SCIENTIFIC ARTICLE

Cartilage degeneration post-meniscectomy performed for degenerative disease versus trauma: data from the Osteoarthritis Initiative

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Abstract

Objective To compare the extent of cartilage deterioration in knees with prior meniscal resection related to trauma versus knees with resection related to degenerative disease, and to compare cartilage deterioration in knees with meniscal surgery to knees without meniscal surgery, controlling for prior knee trauma.

Materials and methods In this cross-sectional study, we assessed cartilage deterioration in right knees of Osteoarthritis Initiative participants: (i) with meniscal surgery due to injury ($n = 79$); (ii) matched control knees with a prior injury but without meniscal surgery ($n = 79$); (iii) with meniscal surgery but without preceding injury ($n = 36$); and (iv) matched control knees without meniscal surgery or prior knee injury ($n = 36$). Cartilage composition was measured using T2 measurements derived using semi-automatic cartilage segmentation of the right. Linear regression analysis was used to compare compartmental values of T2 between groups.

Results Comparing the mean T2 values in surgical cases with and without injury our results did not show significant differences (group i vs. iii, $p > 0.05$). However, knees with previous meniscal surgery showed significantly ($p < 0.001$) higher mean T2 values across all compartments (i.e., global T2) when compared to those without meniscal surgery for both knees with a history of trauma (group i vs. ii) and knees without prior trauma (group iii vs. iv). Similar results were obtained when analyzing the compartments separately.

Conclusions Cartilage deterioration, assessed by T2, is similar in knees undergoing meniscal surgery after trauma and for degenerative conditions. Both groups demonstrated greater cartilage deterioration than nonsurgical knees, controlling for prior knee injury.

Keywords Knee osteoarthritis · Meniscal surgery · Magnetic resonance imaging · Risk factors · Biomarkers

Introduction

The biomechanics of the menisci are a critical component in the functionality of the knee joint and play a crucial role in axial load transmission of the knee [1]. Alterations of the menisci impact biomechanical loading and are a frequent source of pain and disability [2]. In this context, meniscal injuries are one of the most common pathologies of the knee and often require medical attention [3]. In general, meniscal injuries occur over a broad age range. While trauma-related meniscal injuries are found more often in young adults, degenerative injuries are known to be more often associated with increasing age and are seen with work-related repetitive activities [4]. Both types of meniscal injury contribute to the risk of knee osteoarthritis (OA) [5–7] and previous studies have questioned the benefit of treating meniscal

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lesions with arthroscopic surgery compared to nonsurgical treatments [8]. However, arthroscopic partial meniscectomy is a frequently performed treatment of torn menisci [9], and in the United States it is one of the most frequent orthopedic surgical procedure [10].

Based on postoperative outcome scores (Knee Injury and Osteoarthritis Outcome Score – KOOS) previous studies have shown higher evidence of knee OA following excision of degenerated versus traumatic meniscal tears [11, 12]. Additionally, Zikria et al. found that subsequent joint space narrowing (JSN) progression was greater in knees with meniscal surgery without prior trauma compared to meniscal surgery with prior trauma [13]. This is potentially due to the fact that surgical resection of degenerative lesions may only remove the most current evidence of the disorder [14], while the preexisting degraded cartilage architecture of the osteoarthritic knee persists and continues to worsen [15]. However, no previous studies are available to provide insights into the cartilage composition of patients with previous meniscal surgery compared to knees without surgery and the possible differences in the cartilage composition of patients who underwent meniscal surgery for trauma compared to meniscal surgery for degenerative disorders.

To quantitatively assess articular cartilage composition of the knee, MR-based T2 relaxation time measurements have been demonstrated to be a reliable method to reflect changes of hydration and organization of collagen fibrils in the extracellular matrix of the hyaline cartilage [16, 17]. Thus this imaging technique will also provide pertinent insights into the pathophysiology of the cartilage composition in patients who have undergone meniscal surgical procedures.

The purpose of this study was (i) to analyze differences in the articular cartilage composition, using cartilage T2 relaxation time measurements, between knees with previous meniscal surgery related to trauma and those knees with meniscal surgery related to degenerative disorders and (ii) to compare cartilage deterioration between knees with meniscal resection and non-surgical control knees frequency matched for sex, age, Kellgren–Lawrence (K/L) grade, and BMI.

Materials and methods

The Osteoarthritis Initiative database

Participants in our study were selected from the Osteoarthritis Initiative (OAI) database, a multicenter cohort study of knee osteoarthritis, sponsored by the U.S. National Institutes of Health (NIH). In total, 4796 participants were enrolled from February 2004 to May 2006 and completed as of January 1, 2015, creating an ethnically diverse cohort of women and men ages 45 to 79 years (mean age, 61 years) that included participants with symptomatic knee OA and subjects with risk factors for OA but without presenting knee OA symptoms.

Following a nationwide advertising campaign, recruitment and enrollment consisted of an initial eligibility assessment by telephone, a screening clinic visit, and finally an enrollment clinic visit at one of the four clinical centers (University of Maryland, Baltimore, MD; Memorial Hospital of Rhode Island/Brown University, Pawtucket, RI; Ohio State University, Columbus, OH; University of Pittsburgh, Pittsburgh, PA). All clinical enrollment centers were supervised by a steering committee, the primary governing body of the study and scientific leadership, to ensure uniform enrollment goals for gender and age strata in the primary subcohorts. Among data of the MRI scans, radiographs, and biological specimens, the enrollment visit included a detailed clinical assessment of the subjects' knees, questions about use of medication, questionnaires assessing physical disability (due to knee pain and arthritis), knee pain and function as well as the assessment of risk factors for knee OA (including history of knee injury and knee surgery, abnormal biomechanical stress related to physical activity and obesity). Additionally, the participants were given a self-administered questionnaire to complete at home that was reviewed at the enrollment clinic. The questionnaire included information on education, medical history, smoking/alcohol, and income.

The purpose of the OAI database was to develop a public-accessible domain research resource to investigate the role of MRI-based imaging biomarkers in an attempt to better understand the disease onset and ultimately prevent its progression (https://nda.nih.gov/oai/) [18].

Selection of participants from the OAI

In this retrospective cross-sectional analysis study, participants were eligible for inclusion if they had no to mild radiographic signs of knee OA (Kellgren–Lawrence (K/L) classification of osteoarthritis; grade 0–2) and complete data on BMI, sex, and age at the time of the enrollment visit. Participants were excluded if, during the follow-up visits, they self-reported the diagnosis of rheumatoid arthritis or the use of rheumatoid arthritis medication. Finally, to identify participants who underwent meniscal surgery, we used the OAI self-administered questionnaires from each participant (Medical history; Release Version 0.2.2): Participants were asked if they underwent surgery of the meniscus where they repaired or cut away a torn meniscus. Additionally, participants who had meniscal surgery related to an injury episode were identified through (i) having a history of knee injury and (ii) participant stating that the meniscectomy was to treat an injury. As provided by the OAI questionnaire workbook, injury was defined as "knee ever injured badly enough to limit ability to walk for at least 2 days". The second surgical group had no history of knee injury and this group was therefore

considered to have degenerative meniscal tears. To ensure accuracy of the acquired data, as provided by the questionnaires, we only selected participants that clearly answered all relevant questions with yes or no and participants that were uncertain about their medical history (replied with "Not Expected", "Do not know/Unknown/Uncertain", or "Refused") were not included. Additionally, all knees with meniscal surgery identified by self-report were reviewed by a trained musculoskeletal radiologist to confirm the reported postsurgical status (DS). Through identification of the age at the time the injury occurred (self-administered questionnaire: "how old at injury"), age at the time of the arthroscopy (self-administered questionnaire: "how old at arthroscopy"), and the age at the time of the MRI scan (age at the time point of enrollment) the corresponding delta (Δ) between each episode was determined.

At the time point of enrollment (baseline visit), a total of 115 participants with a history of meniscal surgery confirmed by MRI review (case cohort) and 3362 participants without meniscal surgery (control cohort) met the inclusion criteria.

Finally, to examine the association of cartilage degeneration with surgically treated meniscal lesions compared to knees without previous surgery for meniscal lesion, we also selected for each surgical group a non-surgical group that had the same self-report history with respect to knee injuries (nonsurgical control group without history of knee injury, nonsurgical control group with history of knee injury), and frequency matched to each surgical group for age, sex, BMI, and KL grade. The matching did not include the meniscal lesion status of the nonsurgical knees and therefore was unknown and not taken into account in the selection. The flow chart in Fig. 1 illustrates the detailed selection of all participants in this study. All MRI scans and the clinical assessment were performed as part of the OA Initiative.

MR imaging protocol

All scans were acquired using 3.0-T MRI systems (Siemens Magnetom Trio; Siemens Healthcare, Erlangen, Germany) with quadrature transmit–receive coils (USA Instruments, Aurora, OH, USA) at one of the four OAI clinical sites. The scan protocol consisted of a 3D dual echo steady-state (DESS) gradient-echo with water excitation (WE) sequence obtained in the sagittal plane (16.3/4.7/25°, TR/TE/flip angle, spatial resolution = 0.365×0.456 mm, slice thickness = 0.7 mm), a sagittal 2D intermediate-weighted fast spin-echo sequence (TR/TE = 3200/30 ms, spatial resolution = 0.357×0.511 mm, slice thickness = 3.0 mm), a coronal 2D proton density fast spin-echo sequence (TR/TE = 3700/29 ms, spatial resolution = 0.365×0.456 mm, slice thickness = 3.0 mm), as well as a sagittal 2D multi-slice multi-echo (MSME) spin-echo sequence with a total of seven echo times (TEs 10 ms,

20 ms, 30 ms, 40 ms, 50 ms, 60 ms, 70 ms), a repetition time (TR) of 2700 ms, a field of view (FOV) of 120 mm, a slice thickness of 3 mm (with 0.5 mm gap) and an in-plane spatial resolution of 0.313×0.446 mm^2.

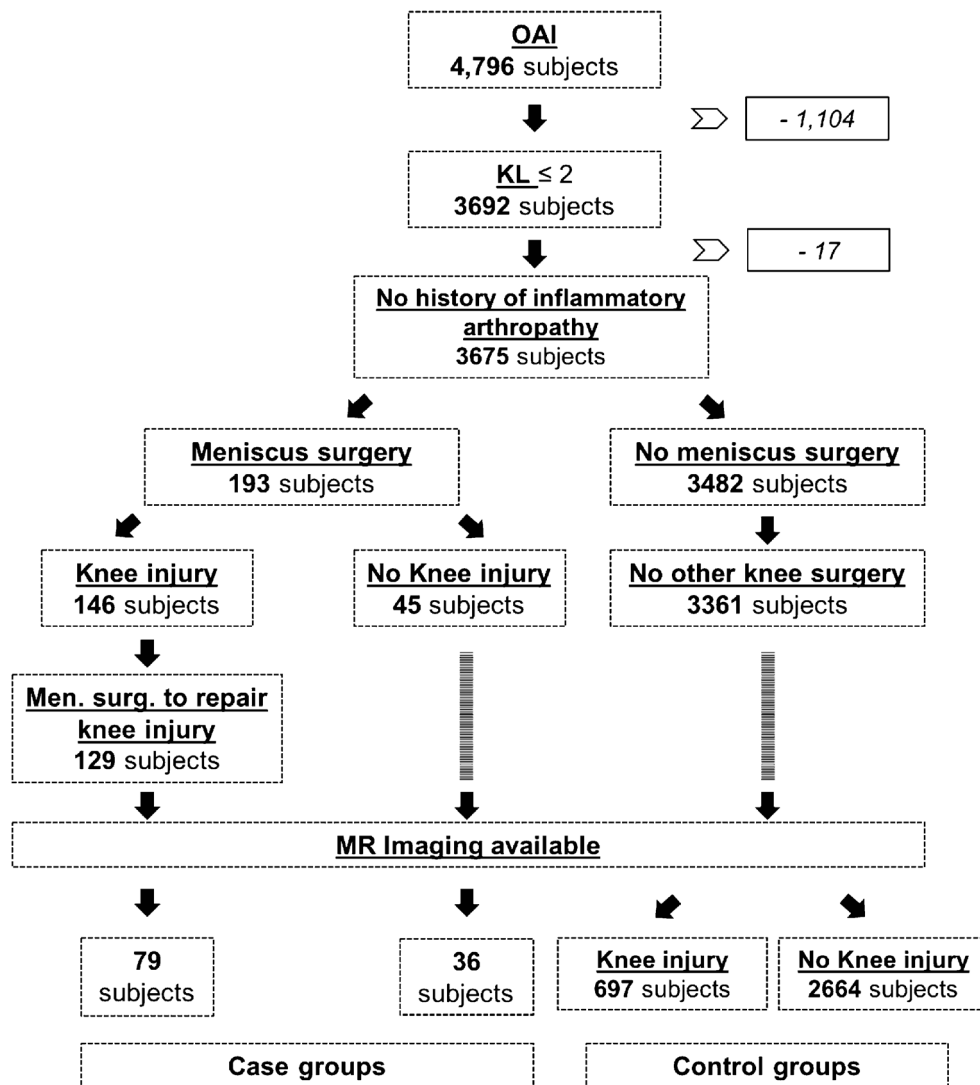## Quantitative cartilage T2 analysis

All cartilage T2 measurements were acquired using the 2D MSME SE images. Cartilage segmentations were obtained for each compartment separately with the compartments being defined as: patella (PAT), lateral femur (LF), medial femur (MF), lateral tibia (LT), and medial tibia (MT). Due to substantial flow artifacts from the popliteal artery, the trochlear region was excluded from the analysis. The cartilage of each compartment was segmented by a trained researcher (KK). The software used for the T2 analysis was an in-house, spline-based algorithm written in MATLAB (The MathWorks, Natick, MA, USA) that allows semi-automatic segmentation of each compartment by analyzing the T2 values in a mono-exponential decay model as a fitting function for the signal intensity using six echoes (TE 20–70 ms) after excluding the first echo in order to minimize systemic errors and improve signal-to-noise ratio [19]. Cartilage T2 analysis was conducted for the mean T2 across all compartments for the global knee joint as well as for each compartment separately.

Statistical analysis

Statistical analysis was performed using STATA software (Version 14, StataCorp, College Station, TX, USA). A p value of < 0.05 was considered to be statistically significant. Demographic data between the study cohorts were assessed using either Pearson's $\chi2$-test, one-way ANOVA, or independent samples t test as appropriate. Linear regression models were used to assess the differences in cartilage T2 parameters between the groups for every single compartment, the mean across all compartments, as well as separately for the weight-bearing compartments (mean of both femoral and tibial compartments). All analyses were adjusted for the common risk factors of knee OA for age, sex, and BMI.

To assess intra-reader reproducibilities, coefficients of variation (CV) were calculated on a percentage basis as the root mean square average [20, 21]. Averaged over all compartments, the inter-reader reproducibility for T2 measurements was 0.88%. The CVs for each compartment were 0.85% for PAT, 0.93% for MF, 1.24% for LF, 0.79% for MT, and 0.57% for LT. Overall, the reproducibilities were similar to those reported previously [22, 23].

Fig. 1 Selection of study participants. Flow chart illustrating patient selection from the OAI cohort

OAI
4,796 subjects

⟶ - 1,104

KL ≤ 2
3692 subjects

⟶ - 17

No history of inflammatory arthropathy
3675 subjects

Meniscus surgery
193 subjects

No meniscus surgery
3482 subjects

Knee injury
146 subjects

No Knee injury
45 subjects

No other knee surgery
3361 subjects

Men. surg. to repair knee injury
129 subjects

MR Imaging available

79 subjects

36 subjects

Knee injury
697 subjects

No Knee injury
2664 subjects

Case groups

Control groups

Results

Participant demographics

The subject characteristics are summarized in Table 1. The average age of all participants ($n = 230$) was 57.9 years (SD ± 8.9) with a BMI of 27.9 (SD ± 4.0). One-hundred-fifty-four (67.0%) participants were male. The overall K/L grade distribution showed a higher percentage of participants with K/L 2 ($n = 128$; 55.7%). K/L grades of 0 and 1 showed a similar distribution with $n = 55$ (23.9%) and $n = 47$ (20.4%), respectively. Overall, the four groups (groups (i) and (ii), and groups (iii) and (iv)) were well matched with no significant differences ($p > 0.05$) in age, sex, BMI, and K/L grade.

Differences in clinical parameters between all groups

Assessing the physical activity, the comparison of all groups did not show statistically significant differences

(PASE score, $p > 0.05$). The total Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) also did not show any statistically significant differences between all groups. Looking at the WOMAC pain subscale, however, we observed an overall statistical difference ($p = 0.022$). Participants that underwent degenerative meniscal surgery showed a significantly higher WOMAC pain score when compared to non-surgical controls without preceding knee trauma ($p = 0.004$). However, WOMAC pain scores were not statistically different in participants with traumatic meniscal surgery compared with non-surgical controls with a preceding knee trauma ($p = 0.415$). With respect to the age at the time of the arthroscopy, as expected, traumatic meniscal surgery was performed at a younger age than meniscal surgery performed for degenerative changes and thus MRIs performed in the degenerative cohort were performed more recently. All clinical parameters are shown in Table 1.

Table 1 Participant characteristics

	All participants (n = 230)	Traumatic meniscal surgery (n = 79)	Non-surgery controls with preceding trauma (n = 79)	p value*	Degenerative meniscal surgery (n = 36)	Non-surgery controls without preceding trauma (n = 36)	p value**	p value***
Age	57.9 ± 8.9	56.5 ± 8.7	56.8 ± 8.5	0.860	61.2 ± 9.3	60.3 ± 9.2	0.675	0.013
BMI	27.9 ± 4.0	28.0 ± 4.0	28.4 ± 3.9	0.454	27.5 ± 4.2	26.9 ± 3.9	0.534	0.287
Sex	154 (67.0%) / 76 (33.0%)	57 (72.2%) / 22 (27.8%)	53 (67.1%) / 26 (32.9%)	0.489	24 (66.7%) / 12 (33.3%)	20 (55.6%) / 16 (44.4%)	0.334	0.379
K/L grade				0.979			0.834	0.993
Grade 0	55 (23.9%)	18 (22.8%)	18 (22.8%)		9 (25.0%)	10 (27.8%)		
Grade 1	47 (20.4%)	16 (20.3%)	17 (21.5%)		8 (22.2%)	6 (16.7%)		
Grade 2	128 (55.7%)	45 (57.0%)	44 (55.7%)		19 (52.8%)	20 (55.6%)		
Surgical/injury characteristics								
Age at MENR		44.9 ± 13.5			54.6 ± 10.7			< 0.001
Age at INJ		43.3 ± 14.3	34.6 ± 15.5	< 0.001				
Δ INJ - MENR		2 ± 6.3						
Δ MENR - MRI		11.6 ± 11.6			6.6 ± 5.4			0.015
Clinical characteristics								
PASE	173.8 ± 88.5	180.0 ± 88.6	183.0 ± 94.2	0.835	161.8 ± 82.6	152.5 ± 79.1	0.629	0.264
WOMTL	10.0 ± 14.6	9.2 ± 16.4	11.8 ± 15.2	0.305	10.2 ± 13.5	7.5 ± 9.7	0.343	0.484
WOMKPR	2.6 ± 3.1	2.9 ± 3.1	2.5 ± 3.1	0.415	3.3 ± 3.3	1.3 ± 2.6	0.004	0.022
WOMSTFL	1.2 ± 1.6	1.0 ± 1.5	1.4 ± 1.7	0.170	1.5 ± 1.4	1.1 ± 1.4	0.207	0.321
WOMADLL	7.0 ± 10.7	6.5 ± 12.1	8.2 ± 11.1	0.358	6.9 ± 10.1	5.2 ± 6.6	0.380	0.526

Age at MENR = how old at the time of meniscal surgery, Age at INJ = how old at the time of the injury, ΔINJ-MENR = time difference (years) between time point of the injury and meniscal surgery, ΔMENR-MRI = time difference (years) between time point of the meniscal surgery and MRI scan. *p value = indicates differences between traumatic meniscal surgery and controls with knee trauma. **p value = indicates differences between degenerative meniscal surgery and controls without knee trauma. ***p value = indicates differences among all groups. Continues data are expressed as mean ± SD. Categorical data are presented in numbers of participants with percentage in parentheses. ***p values were calculated using either Chi-square or one-way ANOVA as appropriate. *⁻**p values were calculated using either Pearson's χ2-test or independent t test as appropriate. PASE = Physical activity score of the elderly, WOMTL = WOMAC total score, WOMKRP = WOMAC knee pain, WOMSTFL = WOMAC stiffness, WOMADLL = WOMAC disability score

Differences in cartilage T2 values between participants with meniscal surgery related to trauma and degenerative disease

Our first analysis focused on participants with meniscal surgery only, to possibly identify differences in the cartilage composition with different surgical indication for meniscal surgery. Overall, comparing participants who underwent meniscal surgery due to an injury with participants who underwent meniscal surgery related to a degenerative tear, the cartilage mean T2 values did not show statistically significant differences between the two groups. For the latter group, higher mean T2 values were seen in the global knee ($p = 0.731$) and in the global weight bearing knee ($p = 0.731$) and in the global weight-bearing knee compartments ($p = 0.354$). Both the tibial and the lateral femur compartments also showed higher mean T2 values in participants with degenerative meniscal tears but these results also did not translate into statistical differences (Table 2).

Differences in cartilage T2 values between participants with meniscal surgery and non-surgical controls

Participants who underwent meniscal surgery in relation to a previous injury showed overall higher mean T2 values when compared to controls without meniscal surgery but with a history of knee injury (Fig. 2). Mean T2 values were significantly higher for the global knee (mean T2 effect size differences in ms [95% CI]: 0.94 [0.45, 1.44], $p < 0.001$) as well as for the global weight-bearing knee compartments (0.97 [0.45, 1.48], $p < 0.001$). Higher mean T2 values were also observed for every single compartment, with significantly higher values for the lateral tibia, the medial femur, and the medial tibia ($p < 0.02$) (Table 3).

Participants who underwent meniscal surgery to repair a degenerative meniscal tear showed also overall higher mean T2 values when compared to the control group without meniscal surgery and without history of knee injury (Table 3). Mean T2 values were significantly higher for the global knee as well the global weight-bearing knee compartments with 1.35 ms [0.60,2.09] ($p < 0.001$) and 1.56 ms [0.79, 2.33] ($p < 0.001$), respectively. Similar to the injury group (as shown in Table 2) mean T2 values were again higher in all separate compartments for participants who underwent meniscal surgery when compared to controls without injury. However, only the lateral femur (1.67 [0.59, 2.75], $p = 0.003$) and medial tibia (1.27 [0.19, 2.34], $p = 0.02$) showed a statistically significant differences.

Discussion

Comparing cartilage T2 values in participants that underwent meniscal surgery our study did not find differences with respect to whether surgery was to repair an injury or degenerative-related meniscal tears. However, when compared to matched non-surgical controls, we found that participants who underwent meniscal surgery showed overall higher mean T2 values. These findings indicate that if patients undergo meniscal surgery, the surgical indication (traumatic vs. degenerative) does not significantly affect the degree of cartilage deterioration and seems to be equally the same for both groups. However, compared to non-surgical controls, the risk of developing OA, as suggested by the higher mean T2 values, remains higher for patients that did undergo meniscal surgery.

Knee injuries are common and meniscus lesions are one of the most frequent sources of knee pain and disability [2]. Treatment options for meniscal lesions involve non-operative treatment, meniscal repair, or meniscal resection. The different treatment options need to be critically explored

Table 2 Differences in cartilage T2 values between knees with meniscal surgery related to trauma and meniscal surgery related to degenerative disease

	Traumatic meniscal surgery		Degenerative meniscal surgery		Effect size		p value
	Adjusted means	[95% CI]	Adjusted means	[95% CI]	Adjusted means	[95% CI]	
Global	32.83	[32.48,33.18]	32.94	[32.42,33.47]	− 0.11	[− 0.75,0.53]	0.731
Global WB	32.92	[32.55,33.29]	33.23	[32.69,33.78]	− 0.31	[− 0.98,0.35]	0.354
LF	34.71	[34.20,35.22]	35.15	[34.39,35.91]	− 0.44	[− 1.37,0.49]	0.351
LT	28.06	[27.59,28.54]	28.81	[28.10,29.51]	− 0.74	[− 1.60,0.11]	0.088
MF	38.38	[37.85,38.90]	38.03	[37.26,38.80]	0.34	[− 0.59,1.28]	0.472
MT	30.48	[29.96,31.00]	30.56	[29.79,31.33]	− 0.08	[− 1.02,0.86]	0.867
PAT	32.39	[31.73,33.05]	31.82	[30.84,32.81]	0.57	[− 0.62,1.76]	0.346

Data are given as adjusted means, corrected for age, sex, and baseline BMI with [95% confidence intervals]. P values < 0.05 are in *bold*. WB = weight-bearing (mean of both femoral and tibial compartments), PAT = patella, MT = medial tibia, LT = lateral tibia, MF = medial femur, LF = lateral femur

Fig. 2 Cartilage T2 color map of participants with and without meniscal surgery. Representative cartilage T2 color maps, overlaid on sagittal 2D multi-slice multi-echo (MSME) spin-echo sequences, showing the medial knee compartment in each of the different groups. **a** and **b** show the knee of participants that underwent meniscal surgery to repair a degenerative (**a**) and a traumatic tear (**b**), whereas, **c** and **d** both show participants without meniscal surgery but with **c** and without **d** preceding trauma. Both surgical participants show overall higher T2 values (indicated by the *yellow* and *red color maps*) with emphasis on the femoral condyle, including the weight-bearing as well as the posterior aspect of the femoral condyle. The controls show overall predominantly lower T2 values (*blue* and *green color coded*)
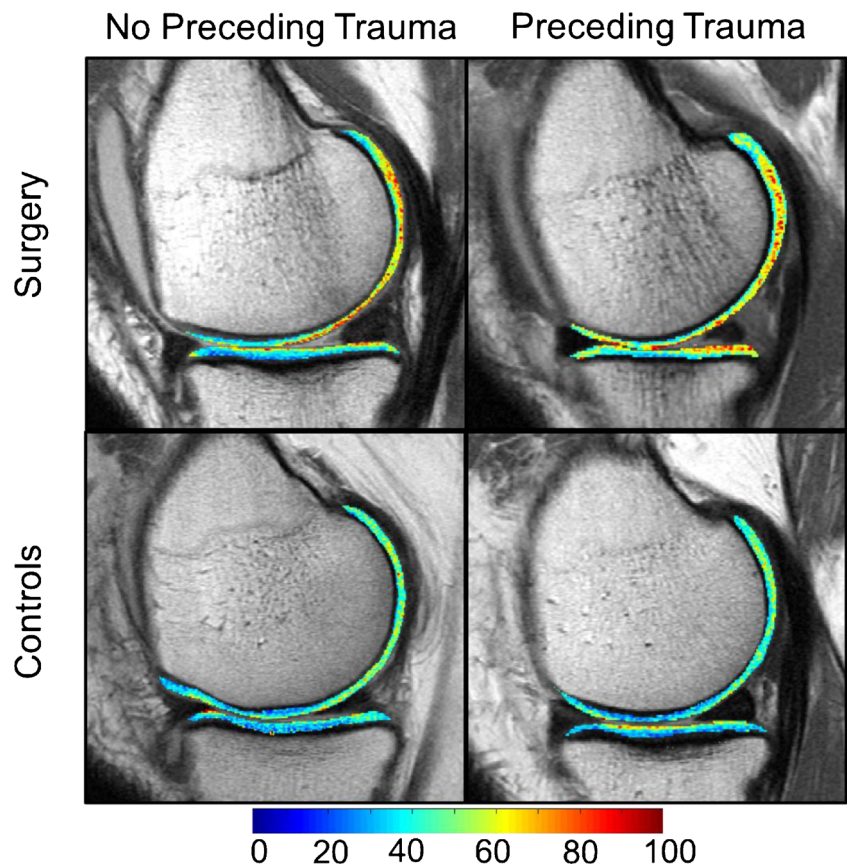
since studies have shown that meniscal lesions, both those treated surgically [14], and those not treated surgically [14], are strong risk factors for developing knee OA. With regard to surgically treated meniscal lesions, this increased risk is due to an altered contact pressure on the cartilage surfaces and other biomechanical and biochemical changes that results from a

Table 3 Differences in cartilage T2 values between participants with meniscal surgery and non-surgical controls

	Traumatic meniscal surgery		Non surgery controls with preceding trauma		Difference in adjusted means		p value
	Adjusted means	[95% CI]	Adjusted means	[95% CI]	Adjusted means	[95% CI]	
Global	32.83	[32.48, 33.18]	31.89	[31.53, 32.24]	0.94	[0.45, 1.44]	**< 0.001**
Global WB	32.92	[32.55, 33.29]	31.96	[31.59, 32.32]	0.97	[0.45, 1.48]	**< 0.001**
LF	34.71	[34.20, 35.22]	34.22	[33.70, 34.74]	0.49	[− 0.23, 1.22]	0.182
LT	28.06	[27.59, 28.54]	27.31	[26.84, 27.78]	0.76	[0.09, 1.42]	**0.025**
MF	38.38	[37.85, 38.90]	37.25	[36.72, 37.77]	1.13	[0.39, 1.87]	**0.003**
MT	30.48	[29.96, 31.00]	29.53	[29.01, 30.05]	0.95	[0.22, 1.68]	**0.011**
PAT	32.39	[31.73, 33.05]	31.54	[30.86, 32.22]	0.85	[− 0.09, 1.79]	0.076
	Degenerative meniscal surgery		Non surgery controls without preceding trauma		Difference in adjusted means		
	Adjusted means	[95% CI]	Adjusted means	[95% CI]	Adjusted means	[95% CI]	
Global	32.94	[32.42, 33.47]	31.55	[31.02, 32.07]	1.35	[0.60, 2.09]	**< 0.001**
Global WB	33.23	[32.69, 33.78]	31.67	[31.12, 32.22]	1.56	[0.79, 2.33]	**< 0.001**
LF	35.15	[34.39, 35.91]	33.48	[32.70, 34.26]	1.67	[0.59, 2.75]	**0.003**
LT	28.81	[28.10, 29.51]	27.23	[26.53, 27.92]	1.58	[0.60, 2.56]	0.053
MF	38.03	[37.26, 38.80]	37.15	[36.38, 37.92]	0.88	[− 0.20, 1.97]	0.109
MT	30.56	[29.79, 31.33]	29.29	[28.53, 30.06]	1.27	[0.19, 2.34]	**0.021**
PAT	31.82	[30.84, 32.81]	30.97	[29.99, 31.94]	0.86	[− 0.51, 2.23]	0.218

Data are given as adjusted means, corrected for age, sex, and baseline BMI with [95% confidence intervals]. *P* values < 0.05 are in *bold*. WB = weight-bearing, PAT = patella, MT = medial tibia, LT = lateral tibia, MF = medial femur, LF = lateral femur

combination of the damaged meniscus and any associated trauma, and changes induced by surgical intervention [24]. The long-term outcomes of meniscectomy in particular have been well studied. In a retrospective study design, Englund et al. evaluated the radiographic and clinical outcome of patients who underwent meniscal resection 15–22 years earlier [5] and found that meniscal resection is associated with a three-fold greater risk of later development of knee OA compared to knees without clinical evidence of meniscal lesions. They also showed that the increased risk of knee OA in the surgically treated knees was associated with pre-existing early stage OA and with risk factors common to knee OA, including female sex and obesity. Rongen et al. studied the risk of knee replacement in 335 participants who underwent arthroscopic meniscectomy and found a threefold increased risk for future knee replacement surgery of osteoarthritis knees in patients with meniscectomy [25]. In a prospective, longitudinal study design, McNicholas et al. were able to show meniscectomy leads to symptomatic osteoarthritis of the knee later in life 30 [26] and 40 [27] years after surgery was done.

Whereas previous studies showed that meniscal surgery was associated with an increased risk of developing knee OA, none of these studies examined whether the cartilage composition itself was altered in knees with preceding meniscal surgery or whether cartilage composition was different when surgery was to repair a meniscal injury episode versus a degenerative meniscal tear. To directly assess differences in the cartilage architecture of participants that underwent meniscal surgery, we based our analysis on cartilage T2 parameters derived from quantitative T2 relaxation time measurements [16]. Overall, our findings support the results of previous studies on meniscal surgery as a risk factor for knee OA. When compared to a non-surgical control group, participants who underwent meniscal surgery showed significantly higher mean T2 values, indicating an altered cartilage matrix composition with an increased risk for knee OA [28, 29]. It is important to acknowledge that since the nonsurgical control knees in our study included an unknown proportion with meniscal lesions that were not treated surgically, this finding cannot be attributed to the effect of meniscal surgery, per se. Meniscal lesions that are not treated surgically are extremely common [30] and have a substantially increased risk of developing radiographic and symptomatic OA [14]. Isolating the impact of surgical treatments on outcomes in knees with meniscal lesions requires randomized trials, and to date most studies suggest that clinical and structural outcomes of meniscal lesions are similar regardless of type of treatment [3, 8, 31].

In order to identify a possible difference in cartilage composition related to the surgical indication, we also investigated the cartilage T2 profile of participants who underwent surgery for a trauma-related meniscal injury compared to surgery for a degenerative lesion. Previous studies using patient-reported outcomes, total knee replacement surgery and radiographic evaluation to determine the outcome of OA have suggested an increased risk of knee OA following resection of degenerated menisci compared to trauma-induced tears [11–13].

We addressed this question using cartilage T2 values, a biomarker data that directly reflects possible differences in cartilage composition between the two groups. In contrast to previous studies using other outcome measures, we did not find differences in cartilage T2 values between these two surgical groups. Given the pathognomonic of meniscal tears, due to the preexisting osteoarthritic changes in knee with degenerative meniscal surgery [32], one would expect to find higher T2 values in participants that underwent degenerative meniscal tear surgery and therefore a more advanced cartilage deterioration when compared to participants that underwent traumatic meniscal tear surgery.

That we did not find such differences may be explained by the fact that the meniscal surgeries and knee injuries in our study may have occurred several years ago, allowing for the long-term impact of the trauma plus the knee surgery to decrease the differences in cartilage deterioration compared to knees with degenerative lesions. In addition, restricting our sample to knees with KL grades of less than 3, the OA resulted in a similar radiographic OA severity between the two groups.

We acknowledge that our study has several limitations. Firstly, data on meniscal surgery and knee injuries in the OAI were based on self-report and no surgical reports were obtained. The OAI database does not provide detailed information about the type of morphological meniscal damage or type of surgery or on how the knee injury occurred (e.g., sport activity, daily activity, work related), which would potentially be helpful in further categorizing participants with a history of knee injury-related meniscal surgery. However, to ensure an accurate distinction between trauma and degenerative surgery, we used the OAI self-administered questionnaire that, in addition to the question of knee injury and meniscal surgery, also asked if the surgery was to repair an injury. In addition, a musculoskeletal radiologist reviewed the MRIs of all knees self-reported as having meniscal surgery to confirm their post-surgery status. Nevertheless, misclassification of surgical vs. nonsurgical knees and surgery for traumatic vs. degenerative lesions is possible and could influence our results. Secondly, the nonsurgical controls were not selected with respect to whether meniscal lesions were present. The presence of meniscal lesions in a portion of control knees likely causes us to underestimate the T2 differences between surgically treated knees and normal knees without lesions and to overestimate the differences between surgically treated and nonsurgically treated knees with meniscal lesions. Thirdly, with respect to our study participants that did not undergo a MRI scan at the enrollment clinic, a different percentage rate between these two groups was observed, posing a potential bias due to a different study participant attrition. The main causes for participants not undergoing a MRI scan were most likely MRI safety, knee replacements, and participants might have

declined the MRI scan due to personal reasons not disclosed by the OAI database. Fourthly, arthroscopy for traumatic meniscal surgery was performed at a younger age than meniscal surgery performed for degenerative changes. Hence, the degenerative cohort received their MRI scans more recently. Finally, we performed a retrospective, cross-sectional analysis in which there may be large variations in the time since injury and surgery. Studies of the outcomes of new meniscal injuries and recent surgeries are needed to better describe the consequences of each.

In conclusion, using quantitative cartilage T2 measurements, our study showed that meniscal tears treated surgically have worse cartilage composition compared to knees without a history of surgery for meniscal tears, supporting studies suggesting that meniscal damage treated with surgery is a risk factor for development of knee OA. However, with respect to indication of surgery, we were able to show that differences in the cartilage matrix were non-significant in participants who received surgery related to trauma or degenerative meniscal disease, suggesting that they have a similar impact on post-surgical cartilage health.

Compliance with ethical standards

Competing interests None of the authors have any financial or other interests related to the manuscript submitted to Skeletal Radiology that might constitute a potential conflict of interest.

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