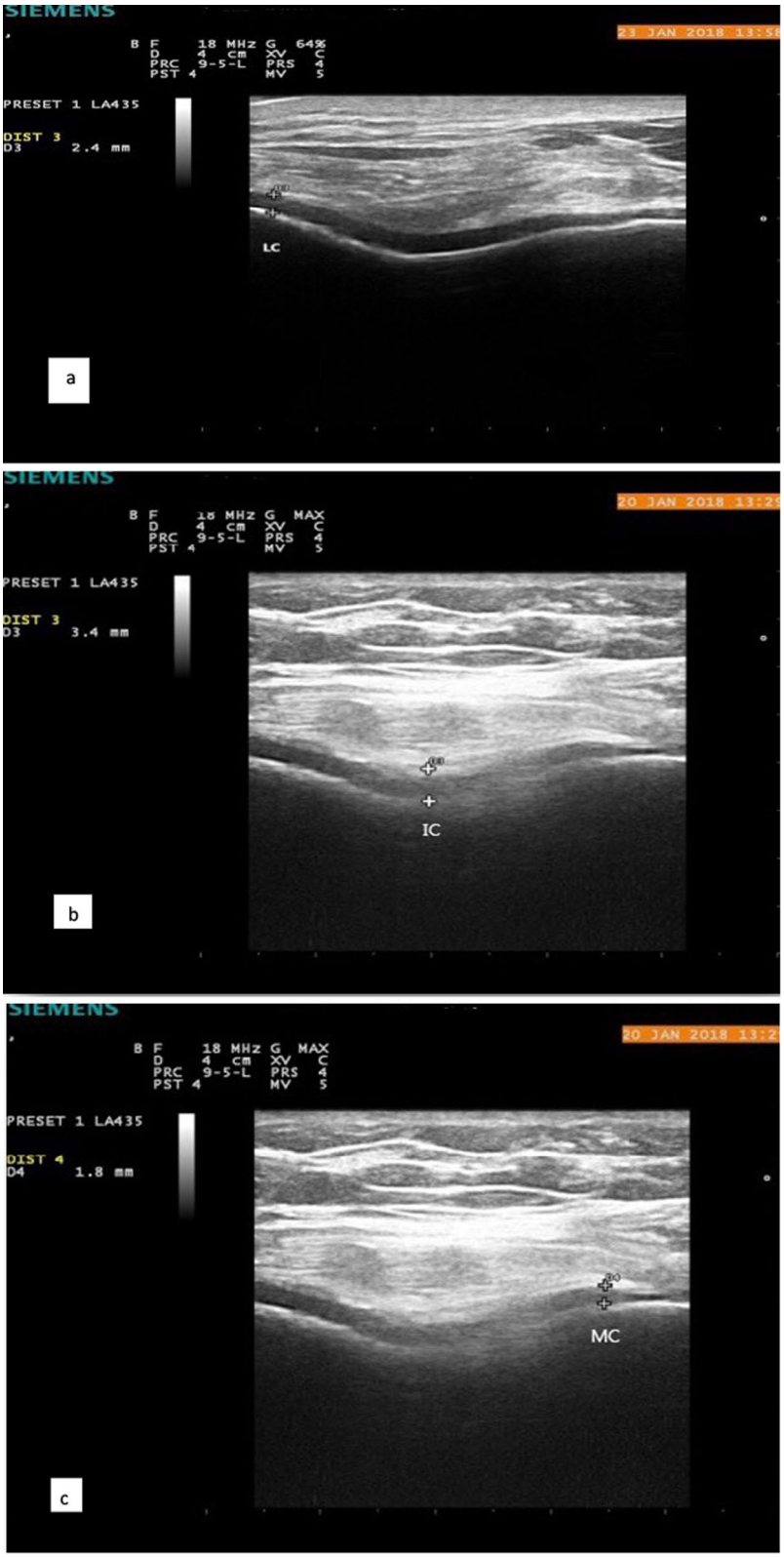

Fig. 3 B-mode ultrasound transverse scan of the anterior knee joint in male patient aged 29 years showing thickness of femoral cartilage at **a** lateral condyle = 2.4 mm, **b** intercondylar area = 3.4 mm, and **c** medial condyle = 1.8 mm

Table 5 Correlations of MRI cartilage thickness measurements at subdivision of femoral and tibial condyles with demographic data and clinical characteristics

	R ant	R middle	R post	L ant	L middle	L post
	(a) *Medial femoral compartment*					
Age	−0.34 (0.04*)	−0.24 (0.25)	−0.41 (0.04*)	−0.41 (0.04*)	−0.12 (0.57)	−0.47 (0.01*)
BASMI	0.16 (0.44)	0.33 (0.11)	−0.52 (< 0.001*)	0.14 (0.51)	0.09 (0.65)	−0.29 (0.05)
BASRI	0.13 (0.54)	−0.41 (0.04*)	−0.46 (0.02*)	0.08 (0.71)	0.10 (0.63)	−0.09 (0.65)
ASDAS ESR	−0.48 (0.01*)	−0.36 (0.05)	0.20 (0.33)	−0.50 (0.01*)	−0.13 (0.53)	−0.40 (0.05)
	(b) *Lateral femoral compartment*					
ASDAS CRP	−0.30 (0.04*)	0.19 (0.36)	0.48 (0.21)	−0.33 (0.04*)	0.20 (0.35)	0.49 (0.73)
ASDAS ESR	−0.50 (0.02*)	−0.16 (0.42)	0.48 (0.09)	−0.53 (0.01*)	−0.16 (0.45)	0.51 (0.52)
	R middle		**R post**	**L middle**		**L post**
	(c) *Medial tibial compartment*					
BASFI	−0.48 (0.01*)		0.26 (0.21)	−0.48 (0.01*)		0.26 (0.21)
BASMI	0.29 (0.15)		−0.45 (0.02*)	0.29 (0.15)		−0.45 (0.02*)
BASRI	−0.31 (0.04*)		0.21 (0.32)	0.31 (0.05)		0.21 (0.32)
	(d) *Lateral tibial compartment*					
Disease duration	−0.35 (0.02*)		−0.09 (0.66)	−0.35 (0.05)		−0.09 (0.66)

Data presented as *r* (*P*)

R = right, L = left, ant = anterior, post = posterior, BASMI = Bath Ankylosing Spondylitis Metrology Index, BASRI = Bath Ankylosing Spondylitis Radiographic Index, ASDAS ESR = Ankylosing Spondylitis Disease Activity Score-erythrocyte sedimentation rate, ASDAS CRP = Ankylosing Spondylitis Disease Activity Score-C-reactive protein, and BASFI = Bath Ankylosing Spondylitis Functional Index, *$P < 0.05$

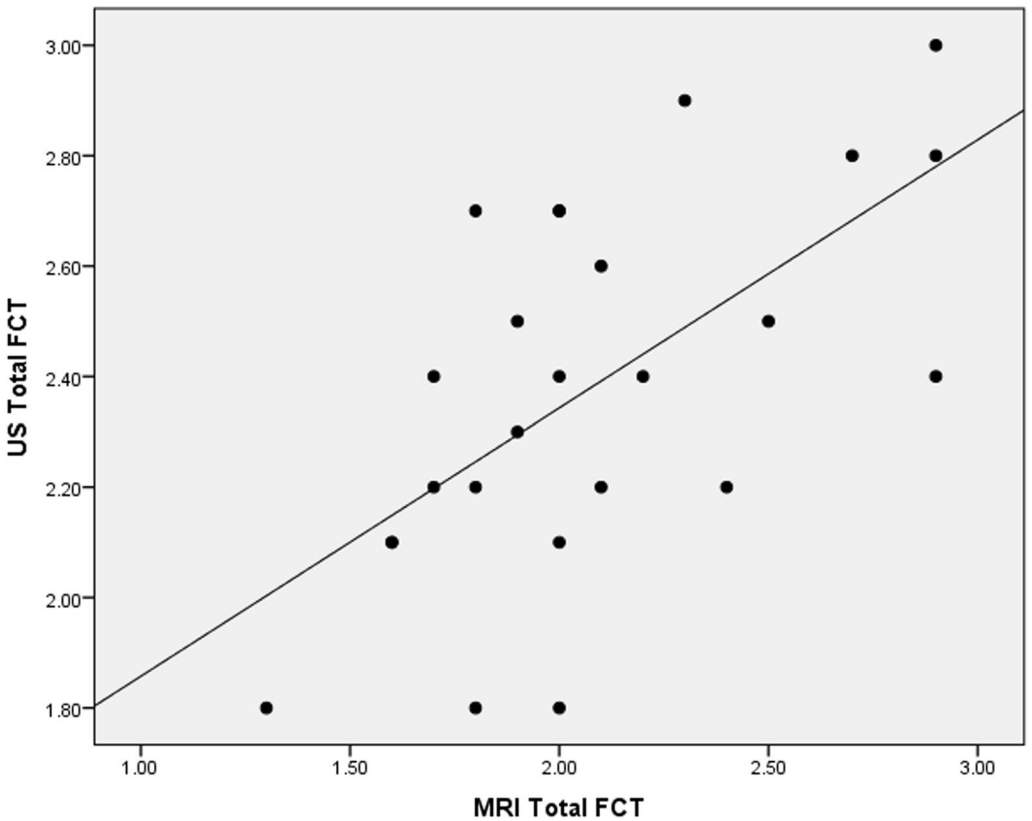

Fig. 4 Correlation between MRI and MSUS total femoral cartilage thickness in AS patients

and of functional limitation (BASFI), measures of disease activity (ASDAS ESR and ASDAS CRP), and measure of radiological changes (BASRI) in AS patients. However, tibial cartilage thickness was negatively correlated with disease duration, BASMI, BASFI, and BASRI. Moreover, we found a very strong positive correlation between the femoral and the tibial cartilage thicknesses, which was in agreement with Cicuttini et al. [32] who reported a strong correlation between the femoral cartilage and the tibial cartilage in both medial and lateral tibiofemoral joints in normal subjects and in those with osteoarthritis.

Due to its high cost, lengthy scanning time, and restricted accessibility, MRI has a limited role in ordinary clinical practice. The US offers a reliable, accessible, affordable, and clinically focused option that could enable more frequent evaluations of the health of the cartilage [33]. Clinicians can measure the thickness at three different sites on the anterior femur to typically establish the size of the anterior femoral cartilage [10].

In the present study, measures of MSUS revealed that AS patients had thinner femoral cartilage than the healthy controls at all measurement sites, with statistically significant differences at both medial femoral condyle ($P=0.02$) and at the right and left intercondylar area ($P=0.04$ and $P=0.03$, respectively).

Contrary to our findings, Batmaz et al. [4] found that individuals with AS had cartilage measures that were considerably thicker at the intercondylar area ($P<0.001$) and left medial femoral condyle ($P=0.01$). A subgroup study (anti-tumor necrosis factor (TNF) users and anti-TNF naive) revealed that cartilage thickness measurements in the left medial femoral condyle and bilateral intercondylar area were higher in AS patients receiving anti-TNF medication (n=65) compared to healthy controls. The authors hypothesized that anti-TNF in their patients may have partially protected the cartilage in the knee joint. Sadly, none of our patients with AS are utilizing anti-TNF.

We are the first to describe a relationship between the values obtained from an ultrasonographic examination of the femoral cartilage and patient features in individuals with AS. Femoral cartilage thickness was negatively correlated with age, the measure of disease activity (ASDAS ESR), and radiological changes (BASRI), but it was not correlated with disease duration or laboratory tests. Batmaz et al. [4] failed to find any correlations between clinical and laboratory parameters and ultrasonographic femoral cartilage thickness in AS patients, and similar findings were reported for patients with Behçet's disease [34]. Moreover, Mesci et al. [35] showed the absence of correlations between ultrasonographic femoral cartilage thickness and age, disease duration, disease activity *score*-28, health assessment questionnaire scores, ESR, and CRP levels in rheumatoid arthritis patients. Differences within the previous studies may be due to different designs, sample sizes, and ages of the patients.

The present study demonstrated that ultrasonographic total femoral cartilage thickness had a significant positive correlation with MRI total femoral cartilage thickness ($r=0.49$, $P=0.02$). Very little data are available regarding the comparison between MRI and ultrasound for the assessment of cartilage thickness. Similar results were reported by Tarhan and Unlu [36] and Eckstein et al. [27] who found that there is a high agreement between MRI and ultrasonography in assessing cartilage thickness in patients with knee OA.

Moreover, Pradsgaard et al. [37] used MRI and MSUS to examine the distal femoral cartilage thickness in juvenile idiopathic arthritis patients. They demonstrated the relationship between sonographic and MRI measurements of cartilage thickness and stated that the medial femoral condyle had cartilage that was thinner than the lateral femoral condyle.

Despite advantages of MSUS, there are some limitations associated with the external US of the knee joint. First, it is possible to scan only a part of the femoral condyle cartilage due to the shadow of the patella. Second, external US has no access to the tibial plateau cartilage because of the narrow aquatic window for ultrasound rays at this site which was considered a major limitation [38].

MRI-derived measurements of cartilage thickness and cartilage thickness pattern had high validity [39]. In quantifying cartilage thickness, central and weight-bearing regions of the femoral condyles can provide a more accurate measurement than boundary and non-weight-bearing regions [20]. The thickness of cartilage as determined by MRI appears to be a reliable way to quantify knee cartilage. Cartilage thickness measurement employing a 3.0-T imaging system showed nonsignificant differences from measurements employing a 1.5-T system [40].

Study limitations

The current study had certain limitations. Firstly, it was cross-sectional with a small sample size. Secondly, only the cartilage's thickness and not the volume was measured. Yet, apart from a wide range of studies on MRI imaging of AS patients, we believe that there are no data regarding assessing femoral and tibial cartilage thickness.

Conclusions

Patients with AS had thinner knee cartilage thickness than healthy controls. Correlations of knee cartilage thickness with measures of disease activity, spinal mobility, functional limitation, and radiological changes reflect the useful value of MRI and MSUS in

determining areas of knee cartilage loss in AS patients. US may serve as a good alternative to MRI for the assessment of femoral (not tibial) cartilage thickness in AS patients. Further studies including a large number of patients were recommended to evaluate the impact of different therapies (specifically TNF inhibitor) on knee cartilage thickness.

Abbreviations

AS	Ankylosing spondylitis
MSUS	Musculoskeletal ultrasound
MRI	Magnetic resonance imaging
BASRI-s	Bath Ankylosing Spondylitis Radiology Index for the spine
BASFI	Ankylosing Spondylitis Functional Index
ASDAS ESR	Ankylosing Spondylitis Disease Activity Score-erythrocyte sedimentation rate
BMI	Body mass index
BASDAI	Bath Ankylosing Spondylitis Disease Activity Index
ASDAS CRP	Ankylosing Spondylitis Disease Activity Score-C-reactive protein
BASMI	Bath Ankylosing Spondylitis Metrology Index
RLC	Right lateral condyle
RIA	Right intercondylar region
RMC	Right medial condyle
LMC	Left medial condyle
LIA	Left intercondylar area
LLC	Left lateral condyle
χ^2	Chi-square
VAS	Visual analog scale for pain
CPII	C-propeptide of type II collagen
Anti-TNF	Anti-tumor necrosis factor

Acknowledgements
Not applicable.

Author contributions
SRK helped in idea, design of work, manuscript writing, and revision. AFD helped in interpretation of data and revision of the manuscript. FAM helped in MSUS assessment and interpretation of data. NFE helped in MRI assessment and interpretation of data. ORA helped in collection, statistical data analysis, and manuscript revision. All authors read and approved the final manuscript.

Funding
No funding was obtained for this study.

Availability of data and materials
All relevant data are incorporated into the manuscript. Other raw data underlying this article will be provided at a reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate
The study protocol complies with the Declaration of Helsinki and was approved by the ethics committee of the Faculty of Medicine, Minia University (19-2016).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 30 May 2023 Accepted: 12 November 2023
Published online: 20 November 2023

References

1. Bakland G, Nossent HC (2013) Epidemiology of spondyloarthritis: a review. Curr Rheumatol Rep 15:351. https://doi.org/10.1007/s11926-013-0351-1
2. Carron P, Van Praet L, Van den Bosch F (2012) Peripheral manifestations in spondyloarthritis: relevance for diagnosis, classification and follow-up. Curr Opin Rheumatol 24(4):370–374. https://doi.org/10.1097/BOR.0b013e32835448de
3. Kim TH, Stone M, Payne U, Zhang X, Ionescu M, Lobanok T et al (2005) Cartilage biomarkers in ankylosing spondylitis: relationship to clinical variables and treatment response. Arthritis Rheum 52:885–891
4. Batmaz I, Kara M, Tiftik T, Çapkın E, Karkucak M, Serdar ÖF et al (2014) Ultraso-nographic evaluation of femoral cartilage thickness in patients with ankylosing spondylitis. West Indian Med J 63:329–332
5. Eckstein F, Muller-Gerbl M, Putz R (1992) Distribution of subchondral bone density and cartilage thickness in the human patella. J Anat 180(3):425–433
6. Shepherd DE, Seedhom BB (1999) Thickness of human articular cartilage in joints of the lower limb. Ann Rheum Dis 58:27–34
7. Grassi W, Lamanna G, Farina A, Cervini C (1999) Sonographic imaging of normal and osteoarthritic cartilage. Semin Arthritis Rheum 28:398–403
8. Kazam JK, Nazarian LN, Miller TT, Sofka CM, Parker L, Adler RS (2011) Sonographic evaluation of femoral trochlear cartilage in patients with knee pain. J Ultrasound Med 30:797–802
9. Maeguchi K, Ito H, Morita Y, Furu M, Fujii T, Azukizawa M et al (2018) How precisely does ultrasonographic evaluation reflect the histological status of the articular cartilage of the knee joint? J Orthop 15(2):636–640
10. Cao J, Zheng B, Meng X, Lv Y, Lu H, Wang K et al (2018) A novel ultrasound scanning approach for evaluating femoral cartilage defects of the knee: comparison with routine magnetic resonance imaging. J Orthop Surg Res 13(1):178
11. Van der Linden S, Valkenburg H, Cats A (1984) Evaluation of diagnostic criteria for anklosing spondylitis: a proposal for modification of the New York criteria. Arthritis Rheum 27:361–368
12. Garrett S, Jenkinson T, Kennedy LG, Whitelock H, Gaisford P, Calin A (1994) A new approach to defining disease status in ankylosing spondylitis: the Bath Ankylosing Spondylitis Disease Activity Index. J Rheumatol 21:2286–2291
13. Van der Heijde D, Lie E, Kvien TK, Sieper J, Van den Bosch F, Listing J et al (2009) ASDAS, a highly discriminatory ASAS-endorsed disease activity score in patients with ankylosing spondylitis. Ann Rheum Dis 68(12):1811–1818
14. Machado P, Landewé R, Lie E, Kvien TK, Braun J, Baker D et al (2011) Ankylosing Spondylitis Disease Activity Score (ASDAS): defining cut-off values for disease activity states and improvement scores. Ann Rheum Dis 70(1):47–53
15. Van der Heijde D, Landewé R, Feldtkeller E (2008) Proposal of a linear definition of the Bath Ankylosing Spondylitis Metrology Index (BASMI) and comparison with the 2-step and 10-step definitions. Ann Rheum Dis 67(4):489–493
16. Calin A, Garrett S, Whitelock H, Kennedy LG, O'Hea J, Mallorie P et al (1994) A new approach to defining functional ability in ankylosing spondylitis: the development of the Bath Ankylosing Spondylitis Functional Index. J Rheumatol 21:2281–2285
17. Jang JH, Ward MM, Rucker AN, Reveille JD, Davis JC Jr, Weisman MH et al (2011) Ankylosing spondylitis: patterns of radiographic involvement—a reexamination of accepted principles in a cohort of 769 patients. Radiology 258(1):192–198
18. Mathiesen O, Konradsen L, Torp-Pedersen S, Jorgensen U (2004) Ultrasonography and articular cartilage defects in the knee: an in vitro evaluation of the accuracy of cartilage thickness and defect size assessment. Knee Surg Sports Traumatol Arthrosc 12:440–443
19. Yoon CH, Kim HS, Ju JH, Jee WH, Park SH, Kim HY (2008) Validity of the sonographic longitudinal sagittal image for assessment of the cartilage thickness in the knee osteoarthritis. Clin Rheumatol 27:1507–1516. https://doi.org/10.1007/s10067-008-0956-3
20. Koo S, Gold GE, Andriacchi TP (2005) Considerations in measuring cartilage thickness using MRI: factors influencing reproducibility and accuracy. Osteoarthritis Cartil 13:782–789

21. Malaviya AN, Agrawal N, Patil NS (2017) Clinical characteristics of peripheral spondyloarthritis without psoriasis, inflammatory enteropathy or preceding infection, from a single rheumatology clinic in northern India. Clin Rheumatol 36(11):2613–2618
22. Naish JH, Xanthopoulos E, Hutchinson CE, Waterton JC, Taylor CJ (2006) MR measurement of articular cartilage thickness distribution in the hip. Osteoarthritis Cartil 14(10):967–973
23. Danve A, O'Dell J (2015) The ongoing quest for biomarkers in Ankylosing Spondylitis. Int J Rheum Dis 18(8):826–834. https://doi.org/10.1111/1756-185X.12779
24. Bay-Jensen AC, Leeming DJ, Kleyer A, Veidal SS, Schett G, Karsdal MA (2012) Ankylosing spondylitis is characterized by an increased turnover of several different metalloproteinase-derived collagen species: a cross-sectional study. Rheumatol Int 32:3565–3572
25. Chen CH, Lin KC, Yu DT, Yang C, Huang F, Chen HA et al (2006) Serum matrix metalloproteinases and tissue inhibitors of metalloproteinases in ankylosing spondylitis: MMP-3 is a reproducibly sensitive and specific biomarker of disease activity. Rheumatology (Oxford) 45(4):414–420
26. Maksymowych WP, Poole AR, Hiebert L, Webb A, Ionescu M, Lobanok T et al (2005) Etanercept exerts beneficial effects on articular cartilage biomarkers of degradation and turnover in patients with ankylosing spondylitis. J Rheumatol 32:1911–1917
27. Eckstein F, Cicuttini F, Raynauld JP, Waterton JC, Peterfy C (2006) Magnetic resonance imaging (MRI) of articular cartilage in knee osteoarthritis (OA): morphological assessment. Osteoarthritis Cartil 14(suppl A):A46–A75
28. Muhlbauer R, Lukasz TS, Faber TS, Stammberger T, Eckstein F (2000) Comparison of knee joint cartilage thickness in triathletes and physically inactive volunteers based on magnetic resonance imaging and three dimensional analysis. Am J Sports Med 28:541–546
29. Faber SC, Eckstein F, Lukasz S, Muhlbauer R, Hohe J, Englmeier KH et al (2001) Gender differences in knee joint cartilage thickness, volume and articular surface areas: assessment with quantitative three-dimensional MR imaging. Skeletal Radiol 30:144–150
30. Hudelmaier M, Glaser C, Hohe J, Englmeier KH, Reiser M, Putz R et al (2001) Age-related changes in the morphology and deformational behavior of knee joint cartilage. Arthritis Rheum 44:2556–2561
31. Roberts HM, Griffith-McGeever CL, Owen JA, Angell L, Moore JP, Thom JM (2021) An exploratory study to investigate the association between age, physical activity, femoral trochlear cartilage thickness and biomarkers of tissue metabolism in adult males. Eur J Appl Physiol 121:1871–1880
32. Cicuttini FM, Wluka AE, Stuckey SL (2001) Tibial and femoral cartilage changes in knee osteoarthritis. Ann Rheum Dis 60:977–980
33. Iagnocco A (2010) Imaging the joint in osteoarthritis: a place for ultrasound? Best Pract Res Clin Rheumatol 24(1):27–38
34. Batmaz I, Kara M, Tiftik T, Yıldız M, Çevik R, Özçakar L (2014) Ultrasonographic measurement of the femoral cartilage thickness in patients with Behçet's disease. West Indian Med J 63:728–731
35. Mesci E, Mesci N, Madenci E (2016) Ultrasonographic evaluation of femoral cartilage thickness in patients with rheumatoid arthritis. J Clin Anal Med 1:31–34
36. Tarhan S, Unlu Z (2003) Magnetic resonance imaging and ultrasonographic evaluation of the patients with knee osteoarthritis: a comparative study. Clin Rheumatol 22(3):181–188
37. Pradsgaard DØ, Fiirgaard B, Spannow AH, Heuck C, Herlin T (2015) Cartilage thickness of the knee joint in juvenile idiopathic arthritis: comparative assessment by ultrasonography and magnetic resonance imaging. J Rheumatol 42(3):534–540
38. Saarakkala S, Waris P, Waris V, Tarkiainen I, Karvanen E, Aarnio J et al (2012) Diagnostic performance of knee ultrasonography for detecting degenerative changes of articular cartilage. Osteoarthritis Cartil 20(5):376–381
39. Graichen H, von Eisenhart-Rothe R, Vogl T, Englmeier KH, Eckstein F (2004) Quantitative assessment of cartilage status in osteoarthritis by quantitative magnetic resonance imaging: technical validation for use in analysis of cartilage volume and further morphologic parameters. Arthritis Rheum 50:811–816
40. Eckstein F, Charles HC, Buck RJ, Kraus VB, Remmers AE, Hudelmaier M et al (2005) Accuracy and precision of quantitative assessment of cartilage morphology by magnetic resonance imaging at 3.0T. Arthritis Rheum 52:3132–3136

Publisher's Note