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Partial meniscectomy is associated with increased risk of incident radiographic osteoarthritis and worsening cartilage damage in the following year

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Abstract

Objectives—To assess whether partial meniscectomy is associated with increased risk of radiographic osteoarthritis (ROA) and worsening cartilage damage in the following year.

Methods—We studied 355 knees from the Osteoarthritis Initiative that developed ROA (Kellgren-Lawrence grade ≥ 2), which were matched with control knees. The MR images were assessed using the semi-quantitative MOAKS system. Conditional logistic regression was applied to estimate risk of incident ROA. Logistic regression was used to assess the risk of worsening cartilage damage in knees with partial meniscectomy that developed ROA.

Results—In the group with incident ROA, 4.4% underwent partial meniscectomy during the year prior to the case-defining visit, compared with none of the knees that did not develop ROA. All

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(*n*=31) knees that had partial meniscectomy and 58.9% (*n*=165) of the knees with prevalent meniscal damage developed ROA (OR=2.51, 95% CI [1.73, 3.64]). In knees that developed ROA, partial meniscectomy was associated with an increased risk of worsening cartilage damage (OR=4.51, 95% CI [1.53, 13.33]).

Conclusions—The probability of having had partial meniscectomy was higher in knees that developed ROA. When looking only at knees that developed ROA, partial meniscectomy was associated with greater risk of worsening cartilage damage.

Keywords

Meniscus; Partial meniscectomy; Cartilage loss; MRI; Osteoarthritis

Introduction

With the introduction of arthroscopic surgical techniques and increasing awareness of the burden of osteoarthritis (OA) following total meniscectomy, partial meniscectomy became the preferred procedure to treat meniscal tears, and the concept of meniscal repair was revived and refined. This further led to the current surgical understanding of preserving as much intact meniscal tissue and function as possible [1, 2]. Although partial meniscectomy is associated less with OA than with total meniscectomy [3], controversy remains as to the best treatment option for patients with meniscal damage [4].

Five randomized clinical trials (RCTs) have been published in recent years assessing arthroscopic partial meniscectomy versus conservative treatment in relation to clinical outcome in patients with degenerative meniscus tears [5-9]. Patients included in these RCTs had mixed stages of radiographic OA, but most had no or only low-grade disease. While all of these studies focused primarily on clinical outcomes, data on the structural consequences of partial meniscectomy on knees without OA are not available [10].

Considering that loss of meniscal function is one of the greatest risk factors for incident knee OA identified to date [11], and partial meniscectomy is the most common type of orthopedic surgery performed [12], the role of surgery is of particular interest for both the patients with knee symptoms and the health professionals treating them. The Osteoarthritis Initiative (OAI) is a unique dataset that can help provide answers to some of these questions.

The primary aim of the current study, therefore, was to assess whether partial meniscectomy was associated with increased risk of incident radiographic OA. As a secondary objective, we aimed to determine whether partial meniscectomy was associated with worsening of MRI-defined cartilage damage during the year following the procedure in knees that developed ROA.

Methods

The Osteoarthritis Initiative (OAI)

The OAI is an ongoing longitudinal cohort study designed to identify biomarkers of the onset and/or progression of knee OA. Both knees of 4796 participants were studied using 3-

Tesla (3T) MRI and fixed–flexion radiography at baseline and at 12, 24, 36, and 48 months of follow-up [13, 14]. The institutional review boards at each of the sites approved the study and all participants gave informed consent.

Radiography

OAI knee radiographs were acquired using the posterior–anterior–fixed flexion weight-bearing protocol [14, 15] with a plexiglass positioning frame (SynaFlexer™; Synarc Inc., San Francisco, CA) [16]. The Kellgren-Lawrence (K-L) grade was determined by central readings of serial fixed–flexion knee radiographs [15]. In brief, each film was centrally assessed by two senior musculoskeletal experts, who are not co-authors and who were blinded to each other's reading and all other data. All radiographs were read in pairs for each participant. The weighted kappa for inter-reader agreement was 0.79 for the K-L grade. Pre-specified discrepancies were adjudicated in a consensus session with a third reader [17].

Case and control knee selection

Cases were defined as study participants who had at least one knee that developed incident radiographic OA during the 4 years of follow-up. Incident radiographic OA was defined as the first occurrence of radiographic findings compatible with OA (K-L grade of ≥ 2) during the course of study. This time point was referred to as P0, with P-1, P-2, P-3, and P-4 representing the time points 1, 2, 3, and 4 years prior to incident radiographic OA. All participants with available MRI images at the point when incidence was read (P0) or the prior time point (P-1) were included. An identical number of control knees were selected that did not develop incident radiographic OA during the study period. The controls were matched to case knees according to gender, age (within 5 years), and K-L status of both the index and contralateral knees. Each case was matched to those who were at risk at the time of case occurrence and those with available images at relevant time points, whether at 12, 24, 36, or 48 months of follow-up. Both case and control knees were either K-L 0 or 1 at baseline. Altogether, 355 case knees and 355 controls were included. A detailed overview of subject inclusion is presented as a flow chart in Fig. 1. Note that knees that showed incident OA at the first follow-up (12 months) and that were K-L grade 1 at baseline and had prevalent OA in the contralateral knee were not read or matched because of concerns that they would be too similar to knees with prevalent OA.

MRI acquisition

MRI of both knees was performed on 3T systems (Siemens Trio; Siemens Healthcare, Erlangen, Germany) at the four OAI clinical sites. MRIs were acquired with a dedicated quadrature transmit/receive knee coil using a coronal intermediate-weighted (IW) two-dimensional (2D) turbo spin-echo, a sagittal three-dimensional (3D) dual-echo steady-state (DESS) sequence, and a sagittal IW fat-suppressed turbo spin-echo sequence. Additional parameters of the full OAI pulse sequence protocol and the sequence parameters were described in detail in a previous publication [13].

MRI assessment

Two musculoskeletal radiologists with 11 (FWR) and 14 (AG) years of experience in semiquantitative assessment of knee OA, and who were blinded to clinical data and case–control status, evaluated the MRIs for medial and lateral meniscal damage and for cartilage morphology at the prior time point and at the case-defining visit using the semiquantitative MRI Osteoarthritis Knee Score (MOAKS) system [18].

Cartilage was scored in 14 articular subregions, incorporating area size per subregion (from 0 to 3) and percentage of subregion that was affected by full-thickness cartilage loss (from 0 to 3). For the current analysis, only the ten tibiofemoral subregions were considered. Longitudinal cartilage loss was defined as any increase in either size or thickness of cartilage damage, or both.

Meniscal status was scored in the anterior horn, body segment, and posterior horn of the medial and lateral menisci, taking into account intrameniscal signal changes, different types of meniscal tears, and meniscal maceration, i.e., substance loss. In order to adjust for additional confounders of longitudinal cartilage loss, bone marrow lesions (BMLs) were assessed, taking into account the percentage of a subregion affected by the BML. Signal alterations in the intercondylar region of Hoffa's fat pad were scored as a surrogate for synovial thickening, termed Hoffa-synovitis. Joint effusion (also called effusion-synovitis, as it is not possible to discern joint fluid from synovial thickening based on the sequences used in the OAI pulse sequence protocol) was graded based on the estimated maximum distention of the synovial cavity. Finally, meniscal extrusion was scored in the coronal planes [18, 19].

To determine intra-reader reliability, one radiologist (FWR) re-scored 20 randomly chosen MRIs in random order for the same features after a 4-week interval. Inter-observer reliability between the two readers was assessed using the same 20 cases.

Definition of meniscal surgery

At each visit, OAI participants were asked about meniscal surgery within the previous year. Images for all potential surgical cases were re-analyzed by an experienced musculoskeletal radiologist to confirm missing meniscal substance compared to the previous visit, indicating a partial meniscectomy. Two knees (one from a knee that developed OA) in which self-reported meniscal surgery could not be confirmed because images were not available were removed from analyses involving surgery.

Statistical analyses

Descriptive comparisons generally included all knees with the relevant available MOAKS data. All knees had baseline meniscal status, but 25 knees were lacking that information at the 1-year point prior to incidence. For odds ratios, conditional logistic regression was applied to the 328 matched case–control pairs in which both had meniscal status data to assess the risk of incident radiographic OA. In addition, the risk of worsening cartilage damage during the year prior to developing radiographic OA was assessed, using a cohort analysis approach for the incident OA cases only, by applying logistic regression adjusted for body mass index (BMI) and the matching criteria (age, gender, and KL grade). An

additional analysis was performed taking into account other potential structural confounders of longitudinal cartilage loss, i.e., prevalent cartilage damage in the medial and lateral compartments, effusion-synovitis, Hoffa-synovitis, and BMLs. In the bivariate analysis, differences were observed between incident knee OA cases undergoing partial meniscectomy and other incident knee OA cases not undergoing surgery, as well as in the rest of the cohort with regard to pain and previous injury status (at any point prior to the finding of ROA). Therefore, we performed sensitivity analyses incorporating these covariates into the model.

We considered a two-tailed p value of less than 0.05 as statistically significant. Weighted kappa statistics were applied to determine inter- and intra-observer reliability. All statistical calculations were performed using Stata/IC 11.2 for Windows (StataCorp LP, College Station, TX, USA) and SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

The study sample consisted of 355 case knees and their matched controls. Participants were 60.2 years old on average (SD ± 8.6), predominantly women (66.5%), and overweight (mean BMI 28.3 SD ± 4.5). The baseline K-L grades for the matched pairs were as follows: 63 (17.8%) grade 0 in both knees, 76 (21.4%) grade 0 in one knee and grade 1 in the contralateral knee, 83 (23.4%) grade 1 in both knees, 59 (16.6%) grade 0 in one knee and grade ≥ 2 in the other, and 74 (20.9%) grade 1 in one knee and grade ≥ 2 in the contralateral knee. The case-defining visit of radiographic OA incidence was 12 months for 119 (33.5%), 24 months for 83 (23.4%), 36 months for 103 (29.0%), and 48 months for 50 (14.1%) knees. Of 710 knees, 25 case knees had missing MRI readings at the time point prior to the case-defining visit (P-1), leaving 683 knees for the time point P-1. An overview of baseline demographics is presented in Table 1.

Summarizing the intra- and inter-observer reliability results, all of the measures showed substantial (0.61–0.8) or almost perfect agreement (0.81–1.0) [20]. Appendix 1 gives a detailed overview of the reliability results.

Thirty-one (4.4%) of 708 knees underwent meniscal surgery in the year prior to the case-defining visit, and 238 (34.9% of 683) knees had a meniscal tear (MOAKS grades 2–5) at the time point prior to the case-defining visit. Forty-two (6.2%) knees showed partial meniscal maceration (MOAKS grade 6, i.e., substance loss, at the same time point). None showed a progressive partial or complete maceration. For five of the knees undergoing partial meniscectomy, MRI data for the year prior to the case-defining visit (P-1) were not available, leaving 26 knees with meniscal surgery for those analyses. A detailed overview of meniscal and radiographic OA status at baseline and 1 year prior to the case-defining visit, and with regard to cartilage loss in the prior year, is presented in Table 2. For both the baseline visit and the visit 1 year prior to the case-defining visit, the frequencies of meniscal tears and macerations were higher in the case group than the controls ($p = 0.002$ and < 0.001, respectively).

Table 3 shows the distribution of meniscal damage for the medial and lateral compartments, collapsed into normal menisci and those exhibiting intrameniscal signal only, any tear type, and any maceration (partial or complete substance loss), which did not differ between surgery cases and other case knees. Pain and previous injury status is also shown. Knees undergoing surgery exhibited significantly higher pain scores and more previous injuries.

All 31 (100%) knees that had undergone meniscal surgery during the previous year had developed incident radiographic OA at the next follow-up visit, while 50.2% of the knees developing incident radiographic OA 1 year later had prevalent meniscal damage, compared to 32.5% of the control knees not developing radiographic OA. A more than twofold greater risk for incident radiographic OA was observed for knees exhibiting prevalent tears or maceration, which is shown in Table 4.

Among all cases and controls, 37.4% of knees with meniscal damage but not surgery and 80.8% of knees with partial meniscectomy showed cartilage loss over the same 1-year follow-up period. For cases that developed ROA, prevalent meniscal damage was not associated with worsening cartilage damage in the tibiofemoral joint (odds ratio (OR) = 0.98, 95% confidence interval (CI) [0.58, 1.67]), but partial meniscectomy was strongly associated with worsening cartilage damage (OR = 4.76, 95% CI [1.63, 13.90]) compared to knees with normal meniscal morphology as the reference. For the fully adjusted model, prevalent meniscal damage again showed no association with cartilage loss (OR = 0.88, 95% CI [0.51, 1.51]), but partial meniscectomy remained strongly associated (OR 4.51, 95% CI [1.53, 13.33]). Details of these results are presented in Table 5. Figure 2 provides an illustrative example of partial meniscectomy between P-1 and P0 and subsequent development of ROA and cartilage loss.

An additional analysis incorporating the above-mentioned confounders for progression of cartilage damage plus pain status at P-1 and previous injury into the statistical model showed that the observed associations remained, although risk for cartilage loss decreased slightly, from 4.63 to 4.21. An overview of the expanded analyses incorporating pain and injury status is given in Table 6.

Discussion

In this nested case–control study, we found a much greater probability of having had partial meniscectomy in the previous year in knees that subsequently developed radiographic OA than in control knees. Furthermore, the probability of worsening cartilage damage was much higher in knees that had developed ROA and had undergone surgery compared to knees that had just developed ROA.

We recently reported on structural risk factors with regard to the development of radiographic OA in relation to several parameters, including the severity of tissue damage and the cumulative effects of the involvement of several joint structures [11]. The strongest association with OA was observed whenever these tissue changes were present in the year prior to the case-defining visit, but none showed a comparable association with incident radiographic OA as was observed for subjects having had partial meniscectomy. However,

also in that study, medial meniscus damage in particular—including meniscal tears and any kind of substance loss—strongly predicted incident ROA 1 or 2 years later [11].

Little information is available in the literature to date on subsequent risk of cartilage loss following meniscal surgery. One study of young athletes in the National Football League (NFL) in the United States who underwent MRI for various reasons reported that knees with previous meniscal surgery had a much higher prevalence of ipsi-compartmental full-thickness cartilage lesions (27% vs. 12% of those without meniscal surgery). This suggests that our findings may also be relevant for a younger active population, although reasons for meniscal surgery might differ from the indications in a non-athlete elderly patient cohort [21]. Furthermore, a repair approach, when feasible, seems to be superior to partial meniscectomy in terms of clinical outcomes [22]. In a sample at increased risk of developing radiographic OA in the Multicenter Osteoarthritis Study (MOST), for knees not undergoing surgery but with prevalent meniscal damage, the likelihood of radiographic OA within a 30-month period increased almost sixfold, which supports the importance not only of surgically induced meniscal alterations, but of meniscal integrity in general [23]. In our sample, we did find an increased risk of ROA but not of cartilage loss in knees with prevalent meniscal damage, which is likely due to the shorter follow-up period of 12 months compared to the 30 months of follow-up in the MOST study.

Our study has several limitations. One point that should be mentioned is that although the OAI is the largest longitudinal study of knee OA, only 31 knees underwent meniscal surgery within the observation period, and only 26 had MRI data available at the time point prior to the case-defining visit.

Im addition, the definition of meniscal surgery was based on participants' answers to a question regarding prior meniscal surgery as part of a clinical assessment during the yearly OAI visits, and not on actual surgery reports. We confirmed self-reports of a partial meniscectomy by the diagnosis of missing meniscal substance on MRI at the follow-up visit, with none of the knees undergoing surgery having any meniscal maceration at the visit prior to surgery, suggesting that the confirmatory readings were valid and the surgeries correctly reported. We also did not explore potential reasons for the surgeries performed. Patients undergoing surgery had higher pain scores at the time point prior to the case-defining visit and more frequent reports of previous injury, which was reason to expand our analyses adding pain and prior knee injury to the model. Despite the odds ratios remaining markedly increased for those who had surgery compared to those who had prevalent meniscal damage only, we cannot fully rule out residual confounding by indication, i.e., those having had meniscus surgery may have had symptoms because of other features of pre-radiographic knee OA rather than symptoms from the meniscal lesion per se [8, 11, 24]. However, we found no significant differences associated with meniscal damage severity in any of the case knees or the entire cohort. Finally, we used a definition of radiographic OA only and did not take into account the clinical manifestation of OA. The meniscus is an important contributor to the normal medial and lateral tibiofemoral joint space [25], and meniscal surgery may lead to a reduction in joint space width through a rapid decrease in the overall meniscal substance, thus contributing to the diagnosis of ROA [26]. In the current analysis, we did not assess other factors associated with meniscal pathology such as previous injury, and we also

did not observe any meniscal root tears, another strong risk factor of structural progression and OA incidence [27]. Although we did assess meniscal extrusion in the coronal plane, as commonly assessed using semiquantitative scoring methods, we acknowledge that change in extrusion across the entire meniscus evaluated using 3D measurements is an alternative approach that we did not include but that might yield additional information [28].

We did include the 2D spin-echo sequences and the reformatted DESS sequence of the OAI protocol for semiquantitative assessment [27]. While the additionally available T2 multi-echo spin-echo (MESE) sequence and fast low-angle shot (FLASH) sequences may add information when applying additional cartilage evaluation including 3D segmentation approaches and compositional evaluation, they do not add information when using scoring approaches [27]. As the OAI protocol was designed more than a decade ago, newer and potentially useful sequences for cartilage assessment were not included [13, 29].

Ultimately, given the data presented with regard to structural consequences and the recent clinical trials focusing on clinical outcomes, patients and their physicians should consider these findings in their clinical decision process. For the middle-aged patient with knee pain and a degenerative meniscal tear, a large body of evidence today suggests that an initial regimen of strengthening-based physical therapy should be the first step in treatment [10, 30].

In summary, the probability of having had partial meniscectomy in the previous year was higher in those who developed incident radiographic OA than in control knees. Furthermore, even when limited to knees that later developed ROA, worsening of cartilage damage within the same 1-year period was higher for knees undergoing partial meniscectomy than those with prevalent meniscal damage only. As partial meniscectomy may have deleterious effects on joint structure in knees without radiographic OA, the treatment alternatives for patients with meniscal damage and symptoms must be carefully discussed between patient and treating physician.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations and Acronyms

MRI	Magnetic resonance imaging
ROA	Radiographic osteoarthritis
RCT	Randomized controlled trial

OAI	Osteoarthritis Initiative
K-L	Kellgren-Lawrence
P0	OAI annual visit when radiographic osteoarthritis was diagnosed
P-1	OAI annual visit 1 year prior to diagnosis of radiographic osteoarthritis

Key points

- Partial meniscectomy is a controversial treatment option for degenerative meniscal tears.
- Partial meniscectomy is strongly associated with incident osteoarthritis within 1 year.
- Partial meniscectomy is associated with increased risk of worsening cartilage damage.

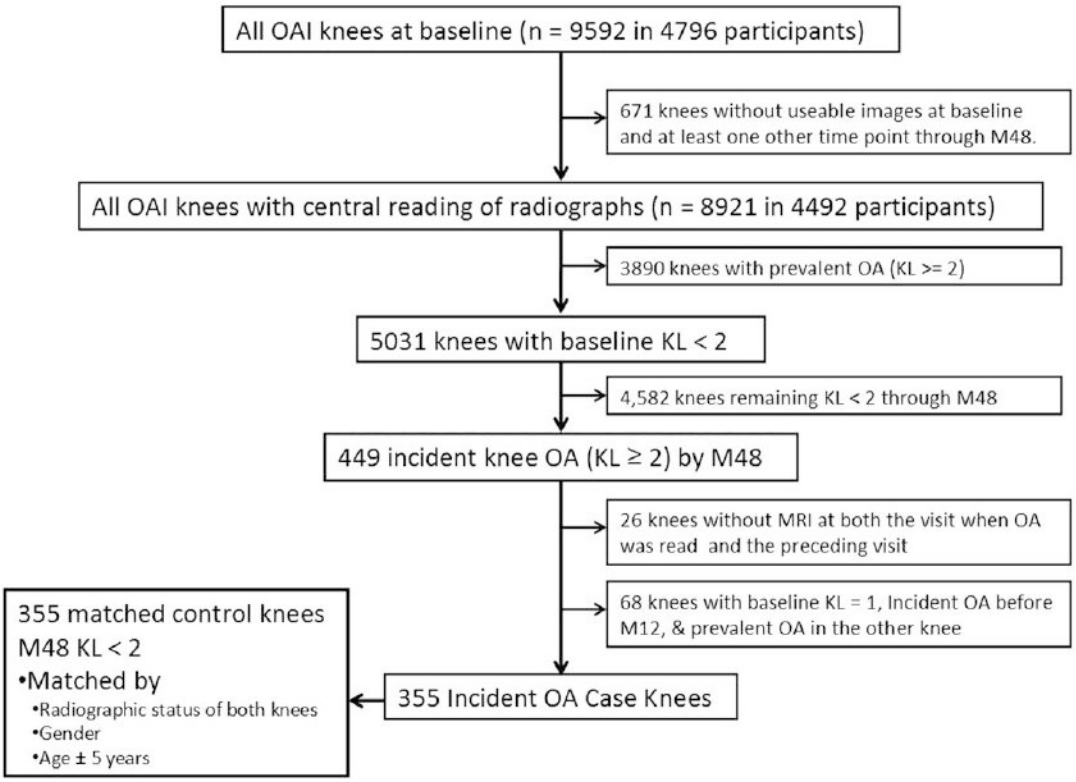
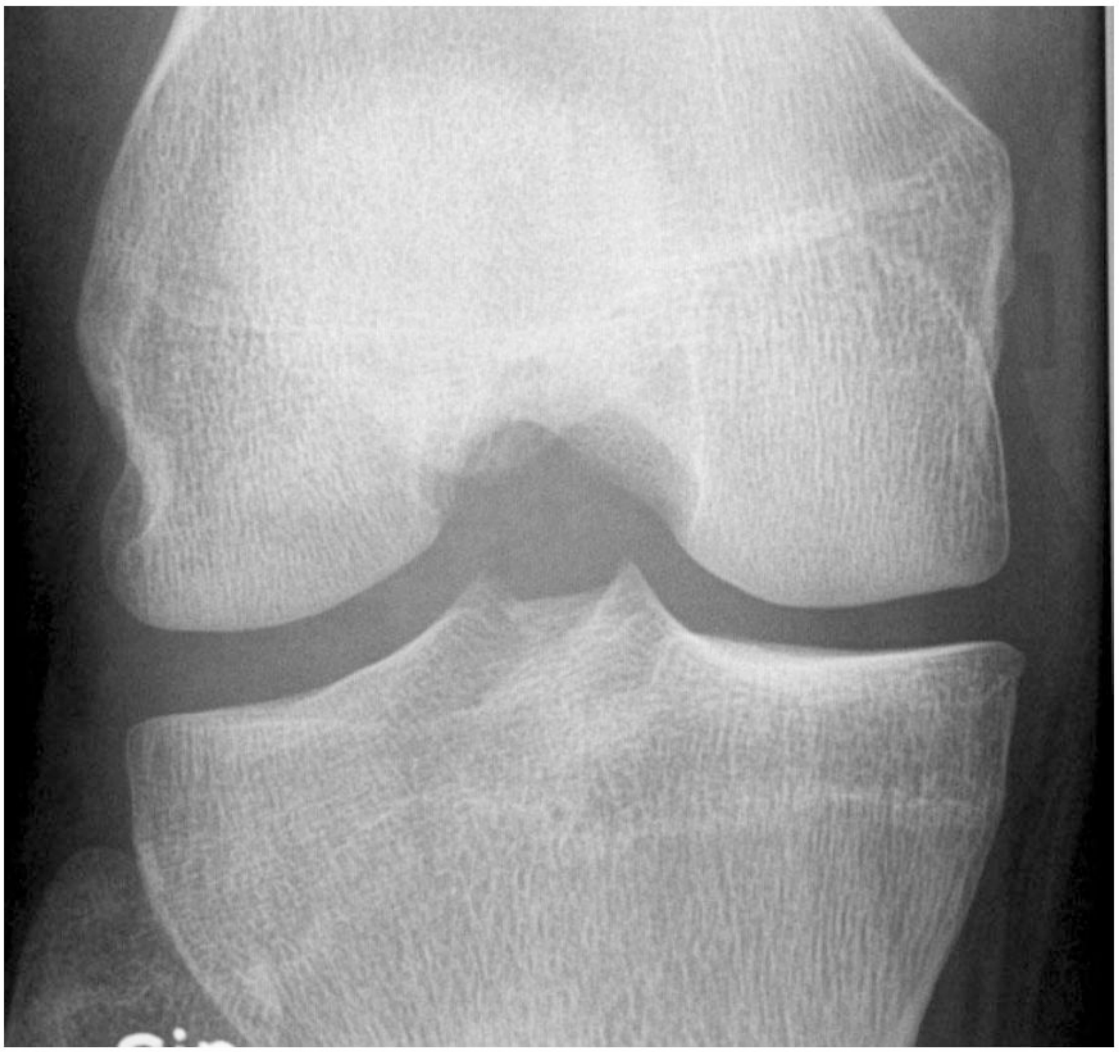
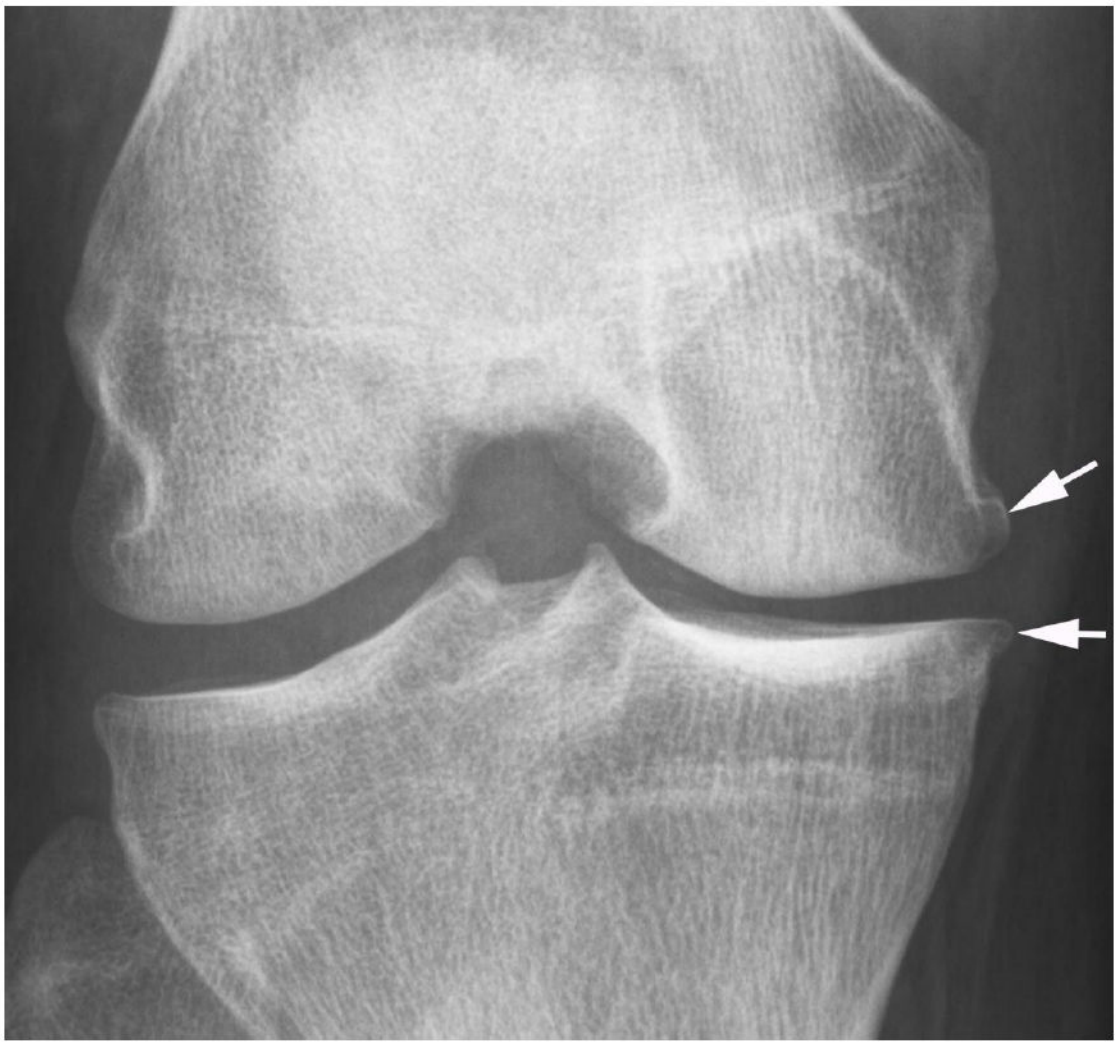


Fig. 1.
Flowchart of subject inclusion





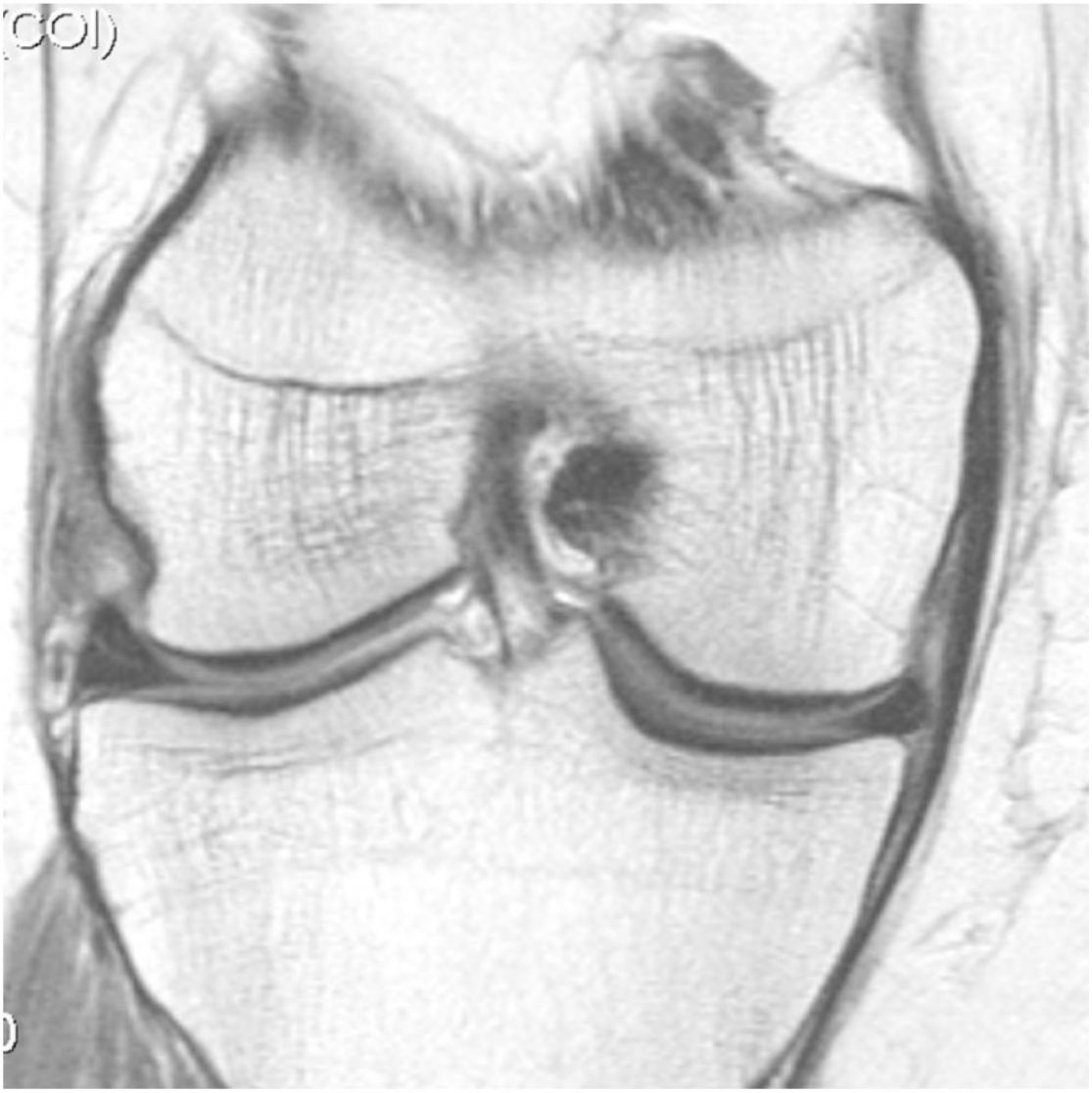


Fig. 2.

Development of radiographic osteoarthritis (OA) after partial meniscectomy. **A.** Baseline anterior–posterior radiograph of the knee shows physiologic joint anatomy without signs of OA. **B.** 12-month follow-up image shows definite radiographic OA with presence of medial tibial and femoral osteophytes at the joint margin consistent with radiographic OA Kellgren-Lawrence grade 2. **C.** Corresponding baseline MRI confirms absence of structural findings of OA. **D.** Follow-up image confirms partial meniscectomy with missing meniscal substance of the meniscal body (*black arrow*) and incident cartilage thinning (*white arrows*). An incident osteophyte is also depicted on the MRI (*arrowhead*).

Table 1

Sample description

		Sample description by knee			
		All knees *n*=710 (%)	**Case knees-incident ROA *n*=355 (%)**	**Control knees-incident ROA *n*=355 (%)**	***p* for differences**
Baseline K-L grade	0	266 (37.46)	133 (37.46)	133 (37.46)	1.000
	1	444 (62.54)	222(62.54)	222(62.54)	
Injury at baseline	Any	152 (21.41)	89 (25.07)	63 (17.75)	0.017
		Sample description by person			
		All *n*=669 (%)	**Cases-incident ROA *n*=323 (%)**	**Controls ROA *n*=346 (%)**	***p* for cases vs. controls**
Women		445 (66.52)	213 (65.94)	232 (67.05)	0.762
White or Caucasian		551 (82.36)	260 (80.50)	291 (84.10)	0.221
Body mass index					0.004
Normal/underweight		168 (25.11)	63 (19.50)	105 (30.35)	
Overweight		268 (40.06)	135 (41.80)	133 (38.44)	
Obese		233 (34.83)	125 (38.70)	108 (31.21)	
Age (±SD)		60.16 (+/- 8.56)	60.25 (+/- 8.69)	60.08 (+/- 8.44)	0.798

Note: Test for differences by chi-square or *t* test.

Table 2

Frequency of meniscal damage and surgery status at enrollment and 1 year prior to the case-defining visit and outcome (incident radiographic osteoarthritis and cartilage loss)

Outcome (incident ROA / cartilage loss)	No incident ROA (%)	Incident ROA (%)	No cartilage loss – medial (%)	Any cartilage loss – medial (%)	No cartilage loss – lateral (%)	Any cartilage loss – lateral (%)
Meniscal status at OAI enrolment (BL)						
	--- (*N* = 708) ---			**--- (*N* = 663 with cartilage loss data) ---**		
Normal or intrameniscal signal at BL[a]	243 (68.5)	209 (59.0)	325 (63.9)	95 (61.7)	378 (65.0)	44 (51.2)
Tear at BL[b]	92 (26.0)	129 (36.4)	157 (30.8)	54 (35.1)	174 (29.9)	37 (43.0)
Meniscal maceration at BL[c]	19 (5.4)	16 (4.5)	27 (5.3)	5 (3.3)	30 (5.2)	5 (5.8)
Meniscal status at 1 year prior to case-defining visit (P-1)						
	--- (*N* = 683) ---			**--- (*N* = 663 with cartilage loss data) ---**		
Normal or intrameniscal signal at P-1[a]	239 (67.5)	164 (49.9)	309 (60.7)	83 (53.9)	354 (60.8)	38 (46.9)
Tear at P-1[b]	95 (26.8)	143 (43.5)	164 (32.2)	65 (42.2)	192 (33.0)	37 (45.7)
Meniscal maceration at P-1[c]	20 (5.7)	22 (6.7)	36 (7.1)	6(3.9)	36 (6.2)	6 (7.4)
Meniscal surgery between P-1 and P0	0 (0.0)	31 (8.8)	8 (1.6)	18 (11.7)	22 (3.8)	4 (4.7)

[a]MOAKS grades 0 and 1

[b]MOAKS grades 2–5

[c]MOAKS grades 6–8 (but only grade 6 observed)

ROA radiographic osteoarthritis, *BL* baseline, *P-1* annual visit 1 year prior to case-defining visit, *P0* annual visit at the time point when incident ROA was diagnosed (i.e., the case-defining visit)

Table 3

Frequency of medial and lateral meniscal damage, extrusion, injury and pain status 1 year prior to the case-defining visit (P-1)

Meniscal status by compartment, pain status and injury status at P-1	Control knees *n*=354 (%)	Case knees - incident ROA *n*=329 (%)	Surgery knees (all cases) *n*=29[a] (%)	*p* for case vs. control knees	*p* for surgery vs. cases
Medial meniscal morphology at P-1 (maximum grade of 3 subregions)				0.001 *	0.236
Normal or Intrameniscal signal only	266 (75.1)	198 (60.2)	16 (55.2)		
Tear	68 (19.2)	113 (34.4)	13 (44.8)		
Radial tear	8 (2.3)	14 (4.3)	2 (6.9)		
Horizontal tear	56 (15.8)	81 (24.6)	9 (31.0)		
Vertical tear	1 (0.3)	6 (1.8)	1 (3.4)		
Complex tear	3 (0.9)	12 (3.6)	1(3.4)		
Partial maceration/substance loss	20 (5.6)	18 (5.5)	0 (0.0)		
Medial extrusion ≥ 2 mm at P-1	110 (31.1)	144 (43.8)	10 (38.5)	0.001 *	0.730
Lateral meniscal morphology at P-1 (maximum grade of 3 subregions)				0.056	0.620
Normal or Intrameniscal signal only	312 (88.1)	276 (83.9)	26 (89.7)		
Tear	42 (11.9)	49 (14.9)	3 (10.3)		
Radial tear	9 (2.5)	5 (1.5)	0 (0.00)		
Horizontal tear	31 (8.8)	40 (12.2)	3 (10.3)		
Vertical tear	0 (0.2)	1 (0.3)	0 (0.00)		
Complex tear	2 (0.6)	3 (0.9)	0(0.00)		
Partial maceration/substance loss	0 (0.0)	4 (1.2)	0 (0.0)		
Lateral extrusion ≥ 2 mm at P-1	6(1.7)	17 (5.2)	1 (3.5)	0.028 *	1.000
Previous injury[b]	70 (19.8)	135 (38.1)	20 (64.5)	< 0.001 *	< 0.003 *
KOOS pain at P-1	90.2 (13.5)	84.8 (16.6)	78.4 (20.6)	< 0.001 *	0.027 *
WOMAC total at P-1	7.1 (11.1)	11.4 (13.8)	16.5 (18.1)	< 0.001 *	0.036 *

[a] Two knees with partial meniscectomy had no MRI at P-1 and were excluded from these analyses

[b] Self-reported injury any time during the course of the OAI participation or prior enrollment

* Statistically significant

KOOS Knee Injury and Osteoarthritis Outcome Score, *WOMAC* Western Ontario and McMaster Universities Osteoarthritis Index

Table 4

Incident radiographic osteoarthritis

Meniscal status at P-1 or surgery case	*N* (%) in controls	*N* (%) in incident ROA knees	Odds of incident ROA*(outcome) Crude odds ratio (95% CI)
	N = 354	*N* = 329	
None/Signal	239 (67.5%)	164 (49.9%)	Reference
Tear or maceration	115 (32.5%)	165 (50.2%)	2.51 (1.73, 3.64)[a]
Meniscal Surgery			
No	35 (100%)	323 (91.2%)	Reference
Yes	0 (0%)	31 (8.8%)	N/A

*Conditional logistic regression using 328 pairs with case and control data at P-1

[a]After adjustment for BMI: OR = 2.66 (95% CI 1.81–3.89)

CI confidence interval, *ROA* radiographic osteoarthritis, *N* number, *N/A* not applicable, *P-1* time point/annual visit 1 year prior to case-defining visit

Table 5

Cartilage worsening in whole knee (medial and lateral compartments), knees developing radiographic osteoarthritis only

Meniscal status at P-1 or surgery case	No cartilage worsening *N* (%)	Cartilage worsening *N* (%)	Adjusted odds of cartilage loss (outcome) Crude odds ratio (95% CI)[a]	Adjusted odds of cartilage loss (outcome) Crude odds ratio (95% CI)[b]
	N = 147	*N* = 162		
No surgery / no meniscal damage	74 (50.3%)	67 (41.4%)	Reference	Reference
No surgery, but presence of meniscal damage (tear or maceration)	68 (46.2%)	74 (45.7%)	0.98 (0.58,1.67)	0.88 (0.51,1.51)
Meniscal surgery[c]	5 (3.4%)	21 (13.0)	4.76 (1.63,13.90)*	4.51 (1.53,13.33)*

[a] Logistic regression adjusted for matching criteria (radiographic OA severity defined by Kellgren-Lawrence grade of index and contralateral knee, age, gender) and BMI

[b] Logistic regression adjusted for matching criteria (radiographic OA severity defined by Kellgren-Lawrence grade of index and contralateral knee, age, gender), BMI and prevalent MRI features (cartilage damage, effusion, synovitis, BMLs)

[c] No data for five knees at P-1

CI confidence interval, *BMI* body mass index, *P-1* annual visit 1 year prior to case-defining visit, *BMLs* bone marrow lesions

Table 6

Cartilage worsening in whole knee (medial and lateral compartments), knees developing radiographic osteoarthritis only

Meniscal status at P-1 or surgery case	Adjusted odds of cartilage loss (outcome) Crude OR (95% CI)[a]	Adjusted odds of cartilage loss (outcome) Crude OR (95% CI)[a]	Adjusted odds of cartilage loss (outcome) Crude OR (95% CI)[a]	Adjusted odds of cartilage loss (outcome) Crude OR (95% CI)[2]	Adjusted odds of cartilage loss (outcome) Crude OR (95% CI)[b]	Adjusted odds of cartilage loss (outcome) Crude OR (95% CI)[b]
	add KOOS to model	add injury to model	add KOOS and injury to model	add KOOS to model	add injury to model	add KOOS and injury to model
	Excluding adjustment for structural MRI features			Including adjustment for structural MRI features		
No surgery / no meniscal damage	Reference	Reference	Reference	Reference	Reference	Reference
No surgery, but presence of meniscal damage (tear or maceration)	0.95 (0.56,1.62)	0.96 (0.57,1.64)	0.93 (0.54,1.59)	0.86 (0.50,1.48)	.85 (0.50,1.48)	0.84 (0.49,1.45)
Meniscal surgery[3]	4.63 (1.57, 13.59)	4.51 (1.53,13.26)	4.36 (1.48,12.90)	4.52 (1.52,13.44)	4.22 (1.41, 12.59)	4.21 (1.41,12.63)

[a] Logistic regression adjusted for matching criteria (radiographic OA severity defined by Kellgren-Lawrence grade of index and contralateral knee, age, gender) and BMI

[b] Logistic regression adjusted for matching criteria (radiographic OA severity defined by Kellgren-Lawrence grade of index and contralateral knee, age, gender), BMI and prevalent MRI features (cartilage damage, effusion, synovitis, BMLs)

[3] No data for five knees at P-1

OR odds ratio, *CI* confidence interval, BMI body mass index, *P-1* annual visit 1 year prior to case-defining visit, *BMLs* bone marrow lesions, *KOOS* knee osteoarthritis outcome score