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Measurement of joint space width in hip osteoarthritis: influence of joint positioning and radiographic procedure

G.-R. Auleley, A. Duche, J.-L. Drape[1], M. Dougados and P. Ravaud[2]

Clinique de Rhumatologie and [1]Service de Radiologie B, Université Paris V-René Descartes, Faculté de Médecine Cochin Port-Royal, Hôpital Cochin, AP-HP, Paris and [2]Université Paris VII, Faculté de Médecine Xavier Bichat and Départment de Biostatistique et d'Epidémiologie Clinique, Hôpital Bichat-Claude Bernard, AP-HP, Paris, France

Abstract

Objectives. We assessed the influence of patient positioning and radiographic procedure, and defined a smallest detectable difference (SDD) in hip osteoarthritis (OA).

Methods. OA hip patients each had a standardized pelvic radiograph and, 5 min later, a modified pelvic radiograph with the feet internally rotated 5° (part 1 of the study), the X-ray beam centred on the umbilicus (part 2), or another standardized pelvic radiograph (part 3).

Results. Corresponding mean differences in joint space width (JSW) measurements (limits of agreement) between views were + 0.03 (− 0.53 to + 0.59), − 0.31 (− 1.15 to + 0.53) and − 0.02 (− 0.48 to + 0.44) mm. The two views differed significantly in mean JSW in part 2 of the study ($P = 1.6 \times 10^{-4}$), but not in part 1 ($P = 0.375$) and part 3 ($P = 0.580$). The SDD estimate was 0.46 mm.

Conclusions. Modifying the X-ray beam and foot rotation increases variability in JSW measurements. Use of urograms to evaluate radiological progression should be avoided. A change greater than 0.46 mm could define radiological hip OA progression.

KEY WORDS: Hip, Joint space width, Osteoarthritis, Radiographic measurement, Smallest detectable difference.

The plain radiograph is a readily available, safe and cost-effective tool for diagnosing and assessing the progression of osteoarthritis (OA) [1, 2]. In both epidemiological studies and clinical trials, the best established method of assessing OA progression is by cartilage loss as measured by joint space width (JSW) at the narrowest point on plain radiographs [2, 3]. Radiographic OA progression is slow [4], varying from 0.1 to 0.6 mm/yr [5–7].

However, reliable assessment of OA progression requires reproducible radiographs to be obtained on successive visits [8, 9]. Numerous sources of variability can modify JSW measurements and compromise their reliability [8–11]. Such variability has been widely studied in the knee. Foot rotation has been found to be related to measurement error [10] and to significant change in JSW measurements compared with ideal joint positioning [11]. On the other hand, changes associated with directing the X-ray beam below the centre of the joint space do not appear to be significant [10].

Such changes have been less studied in the hip, although differences in patient positioning and radiographic procedure remain in the assessment of radiological hip OA. First, pelvic or hip radiographs can be performed with the patient's feet internally rotated by an amount ranging from 5° to 25° [2, 12–18]. Second, hip JSW is sometimes measured on i.v. urograms [19–23], in which the X-ray beam is centred approximately 10 cm higher than for standard anteroposterior pelvic radiographs. Although the minimum joint space in the hip may be altered by modifying foot rotation [24] or X-ray beam centring [16], the effects of these modifications on JSW measurements in hip OA are largely unknown. Thus, the aims of this study were (i) to assess the influence of internal foot rotation and X-ray beam centring on JSW measurements, and (ii) to determine a cutoff that allows a definition of radiological hip OA progression beyond the variability related to radiographic procedure and measurement process.

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Correspondence to: P. Ravaud, Clinique de Rhumatologie, Hôpital Cochin, 27 rue du faubourg Saint-Jacques, 75014 Paris, France.

Patients and methods

Patients

Patients of both sexes with symptomatic hip OA attending the Department of Rheumatology and willing to participate were included in this study. Hip OA was determined by the presence of pain and at least two of the following factors: radiographic osteophytes, radiographic joint space narrowing and an erythrocyte sedimentation rate of $\leqslant 20$ mm/h [25]. Patients were excluded if they had secondary hip OA, defined by a history of hip fracture, or the presence of calcium deposition in the hip joint, osteonecrosis, inflammatory rheumatic disease, Paget's disease, infectious joint disease, or other hip diseases [25].

Radiography procedure

Pelvic radiographs were taken in three successive groups of 20 consecutive patients. Each patient had two pelvic radiographs taken 5 min apart. Radiographs of a given patient were taken by the same technician in a single radiology unit, using a fast screen, cassette film and a standardized procedure. The cassette was adjusted in the holder so that the midline of the film was in alignment with the midheel line. The focus-to-film distance was 100 cm. Anteroposterior, standardized radiographs including both hips were taken in the supine position with the X-ray beam vertical, perpendicular to the table. To obtain a constant and reproducible foot position, the inner side of each foot was aligned on a study-specific V-shaped positioning frame, positioned on the table, with the backs of the patient's heels lying directly on the table. For these standardized radiographs, the X-ray beam was centred 2 cm above the superior aspect of the symphysis pubis and the feet were internally rotated 15° [2, 12–15] using the V-shaped positioning frame.

The first part of the study evaluated the influence of internal foot rotation. Patients first had a standardized radiograph taken with the feet internally rotated 15°; 5 min later a modified radiograph was taken with the feet internally rotated 5° using another study-specific V-shaped positioning frame. The other parameters (patient positioning and radiograph procedure) were unchanged.

The second part of the study evaluated the influence of X-ray beam centring. Patients had a standardized radiograph taken with the X-ray beam centred 2 cm above the superior aspect of the symphysis pubis; 5 min later a modified radiograph was taken with the X-ray beam centred on the umbilicus. The other parameters (patient positioning and radiograph procedure) were unchanged.

The third part of the study (referred to as the standardized part) evaluated the reproducibility of pelvic radiographs. Pelvic radiographs were taken twice for each patient using a standardized procedure.

Radiographic assessment

Both hips of a given patient were eligible. Hips with Kellgren and Lawrence grade 2 or 3 [26] were included. In each part of the study, the two radiographs of a single patient were placed side by side on a light box and landmarks for measurements were drawn by the person who read the radiograph. The landmarks consisted of two points at the narrowest point: one was on the distal margin of the condylar cortex for the femoral surface, and the other was on the margin of the bright radiodense band of the subchondral cortex in the floor of the articular fossa for the acetabulum. The patient's identification and the type of view were then masked with adhesive tape. The patient's identification was replaced by a random code number.

Radiographs were assessed by a single reader (GRA). The interbone distance determined by the landmarks was measured in millimetres using a 0.1 mm graduated magnifying glass laid directly over the radiograph.

Statistical analysis

In order to determine the influence of foot rotation and X-ray beam centring on JSW measurements, the magnitude of changes related to each modified view was assessed with the graphic analysis method of Bland and Altman [27–29]. According to this analysis, differences between pairs of JSW measurements of the same joint of a given patient were plotted against their corresponding mean, including the limits of agreement defined as $d_{\text{mean}} \pm 2$ S.D., where d_{mean} is the mean difference and S.D. is the standard deviation of the difference. Differences between pairs of JSW measurements of the same joint on the standardized and modified radiographs of a given patient were plotted against their corresponding mean. For each part of the study, a graph was plotted, including the limits of agreement defined as above.

The reproducibility of standardized pelvic radiographs was also assessed using the graphic analysis method of Bland and Altman [27–29]. Differences between pairs of JSW measurements of the same joint of a given patient were plotted against their corresponding mean, including the limits of agreement. Such differences between JSW measurements on standardized radiographs repeated 5 min apart reflected the variability inherent in the radiographic procedure and the measurement process. Thus, to be considered a statistically relevant progression, any difference between serial radiographs had to be greater than this variability. The smallest detectable difference (SDD) was based on the reproducibility of radiographic measurement (i.e. related to repeating the standardized radiographic procedure and measurement process) in hip OA. For a risk of $\alpha = 5\%$, the SDD in radiological progression in hip OA for one individual was defined as 2 S.D. of the difference between pairs of standardized radiographs [30, 31].

In addition, means of pairs of JSW measurements were compared in each part of the study using the paired t-test. We used a two-tailed formulation, and $P < 0.05$ was considered statistically significant.

Results

Twenty patients were included in each part of this study. Table 1 summarizes the demographic and radiological characteristics of the patients.

Thirty-seven hips were available for assessment in the foot rotation part of this study. An artificial hip in one patient and one hip with Kellgren and Lawrence grade 1 in two patients were excluded. Mean (S.D.) of JSW was 3.10 (1.01) mm on the standardized pelvic radiograph. Thirty-nine hips were available for assessment in the X-ray beam centring part of the study. One hip with JSW = 0 mm was excluded. Mean (S.D.) of JSW was 3.17 (0.81) mm on the standardized pelvic radiograph. Thirty- seven hips were available in the standardized part of the study. One artificial hip in one patient, one hip with JSW = 0 mm, and one hip with Kellgren and Lawrence grade were excluded. Mean (S.D.) of JSW was 3.39 (1.02) mm.

Influence of internal foot rotation

Mean (S.D.) JSW was 3.07 (1.01) mm in pelvic radiographs 5° internal foot rotation, i.e. it was of a similar magnitude to that of pelvic radiographs with 15° internal foot rotation. The two views did not differ significantly in JSW measurements ($P = 0.375$). Thus, internal foot rotation at 5° did not modify JSW on pelvic radiographs performed in the supine position. The difference in JSW between 15° and 5° internal foot rotation was 0.03 mm on average (Table 2) but varied from − 0.70 mm to + 0.60 mm. Absolute differences between the two views in JSW measurements ⩾ 0.50 mm were observed in four of 37 cases. No specific relationship existed between the difference and the mean (Fig. 1A).

TABLE 1. Demographic and radiological characteristics of patients with hip osteoarthritis assessed for the influence of X-ray beam centring and internal foot rotation on joint space width measurement, and reproducibility of standardized pelvic radiographs

	Part of study		
	Foot rotation	X-ray beam centring	Standardized
Number of patients	20	20	20
Age, mean (S.D.)	67.8 (10.11)	70.7 (12.59)	64.6 (10.20)
range (yr)	52–83	50–87	50–84
Number of females	11	15	11
Height, mean (S.D.)	162.4 (8.70)	162.6 (9.02)	163.1 (8.13)
range (cm)	147–176	143–176	146–180
Weight, mean (S.D.)	74.63 (16.41)	77.0 (14.45)	77.79 (11.89)
range (kg)	45–107	49–101	58.5–102
Number of hips	37	39	37
Kellgren and Lawrence grade			
2	18	17	13
3	19	22	24

Influence of X-ray beam centring

On radiographs performed with the X-ray beam centred on the umbilicus, mean (S.D.) JSW was 3.48 (0.90) mm. JSW increased on average by 10.26% (12.99%) in this view compared with the standardized pelvic radiographs. The two views differed significantly in JSW measurements ($P = 1.6 \times 10^{-4}$). The difference in JSW between these views was − 0.31 mm on average (Table 2) but varied from − 1.60 mm to + 0.60 mm. Absolute differences between the two views in JSW measurements ⩾ 0.50 mm were observed in 10 of 39 cases. No specific relationship existed between the difference and the mean (Fig. 1B).

Reproducibility of pelvic radiographs and SDD

JSW measurements did not differ ($P = 0.580$) between the two standardized radiographs [3.39 (1.02) and 3.41 (1.02) mm respectively]. The absolute difference in JSW between repeated radiographs was 0.02 mm on average (Table 2) but varied from − 0.40 mm to + 0.80 mm. Absolute differences in JSW measurements ⩾ 0.50 mm were observed in one of 37 cases between standardized repeated radiographs. No specific relationship existed between the difference and the mean (Fig. 1C). The estimated radiological progression in hip OA as defined by the SDD for one individual, i.e. twice the S.D. of the difference between standardized radiographs, was 0.46 mm.

Discussion

In this study, changing foot rotation by 10° did not change JSW significantly on pelvic radiographs. In contrast, centring the X-ray beam on the umbilicus instead of on the superior aspect of the symphysis pubis resulted in an average increase in JSW of about 10%. Radiological progression based on analysis of radiographic reproducibility was 0.46 mm in this population, using a defined standardized radiographic procedure and measurement process, with this particular reader and measurement instrument.

Differences in JSW measurements related to modification of foot rotation were insufficient (0.03 mm) to be detectable with the measuring instrument we used.

TABLE 2. Mean differences in JSW (mm) between a standardized pelvic radiograph and either a pelvic radiograph with 5° internal foot rotation (foot rotation part of study) or X-ray beam centring on the umbilicus (X-ray beam centring part of study), and between two standardized pelvic radiographs (standardized part of study). Differences are calculated on JSW measurements as values on both standardized radiographs, and as values on standardized radiographs minus modified radiographs when appropriate

Part of study	Number of patients	Mean of difference	Standard deviation	95% confidence interval	Limits of agreement
Foot rotation	37	+0.03	0.28	−0.06, +0.12	−0.53 to +0.59
X-ray beam centring	39	−0.31	0.42	−0.44, −0.18	−1.15 to +0.53
Standardized	37	−0.02	0.23	−0.07, +0.05	−0.48 to +0.44

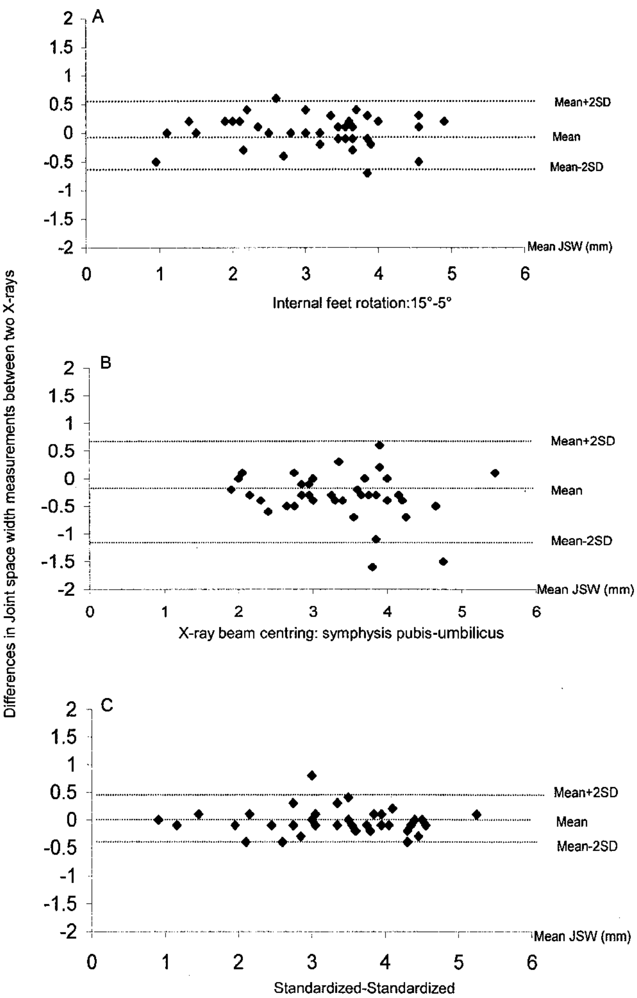

FIG. 1. (A) Differences in the measurement of JSW (mm) between the standardized pelvic radiographs performed with 15° internal foot rotation and pelvic radiographs performed with 5° internal foot rotation (15° minus 5°) plotted against mean JSW measurement. (B) Differences in the measurement of JSW (mm) between the standardized pelvic radiographs performed with the X-ray beam centred 2 cm above the superior aspect of the symphysis pubis and radiographs performed with the X-ray beam centred on the umbilicus (pubis minus umbilicus) plotted against mean JSW measurement. (C) Differences in the measurement of JSW (mm) between two standardized pelvic radiographs performed with 15° internal foot rotation and the X-ray beam centred 2 cm above the superior aspect of the symphysis pubis plotted against mean JSW measurement. Limits of agreement correspond to mean ± 2 S.D.

Moreover, the effect of foot rotation seems to be less in the hip than in the knee joint [10, 11]. It is thought that internal foot rotation applies a load to the articular hip surfaces [14], possibly by tightening the powerful lateral rotator muscles of the hip joint that drive the femoral head internally into the acetabulum [24]. Our findings in this study suggest that a 10° difference in internal foot rotation does not induce bias in JSW measured on pelvic radiographs of patients with hip OA, as assessed by the mean difference. However, we cannot exclude the possibility that a greater difference in foot rotation induces a significant bias, as suggested by Buckland-Wright [24]. This author studied nine cadavers and reported that the joint space of the hip was narrower in radiographs obtained with the foot rotated internally than with the foot in the neutral position. However, our results suggest that a 10° difference in internal foot rotation increases the variability in JSW measurement as assessed by the S.D. of the differences (Fig. 1A and C and Table 2).

More interesting was the effect on JSW measurements of centring the X-ray beam on the umbilicus. In the knee, displacement of the X-ray beam direction led to conflicting results [10, 11]. In the hip, however, the results of Conrozier *et al.* [16] suggest that such a displacement of the X-ray beam from the hip joint to 2 cm above the symphysis pubis can influence JSW measurement. Nevertheless, their study did not directly compare the two different patient groups, one having hip radiographs and the other pelvic radiographs. In this study, we evaluated the effect of two X-ray beam centrings, both away from the hip joint, on the same patient group. The increase in JSW on radiographs performed with the X-ray beam centred on the umbilicus compared with the standardized pelvic radiograph may be due to modifications induced by the downward inclination of the X-ray exploring the joint space.

Our study assessed the reproducibility of the standardized pelvic radiograph in patients in stable condition (two radiographs 5 min apart). The cutoff observed in this study (0.46 mm) is smaller than that reported in the knee (0.62 mm) [30]. Greater variation in the radiographic process in the knee [11] may explain this difference. This cutoff is indeed close to that (0.56 mm) reported by Dougados *et al.* [32] for hip OA despite the use of a different approach (two radiographs 1 yr apart).

A limitation of this study is that the radiographs were performed in the supine position. Although JSW measurements made on standing and supine knee radiographs differ [33–36], results in the hip remain contradictory [16, 37, 38]. However, we previously reported no significant difference in JSW measurement between the two views. In addition, technically better images may be obtained with supine than with standing pelvic radiographs, particularly in obese patients. Another limitation is that we did not compare the greatest possible degrees of rotation that can be used in radiography of the hip, i.e. 5° and 25°. Such a range of rotation may result in significant differences in JSW measurements. However, most guidelines recommend 15° internal foot rotation to radiograph the hip joint [8, 12, 14, 15].

In longitudinal studies, reproducible radiographs taken at different times allow reliable assessment of OA progression. For this reason, the sources of variability in JSW measurement must be minimized. First, we recommend using a positioning frame for pelvic radiographs in order to obtain a fixed degree of internal foot rotation, e.g. 15° in studies measuring JSW, instead of allowing a varying degree of rotation, e.g. 15 ± 5°. Although our study does not support a statistically significant change in mean JSW measurement due to modifications in internal foot rotation, such a change remains possible [24]. However, our study does suggest that the difference in internal foot rotation increases the variability of JSW measurements in the hip. Thus, using a standardized positioning frame will assure that the same rotation is used in repeated radiographs in a given patient and across studies. Secondly, we do not recommend evaluating radiological progression in hip OA using urograms. Pelvic radiographs should be taken with the X-ray beam centred precisely on the superior aspect of the symphysis pubis.

We have assessed the influence of some sources of variability in JSW measurement in hip OA and defined an SDD in radiological hip OA progression. These results need to be confirmed. Long-term longitudinal studies using standardized procedures as recommended in this study are also needed.

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