Joint space width measures cartilage thickness in osteoarthritis of the knee: high resolution plain film and double contrast macroradiographic investigation

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Abstract
Objective—To test reliability of joint space width (JSW) measurements as a predictor of cartilage thickness in knees of patients with osteoarthritis (OA), using high definition microfocal radiography.
Method—JSW was measured from weight bearing plain film macroradiographs taken in the tunnel view and compared with the sum of femoral and tibial cartilage thicknesses measured from double contrast macroradiographs of the same regions of the same knees obtained in the non-weight bearing lateral position.
Results—All knees had medial compartment OA. Comparison of the JSW with the sum of the tibial and femoral cartilage thicknesses revealed a highly significant correlation ($p < 0.0001$) between the two measurements in the medial but not the lateral compartment. In the middle region of both compartments, JSW was smaller than the cartilage thickness, indicating that, on standing, the curvature of the femoral condyles compressed the cartilage in this region.
Conclusions—JSW reliably measured cartilage thickness in the medial but not the lateral compartment of knees with medial compartment OA. Depending upon the stage of OA disease, JSW reliably reflects cartilage thinning and compression.

Patients and methods

PATIENTS
We studied 20 patients (six male) with a mean age of 58.1 (range 35–74) years, a mean disease duration (based on the pain in the worst, most painful knee) of 5.7 (range 3–20) years, and a mean weight of 73.4 (range 54–104) kg. Patient selection was based upon clinical and radiographic criteria. The status of the study knee was graded using the Kellgren and Lawrence criteria. Exclusion criteria included evidence of other types of arthritis, previous trauma, surgical intervention, or treatment with corticosteroids. All patients were seronegative for rheumatoid factor and had an erythrocyte sedimentation rate within the normal range.
As ethical considerations precluded subjecting non-diseased age and sex-matched hospital attendees to radiography, macroradiographs of 14 healthy, non-arthritic volunteers (seven men and seven women, mean age 35.5 (range 23–56) years; mean weight 73.2 (range 60–89) kg) were obtained from medical and laboratory staff. Radiographically, the knees of all reference subjects were devoid of both osteophytes and sclerosis. The dimensions of their joint space width provided a reference range for the distance between bones in anatomically normal healthy knee joints of subjects with a body weight similar to that of the patients. These JSW data are referred to as the reference values and were used to define the degree to which JSW was narrowed in the OA knees. The difference in the mean age, of approximately 20 years, between the reference subjects and OA patients might result in some joint space loss in the latter, due to age. Whether age related changes are significant between the groups in this study, remains speculative since significant changes have been reported only in studies in which the ages of the subjects were between 10 and 86 years and between 22 and 78 years.10

DOUBLE CONTRAST MACROARTHROGRAPHY IN THE NON-WEIGHT BEARING LATERAL POSITION

Niopam 200 (E Merck Ltd, Hampshire, UK) was chosen as the contrast medium for the arthographic examination, as an earlier study13 had shown that a contrast medium containing iodine 200 mg/ml provided better definition of the articular cartilage in macroradiographs of the knee than contrast media with the greater iodine concentrations used conventionally.

After injection of a local anaesthetic, fluid found in the joint was aspirated. Five to 10 ml of the contrast medium was injected into the joint cavity, followed by 40–80 ml of air. A bandage was then wrapped tightly around the leg immediately above the patella in order to restrict both medium and air from entering the suprapatellar pouch. After injection of the contrast medium and air, the knee was flexed and extended several times to spread the medium over the inner surface of the joint. This process was further aided by the patient walking from the examination bed to the x-ray unit.

For radiography, the patient lay on the table in the lateral position with the joint space to be examined uppermost. By flexing the knee to 130° the joint space was spread open to display the intra-articular components. With the knee resting in this position, anteroposterior stereopair macroradiographs (magnification \( \times 7 \) to \( \times 9 \)) of the medial and lateral tibiofemoral compartments were obtained at the same angle as in the weight bearing modified tunnel view. As already explained, it was necessary to obtain the macroarthrograms in the non-weight bearing position to avoid the appearance of a fluid level in the joint. The remaining details were as already described for preparation of the stereopair macroradiographs in the tunnel view of the joint.

METHODS OF ASSESSMENT

Qualitative assessment. The stereopair macroradiographs obtained were examined, by a single observer, under a Large Format Stereoscope (Ross Instruments, Salisbury, UK), which permitted a three dimensional evaluation of the joint structure.16 Articular cartilage damage was graded as none (smooth cartilaginous surface with no apparent thinning), mild (minimal thinning and irregularity), moderate (large localised defects and moderate thinning and irregularity), or severe (severe denudation of cartilage). Its extent was judged by assessing whether it was confined to only the outer, middle or inner thirds of the femoral and tibial cartilages in the medial and lateral compartments. Additional

Figure 1 Plain film macroradiograph of an osteoarthritic knee in the load bearing tunnel view showing the position in which the joint was radiographed at \( \times 5 \) magnification. Horizontal bar represents 41 mm.
observations included the extent of osteo-
phytosis,1 subchondral sclerosis4 and meniscal
cartilage damage. Using a four point scale, the
meniscal cartilages were graded as not
damaged (normal contour without evidence of
swelling or tear), mildly damaged (localised
meniscal swelling or tear), moderately
damaged (moderate size tear or degeneration),
or severely damaged (extensive tear or
disintegration).

Quantitative assessment. For this procedure,
the same observer examined the stereopair
macroradiographs under the stereoscope. The
right hand, back illuminated carriage com-
priised a digitiser tablet linked to an MOP-
Videoplan (Zeiss, Hertfordshire, UK).16

A detailed description of the method of
measuring the x-ray features and its accuracy
in recording them is reported elsewhere;16 its
coefficient of variation for linear JSW
measurements is 3.7%.16 The data, which were
initially recorded on microcomputer disks,
were transferred to an IBM PC/AT computer
and combined into a single large data file.
Statistical analysis was carried out using the
SPSS/PC+ package.17

MEASUREMENTS
Joint space width was measured using the
macroradiographs of the weight bearing tunnel
view of the knee. As shown in figure 2, JSW
(defined as the interbone distance) was
measured (in millimetres) at three sites along
the joint margin of both the medial and lateral
tibiofemoral compartments. The sites were
obtained by subdividing the articulating
surface of the joint into four and the
measurements were taken at the quarter, mid
and three-quarter divisions.

Articular cartilage thickness was measured
using the double contrast macroarthrograms.
It was represented by the distance between the
articular surface, identified by the presence of
a thin layer of contrast medium over and within
it (fig 3), and the mineralised osteochondral
junction. This distance was measured (in
millimetres) at the same sites over the femoral
condyles and tibial plateaux as those chosen for
the measurement of JSW in the plain film
macroradiographs and shown in figure 2.

ANALYSIS OF THE DATA
Comparability of JSW and articular cartilage
thickness measurements made at the individual
sites in the two compartments was assessed
using the Wilcoxon matched pairs test.
Comparison of each parameter between the
reference and OA knees was assessed using the
Mann-Whitney test. The degree of correlation
between JSW and articular cartilage thickness
within the medial and lateral knee compart-
ments of the OA patients was assessed using
Pearson’s correlation coefficient (r) and the
non-parametric Kendall’s TC test methods.
The latter test was used because of its greater
power in determining the degree of association
between parameters which may not have a
strict linearity of fit.18 For all tests, p values
less than 0.05 were considered statistically
significant.

Results
Qualitative assessment of the plain films
revealed 11 knees were Kellgren and Lawrence
grade I, six were grade II, and three grade III;
there were none at grade IV.

PLAIN FILM MACRORADIOGRAPHY IN THE
WEIGHT BEARING TUNNEL VIEW
Osteophytes that were doubtful on con-
ventional radiography were clearly visible on
macroradiography. The latter revealed that
osteophytes and subchondral sclerosis were
present in the medial compartment of all 20
OA knees. In the lateral compartment
osteophytes were present in seven and
subchondral sclerosis in 15.
Joint space width measurements. Compared with the reference range, the mean JSW in OA knees was significantly decreased in the medial, but not in the lateral compartment (table 1). It was decreased at all the three measurement sites: p < 0.0008 for the outer, p < 0.01 for the middle, and p < 0.0006 for the inner site of the joint margin (Mann-Whitney test) (table 1).

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Site</th>
<th>JSW (mm)</th>
<th>JSW (mm)</th>
</tr>
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<tbody>
<tr>
<td>Medial</td>
<td>Outer</td>
<td>4.45 (4.14-4.76)</td>
<td>3.21 (2.54-3.88)*</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>4.55 (4.15-4.95)</td>
<td>3.35 (2.65-4.05)**</td>
</tr>
<tr>
<td></td>
<td>Inner</td>
<td>7.77 (5.33-6.20)</td>
<td>4.56 (4.09-5.12)**</td>
</tr>
<tr>
<td>Lateral</td>
<td>Outer</td>
<td>5.46 (4.88-6.04)</td>
<td>4.74 (4.03-5.45)</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>5.20 (4.68-5.72)</td>
<td>5.15 (4.51-5.79)</td>
</tr>
<tr>
<td></td>
<td>Inner</td>
<td>5.66 (5.09-6.22)</td>
<td>5.04 (4.53-5.53)</td>
</tr>
</tbody>
</table>

Values are mean (95% confidence interval). Significant differences between healthy and OA knees: *p < 0.0008; **p < 0.01; ***p < 0.006 (Mann-Whitney test).

DOUBLE CONTRAST MACROARTHROGRAPHY IN THE NON-WEIGHT BEARING LATERAL POSITION

Meniscal and articular cartilage damage. Table 2 summarises the qualitative results of the meniscal and articular cartilage damage. Both articular cartilage and menisci were more severely damaged in the medial than the lateral compartments. In the medial compartment, damage to the meniscus was similar to that on the surface of the tibial cartilage.

Imbibition of contrast medium, observed as a bright radiodense band on the surface of an articular cartilage, was more extensive in cartilage with moderate to severe (figs 4–6) compared with mild damage (fig 3). In joints where cartilage was grossly thinned and absent (fig 7), contrast medium had entered the subchondral region.

Articular cartilage thickness measurements. Across the medial compartment of OA knees there was a gradient of articular cartilage thinning (table 1, figs 4–7): on average it was thinnest at the outer site, intermediate at the middle site, and thickest at the inner site on both tibial and femoral surfaces (table 1). The differences between sites were more pronounced on the tibial than the femoral surfaces. By contrast, in the lateral compartment (table 1) the cartilage was on average thickest at the middle site on both the joint surfaces.

COMPARISON OF JSW AND CARTILAGE THICKNESS MEASUREMENTS IN OA KNEES

The degree of correlation between the two measurements differed in the two compartments. They were strongly correlated at all three sites in the medial compartment (fig 8A), but only at the middle site in the lateral compartment, where the correlation was weaker (fig 8B). The Pearson r values for the three sites in the medial compartment were greater than 0.911, with a Tc greater than 0.607 (p < 0.0001); that for the middle site in the lateral compartment was 0.657, with Tc 0.305 (p < 0.03).

Comparison of the two parameters at individual sites within the two compartments showed the JSW to be significantly smaller than the sum of the femoral and tibial cartilage thicknesses over the middle, but not over either
JSW as a measure of cartilage thickness in knee OA

Discussion

Comparison of the JSW obtained from weight bearing tunnel view macroradiographs of OA knees with the sum of the tibial and femoral cartilage thicknesses measured from macroarthrograms of the same knees in the non-weight bearing lateral position revealed a highly significant correlation between the two measurements in the medial but not the lateral compartment. Thus JSW reliably measures cartilage thickness in the medial compartment of OA knees.

The present study indicates that, in OA, cartilage thinning occurs in a gradient across the joint surface: the thinning was most pronounced, in all patients, over the outer and least over the inner regions of the joint surface. Thinning at the outer region was greater on the tibial plateau than on the femoral condyle—an observation that is consistent with there being a greater load per unit area at the concave tibial compared with the convex femoral articular surfaces, and with the occurrence of meniscal damage in virtually all the patients. Under these circumstances the menisci can no longer be assumed to have shock absorbing functions.

In the lateral compartment of the knee, although there was a poor correlation between JSW and the sum of the cartilage thicknesses across the compartment as a whole (fig 8B), this was not the case in the middle region. Comparison with the reference value for healthy knees showed that there was little if any thinning. However, cartilage thinning was present in the outer and inner thirds, but only in the group of patients who already had advanced joint space narrowing in the medial compartment. The arthrogram confirmed that in the knees studied cartilage damage was present over either the outer or the inner thirds of the femoral and tibial surfaces, but not of the other sites (p < 0.001 and < 0.002 for the medial and the lateral compartments, respectively).

Figure 6 Part of a double contrast macroarthrogram of the medial compartment of an osteoarthritic knee taken at ×7.5 magnification, showing total articular cartilage loss from the outer third and pronounced thinning over the middle region of the tibial plateau (arrowed). On the femoral condyle the surface of the cartilage is irregular and shows thinning more clearly over the outer region. The free edge of the meniscus is badly damaged. Osteophytes are present at the condyle and tibial margins. Horizontal bar represents 30 mm.

Figure 7 Part of a double contrast macroarthrogram of the medial compartment of an osteoarthritic knee taken at ×7-5 magnification, showing exposed subchondral bone over the outer and middle regions of the femoral tibial surfaces. A remnant of articular cartilage is visible at the inner region of the tibia and at the inferior margin of the femoral notch (arrowed). The femoral condyle is overlayed by a soft tissue layer rich in contrast medium. Breaks in the femoral cortex are present, permitting contrast to enter the subchondral bone. The meniscus has been severely damaged and truncated. Horizontal bar represents 32 mm.

Figure 8 Comparison of the joint space width from plain film macroradiographs and the sum of femoral and tibial articular cartilage thicknesses measured from the double contrast macroradiographs at the chosen outer (●), middle (●) and inner (▲) sites of the joint in (A) the medial and (B) the lateral tibiofemoral compartments.
simultaneously over both the regions. This suggests that two distinct mechanisms may bring about cartilage destruction in this compartment. Such details are missing from publications on double contrast arthrography by Thomas et al.,13 Butt et al.,21 and Staple,24 presumably because of the lack of magnification when using conventional radiography.

The present study further stresses the value of weight bearing views when assessing cartilage changes in OA knees. In addition, it reveals a new finding: namely, that the JSW in the middle region of both compartments is smaller than the sum of the cartilage thicknesses. The radioanatomical meaning of this finding becomes apparent when we take into account the fact that the films used to measure JSW were obtained in the weight bearing position, while those used to measure the cartilage thicknesses were obtained in the non-weight bearing position. In the weight bearing tunnel view, the femoral condyle may be expected to exert the greatest load across the middle region of the tibial plateau,19 therefore the articular cartilage over the middle region in both the compartments can be expected to be compressed. Thus, depending upon the stage of OA disease in the compartment, and the extent to which the biophysical properties of cartilage may have been altered, JSW will reliably reflect cartilage compression and thinning.

Utilising high definition x ray equipment we have shown that standardised joint position, radiography and mensural procedures help to measure cartilage thickness accurately and reliably as JSW. Similar attention to detail would potentially improve the accuracy and reliability of JSW measurements using conventional radiography.

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