Radiographic Joint Space Width in Patients with Crowe Type-I Dysplastic Hips

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Abstract Radiographic evaluation of preoperative joint space width is believed important to predict the long-term results of osteotomy. We asked whether joint space width differs in the supine and standing positions in patients with Crowe Type-1 osteoarthritis (OA) secondary to developmental dysplasia of the hip (DDH). Joint space width was measured in the supine and standing positions in 146 women and 16 men (231 hips) with OA. Subjects had a mean age of 46.7 years (range, 22–59 years). Differences were seen on radiographs in joint space width between supine (2.35 ± 1.65 mm; range, 0.1–6.2 mm) and standing (2.04 ± 1.78 mm; range, 0.0–5.9 mm). In 27 of 172 hips with greater than 1 mm joint space in the supine position, joint space width was decreased by greater than 1 mm in the standing position. To evaluate preoperative joint space width in patients scheduled for osteotomy, radiographs should be obtained with the patient in the standing position. **Level of Evidence:** Level IV, diagnostic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Introduction

Developmental dysplasia of the hip is the most common cause of secondary OA in young adults [14, 16, 21]. For particularly young patients with DDH, periacetabular osteotomy often is considered rather than THA [10, 17, 23, 28, 29].

Preoperative radiographic evaluation of the stage of OA is believed important to predict the long-term results of osteotomy [12, 22, 34]. Radiographic staging systems for OA, for example, those of Tönnis [31], Kellgren and Lawrence [18], and the Japanese Orthopaedic Association (JOA) [22], are based primarily on narrowing of joint space width (JSW) as seen on anteroposterior radiographs. To determine the presence of OA of the hip, radiographs are obtained with patients in either the supine [1, 19] or standing position [8, 9, 15]. Studies comparing JSW of the hip measured on weightbearing and nonweightbearing radiographs report conflicting results [2, 6, 11]. In Japan, primary OA is reportedly rare [21], and osteotomy often is considered the preferred treatment for young patients with secondary OA. Recently, one study suggested preoperative JSW was an important factor in predicting the long-term results of osteotomy [34].

To address the existing controversy in the literature, we asked whether JSW is narrower in the standing position in patients with OA secondary to DDH.

Materials and Methods

We measured JSW on radiographs taken in the supine and standing positions in patients with OA secondary to DDH and examined the severity of dysplasia and deformity of the femoral head in the hips in which differences in JSW were observed between these positions.

Since 2002, we have routinely obtained anteroposterior radiographs of the hip in the supine and standing positions in patients with hip pain. For this study, we selected only patients diagnosed with OA of the hip. Patients with bilateral end-stage OA and secondary hip OA (presence or a history of hip fracture, inflammatory rheumatic disease, osteonecrosis, and infectious disease) were excluded. We also excluded patients younger than 19 years if there were no clear indications for osteotomy and patients older than 60 years because of confounding anatomic factors resulting from age-related spinal lordosis and because there usually is no indication for osteotomy in patients older than 60 years. Finally, patients with severe subluxation were excluded, defined as Crowe Types II to IV (greater than 50% subluxation) [7], because of discrepancy in leg length, which may cause the pelvis to tilt laterally in the standing position. This left both hips in 162 patients (146 women and 16 men) with a mean age of 46.7 years (range, 22–59 years). Of the 162 patients, 41 had one normal hip, 50 had one hip with end-stage OA, and two had a unilateral prosthetic hip related to OA; excluding these 93 hips left 231 for analysis. We also measured JSW of 41 normal (contralateral) hips in 162 patients with OA as controls. There were no differences in age (average 48.3, range 22–59 years in OA; average 47.1, range 23–59 years in controls; $p = 0.83$) or body mass index (average 23.1, range 16–30 kg/m² in the OA group; average 23.3, range 17–30 kg/m² in the control group; $p = 0.86$) between the 231 OA and 41 control hips.

All radiographic films were obtained in the same radiology unit based on a standardized procedure. For each patient, two conventional pelvic radiographs were obtained. The first film was obtained in the standing position. Anteroposterior radiographs were taken with a source-to-film distance of 110 cm. The patient's feet were rotated internally with the toes at $15^\circ \pm 5^\circ$ and the xray beam was centered on the superior aspect of the pubic symphysis using fluoroscopy. The xray beam was horizontal perpendicular to the table. Patients were standing on both legs and we asked them to distribute their weight equally on both feet. The second film was taken with the patients in the supine position using the same radiographic procedure as previously described (incidence, source-to-film distance, rotation of the patients' feet) as for standing films except the xray beam was vertical.

The two radiographs (supine and standing positions) were placed side by side on a light box, and the landmarks for measurements were drawn by one reader (KO). The landmarks comprised two points; on the margin of the femoral head and on the acetabular margin at the narrowest point of the hip JSW. Next, the patients' identity and type of view (supine or standing) were masked with adhesive tape on all the radiographs by one investigator (NK). The

patients' identification was replaced by a random code number. One reader (KO), blinded to the view, examined the radiographs. The interbone distance was measured in millimeters using a 0.1-mm graduated magnifying glass placed directly over the radiograph at the narrowest point for the hip JSW. One week later, the same reader (KO), unaware of the results of the first reading session, again measured JSW of all hips. In this session, the radiographs with the random code numbers were evaluated in a different order.

One author (KO) classified the severity of OA using JOA criteria [22]. Osteoarthritis was classified into the following four stages: prearthritis stage (no osteoarthritic change), early stage (slight narrowing of the joint space associated with sclerosis of the subchondral bone), advanced stage (narrowing of the joint space with cystic radiolucencies and small osteophytes), and end stage (almost total disappearance of the joint space and marked osteophyte formation). The hips were categorized as being in the prearthritis stage ($n = 65$), early stage ($n = 59$), and advanced stage ($n = 107$) according to the JOA classification. Osteoarthritis of the hip secondary to DDH was identified in 228 of the 231 hips (98.7%); only three hips were considered to have primary OA.

To evaluate hip deformity secondary to DDH, we measured the severity of dysplasia of the acetabulum and deformity of the femoral head. To evaluate the deformity of the femoral head, one of us (KO) measured the roundness index of the femoral head [26], which is calculated as the ratio between the distances from the medial border to the top of the femoral head and from the medial to lateral border of the femoral head (Figs. 1, 2). Parameters evaluated in determining the severity of dysplasia of the acetabulum included the center edge (CE) angle [33], acetabular head index (AHI) [13], and acetabular angle [27]. We defined DDH as a CE angle less than 20° , an acetabular angle greater than 45° , or an AHI less than 75% on anteroposterior radiographs.

To evaluate pelvic inclination, one of us (KO) measured the vertical distance (a) between the upper border of the symphysis and the sacrococcygeal joint in women so any differences related to gender could be avoided [30].

In 231 hips with OA, the mean values of CE angle, AHI, acetabular angle, distance (a), and roundness index were $6.97^\circ \pm 9.2^\circ$ (range, -28° – 25°), $64.4\% \pm 13.6\%$ (range, 27.1%–100.0%), $45.1^\circ \pm 5.2^\circ$ (range, 35.0° – 58.0°), 66.8 ± 9.6 mm (range, 39–85 mm), and $55.9\% \pm 8.1\%$ (range, 44.4%–79.6%), respectively.

To evaluate lateral subluxation of the femoral head and pelvic inclination from the supine to standing positions, we also measured the changes in CE angle and AHI as lateral subluxation of the femoral head and distance (a) as pelvic inclination from supine to standing positions.

Fig. 1 The roundness index of the femoral head was calculated as the ratio between the distances from the medial border to the top of the femoral head (a) and from the medial to lateral borders of the femoral head (b). (Reprinted with permission from Okano K, Enomoto H, Harada S, Ito S, Doiguchi Y, Shindo H. [Clinical results of rotational acetabular osteotomy (RAO) for advanced osteoarthritis of the hip: evaluation of the shape of the femoral head.] *Hip Joint*. 2003;29:102–108.)

We calculated means and standard deviations (SDs) of JSW measurements in both views during each reading session and their differences. Joint space width of hips measured on standing radiographs also were presented as a relative percentage of JSW measured on supine radiographs using the difference between JSW on supine and standing radiographs as the numerator and JSW on supine radiographs as the denominator.

The first step of analysis was to estimate the degree of intraobserver variability in JSW measurement. The graphic analysis described by Bland and Altman [3] was applied on procedures repeated 1 week apart on hips either on standing or supine radiographs. This method focuses on differences

between pairs of measurements of the same quantity against their corresponding mean. Graphs were plotted for each of these groups (Fig. 3). We estimated the limits of agreement as $d_{\text{mean}} \pm 2 \text{ SD}$, where d_{mean} is the mean difference and SD, the standard deviation of the differences (Table 1).

Two of the investigators (KO, NK) measured the CE angle, AHI, acetabular angle, distance (a), roundness index, and OA stage in 100 randomly selected hips. The respective indices were measured two times for each hip at 1-week intervals. The mean values of each index then were derived accordingly. The data were analyzed for intraobserver and interobserver variations, and the coefficient of variation was calculated to less than 5%. Interobserver and intraobserver reproducibilities of the osteoarthritis stage, analyzed using kappa statistics were 0.89 and 0.94, respectively. Therefore, reproducibility of the measurements was reliably established.

The second step in the analysis was to evaluate the differences between JSW measurements on standing and supine radiographs. For this purpose, JSW in the supine position and the differences in JSW measurement between the supine and standing positions were plotted on a graph and analyzed (Fig. 4).

Joint space width of hips with was classified into four stages: less than 1 mm, 1 mm to less than 2 mm, 2 mm to less than 3 mm, and 3 mm or greater, and the results for each hip obtained in the supine position were compared with those obtained in the standing position (Table 2). We also divided hips with OA into two groups; the first consisting of 121 hips classified as having narrowed JSW (defined as 2.5 mm or less JSW in the supine position) and the second group consisting of 110 hips classified as having normal JSW (defined as greater than 2.5 mm JSW). We next performed an intergroup comparison of JSW measurements between the supine and standing positions. We selected the 172 hips that had greater than 1 mm JSW remaining in the supine position. Of these, 27 hips (24 women, three men), classified as the Change group had 1 mm or greater JSW narrowing from the supine to standing positions. The remaining 145 hips (130 women, 15 men), classified as the No-change group had a reduction

Fig. 2A–E (A) Fifty percent, (B) 56%, (C) 61%, (D) 70%, and (E) 75% deformities of the femoral head and the associated roundness index are shown. As deformation of the femoral head increases, the top of the femoral head moves laterally. The black point shows the top of the femoral head. (Reprinted with permission from Okano K,

Enomoto H, Harada S, Ito S, Doiguchi Y, Shindo H. [Clinical results of rotational acetabular osteotomy (RAO) for advanced osteoarthritis of the hip: evaluation of the shape of the femoral head.] *Hip Joint*. 2003;29:102–108.)

Fig. 3A–B (A) Differences in JSW (in millimeters) are shown for supine radiographs between two reading sessions compared against the mean. The limits of agreement correspond to mean $\pm$ 2 standard deviations (SDs). (B) The differences in JSW (in millimeters) are shown for standing radiographs between two reading sessions compared against the mean. The limits of agreement correspond to mean $\pm$ 2 SD.

Table 1. Variability between reading sessions of joint space width (in mm)*

Position	Mean differences	Standard deviation	95% Confidence intervals	Limits of agreement
Between reading sessions (supine)	0.01	0.10	0.0 to 0.02	−0.19 to 0.21
Between reading sessions (standing)	0.01	0.13	−0.01 to 0.03	−0.25 to 0.27

* From radiographs of the same patients.

Fig. 4 The differences in JSW (in millimeters) between standing and supine radiographs compared against JSW in the supine position are shown. The limits of agreement correspond to mean $\pm$ 2 standard deviations (SD).

Table 2. Comparison of JSW measurements in patients with osteoarthritis

Standing radiographs	Supine radiographs				Total
	Less than 1 mm	1 to less than 2 mm	2 to less than 3 mm	3 mm or greater	
Less than 1 mm	58	34	5	0	97
1 to less than 2 mm	0	15	7	0	22
2 to less than 3 mm	0	1	12	12	25
3 mm or greater	0	0	1	86	87
Total	58	50	25	98	231

Table 3. Comparison of radiographic parameters between change* and no-change† groups

Variable	Change (n = 27)	No-change (n = 145)	p Value
Age (years)	44.4 ± 9.1 (25–57)	48.8 ± 9.6 (22–59)	0.70
Height (cm)	153.4 ± 8.6 (142–175)	154.5 ± 6.3 (140–175)	0.13
Weight (kg)	55.9 ± 11.3 (37–74)	54.8 ± 9.4 (36–84)	0.40
Body mass index (kg/m ²)	22.7 ± 3.4 (16.3–30.2)	23.8 ± 3.2 (17.4–30.0)	0.23
Distance a (mm)	65.1 ± 9.7 (39–85)	67.3 ± 9.5 (40–82)	0.80
JSW on supine (mm)	1.99 ± 0.77 (1.3–4.3)	3.45 ± 1.43 (1.1–6.5)	< 0.0001
Center edge angle (degrees)	1.6 ± 9.5 (–28–18)	7.97 ± 9.2 (–3–25)	0.006
AHI (%)	54.5 ± 15.1 (27–91)	66.0 ± 12.7 (34–100)	0.003
Acetabular angle (degrees)	47.8 ± 4.0 (42–54)	44.7 ± 5.3 (35–58)	0.031
Roundness index (%)	66.3 ± 7.6 (47–75)	54.3 ± 6.9 (44–80)	< 0.0001

* Greater than 1 mm difference in JSW; † less than 1 mm difference in JSW; all values are mean ± standard deviation with the range in parentheses; JSW = joint space width; AHI = acetabular head index.

less than 1 mm in JSW from the supine to the standing positions (Table 3).

We assessed differences between the supine and standing positions using the Wilcoxon rank test with StatView software (Abacus Concepts, Berkeley, CA).

Results

We observed differences in JSW between supine and standing radiographs in hips that had reduced JSW on supine radiographs, a deformed femoral head, and severe dysplasia. The JSW was greater ($p = 0.0078$) on the supine than on the standing radiographs (2.35 ± 1.65 mm, range, 0.1–6.2 mm versus 2.04 ± 1.78 mm, range, 0.0–5.9 mm, respectively). On average, JSW was 23% less on standing than on supine radiographs (Fig. 4). However, in the 41 normal hips, there were no differences ($p = 0.74$) in JSW on supine (4.53 ± 0.58 mm, range, 3.6–5.9 mm) and standing (4.50 ± 0.59 mm, range, 3.5–5.9 mm) radiographs. Several hips were reclassified to a more narrowed stage of JSW based on the differences observed between the supine and standing positions (Table 2). Thirty-four (70%) of 50 hips with 1 mm to less than 2 mm JSW in the supine position were classified as having less than 1 mm JSW in the standing position (Table 2). Joint space width was greater ($p < 0.0001$) on the supine than on the standing radiographs (1.07 ± 0.69 mm, range, 0.1–2.5 mm versus 0.55 ± 0.58 mm, range, 0.0–2.5 mm, respectively) in the narrowed JSW group (≤ 2.5 mm on supine radiographs). However, in the normal JSW group (> 2.5 mm on supine radiographs), no differences ($p = 0.44$) were observed (4.16 ± 0.95 mm; range, 2.5–6.2 mm on supine versus 4.02 ± 0.11 mm; range, 2.5–5.9 mm on standing radiographs). Although no major differences were observed in age, height, weight, body mass index, or distance (a) between the change and no-change groups, they were

observed in the joint space, CE angle, AHI, acetabular angle, and roundness index on supine radiographs (Table 3). Mean differences in CE angle, AHI, and distance (a) between supine and standing positions were $0.34^\circ \pm 1.5^\circ$, $0.73^\circ \pm 2.3^\circ$, and -6.9 ± 6.1 mm in the change group and $-0.19^\circ \pm 1.3^\circ$, $-0.53^\circ \pm 1.8^\circ$, and -7.1 ± 6.3 mm in the no-change group, respectively. No differences were observed between the two groups ($p = 0.23, 0.16$, and 0.87 , respectively).

Discussion

Developmental dysplasia of the hip is the most common cause of secondary OA in young adults [14, 16, 21], and osteotomy often is considered the preferred treatment [10, 23, 28, 32]. Recently, one study suggested preoperative JSW was an important factor in predicting the long-term results of osteotomy [34]. We sought to determine whether JSW is narrower in the standing position in patients with OA secondary to DDH.

We are unable to explain the mechanism of decreased JSW with OA secondary to DDH. The hips in which obvious JSW narrowing was observed on standing radiographs were characterized by reduced JSW on supine radiographs, deformed femoral head, and severe dysplasia; however, no differences were observed in femoral head shift and pelvic inclination on the standing radiographs between the groups with and without obvious joint space narrowing on standing radiographs. Articular cartilage has a nonlinear viscoelastic behavior in compression, and cartilage deformation under mechanical loading correlated with proteoglycan content and matrix integrity [20]. Recently, evaluation of the femoral head cartilage condition using MRI was described [24], and preoperative information from delayed gadolinium-enhanced MRI of cartilage was reportedly a useful predictor of failure after

periacetabular osteotomy [8]. The phenomenon of decreased JSW observed on the radiographs in patients with dysplastic hips in the standing position may be attributed to the quality of the cartilage.

Conrozier et al. [6] reported maximum joint space narrowing of the hip decreased on weightbearing views compared with supine views only when considering osteoarthritic hips with 2.5 mm or less JSW. Hansson et al. [11] reported JSW narrowing on weightbearing radiographs in 12 of 117 hips considered normal on nonweightbearing views. Of their 34 hips considered narrowed on nonweightbearing radiographs, only one was termed normal on weightbearing views. Therefore, they did not recommend supine radiographs for assessing OA of the hip. Auleley et al. [2] compared JSW in 70 normal and 46 osteoarthritic hips on supine and standing radiographs and reported measurement of JSW of the hips on both radiographs were concordant. In our study, we measured 231

hips with OA. Joint space width of patients on standing radiographs was narrower than on radiographs in the supine position. In 27 of 172 hips that had greater than 1 mm JSW on supine radiographs, there was a decrease in JSW greater than 1 mm in the standing position.

Compared with earlier studies by investigators (Table 4) [2, 6, 11] who reported the differences in JSW between the supine and standing positions, our data suggest a greater number of hips in which JSW was narrower in the standing position than in the supine position. The extent of difference in values between both of the positions also was greater in our study. The differing degrees of dysplasia in the patients in our study may have contributed to the increased percentage of change noted. We found 98.7% of hips had OA secondary to DDH, and many hips with obvious JSW narrowing in the standing position showed severe dysplasia and a deformed femoral head (Fig. 5).

Table 4. Studies of joint space width

Authors	Number of hips	JSW on supine (mm) radiographs	JSW on standing (mm) radiographs	Differences between supine and standing
Hansson et al. [11]	Normal 27	4.9 ± 0.9	4.7 ± 0.8	No data
	OA (previous SCFE) 151	4.2 ± 1.7	3.9 ± 1.7	p < 0.0001
Conrozier et al. [6]	Normal 11	3.61 ± 1.02	3.61 ± 0.91	NS
	OA 46	2.33 ± 0.80	2.24 ± 0.87	NS
	OA (≤ 2.5 mm) 23	1.94 ± 0.61	1.81 ± 0.54	p < 0.05
	OA (> 2.5 mm) 23	3.44 ± 0.71	3.45 ± 0.73	NS
Auleley et al. [2]	Normal 70	4.43 ± 0.90 (2.7–7.0)	4.51 ± 0.90 (2.7–7.0)	NS
	OA 46	2.50 ± 1.36 (0.1–4.7)	2.51 ± 1.33 (0.0–5.0)	NS
Current study	Normal 41	4.53 ± 0.58 (3.6–5.9)	4.50 ± 0.59 (3.5–5.9)	p = 0.70
	OA 231	2.35 ± 1.65 (0.1–6.2)	2.04 ± 1.78 (0.0–5.9)	p = 0.0078
	OA (≤ 2.5 mm) 121	1.07 ± 0.69 (0.1–2.5)	0.55 ± 0.58 (0.0–2.5)	p < 0.0001
	OA (> 2.5 mm) 110	4.16 ± 0.95 (2.5–6.2)	4.02 ± 0.11 (2.5–5.9)	p = 0.44

NS = nonsignificant differences.

Fig. 5A–B (A) In the supine position, JSW is 1.8 mm at the narrowest point. (B) In the standing position, the same point measures 0.3 mm.

Radiographic staging systems for OA, such as those of Tönnis [31], Kellgren and Lawrence [18], and the JOA [22], are based primarily on JSW narrowing on anteroposterior radiographs. According to our data and that of Conrozier et al. [6], JSW was decreased on supine views in patients with 2.5 mm or less JSW. This phenomenon may explain the variable results of periacetabular osteotomy for advanced-stage OA, because it is possible advanced-stage OA on supine radiographs may appear as end stage on radiographs taken in the standing position.

The minimum preoperative JSW may be an important predictor of long-term results of periacetabular osteotomy in patients with advanced-stage OA: patients with a preoperative JSW greater than 2.2 mm and postoperative JSW greater than 2.5 mm had favorable radiographic results at followup after rotational acetabular osteotomy for advanced-stage OA [34]. However, the authors did not comment on whether they used supine or standing radiographs for evaluation. The preoperative and postoperative minimum JSW in patients treated with periacetabular osteotomy were discussed in a previous study, and less than 1 mm JSW on supine radiographs at followup was defined as the end point [12].

Untreated severe dysplasia of the hip frequently leads to OA, and periacetabular osteotomy usually is the preferred treatment for young patients with severe dysplasia [4, 25] and deformity of the femoral head [5]. Our data suggest anteroposterior radiographs of the hip in the standing position should be obtained when evaluating the preoperative stage of OA to determine the indications for periacetabular osteotomy in patients with dysplasia. Investigators who report results of osteotomies should describe whether radiographs were taken with the patients in a supine or a standing position.

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