KNEE JOINT SPACE WIDTH MEASUREMENT: AN EXPERIMENTAL STUDY OF THE INFLUENCE OF RADIOGRAPHIC PROCEDURE AND JOINT POSITIONING

P. RAVAUD, G.-R. AULELEY, C. CHASTANG,* B. ROUSSELIN,† L. PAOLOZZI,‡ B. AMOR and M. DOUGADOS

Department of Rheumatology, Cochin Hospital, Paris, *Department of Biostatistics and Medical Informatics, Saint-Louis Hospital, Paris, †Department of Radiology, Ambroise Pare Hospital, Boulogne and ‡Laboratoires Cassenne, France

SUMMARY

We studied the influence of the radiographic procedure and joint positioning on knee joint space width (JSW) in 10 healthy volunteers, and the intrareader reproducibility of JSW measurements on radiographs performed 2 weeks apart using a standardized procedure. Results show that a 5 or 10° downward inclination of the X-ray beam and 15 or 30° of induced external foot rotation significantly reduced JSW. In contrast, knee flexion increased JSW. The mean differences and s.d. in the measurement of JSW between two sets of radiographs taken 2 weeks apart were not statistically significant, ranging from —0.07 mm (s.d. 0.38) to 0.020 mm (s.d. 0.38). Our findings indicate that modifications in knee flexion, foot rotation and X-ray beam inclination influence JSW. Therefore, standardization of joint positioning and of the radiographic procedure is necessary to obtain comparable radiographic images on successive X-rays.

KEY WORDS: Knee, Joint space width, Cartilage, Radiograph measurement, Osteoarthritis.

MEASUREMENT of joint space width (JSW) from plain radiographs is widely considered the best available surrogate criterion to assess the progression of osteoarthritis (OA) in clinical trials and epidemiological studies [1, 2].

OA progresses slowly and joint space narrowing varies from 0.1 to 0.6 mm/year [3-5]. Many efforts have been made to improve the reliability of joint space assessment, particularly the choice of the measuring instrument, that of the site of measurement and the quality of reading (training session, centralized reading) [1, 2, 5]. In contrast, the influence of patient positioning and of the radiographic procedure has never been carefully studied, except for the influence of weight bearing [6]. According to some authors, slight changes in patient positioning or radiographic procedure may modify JSW and compromise the reliability of measurements [7-10]. Fife et al. [8] found that JSW in a normal volunteer decreased by 17% when the X-ray beam was lowered by 1 cm below its original alignment, initially centred at the midpoint of the patella. They also found that with 10° flexion the medial joint space width decreased by 25% compared to 0° flexion. Lynch et al. [10] studied the influence of knee position in five post-mortem subjects and found that the error of JSW measurement was ~0.15 mm/10° of internal or external rotation of the knee joint. Therefore, standardization of patient positioning and radiographic procedure seems necessary, particularly for the quantitative assessment of JSW. However, in many studies there is no standardization of the radiographic procedure or of patient positioning. The knees are generally radiographed standing, with the joint in a fully extended position [9, 11, 12], but X-ray beam inclination or direction are rarely specified [4, 13-17]. In other studies, the X-ray beam was horizontal or parallel to the joint surface [18] and directed at the midpoint or the lower pole of the patella [11, 19].

We undertook the present study to evaluate the influence of changes in patient positioning (knee flexion or foot rotation) and the radiographic procedure (X-ray beam direction and inclination) on JSW in normal volunteers, and to assess the reproducibility of JSW measurements on radiographs performed 2 weeks apart using a standardized procedure. In the light of these results, we propose guidelines for optimizing radiographs in clinical trials and longitudinal epidemiological studies in order to improve the accuracy of measurement.

SUBJECTS AND METHODS

Subjects

Ten healthy volunteers (four women and six men), mean age 36.2 (range 26-55) yr and mean weight 69 (range 46-89) kg, were recruited from the medical and laboratory staff. Written informed consent was obtained from all participants. Radiographically, the knees of all volunteers were devoid of osteophytes or joint space narrowing.

Design

In the first part of the study, we compared ideal radiographs to radiographs performed using a modified procedure. This procedure was varied by modifying only one of the following factors at a time: position of the knee (knee flexion 5 or 10°), foot
rotation (15 or 30° of induced external foot rotation), X-ray beam direction (0.5 or 1 cm below the centre of the joint space), X-ray beam inclination (5 or 10° upward compared to the initial position) (Fig. 1). For each radiograph, only one of the four studied factors was modified; the others were unchanged with regard to the ideal radiographs.

In the second part of the study, we compared ideal radiographs performed on day 0 with ideal radiographs performed 2 weeks later using the same standardized procedure.

Radiographs

All radiographs were performed in the same radiology unit, by a single technician and a single radiologist using a fluoroscopic table with a 0.3 mm focal spot capable of filming at 100 mA, 55-70 kV and digital display of the X-ray beam inclination. Radiographs were obtained with fast screen cassette film. Source to film distance was 115 cm. Anteroposterior radiographs were taken under brief fluoroscopic control with patients standing on both legs with their weight equally distributed on both feet. Ten radiographs were performed for each patient (five for each knee).

First, 'ideal' radiographs of each knee were taken. The patient stood with the knee in full extension. The lower limb was rotated so that the tibial spines appeared centrally placed relative to the femoral notch; its location was checked fluoroscopically. Foot rotation was then measured as the angle between the line of the second toe ray and the anteroposterior axis. The central X-ray beam was directed at the centre of the joint space and its location on the skin was determined with the aid of the tube's positioning light and marked with a pen. Brief fluoroscopy was used to screen the joint to ensure that the medial tibial plateau was parallel to the central ray of the X-ray beam. The angle of inclination of the X-ray beam was noted.

The set-up positioning and radiographic procedure was then varied by modifying only one of the following factors at a time: position of the knee, foot rotation, X-ray beam direction, X-ray beam inclination. For one knee, the four following radiographs were performed: (i) knee in 10° flexion; (ii) 30° of induced external foot rotation compared to initial position; (iii) X-ray beam directed 1 cm below the centre of the joint space with the aid of the tube's positioning light; (iv) X-ray beam inclined 10° upward compared to the ideal angle.

For the other knee, the following four radiographs were performed: (i) knee in 5° flexion; (ii) 15° of induced external foot rotation compared to initial position; (iii) X-ray beam directed 0.5 cm below the

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**Fig. 1.—Modification of radiographic procedure.** (A) Modification of X-ray beam inclination. Three X-ray beams are represented with ideal inclination (line a), 5° upward inclination compared to the ideal angle (line b) and 10° upward inclination compared to the ideal angle (line c). (B) Modification of X-ray beam direction. Three X-ray beams are represented: ideal X-ray beam directed at the centre of the joint space (line d), X-ray beam directed 0.5 cm below the centre of the joint space (line e) and X-ray beam directed 1 cm below the centre of the joint space (line f).
centre of the joint space; (iv) X-ray beam inclined 5° upward compared to the ideal angle.

For each of these radiographs, the three unmodified factors were reproduced identical to the ideal radiographs, except for the radiographs performed with knee flexion. For these radiographs, the required degree of flexion was determined with the aid of a goniometer. The X-ray beam inclination was modified with the aid of fluoroscopy in order to obtain a position parallel to the medial plateau and the radiograph was taken immediately following this procedure.

In a second part of the study, one ideal radiograph of each knee was repeated 2 weeks later. Then the same standardized procedure was used with the knee in full extension and identical foot rotation, X-ray beam inclination and X-ray beam direction.

Radiographic assessment

All radiographs were collected and the patient's identification was masked with adhesive tape and replaced by a random code number. One reader (PR) assessed all radiographs using a clear plastic ruler graduated in half millimetres. We have focused this study on the medial compartment of the femorotibial joint. JSW was measured in millimetres along a vertical line drawn from the midpoint of the medial femoral condyle to the medial tibial plateau. JSW was defined as the interbone distance between the distal convex margin of the femoral condyle and the floor of the tibial plateau. All radiographs were assessed blind to the position and radiographic procedure used.

In one reading session, the reader (PR) assessed the 10 sets of 10 radiographs performed on day 0 (10 subjects, two knees, five radiographs, i.e. ideal radiographs and radiographs performed with changes in patient positioning or radiographic procedure). In two other reading sessions, the reader assessed only the 20 ideal radiographs performed on day 0 and the 20 ideal radiographs repeated 2 weeks later. In the first session, the 10 ideal radiographs of the right knee performed on day 0 and the 10 ideal radiographs of the left knee performed 2 weeks later were assessed. In the second session, the 10 ideal radiographs of the left knee performed on day 0 and the 10 ideal radiographs of the right knee performed 2 weeks later were assessed.

Statistical analysis

In the first part of the study, in order to determine the influence on the JSW of changes in patient positioning and in radiographic procedure, mean (s.d.) and confidence intervals of JSW measurement differences between the ideal radiographs performed on day 0 and the different radiographs obtained by varying the radiographic procedure and joint positioning were calculated.

In the second part of the study, we compared the relative contribution of the variation inherent in the measurement process itself, and the variation inherent in re-radiographing, to the variability of JSW. We used the graphical method proposed by Bland and Altman [20], which focuses on the mean differences between pairs of repeated measurements and the s.d. of these differences.

Plots were made and mean differences and s.d. of repeated JSW measurement for the same set of ideal radiographs between the two reading sessions and between the first and the second ideal X-ray sets (ideal X-rays performed on day 0 and 2 weeks later) at the same reading session were calculated.

The significance of differences was assessed in the two parts of the study using the Wilcoxon signed-rank matched pairs test. P values <0.05 were considered statistically significant (two-tailed tests).

RESULTS

The ideal X-ray beam inclination to be parallel to the medial tibial plateau was 3.6 ± 3.4° downward (range from 0 to 9° downward). The ideal foot rotation to obtain central placement of the tibial spines relative to the femoral notch was 13.5 ± 6.5° of external rotation (range from 0 to 25°). The mean differences (s.d.) between the right and left knees was 1.6 ± 1.3° for the ideal X-ray beam inclination (range from 0 to 4°) and 4.8 ± 4.5° for the foot rotation (range from 0 to 15°).

Influence of radiographic procedure or joint positioning

The mean differences in JSW measurement (mm) in the medial compartment between the ideal radiographs and the other radiographs are shown in Table I.

The direction of the X-ray beam did not seem to modify JSW. Inclination of the X-ray beam and induced external foot rotation significantly reduced the JSW. This reduction was more pronounced for a 10° inclination than for a 5° inclination (20.4 and 14.8%, respectively) and for a 30° external foot rotation than for a 15° external foot rotation (18 and 10%, respectively). Knee flexion significantly increased JSW:

<table>
<thead>
<tr>
<th>X-ray beam inclination</th>
<th>Mean differences (mm)</th>
<th>95% confidence interval</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.05 ± 0.32</td>
<td>[-0.18, 0.028]</td>
<td>NS</td>
</tr>
<tr>
<td>-1 cm</td>
<td>0.15 ± 0.33</td>
<td>[-0.87, 0.39]</td>
<td>NS</td>
</tr>
<tr>
<td>5°</td>
<td>0.95 ± 0.68</td>
<td>[0.46, 1.44]</td>
<td>0.01</td>
</tr>
<tr>
<td>10°</td>
<td>1.13 ± 0.56</td>
<td>[0.73, 1.53]</td>
<td>0.01</td>
</tr>
<tr>
<td>Foot rotation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+15°</td>
<td>0.63 ± 0.53</td>
<td>[0.28, 1.01]</td>
<td>0.01</td>
</tr>
<tr>
<td>+30°</td>
<td>1.12 ± 0.60</td>
<td>[0.66, 1.51]</td>
<td>0.01</td>
</tr>
<tr>
<td>Knee flexion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5°</td>
<td>0.65 ± 0.34</td>
<td>[-0.90, -0.40]</td>
<td>0.01</td>
</tr>
<tr>
<td>10°</td>
<td>0.70 ± 0.36</td>
<td>[-0.96, -0.44]</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Significance of differences calculated from Wilcoxon's matched pairs t-test.

NS, not significant.
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Tint muling session, two X-ray visits

Second reading union, tn» X-ray rfrits

FIG. 2.—Differences in the measurement of JSW (in mm) between the ideal radiographs performed on day 0 (first X-ray visit) and 15 days later (second X-ray visit) at the same reading session plotted against mean JSW measurement. The 95% limits of agreement between two sets of radiographs were —0.83 and 0.69 mm for the first reading session and —0.77 to 0.81 mm for the second reading session.

Reproducibility of standardized radiographs

The mean differences and s.d. in the measurement of JSW between two readings of the same set of radiographs were —0.015 mm (s.d. 0.15) for the first set and 0.075 mm (s.d. 0.16) for the second set. The mean differences and s.d. in the measurement of JSW between the two sets of radiographs taken 2 weeks apart were —0.07 mm (s.d. 0.38) for the first reading session and 0.020 mm (s.d. 0.38) for the second reading session. None of these differences were statistically significant. As shown in Figs 2 and 3, differences of >0.5 mm in JSW measurements were infrequent. Such differences were observed in five of 20 cases between the two sets of radiographs and never between the two readings of the same set.

DISCUSSION

Evaluation of radiographic progression in OA has been used to describe the natural course of the disease and to estimate the efficacy of disease-modifying OA drugs. Several difficulties arise in measuring disease progression. The disease progresses slowly, and the changes due to the effect of the disease should exceed those due to the combination of errors associated with the variability of radiographic image and of measurement techniques [7]. Measuring disease progression necessitates both good-quality radiographs on which the landmarks of measurement can be easily located, and reproduction of the same appearance of the joint on successive X-ray visits. This experimental study demonstrates that slight changes in radiographic procedure or in joint positioning lead to important modifications in JSW. It also indicates that the use of precise guidelines for patient positioning and the radiographic procedure limits mean differences in JSW measurement between two successive X-rays.

Modifications of X-ray beam inclination or foot rotation result in apparent joint space loss. On the other hand, increased flexion of the knee increases JSW. Our results do not confirm the observations of Fife et al. [8] in one normal subject where when the X-ray beam was directed 1 cm below the original alignment (midpoint of the patella), the medial JSW decreased by 17%. Our study demonstrates that a change in X-ray beam direction, but with fixed X-ray beam inclination, does not modify JSW significantly. Our results are consistent with those obtained by Lynch et al. [10] in post-mortem knees. In this study, the error of JSW measurement was only ~0.02 mm/1 mm of vertical displacement of the centre of the knee away from the central ray of the X-ray beam. Errors in JSW measurement as minor as this cannot be detected with the measuring instrument chosen in our measurements.

~10% for a 5° knee flexion and 12.5% for a 10° knee flexion.
study. On the other hand, small changes in X-ray beam inclination result in large changes in JSW. Fife et al. [8] also found that increased flexion results in apparent joint space loss. In our study, JSW is increased by knee flexion. This can be attributed in the flexed knee position to the augmentation of the distance between the centre of the joint and the X-ray film, which results in magnification of the shadow image.

A limitation of this study is that the studied subjects were healthy volunteers and not OA patients. In normal subjects, assessment of JSW is usually easier, and it was possible to obtain accurate measurements of interbone distance. However, the results observed in healthy subjects are probably transposable to OA patients, except for the influence of knee flexion, which involves other factors. During flexion, the weight-bearing surfaces move backwards on the tibial platesaus [21]. In this position, JSW measurement reflects a more posterior portion of the articular cartilage than in radiographs taken in full extension and some discrepancies may be observed in the absence of generalized loss of cartilage [7, 22, 23].

It seems difficult to obtain ideal radiographs without the aid of fluoroscopy. As shown in this study, some differences in the ideal radioanatomical position, particularly the tilt of the tibial plateau, exist among patients and between the right and left knee of the same patient. Therefore, at the initial X-ray visit, fluoroscopy seems useful to check that the X-ray beam is parallel to the studied tibial plateau, and that tibial spines appear centrally placed relative to the femoral notch. In our study, the duration of fluoroscopic examination was <10 s and the additional radiation dose is limited, estimated to 15 mGy, approximately equivalent to 20% of the radiation of a standard knee X-ray [24, 25]. Furthermore, the tilt of the medial and lateral tibial plateaus differs slightly, and it is difficult to capture fully both compartments. Consequently, we favoured the study of the medial compartment. We therefore prefer taking radiographs of each knee, separately, because significant differences may be observed between knees, e.g. in the case of a discrepancy in leg length.

To obtain comparable X-rays in longitudinal studies, two possibilities must be considered. First is the use of a custom-built apparatus to standardize positioning of the patient, but this apparatus is not widely available [26, 27]. Second is the use of precise guidelines concerning the position of the patient and the radiographic procedure. We demonstrated that JSW measurement on plain radiographs of the same individuals on successive visits is reproducible. The mean difference, which is an estimate of the average bias of one measurement relative to the other [28], is negligible both for the mean differences between two sets of radiographs and between two reading sessions. Therefore, we can conclude that these measurements agree excellently on average. However, it is also important to consider the S.D. of the differences which is used for determining the agreement between measurements for an individual. The S.D. of the differences between the two sets of radiographs was greater than that of the differences between the two reading sessions. These results suggest that, despite the use of precise guidelines, the relative contribution of radiographic procedure and joint positioning to JSW variability is greater than that of the measurement error.

Slight changes in radiographic procedure or in knee joint positioning lead to important modifications in JSW in normal subjects. JSW measurement is frequently the endpoint of clinical studies of disease-modifying anti-OA drugs. Careful attention, not only to the measurement techniques, but also to the collection of easily readable and reproducible X-rays on successive visits, could greatly improve the sensitivity of such studies. Therefore, we propose the following guidelines for performing knee X-rays in clinical trials designed for studying the effects of disease-modifying anti-OA drugs in knee OA of the medial compartment. Anteroposterior weight-bearing views of each knee should be taken separately. The patient should be in full extension with the back of the knees as near as possible to the film plate. The distance between the back of the knees and the plate should be noted. At the first visit, if possible, fluoroscopy must be used to check ideal X-ray beam inclination (the angle of inclination should be noted) and ideal foot rotation (the angle between the line of the second toe ray and the anteroposterior axis should be noted or the position of the foot should be outlined on a sheet of paper).

Successive X-ray visits must be performed in the same radiology unit. The same position and the same radiographic procedure should be repeated, particularly the position of the foot, with the same angle of rotation and the same inclination of the X-ray beam. If the distance between the back of the knee and the film plate is modified, particularly in case of fixed flexion deformity, the X-ray beam inclination should be modified with the aid of fluoroscopy. In this case, the accuracy of the JSW measurement could be questionable when a magnification factor is not taken into account.

If fluoroscopy is not available, a fixed foot rotation angle and X-ray beam inclination angle should be used. We propose, for medial compartment assessment, to direct the X-ray beam 5° downward and to use 15° of induced external foot rotation.

Long-term longitudinal studies in patients with knee OA are required to confirm the interest of such guidelines.

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References


