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Chapter 2

Localized development of knee osteoarthritis (OA) can be predicted from MRI findings a decade earlier

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Abstract

Purpose
To define localized development of knee osteoarthritis (OA) that arises from anterior cruciate ligament (ACL) and meniscal injuries identified at magnetic resonance (MR) imaging performed a decade ago and the subsequent management of those findings in patients with subacute knee symptoms.

Materials and Methods
The present study was approved by local medical ethics review boards, and written informed consent was obtained. Three hundred twenty-six patients (mean age, 42 years; 108 female) from a previously reported series of 855 patients were followed up with regard to the effect of MR imaging–guided treatment for subacute knee problems. The mean follow-up period was 10 years. Initial findings and treatment were compared with the follow-up radiograph and 3.0-T MR image findings. Odds ratios (ORs), with corresponding 95% confidence intervals, were used to identify the effects between variables.

Results
Patients with ACL ruptures had an increased risk of developing joint space narrowing (JSN), cartilaginous defects, osteophytes, bone marrow lesions, and subchondral cysts medially or laterally (OR, 2.4–9.8). Patients with medial meniscal tears had an increased risk of developing JSN, cartilaginous defects, osteophytes, and bone marrow lesions medially (OR, 2.0–15.3). Patients with lateral meniscal tears had an increased risk of developing JSN, cartilaginous defects, osteophytes, bone marrow lesions, and subchondral cysts laterally (OR, 2.1–10.5). Meniscectomy had no effect on the risk of developing OA.

Conclusion
Localized knee OA developed from risk factors identified from the findings of MR imaging performed a decade ago in patients with subacute knee symptoms and did not depend on the surgical treatment of those findings.
Introduction

Osteoarthritis (OA) of the knee is a common public health problem. More than 30% of the population that is aged 60 years or older has radiographically detectable knee OA (1). Knee OA has been primarily visualized and assessed on radiographs by using the Kellgren and Lawrence (KL) scoring system (2). Investigators in large prospective studies have used radiographs with follow-up times of 10–22 years to assess the effect of meniscal and anterior cruciate ligament (ACL) lesions on the development and progression of knee OA (3–10).

Magnetic resonance (MR) imaging, owing to its ability to depict cartilage damage, subchondral bone, and bone marrow lesions, has potential advantages in assessing the development of OA (11,12). Recently published MR imaging studies, however, have been cross-sectional or have involved a maximal follow-up time of only 3 years (13–16).

Ten years ago, the effect of MR imaging–guided treatment on the outcomes of 855 patients with subacute knee problems was studied (17). The aim of the present study was to define localized knee OA detected at radiography and 3.0-T MR imaging that developed from risk factors identified on MR images obtained a decade ago and the subsequent management of those findings in patients with subacute knee symptoms 10 years ago.

Material and Methods

Study population

The current study was approved by the medical ethics review boards of the three participating hospitals, and written informed consent was obtained from each participant. Patient records were retrieved from the database of a previous prospective study, which was performed in 1996 and 1997 in three different hospitals. The study sponsor (Dutch Arthritis Association) had no involvement in the study design, data collection, data analysis, or results interpretation.

The objective of the previous study was to evaluate the diagnostic value of knee MR imaging relative to arthroscopy in patients with subacute knee problems (17). Subacute knee problems were defined as persistent knee problems lasting for more than 4 weeks. Only patients with
persistent knee problems lasting for more than 4 weeks who sought physician attention were included. A total of 855 patients between the ages of 16 and 45 years (mean age, 31 years ± 8.0 [standard deviation]) participated. Exclusion criteria were knee problems lasting less than 4 weeks, clinical symptoms of a locked knee, known inflammatory diseases such as rheumatoid arthritis, known OA (KL score ≥ 4), or history of knee surgery. All participants underwent physical knee examination, MR imaging, and radiography of the knee. Knee arthroscopy was performed randomly in 161 (50%) of 321 patients with abnormal clinical examination results and normal MR findings.

The current study is a follow-up of the above described study population (mean follow-up, 10 years ± 0.90). All 855 patients from the original cohort were invited by mail for follow-up. A total of 326 patients (38%) were included. Of the 529 excluded subjects, five patients had died, 21 patients were excluded because of MR imaging or radiographic contraindications, 87 patients refused participation, and 416 patients did not respond to the contact letter sent by mail, a second letter sent after 2 months, or the three contact attempts by telephone. To assess for selection bias in the follow-up study, the patient characteristics of the follow-up study population were compared with those of the initial study (Table 1).
Table 1

*Differences in Patient Characteristics between Original and Current Study*

<table>
<thead>
<tr>
<th>Patients not included in the current study population (n = 529)</th>
<th>Current population (n = 326)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age distribution</strong></td>
<td></td>
<td>0.006* (Mann-Whitney)</td>
</tr>
<tr>
<td>30 (median age)</td>
<td>32 (median age)</td>
<td></td>
</tr>
<tr>
<td><strong>Number of women</strong></td>
<td></td>
<td>1.000 (Chi-square test)</td>
</tr>
<tr>
<td>173 (33%)</td>
<td>108 (33%)</td>
<td></td>
</tr>
<tr>
<td><strong>ACL ruptures</strong></td>
<td></td>
<td>0.021* (Chi-square test)</td>
</tr>
<tr>
<td>50 (10%)</td>
<td>48 (15%)</td>
<td></td>
</tr>
<tr>
<td><strong>MM tears</strong></td>
<td></td>
<td>0.072 (Chi-square test)</td>
</tr>
<tr>
<td>162 (31%)</td>
<td>119 (37%)</td>
<td></td>
</tr>
<tr>
<td><strong>LM tears</strong></td>
<td></td>
<td>0.725 (Chi-square test)</td>
</tr>
<tr>
<td>104 (20%)</td>
<td>68 (21%)</td>
<td></td>
</tr>
<tr>
<td><strong>No meniscus tears or ACL rupture</strong></td>
<td></td>
<td>0.048* (Chi-square test)</td>
</tr>
<tr>
<td>283 (54%)</td>
<td>151 (47%)</td>
<td></td>
</tr>
</tbody>
</table>

*LM = lateral meniscus, MM = medial meniscus.*

Clinical data regarding the length and severity of symptoms were measured by using the Noyes knee scoring system for function and symptoms (18,19). Noyes scores were determined at the time of inclusion, after 3 and 6 months, and after 10 years.

Radiographs and MR images of the knee that was symptomatic 10 years ago were acquired. The time interval between these follow-up examinations was less than 2 weeks. ACL and meniscal injuries detected on the initial 0.5-T MR and/or arthroscopic images were compared with findings on the follow-up radiographs and 3.0-T MR images.

**Radiographic knee examination and assessment**

Standardized weight-bearing posterior-anterior knee radiographs were obtained with the knee in a semi-flexed position (20). Supine lateral radiographs of the knee were also obtained. An
experienced musculoskeletal radiologist (I.W., 30 years of musculoskeletal radiology experience) and a research fellow (K.H.) scored the radiographs for features of OA. Overall severity was scored by using the KL system (2). Radiographs were also scored on a scale of 0–3 for joint space narrowing (JSN) assigned to three regions: the medial tibiofemoral compartment, the lateral tibiofemoral compartment, and the patellofemoral compartment. Osteophytes were assigned to five regions: the medial femoral compartment, the medial tibiofemoral compartment, the lateral femoral compartment, the lateral tibiofemoral compartment, and the patellofemoral compartment. JSN and osteophytes were scored by using the Osteoarthritis Research Society International atlas (21). A lesion was considered to be present when a score of 1–3 was given.

**MRI knee examination and assessment**

For the first MR study, a 0.5-T system (Gyroscan T5; Philips Medical Systems, Best, The Netherlands) was used. The MR imaging protocol consisted of three sequences: sagittal and coronal dual spin-echo sequences and a sagittal T1-weighted three-dimensional gradient-echo sequence with frequency-selective fat suppression. Ten years ago, one of six radiologists (including J.L.B.) with at least 4 years of experience with musculoskeletal MR imaging evaluated the initial 0.5-T MR images in each patient. The locations and types of meniscal tears and ACL ruptures were scored. For the follow-up study, the initial 0.5-T MR images were compared with the follow-up 3.0-T MR images and were reinterpreted in consensus by an experienced musculoskeletal radiologist (I.W.) with more than 20 years of MR imaging experience and a research fellow (K.H.). In 51 subjects who received a diagnosis of meniscal degeneration 10 years ago and in three subjects who initially received a diagnosis of meniscal tear, the 0.5-T MR images were considered to be normal in the current consensus reading. The corrected interpretations for these 54 patients were used for analysis in the current follow-up study.

The follow-up MR imaging examinations were performed by using a 3.0-T system (Achieva 3T; Philips Medical Systems). The MR imaging protocol comprised six sequences: coronal and transverse fast spin echo with fat suppression, coronal and sagittal fast spin echo with driven equilibrium, and transverse and sagittal gradient echo with water excitation.
The parameters for coronal and transverse fat-suppressed fast spin-echo MR imaging were repetition times of 2625 and 1247 msec for the coronal and transverse planes, respectively. For both planes, the echo time was 34 msec, the field of view was 150 mm, and the matrix was 304 × 238. A 3-mm section thickness with a 0.60-mm intersection gap for coronal imaging and a 4-mm section thickness with a 0.80-mm intersection gap for transverse imaging were used. The parameters for sagittal and coronal fast spin-echo imaging with driven equilibrium were 3000/34 (repetition time msec/echo time msec) and a field of view of 150 mm. In the sagittal plane, a matrix of 304 × 238 and a 3.5-mm section thickness with a 0.70-mm intersection gap were used, and in the coronal plane, a matrix of 304 × 242 and a 3-mm section thickness with a 0.60-mm intersection gap were used. The parameters for sagittal and transverse three-dimensional gradient-echo imaging with water excitation were a 35° flip angle, 16/9.21, a 150-mm field of view, a matrix of 304 × 512, and 0.75-mm section thickness. The imaging time for the entire MR imaging protocol was 28 minutes 22 seconds.

Two experienced musculoskeletal radiologists (J.L.B., I.W., more than 20 years of MR experience) and a research fellow (K.H.), who were blinded to the patient characteristics, scored all of the acquired data in consensus by using the validated knee osteoarthritis scoring system (22). Lesions were localized to any of five regions: medial femoral compartment, medial tibiofemoral compartment, lateral femoral compartment, lateral tibiofemoral compartment, and patellofemoral compartment.

The scored parameters were focal and diffuse cartilaginous defects. A focal cartilaginous defect was defined as an abrupt transition (acute angle) between the cartilage defect and the surrounding cartilage. A diffuse cartilaginous defect was defined as a smooth and gradual transition between normal and thinned cartilage. When a focal chondral defect was superimposed on diffuse cartilage loss, both defects were scored. Other scored parameters were meniscal tears (Fig 1) and subluxations, osteophyte formation, bone marrow lesions, and subchondral cysts (Figs 2 and 3). With the knee osteoarthritis scoring system, values of 0 (absent) to 3 (severe) are assigned to the MR imaging–depicted features (22). A lesion was considered to be present when a score in the range of 1–3 was given.
Figure 1:
Sagittal 0.5-T intermediate-weighted spin-echo MR image (2250/20) shows MM tear in 29-year-old man after traumatic knee injury. This isolated MM tear was treated with partial meniscectomy 10 years ago.

Figure 2:
Sagittal three-dimensional gradient-echo MR image shows cartilaginous defect (arrow) and bone marrow lesion in lateral femoral condyle in 54-year-old woman with ACL rupture and meniscal tears 10 years ago. This sequence was used to score the cartilage lesions. Fat-suppressed fast spin-echo sequence was used to score the bone marrow lesion. The ACL rupture was not reconstructed, and the MM tear was treated with partial meniscectomy.
Figure 3:

Coronal fat-suppressed fast spin-echo MR image in 46-year-old man shows ill-defined bone marrow edema-like pattern in lateral tibial condyle (arrow) and cartilage loss in lateral tibia. Patient had torn LM and was treated with partial meniscectomy.

Data Analysis

To determine the prevalence of structural abnormalities, the arthroscopic and MR imaging findings from the initial study were used; in the patients who did not undergo arthroscopy, the MR findings were used. The follow-up radiographic and MR results were categorized in a binary fashion as normal or abnormal.

The Mann-Whitney test was used to compare differences in age distribution, and the $\chi^2$ test was used to compare differences in sex and structural abnormalities between the current study population and the patients who participated in the initial study but were not included in the current study population. The $\chi^2$ test was used to determine if there were differences in OA development among the knees with different structural abnormalities detected with MR imaging or arthroscopy. One-way analysis of variance was used to compare the Noyes knee function and symptom scores among five groups: patients with ACL ruptures, patients with medial meniscal tears, patients with lateral meniscal tears, patients with combined ACL ruptures and/or meniscal tears, and patients without ACL ruptures or meniscal tears.

Odds ratios (ORs), with 95% confidence intervals (CIs), were used to show the association between different risk factors and presence of OA features 10 years after subacute knee problems.
Multivariate logistic regression models were used to assess the association between MR imaging findings 10 years earlier and subsets of knee OA based on current MR imaging results while adjusting for age, sex, and body mass index. Age and body mass index were analyzed as continuous variables. When the odds ratio estimates were zero, exact logistic regression was used to obtain upper 95% CI limits.

All tests were two tailed, and P < .05 was considered to indicate statistical significance. All statistical analyses were performed by using SPSS, version 16.0.2, for Windows (SPSS, Chicago, Ill) and SAS Statistics, version 9.1 (SAS, Cary, NC), software.

Results

Population characteristics

The median age of the 326 patients whose data were included in the follow-up study was 42 years (mean age, 42 years ± 7.6 [standard deviation]). At the time of their inclusion in the initial study 10 years ago, their median age was 32 years (mean age, 32 years ± 7.7), which differed from the median age of the 529 patients not included in the current study population (30 years; mean age, 30 years ± 8.1, P = .006) (Table 1). At the current follow-up, 108 (33%) patients were female; this was the same percentage of female patients as that in the original study (n = 281[33%]) and in the cohort of patients not included in the current study population (n = 173 [33%]) (Table 1). More ACL ruptures were found in the current study population (48 [15%]) than in the group of patients not included (50 [9%]) (P = .021) (Table 1). Furthermore, the frequency distribution of meniscal lesions found 10 years ago among the patients not included in the current study was similar to that in the current study population (Table 1).

The follow-up population can also be considered representative of the initial study population in terms of surgical history. The partial meniscectomies performed in 263 (31%) patients in the original study population within 6 months after inclusion 10 years ago were not significantly different from the 115 (35%) meniscectomies performed 10 years ago in the follow-up population.
within 6 months after inclusion. An additional 14 (4%) patients in the follow-up population underwent a partial meniscectomy after 6 months but within 10 years of follow-up. Because of the nonresponders, the number of partial meniscectomies performed after 6 months in the complete initial population is not available.

The Noyes knee function and symptom scores (18,19) at the time of inclusion, after 3 and 6 months, and after 10 years were not significantly different between patients with an ACL rupture, patients with a medial meniscal tear, patients with a lateral meniscal tear, patients with combined ACL ruptures and/or meniscal tears, and patients without ACL ruptures or meniscal tears (P ≥ 0.05 for all comparisons). No major trauma was reported by any patient during the 10-year interval; no information about minor injuries was available.

Ten years ago, most meniscal tears—110 (94%) of 117 MM tears and 48 (73%) of 66 LM tears—were found in the posterior horn and body. Of the 117 MM tears, two (2%) were smaller than 0.5 cm, 90 (77%) were larger than 0.5 cm, and 25 (21%) were bucket-handle tears. Of the 66 LM tears, 14 (21%) were smaller than 0.5 cm, 47 (71%) were larger than 0.5 cm, and five (8%) were bucket-handle tears.

**Surgical treatment**

In the knees with ACL rupture, 16 ACLs (33%) were reconstructed. The majority of these reconstructions (13 [81%]) were performed within 2 years after inclusion in the initial study. Partial meniscectomy was performed in 129 (71%) (86 MM, 43 LM) of the 183 knees with meniscal tears. The other 54 (29%) (31 MM, 23 LM) tears were treated conservatively. The majority (115 [89%]) of the meniscectomies were performed within 6 months after inclusion in the initial study. Meniscectomy was performed in 25% of the 16 meniscal tears smaller than 0.5 cm (0 MM, four LM), in 71% of the 137 meniscal tears larger than 0.5 cm (62 MM, 35 LM), and in 93% of the 30 bucket-handle tears (24 MM, four LM).
Radiographic sequelae

ACL lesions.—In patients with ACL ruptures, an increased risk of advancing more than one point in the KL score over 10 years was found (OR, 2.8). There was an increased risk of developing JSN in the medial tibiofemoral compartment (OR, 5.5) and an increased risk of developing osteophytes in the medial femoral (OR, 7.0) and medial tibiofemoral (OR, 2.0) compartments (Table 2) (Fig 4a).

MM lesions.—In the knees with torn MMs, there was an increased risk of advancing more than one point in the KL score (OR, 2.0). There was an increased risk of developing JSN (OR, 15.3) and of developing osteophytes (OR, 3.9) in the medial tibiofemoral compartment (Table 2) (Fig 5a). Differences in the size and location of the MM tears had no significant effect on the risk of developing these radiographic features.

LM lesions.—Patients with LM tears had an increased risk of advancing more than one point in the KL score over 10 years (OR, 2.3). There was an increased risk of developing JSN in the lateral medial tibiofemoral compartment (OR, 10.7) and an increased risk of developing osteophytes in the lateral tibiofemoral (OR, 4.8) and patellofemoral (OR, 2.1) compartments (Table 2) (Fig 6a). Differences in the size and location of the LM tears had no significant effect on the risk of developing these radiographic features.
Table 2 Radiographic Sequelae in Relation to Old Meniscal Tears and ACL Ruptures

<table>
<thead>
<tr>
<th></th>
<th>ACL rupture n = 48</th>
<th>MM tear n = 117</th>
<th>LM tear n = 66</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
<td>P value</td>
</tr>
<tr>
<td>K&amp;L Difference &gt;1</td>
<td>2.8</td>
<td>1.2-6.4</td>
<td>0.013*</td>
</tr>
<tr>
<td>JSN Medial TFC</td>
<td>5.5</td>
<td>1.6-18.6</td>
<td>0.006*</td>
</tr>
<tr>
<td>JSN Lateral TFC</td>
<td>1.4</td>
<td>0.5-4.4</td>
<td>0.516</td>
</tr>
<tr>
<td>JSN PFC</td>
<td>0.5</td>
<td>0.0-3.7</td>
<td>0.569</td>
</tr>
<tr>
<td>Osteophytes MFC</td>
<td>7.0</td>
<td>1.5-33.6</td>
<td>0.015*</td>
</tr>
<tr>
<td>Osteophytes MTC</td>
<td>2.0</td>
<td>1.1-5.7</td>
<td>0.032*</td>
</tr>
<tr>
<td>Osteophytes LFC</td>
<td>0.4</td>
<td>0.0-2.5</td>
<td>0.365</td>
</tr>
<tr>
<td>Osteophytes LTC</td>
<td>1.7</td>
<td>0.7-4.4</td>
<td>0.282</td>
</tr>
<tr>
<td>Osteophytes PFC</td>
<td>0.9</td>
<td>0.4-2.0</td>
<td>0.720</td>
</tr>
</tbody>
</table>

LFC = lateral femoral compartment, LTC = lateral tibial compartment, MFC = medial femoral compartment, MTC = medial tibial compartment, PFC = patellofemoral compartment. *Significant difference.

MR Imaging sequelae

ACL lesions.—Patients with an ACL tear 10 years ago had an increased risk of developing diffuse cartilaginous lesions in the medial tibiofemoral compartment (OR, 4.1) and/or focal cartilaginous
lesions in the lateral femoral (OR, 3.0) and/or lateral tibiofemoral (OR, 3.1) compartment. They also had an increased risk of developing a subluxation of the MM (OR, 6.7) and of developing osteophytes in the medial femoral (OR, 3.8), medial tibiofemoral (OR, 3.0), and/or lateral tibiofemoral (OR, 2.7) compartment. Patients with ACL ruptures had an increased risk of developing bone marrow lesions (OR, 5.5) and subchondral cysts (OR, 9.8) in the lateral femoral compartment (Tables 3–7, Fig 4b).

MM lesions.—Patients with MM tears had an increased risk of developing MR imaging–detectable diffuse cartilaginous defects in the medial femoral (OR, 2.8) and/or medial tibiofemoral (OR, 3.6) compartment. There was an increased risk of developing MM subluxations (OR, 2.9) and a reduced risk of developing LM subluxation (OR, 0.2). There was an increased risk of developing osteophytes (OR, 2.8) and bone marrow lesions (OR, 4.1) in the medial tibiofemoral compartment. Patients with MM tears did not have an increased risk of developing subchondral cysts in any compartment (Tables 3–7) (Fig 5b). Differences in the size and location of the MM tears had no significant effect on the risk of developing these MR features.

LM lesions.—Patients with LM tears had an increased risk of developing focal cartilaginous lesions in the lateral tibiofemoral (OR, 2.9) and/or lateral femoral (OR, 3.3) compartment. There was an increased risk of developing a subluxation of the LM (OR, 10.5) and osteophytes in the lateral femoral compartment (OR, 2.5). Patients with LM tears had an increased risk of developing bone marrow lesions in the lateral tibiofemoral compartment (OR, 4.4) and a decreased risk of developing bone marrow lesions in the patellofemoral compartment (OR, 0.2). There was an increased risk of developing subchondral cysts in the lateral tibiofemoral compartment (OR, 4.1) (Tables 3–7) (Fig 6b). Two patients with LM bucket-handle tears developed bone marrow lesions in the lateral femoral compartment. None of the patients with smaller LM tears developed bone marrow lesions in the lateral femoral compartment, and the difference between these two groups was significant (P = .008). No other differences related to the size or location of the LM lesions were observed.
**Figure 4:** (a) Drawing shows characteristic abnormalities, as seen on radiographs, that have increased risk of developing after rupture of ACL: JSN and osteophytes medially. (b) Drawing shows characteristic abnormalities, as seen on MR images, that have increased risk of developing after rupture of ACL: diffuse cartilaginous defects and osteophytes medially, and focal cartilaginous defects, osteophytes, bone marrow lesions, and subchondral cysts laterally.

![Figure 4](image)

**Figure 5:** (a) Drawing shows characteristic abnormalities, as seen on radiographs, that have increased risk of developing after MM tear: JSN and osteophytes medially. (b) Drawing shows characteristic abnormalities, as seen on MR images, that have increased risk of developing after MM rupture: diffuse cartilage defects, osteophytes, and bone marrow lesions medially.

![Figure 5](image)
Figure 6a: (a) Drawing shows characteristic abnormalities, as seen on radiographs, that have increased risk of developing after LM tear: JSN and osteophytes laterally. (b) Drawing shows characteristic abnormalities, as seen on MR images, that have increased risk of developing after LM rupture: focal cartilaginous defects, osteophytes, bone marrow lesions, and subchondral cysts laterally.
Table 3 Focal and Diffuse Cartilage Defects in Relation to Old Meniscal Tears and ACL Ruptures

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Cartilage Defects</th>
<th>ACL rupture n = 48</th>
<th>MM tear n = 117</th>
<th>LM tear n = 66</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
<td>P value</td>
<td>OR</td>
</tr>
<tr>
<td>MFC</td>
<td>Focal</td>
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<td>0.7-2.1</td>
<td>0.242</td>
</tr>
<tr>
<td></td>
<td>Diffuse</td>
<td>1.7</td>
<td>0.7-4.2</td>
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<tr>
<td>MTC</td>
<td>Focal</td>
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<td>0.3-4.9</td>
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</tr>
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<td>4.1</td>
<td>1.5-11.2</td>
<td>0.006*</td>
</tr>
<tr>
<td>LFC</td>
<td>Focal</td>
<td>3.0</td>
<td>1.4-6.4</td>
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<tr>
<td></td>
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<td>0.6-3.6</td>
<td>0.453</td>
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<tr>
<td>LTC</td>
<td>Focal</td>
<td>3.1</td>
<td>1.3-7.3</td>
<td>0.009*</td>
</tr>
<tr>
<td></td>
<td>Diffuse</td>
<td>0.8</td>
<td>0.1-4.0</td>
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<td>PFC</td>
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*Significant difference. LFC = lateral femoral compartment, LTC = lateral tibial compartment, MFC = medial femoral compartment, MTC = medial tibial compartment, PFC = patellofemoral compartment.
Table 4 Meniscal Subluxation and Newly Developed Meniscal Tears in Relation to Old Meniscal Tears and ACL Ruptures

<table>
<thead>
<tr>
<th>Meniscal findings</th>
<th>ACL rupture n = 48</th>
<th>MM tear n = 117</th>
<th>LM tear n = 66</th>
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<tbody>
<tr>
<td></td>
<td>OR</td>
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<td>P value</td>
</tr>
<tr>
<td>MM subluxation</td>
<td>6.7</td>
<td>2.1-21.0</td>
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<tr>
<td>LM subluxation</td>
<td>0.5</td>
<td>0.1-2.0</td>
<td>0.312</td>
</tr>
<tr>
<td>New MM tear</td>
<td>2.9</td>
<td>1.0-9.3</td>
<td>0.069</td>
</tr>
<tr>
<td>New LM tear</td>
<td>2.1</td>
<td>0.5-9.1</td>
<td>0.303</td>
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</tbody>
</table>

*Significant difference. MM = medial meniscus, LM = lateral meniscus

Table 5 MR Imaging–depicted Osteophytes in Relation to Old Meniscal Tears and ACL Ruptures

<table>
<thead>
<tr>
<th>Osteophytes</th>
<th>ACL rupture n = 48</th>
<th>MM tear n = 117</th>
<th>LM tear n = 66</th>
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<td>Compartment</td>
<td>OR</td>
<td>95% CI</td>
<td>P value</td>
</tr>
<tr>
<td>MFC</td>
<td>3.8</td>
<td>1.8-8.1</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>MTC</td>
<td>3.0</td>
<td>1.2-7.2</td>
<td>0.014*</td>
</tr>
<tr>
<td>LFC</td>
<td>1.1</td>
<td>0.4-3.4</td>
<td>0.819</td>
</tr>
<tr>
<td>LTC</td>
<td>2.7</td>
<td>1.1-6.4</td>
<td>0.024*</td>
</tr>
<tr>
<td>PFC</td>
<td>1.5</td>
<td>0.7-2.9</td>
<td>0.276</td>
</tr>
</tbody>
</table>

*Significant difference. LFC = lateral femoral compartment, LTC = lateral tibial compartment, MFC = medial femoral compartment, MTC = medial tibial compartment, PFC = patellofemoral compartment.
Surgical treatment and differences in Radiographic and MRI sequelae

The ORs for all structural abnormalities in the patients treated with ACL reconstruction or partial meniscectomy were not significantly different from those for the patients who were not treated. (All 95% CIs for ORs included an OR equal to 1.) In terms of the manifestation of all OA features in all compartments after 10 years, it made no difference if the initial ACL, MM, or LM lesion was detected at MR imaging or arthroscopy (P≥.05 for all comparisons).

Meniscal tears were also present in 31 (65%) knees with ACL ruptures. Logistic regression analysis revealed that the increased risk of developing OA was not dependent on meniscal lesions, but rather it could be attributed to ACL rupture only. None of the structural abnormalities evaluated 10 years ago indicated an increased risk of developing meniscal tears. (All 95% CIs for ORs included an OR equal to 1 [Table 4].)

Discussion

Localized knee OA developed, irrespective of treatment, from ACL and meniscal injuries identified at MR imaging performed a decade ago in patients with subacute knee symptoms. Patients who have had an ACL rupture and/or a meniscal tear have a significantly increased risk of developing JSN, cartilage lesions, osteophytes, and/or bone marrow lesions.

Treatment, partial meniscectomy and ACL reconstruction in particular, did not decrease the risk of developing the features of OA demonstrated on radiographs or MR images. This is in contrast to results reported previously (4). Englund et al (4) examined 155 patients with isolated meniscal tears who were treated with meniscectomy. Their results showed that, 16 years later there was an increased risk of developing radiographically detectable knee OA in patients whose meniscal tears were treated with meniscectomy as compared with this risk in a control group. The results of our study, however, show that, after 10 years, patients with meniscal tears have an increased risk of developing radiographic OA, but partial meniscectomy has no significant effect (positive or negative) on the development of radiographically detectable OA. Because Englund et al (4) examined patients who had undergone meniscectomy only, it is not clear to what extent the
development of OA in that study population could be attributed to the meniscal tear and to what extent it could be attributed to meniscectomy.

More abnormalities were found on the MR images than on the radiographs, in accordance with previously reported observations that MR imaging enables a more detailed and comprehensive display of OA-related changes than does radiography (11,12).

With rupture of the ACL, increased internal tibial rotation and anterior tibial translation occur (23–28). This leads to a higher point rotation pressure in the medial knee compartment and higher shearing forces in the medial and lateral compartments. Shearing forces are important in developing cartilaginous defects, because cartilage is known not to withstand shear stress as well as compressive forces (29–31). As a consequence, 10 years after ACL rupture, MR images depict diffuse cartilaginous lesions in the medial tibiofemoral compartment (OR, 4.1) and focal cartilaginous lesions in the lateral femoral (OR, 3.0) and lateral tibiofemoral (OR, 3.1) compartments. Our result of an increased risk of OA development in the patients with isolated ACL ruptures differed from the findings of Neuman et al (9). They found that 15 years after ACL rupture, only those patients who were also treated with meniscectomy developed radiographically detectable OA. However, as stated by Neuman et al, because of the low incidence of knee OA and the small sample size, multivariate modeling of multiple risk factors was not performed in their statistical analysis. In our study, multivariate modeling was used to compare the risks of developing OA after ACL and meniscal lesions. The effect of surgical treatment on the development of OA in these groups was analyzed separately. This makes it difficult to compare the outcomes of both studies.

Menisci are important load transmitters (32). The results of our study show that there is an increased risk of developing cartilaginous lesions after meniscal tears. This is in concordance with the results of other MR imaging studies (4,13,14,16). Our results show that there is an increased risk of developing diffuse cartilaginous defects medially in patients who have had MM tears and an increased risk of developing focal cartilaginous defects laterally after LM tears. A possible explanation for these findings is that with normal knee movements, rotation occurs mainly around a medially positioned axis, resulting in shear stress at the lateral articular surface and
point rotation pressure at the medial surface (33,34). Because cartilage is less tolerant to shearing forces, the impaired load transmission of torn menisci has a greater effect on the lateral compartment, increasing the risk of developing focal cartilaginous defects. The increased point rotation pressure in combination with the increased joint load medially during walking (35) might cause the anatomically vulnerable MM (32) to tear and increase the risk of developing diffuse cartilaginous defects medially.

Radiographically depicted JSN is reportedly influenced by meniscal position, meniscal degeneration, and cartilaginous defects (36). The results of our study show that after ACL rupture, there is an increased risk of developing medial JSN, which can contribute to the increased risk of developing cartilage lesions in the medial tibiofemoral compartment (OR, 4.1) and/or MM subluxations (OR, 6.7). The increased risk of developing JSN meniscal tears in the ipsilateral tibiofemoral compartment can be explained by the increased risk of developing cartilaginous lesions (OR range, 2.8–3.6 [Table 3]), the increased risk of developing meniscal subluxations (OR: 2.9 for MM, 10.5 for LM), and/or the meniscal tear itself. Although osteophytes can develop without explicit cartilage damage (37), the increased risk of developing radiographically and MR imaging–detectable osteophytes seems to be related to the presence of cartilaginous defects. In three of four radiographically determined locations and four of five MR imaging–determined locations with an increased risk of developing osteophytes, there was also an increased risk of developing cartilaginous lesions.

The development of MR imaging–detectable patellofemoral OA features was not related to ACL or MM lesions, but the risk of developing radiographically detectable osteophytes in the patellofemoral joint after LM tearing was increased (OR, 2.1). These results are in accordance with previous study findings that indicated that other risk factors may be involved in patellofemoral OA as opposed to tibiofemoral OA (38–41). The increased risk of radiographically detectable patellofemoral osteophytes and the decreased risk of bone marrow lesions in knees with LM tears might be explained by varus malalignment and erratic rotational movements at the femorotibial articulation with subsequent abnormal patellofemoral stresses (42).
The main limitation of the present study was the large number of patients lost to follow-up (529 [62%] of 855 patients). There are some possible reasons for this limited response rate. The study originally was not designed to be a follow-up investigation, and all patients had to be traced and asked to participate. Because the study population was relatively young, it was difficult to trace all patients: Often, their addresses and phone numbers had changed during the 10 years. Another limitation of the study was that only those patients with persistent knee problems might have been interested in participating in the follow-up study, possibly biasing the results. To investigate this, all 87 subjects who refused participation were asked if they still had knee problems. The majority of these subjects, 49 (56%) patients, had knee problems, but they also had other reasons for not participating in the study. Furthermore, no significant differences in population characteristics between the complete initial (n = 855) and current study (n = 326) populations were found (P ≥ .05 for all comparisons). However, when the current study population was compared with the 529 patients who participated in the initial study but were not included in the current study population, there were some significant differences. The current population was slightly older at the time of inclusion 10 years ago (mean age, 32 years ± 7.7) compared with the initial study subgroup (mean age, 30 years ± 8.1) (P = .006) and had more ACL lesions (48 [15%] compared with 50 [9%] in the initial study subgroup [P = .021]) (Table 1). There were no significant differences in meniscal tears (P ≥ .005). These results suggest that the current population could be considered representative of the initial study group; only the age and frequency of the ACL ruptures were different; therefore, selection bias for these two items cannot be excluded.

In summary, irrespective of treatment, the risk factors seen on knee MR images resulted in localized development of OA 10 years later. The different patterns of developing OA are determined according to the initial ACL and meniscal injuries and can be explained by ensuing changes in biomechanical loading. The hallmark finding of OA development after MM tears is diffuse medial cartilage loss, and after LM tears, it is focal lateral cartilage loss. After ACL rupture, OA characteristics are seen medially and laterally.
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