Meniscal and articular cartilage changes in knee osteoarthritis: a cross-sectional double-contrast macroradiographic study

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Abstract

Objective. In knee osteoarthritis (OA) damage to meniscal cartilage is associated with the changes in articular cartilage. Using double-contrast macroradiographs we determined whether the degree of meniscal cartilage damage was similar to or different from that at the corresponding regions of the articular cartilage on the tibia and femur.

Design. Double-contrast microfocal macroradiographs, ×7–×9 magnification, were obtained of the tibio-femoral joint in 20 osteoarthritic knee patients with medial compartment disease (Kellgren and Lawrence grades I–III). The appearance of the meniscus and the femoral and tibial articular cartilage were graded separately using a 5-point scale.

Results. In the medial diseased compartment, articular cartilage damage on the tibia was similar to that of the meniscus, which had significantly greater (P < 0.02) degenerative changes than the cartilage on the femur. In the lateral compartment, meniscal damage was significantly worse than in either tibial (P < 0.04) or femoral articular cartilages (P < 0.01), respectively; none was as severe as that in the medial osteoarthritic compartment.

Conclusion. Although the cross-sectional nature of this study precluded definite aetiological inferences, this study showed that degenerative changes in the meniscal and articular cartilages were not totally variable. Because of its larger articular surface, changes in the medial femoral cartilage were less marked than at the meniscal and tibial cartilages in the osteoarthritic compartment. In the lateral compartment, meniscal damage precedes tibial and femoral articular cartilage changes. In knees with medial compartment OA, combined meniscal and articular cartilage damage would account for detection of radiographic joint space loss and not meniscal extrusion only.

KEY WORDS: Knee, Osteoarthritis, Meniscus, Cartilage.

The function of the fibrocartilaginous menisci in the knee improves tibio-femoral congruence, joint lubrication and stability and assists in the distribution of large loads across the joint [1, 2]. These loads can range from 50% of the compressive force with the knee in extension, to 85% with 90° of flexion [2]. While proteoglycans in the healthy menisci permit this tissue to resist large loads, it is the collagen fibrils arranged in fibrous lamellae that make menisci efficient shock absorbers [3]. The menisci absorb most of the shocks generated at the joint because their combined mass is greater than that of the tibio-femoral articular cartilage [2]. Because of these roles, damage to or loss of the menisci affects the articular cartilage, as shown by the increased risk of developing osteoarthritis (OA) after meniscectomy [4].

Post mortem examination of meniscal pathology found that degenerative changes in this tissue were more common in patients with articular cartilage degeneration [5]. However, both Noble et al. [5] and Casscells [6] reported a lack of correlation between torn or degenerate menisci and the degenerative changes in adjacent weight bearing articular cartilage. Similarly, Fahmy et al. [7] found little evidence that degenerative meniscal tears led to OA or vice versa.

The arthrographic appearance of the menisci in the osteoarthritic knee joint of patients exhibited a loss of the normal smooth triangular shape with irregularities to the surface indicative of degeneration [8]. In a double-contrast macroradiographic study of knee OA [9], in which meniscal and the articular cartilage damage was scored, these tissues were found to be more severely damaged in the diseased medial tibio-femoral compartment than the lateral, however, changes
in the meniscus were not compared with those of the corresponding articular surfaces.

Meniscal degeneration is a feature of osteoarthritic knee joints frequently revealed on magnetic resonance imaging, suggesting a strong relationship between this feature and the degenerative changes in these joints [10]. McAlindon et al. [11] also reported a high incidence of meniscal deterioration amongst soft tissue lesions, commenting that ‘the high prevalence of meniscal lesions in OA of the knee has not been previously emphasised and the universality in this series raises a question of cause or effect’. The fact that these lesions were accompanied by a low prevalence of cartilage thinning led this group to suggest that ‘meniscal deterioration contributes to the major part of joint space loss’. Recently, it has been shown that meniscal subluxation is associated with symptomatic knee OA and that increasing subluxation demonstrated on MR images correlated with joint space narrowing (JSN) [12]. Furthermore, it was suggested that the JSN seen on conventional radiographs in early OA is secondary to meniscal extrusion, rather than loss of articular cartilage [13].

For this study we used high definition macroradiography. The advantages of this radiographic technique of magnification (×5–×10) [14, 15] and high spatial resolution, in which detail recorded in the film approximates to that of histology (0.05 mm) [15], were combined with those of contrast medium, a procedure which had been shown to provide a reliable indication of the degree of articular cartilage damage [16]. These methods together permitted a comparison to be made of the relative changes in the appearance of meniscal and articular cartilages in patients with OA of the knee. Five-point scales were developed for assessing separately changes in the meniscal and articular cartilages. The assessment was undertaken to determine whether the appearance of meniscal cartilage damage was similar or different to the corresponding regions of the articular cartilage on the tibia and femur and hence to determine whether changes in the meniscus preceded those in the articular cartilage as recently suggested [11–13].

 Patients and methods

 Patients
Following Ethical Committee approval, 20 patients (six males) who met the ACR knee OA criteria were recruited. They had appropriate symptoms of knee pain (i.e., > 15 days in the last month) and radiographic abnormality consisting of either JSN and/or the presence of an osteophyte in either the medial or lateral tibio-femoral compartment. They had a mean age of 58.1 yr (range 35–74), a mean disease duration of 5.7 yr (range 3–20) (based upon duration of pain in the worst affected knee) and a mean weight of 73.4 kg (range 54–104). Patient selection was based upon both clinical and radiographic criteria. The status of each knee was graded from plain film radiographs taken at the time using the Kellgren and Lawrence criteria [17]. Eleven knees had a Kellgren and Lawrence grade I, six were grade II, and three grade III; there were none at grade IV. Exclusion criteria included evidence of other types of arthritis, previous trauma, and previous surgery or corticosteroid therapy. Haematology revealed all patients to have an ESR within normal range and were seronegative for rheumatoid factor.

Double-contrast macroradiography in non-weight-bearing lateral position
Stereopair double-contrast macroradiographs (×7–×9 magnification) of the medial and lateral tibio-femoral compartments were undertaken following the procedures described elsewhere [9]. Niopam 200 (E. Merck Ltd, Hampshire, UK) was chosen as the contrast medium for arthrographic examination, as an earlier study [16] had shown that a contrast medium containing iodine 200 mg/ml provided better definition of articular cartilage in macroradiographs of the knee than contrast media with greater iodine concentration, used conventionally.

After injection of local anaesthetic, fluid found in the joint was aspirated and 5–10 ml of contrast medium injected, followed by 40–80 ml of air. After injection the knee was flexed and extended several times to spread the medium over the inner surface of the joint. The patient lay on a table, in the lateral position, with the joint to be examined uppermost. The knee was flexed to 130° and the joint space spread open to display the intra-articular components. Macroradiographs of each compartment were obtained once the X-ray beam was aligned with the joint space. A stereopair macroradiograph was obtained by displacing the patient table by 1 cm in the vertical plane.

Grading of meniscal and articular cartilage damage
The double-contrast macroradiographs of the medial and lateral tibio-femoral compartments were examined under a large format stereoscope (Ross instruments, Salisbury, UK). The three-dimensional evaluation of articular structures permitted by this stereoscopic system facilitated the identification of the margins of the cartilage. The articular and meniscal cartilages of the medial and lateral compartments were evaluated by the authors, with attention being paid to evidence of cartilage thinning, focal lesions, contrast medium imbibition and any discontinuity or breaks in the contour of the cartilages. The presence of osteophytes was noted. By comparing the extent of the change observed in the articular and meniscal cartilage of these patients’ knees with the description for normal, healthy joints [8], a 5-point grading scale was devised separately for the meniscus and articular cartilages ranging from 0 (normal) to IV (destructive damage).

Grading changes in meniscal cartilage. Grade 0 was defined as those menisci which had minimal contrast
medium absorption and a good triangular shape, grade I had uniform, well defined contrast medium absorption along the superior and inferior surfaces, which was occasionally more marked at the inner angle associated with tissue damage [16]. Grade II had increased contrast medium absorption, which was maximal at the inner angle, compared with the superior and inferior surfaces. Grade III had a similar pattern of contrast absorption, but was deeper and more diffuse and was distinguished by distortion of the superior and inferior surface contours. In grade IV, the inner margin of the meniscus was absent and the remaining tissue showed marked absorption of the contrast medium.

Grading changes in articular cartilage. The grading system for articular cartilage defined grade 0 as showing full cartilage thickness and minimal to no contrast medium absorption. Grades I, II and III had minimum, moderate and marked loss of cartilage thickness, respectively, associated at each stage with evidence of increased contrast medium absorption with each grade. In addition, focal lesions of the articular cartilage surface were occasionally seen in grade III. In grade IV, most of the subchondral bone was exposed with some articular cartilage remaining adjacent to the intercondylar region.

Having established the grading scales, the medial and lateral tibio-femoral compartments in each film were reassessed by one observer (L.B.), following a 2-month period of training in reading macroradiographs and macroarthrograms of osteoarthritic knees. Each film was scored on each occasion in random order and blinded to patient identity, initially for changes in the meniscus and then subsequently for changes in the articular cartilage. Separate grading of the meniscal and articular cartilages, employing different scoring systems, was undertaken, not only because they assessed different anatomical components, viz. the inner angle of the meniscus, tissue thickness in the articular cartilage, but also to reduce the effect of a scoring bias by separating in time the assessments of the meniscus from those of the articular cartilage.

Analysis of the data
To test the intra-observer variability of the scoring system, 10 randomly selected films were evaluated on eight independent occasions, at weekly intervals, by one observer (L.B.). The same 10 films were viewed and scored by three further readers (qualifications of all were BSc, MB BS, following similar training to that described above) to determine the inter-observer variability. Concordance between replicate gradings was quantified using the kappa statistic.

The scores obtained for meniscal damage were compared with those for the corresponding regions of articular cartilage in each compartment, respectively, using the non-parametric Wilcoxon matched pairs tests, \( P \)-values \(<0.05\) were considered statistically significant.

Results
Qualitative assessment of articular and meniscal cartilages
Medial compartment. The meniscal cartilage exhibited contrast medium imbibition ranging from mild, visible as a thin layer on the surface of the tissue, to marked where the medium increased both in amount and depth, consistent with greater damage to the meniscus. Physical damage to the meniscus ranged from its inner free edge appearing frayed (Fig. 1) to its truncation and loss (Fig. 2). The surface contours of the menisci were also altered, appearing convex, bulging into and occasionally filling the entire joint space.

**FIG. 1.** Part of a double-contrast macroarthrogram of the medial compartment of an osteoarthritic knee, showing the frayed appearance of the inner edge of the meniscus and cartilage thinning at the outer third of the tibial plateau and femoral condyle. There is marked contrast medium imbibition in both articular cartilages and several focal lesions on the femoral cartilage. Horizontal bar represents 18 mm in the film.

**FIG. 2.** Part of a double-contrast macroarthrogram of the medial compartment of an osteoarthritic knee, showing the truncated appearance of the inner part of the meniscus and the loss of articular cartilage from the outer edge and pronounced thinning over the middle region of the tibial plateau. On the femoral condyle, the surface of the cartilage is irregular and shows thinning more clearly over the outer region. Horizontal bar represents 30 mm in the film.
Femoral articular cartilage in the medial compartment, in nearly all cases, appeared thickest centrally. Articular cartilage narrowing was greatest over the outer (medial) part of the condyle, above the meniscus (Fig. 2). The tibial articular cartilage showed a gradual thinning from the thickest region close to the tibial spines to its narrowest at the outer (medial) margin (Figs 1 and 2). In knees with more advanced disease the loss of articular cartilage on the tibia progressed from the outer (medial) edge towards the inner margin (Fig. 2).

**Lateral compartment.** The menisci showed changes similar to those observed in the medial compartment. The femoral articular cartilage appeared either similar to that in the medial compartment (thickest centrally) (Fig. 3) or narrowest at the outer (lateral) margin, increasing in thickness towards the intercondylar region. The tibial cartilage was observed to be thicker centrally over the plateau and narrowed towards the tibial spine and outer (lateral) margin (Fig. 3).

**Intra- and inter-observer variability**

Intra-observer variability for grading meniscal damage gave a kappa score of 0.9, indicating good agreement. The inter-observer variability had kappa of 0.5, indicating a moderate agreement. Intra- and inter-observer variability for articular cartilage grading was 0.6 and 0.4, respectively.

**Quantitative assessment of meniscal and articular cartilage damage**

**Medial compartment.** In the diseased compartment, the tibial and meniscal cartilages had a comparable degree of damage, which was more severe than that observed in the femoral cartilage (Tables 1 and 2). The grades for meniscal damage were statistically significantly greater than that for medial femoral articular cartilage ($P < 0.02$ for significant difference), but not statistically significantly different between the meniscal and tibial articular cartilages. Thus, changes in the medial meniscal and tibial cartilages were similar and significantly more advanced than those in the femoral cartilage.

**Lateral compartment.** In the lateral compartment, meniscal and articular cartilage damage was generally not as marked as in the medial (diseased) side (Tables 1 and 2). However, meniscal damage in the lateral compartment was statistically significantly more severe than in either tibial ($P < 0.04$ for significant difference) or the femoral articular cartilage ($P < 0.01$ for significant difference), respectively.

**Discussion**

As one of the purposes of this study was to understand the relationship between the meniscal and articular cartilages in early stages of OA, over half of the knees of patients recruited for this study had early disease. All patients had knee pain, including the 11 knees with a range of radiographic abnormality comprising mild JSN and possible osteophytes. These knee films, scoring ‘I’ on the Kellgren and Lawrence scale, correspond to patients that can be considered to have early disease [18].

We found it necessary to devise a system for grading meniscal cartilage degeneration as existing methods [8, 19] used in radiographic examinations, were inappropriate for this study as they emphasized the incidence of tears, whereas the method we used in grading articular cartilage was an elaboration of one

<table>
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<th>Compartment</th>
<th>Cartilage</th>
<th>Normal 0</th>
<th>Mild I</th>
<th>Moderate II</th>
<th>Severe III</th>
<th>Destructive IV</th>
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that had been published previously [9]. Assessment of patients’ macroarthrograms from this study revealed few knees to have meniscal tears (two in grade II), however, menisci in grade IV were severely truncated indicating that a large fragment of the meniscus had broken off. Thus, the grade III meniscal damage, described here, is intermediate between tearing (grade II) and fragmentation (grade IV). Grade IV, proposed here, corresponds to the destruction and loss of most of the meniscal and articular cartilages, consistent with a radiographic score for knee OA of Kellgren and Lawrence grade IV. The advantage of the scoring system described here is that it assesses the degree of contrast medium imbibition as an indicator of cartilage fibrillation [16].

The scoring systems developed permitted the separate evaluation of the meniscus and articular cartilages. The intra-observer variability for scoring changes in the latter was greater than that for the meniscal damage. This was attributed to the difficulty in defining the articular cartilage surface in a number of the images due to factors which included the presence of overlapping structures such as the tibial plateau margins on the medial and the tendon of popliteus muscle in the lateral compartment (Figs 1 and 3). These factors would also contribute to the variability present in the inter-observer reproducibility. The variability between readers reported here indicated that only a moderate agreement was obtained, illustrative of the difficulties of obtaining consistent scores from different observers. Although we have assessed the inter-observer variability, it is not our intention here to present a new scoring system for knee arthrograms, as this would have required a different study design.

Study limitations

There are several limitations to the present study. First, as described above, the small number of patients included in this study. A large number would assist in determining whether the results of this study are generalizable beyond that described here. Secondly, that the cross-sectional nature of this study precludes definite aetiological inferences. It is only from longitudinal studies one can determine, in the medial osteoarthritic compartment, whether the progression of meniscal and articular cartilage degeneration is similar, as suggested here, or whether at different stages of the disease the changes in one tissue precede or follow that in the other. Thirdly, in the scoring method there was the risk of bias when grading the condition of the meniscus in the presence of the changes visible in the articular cartilage. We attempted to minimize this bias by having two separate scoring systems, with each method evaluating a different structural feature, i.e. thickness in the articular cartilage and attrition at the inner angle of the meniscus. Furthermore, we carried out the evaluation of the meniscus at a different time from that of the articular cartilage. In retrospect, proper blinding of the readers would have been attained by covering (e.g. with tape) the meniscus before assessing the articular cartilage and similarly covering the latter before assessing the meniscus. However, we suggest that the study data on the differences in the pattern of cartilage damage between the medial and lateral compartments of the knee, indicate that a measure of independence was achieved in the separate methods for scoring tissue damage.

Comparison between meniscal and articular cartilage damage in the medial compartment revealed that the tibial and meniscal cartilages were significantly more severely damaged than the femoral articular cartilage. This difference is due to the articular surface of the femur presenting a larger surface area for articulation throughout the range of the joint’s movement, whereas the corresponding tibial articular surface is smaller and under constant load [20]. In the lateral (non-OA) compartment, meniscal and articular cartilage damage was present although neither was as severe as in the medial compartment (Tables 1 and 2) [9].
Nevertheless, meniscal damage on the lateral side appeared to precede tibial and femoral articular cartilage changes. These changes may be due to forces exerted on this tissue consequent upon medial compartment cartilage loss.

Changes to the articular contour of the menisci in which the surfaces appeared convex and to bulge into the joint space, would suggest alterations in the tissue similar to the swelling of articular cartilage in early OA associated with increased tissue hydration [21–23]. This observation is supported by Ghadially et al. [3] who reported that the spaces created by fragmentation and parting of collagen fibrils in the matrix of damaged menisci was filled with proteoglycan molecules. This group [3] commonly found inner angle fraying in routine autopsy and surgically removed menisci, consistent with the prevalence of inner angle damage, seen as marked contrast medium imbibition, observed in this study (Fig. 1).

Although this study was limited by the small number of patients, the results clearly show that in the medial (OA) compartment, the degree of meniscal and articular cartilage damage was similar within knees, ranging from early to advanced OA. There was no evidence to suggest that the changes in one tissue might lead or contribute to those in another as implied by some [11–13], or that the pattern of change was totally variable as suggested by others [5–7]. Indeed, the similarity in the degree of medial compartment cartilage damage observed at the articular and meniscal surfaces strongly suggests that there is a close anatomical relationship between these two tissues with disease progression and that the radiographic JSN is not largely due to changes in the meniscus as suggested recently [12, 13], but to changes in both tissues. Furthermore, as meniscal extrusion occurs early in knee OA [12, 13], the minimum joint space width measurement for assessing articular cartilage loss in the medial compartment, excludes the meniscal region (Fig. 4). Thus, minimum joint space width measures articular cartilage thickness only, as confirmed by a previous study where articular cartilage thickness correlated significantly (Pearson correlation \( R = 0.91 \)) with joint space width measurement in the medial diseased compartment [9]. These observations are relevant to OA research, as radiographic JSN is the primary outcome measure in structure-modifying OA drug trials [24].

In conclusion, our data show that in the medial diseased compartment of osteoarthritic knees the degree of meniscal and articular cartilage degeneration was similar and that this combined damage would account for detection of radiographic joint space loss and not meniscal extrusion only.

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