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# Which Radiographic Hip Parameters Do Not Have to Be Corrected for Pelvic Rotation and Tilt?

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## Abstract

*Background* Acetabular anatomy on AP pelvic radiographs depends on pelvic orientation during radiograph acquisition. However, not all parameters may change to a clinically relevant degree with differences in pelvic orientation. This issue may influence the diagnosis of acetabular pathologies and planning of corrective acetabular surgery (reorientation or rim trimming). However, to this point, it has not been well characterized.

*Questions/purposes* We asked (1) which radiographic parameters change in a clinical setting when normalized to neutral pelvic orientation; (2) which parameters do not change in an experimental setting when the pelvis is experimentally rotated/tilted; and (3) which of these changes are "ultimately" relevant based on a prespecified definition of relevance.

*Methods* In a clinical setup, 11 hip parameters were evaluated in 101 patients (126 hips) by two observers and the interobserver difference was calculated. All parameters were normalized to an anatomically defined neutral pelvic orientation with the help of a lateral pelvic radiograph and specific software. Differences between nonnormalized and normalized values were calculated (effect of normalization). In an experimental setup involving 20 cadaver pelves (40 hips), the maximum range for each parameter was computed with the pelvis rotated (range, −12° to 12°) and tilted (range, −24° to 24°). "Ultimately" relevant changes existed if the effect of normalization exceeded the interobserver difference (eg, 37% versus 6% for prevalence of a positive crossover sign) and/or the maximum experimental range exceeded 1 SD of interobserver difference (eg, 27% versus 6% for anterior acetabular coverage).

*Results* In the clinical setup, all parameters except the ACM angle and craniocaudal acetabular coverage changed when being normalized, eg, effect of normalization for lateral center-edge angle, acetabular index, and sharp angle ranged from −5° to 4° ($p$ values $< 0.029$). In the experimental setup, five parameters showed no major changes, whereas six parameters did change (all $p$ values $< 0.001$). Ultimately relevant changes were found for anteroposterior acetabular coverage, retroversion index, and prevalence of a positive crossover or posterior wall sign.

*Conclusions* Lateral center-edge angle, ACM angle, Sharp angle, acetabular and extrusion index, and craniocaudal acetabular coverage showed no relevant changes with varying pelvic orientation and can therefore be acquired independent from individual pelvic tilt and

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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rotation in clinical practice. In contrast, anteroposterior acetabular coverage, crossover and posterior wall sign, and retroversion index call for specific efforts that address individual pelvic orientation such as computer-assisted evaluation of radiographs.

*Level of Evidence* Level III, diagnostic study. See the Guidelines for Authors for a complete description of levels of evidence.

## Introduction

The correct interpretation of an AP pelvic radiograph has direct implications for diagnosis and treatment of hip pathomorphologies. Several angles, indices, and ratios have been developed to describe the acetabular morphology. On the AP pelvic radiograph, the projected anatomy of the acetabulum directly depends on pelvic tilt and rotation during radiograph acquisition. Several parameters, including Wiberg's lateral center-edge (LCE) angle [5, 7, 11] and the acetabular index [5, 11], have been shown to change with pelvic orientation. However, in clinical practice and in the vast majority of scientific publications related to this topic, parameters are usually measured regardless of the individual pelvic orientation. The main reason for this is the lack of an appropriate method of correction.

Recent advancements in the field of image processing and analysis of pelvic radiographs now offer the opportunity to correct radiographic hip parameters for malpositioning of the pelvis during radiograph acquisition [18, 26]. This methodology also allows the investigation of whether specific radiographic parameters need to be corrected for pelvic malposition. However, not all parameters may change–or change in a clinically relevant degree (defined as a change that exceeds the interobserver variability)–with differences in pelvic orientation. As noted, this issue may influence planning and execution of any type of joint-preserving surgery of the acetabulum, for example acetabular reorientation or rim trimming. However, to this point, it has not been well characterized.

We therefore asked (1) which radiographic hip parameters acquired in a clinical setting change when being normalized to an anatomically defined neutral pelvic orientation; (2) which radiographic hip parameters do not change when the pelvis is virtually rotated and tilted in an experimental setting; and (3) which of these changes from the clinical and experimental setting exceed interobserver variability and can therefore be considered ultimately relevant.

**Table 1.** Patient demographics

| Parameter | Value |
|---|---|
| Total number of patients (hips) | 101 (126) |
| Age (years) | 35 ± 11 (15–61) |
| Sex (percent male of all hips) | 59 |
| Side (percent right of all hips) | 60 |
| Height (cm) | 171 ± 8 (150–192) |
| Weight (kg) | 85 ± 16 (65–133) |
| Body mass index (kg/m$^2$) | 27.4 ± 5.2 (21–42) |
| Type of femoroacetabular impingement (%) | |
| Pure pincer hips | 10 |
| Pure cam hips | 17 |
| Mixed cam-pincer hips | 73 |
| Pelvic tilt around the transverse axis (degrees) | −5.2 ± 6.5 (−19 to 10) |
| Pelvic rotation around the longitudinal axis (degrees) | 0.2 ± 2.4 (−10 to 5) |

Values of continuous parameters are expressed as mean ± SD with range in parentheses.

## Materials and Methods

This retrospective study was approved by the local institutional review board. The study was subdivided into two parts: a clinical and an experimental part.

For the clinical part of the study, we initially identified 378 consecutive patients (481 hips, 103 bilateral) with documented symptomatic femoroacetabular impingement between September 2003 and February 2008 using our digital institutional database. Inclusion criteria were the availability of an AP and a true lateral pelvic radiograph, both taken with a standardized technique [21]. Exclusion criteria were incomplete or incorrect radiographic information regarding the acquisition technique (207 patients [260 hips], 53 bilateral) and a history of previous hip surgery (30 patients [37 hips]) or known pediatric hip disorders (40 patients [58 hips]). After applying these exclusions, this left 101 patients (126 hips) who met the inclusion criteria (Table 1).

We used a previously described protocol for obtaining AP pelvic radiographs [21]. Briefly, the patient was placed in a supine position on the radiographic table. The film focus distance was 120 cm, and the central beam was directed to the midpoint of the symphysis and a line connecting the anterosuperior iliac spines. The legs were 15° internally rotated to compensate for femoral antetorsion. The true lateral pelvic radiograph was taken immediately after the AP pelvic radiograph without repositioning the patient. The central beam was directed to the tip of the greater trochanter (Fig. 1).

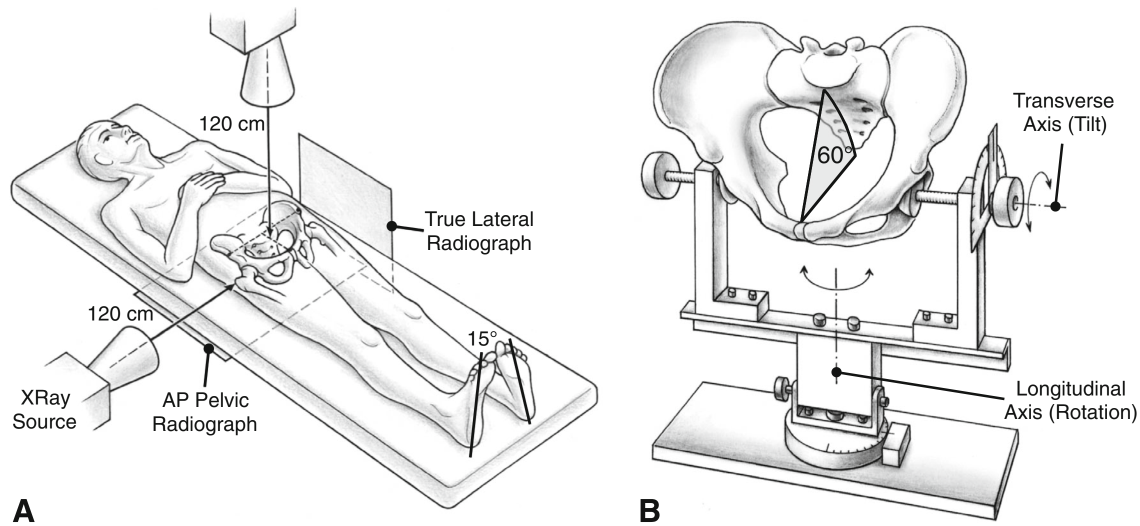


**Fig. 1A–B** (**A**) For the clinical part of the study, the AP pelvic radiograph was acquired with the patient placed in a supine position and 15° internally rotated legs to compensate for femoral antetorsion. The film focus distance was 120 cm and the central beam was directed to the midpoint of the symphysis and a line connecting the anterosuperior iliac spines. The true lateral pelvic radiograph was taken immediately after the AP pelvic radiograph without repositioning of the patient. The film focus distance was 120 cm and the central beam was directed to the greater trochanteric tip. (**B**) For the experimental part of the study, the pelvic radiographs were acquired with the pelvis mounted on a holding device and in the neutral position (neutral pelvic rotation and a pelvic inclination of 60° [25]). Reprinted with kind permission from Springer Science+Business Media: Kakaty DK, Fischer AF, Hosalkar HS, Siebenrock KA, Tannast M. The ischial spine sign: do pelvic tilt and rotation matter? *Clin Orthop Relat Res.* 2010;468:769–774.

All radiographs were blinded and randomized. Two independent observers (MT, SDS) with more than 10 years of experience in evaluating pelvic radiographs analyzed the radiographs with validated and commercially available software Hip$^2$Norm (University of Bern, Bern, Switzerland) [18, 22, 26]. This software is able to correct the projected acetabular rim and the corresponding radiographic hip parameters for pelvic malpositioning based on a cone projection model. In addition, this software allows calculating acetabular coverage in AP, posteroanterior, and craniocaudal directions comparable to coverage based on a CT scan (Fig. 2). The software was validated based on a set of 30 cadaver hips including CT scans and a set of 100 clinical AP pelvic radiographs [18]. The mean accuracy to correct for pelvic malpositioning ranged from 0.1° to 0.7° for the angular measurements and from −0.4% to 2.0% for the relative units/acetabular coverage. A good to very good reproducibility and reliability (intraclass correlation coefficient [ICC] > 0.6) was found for all parameters except for the reliability of the retroversion index (ICC of 0.56) [18]. Eleven commonly used radiographic hip parameters were evaluated (Table 2). All parameters (Fig. 3) were first measured regardless of the individual pelvic tilt and rotation. These nonnormalized values were then compared with the computed normalized values for neutral pelvic orientation. This neutral pelvic orientation was defined by neutral pelvic rotation (around the longitudinal axis) and an inclination (tilt around the transverse axis) of 60° [25] (Fig. 1). A neutral pelvic rotation was defined when the center of the sacrococcygeal joint was aligned vertically with the middle of the pubic symphysis. Pelvic inclination was measured on the true lateral pelvic radiograph as the angle formed by a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory (Fig. 4) [21]. Each of the 11 radiographic parameters was recorded by the software for the nonnormalized and the normalized pelvic orientation.

For the experimental part of the study, 20 cadaver pelves (10 male, 10 female; 40 hips) were mounted on a specifically designed holding device [18] (Fig. 1). The pelves appeared macroscopically normal without any evidence of previous trauma or hip deformity. For improved detectability of the acetabular rim on the radiograph, the rim was marked with a metal wire of 1 mm thickness. Then, each pelvis was mounted in the holding device (Fig. 1) and placed in the previously defined neutral orientation. An AP pelvic radiograph was taken with the standardized technique described previously. The center of the xray beam was marked with a radiopaque ball. This marker was fixed at the midpoint between a line connecting the anterosuperior iliac spines and the pubic symphysis. The radiograph was analyzed with the same software, Hip$^2$Norm. The pelvis was then virtually rotated in 3° increments from −24° to 24° of pelvic tilt and from −12° to 12° of pelvic rotation. These ranges for tilt and rotation were chosen to cover the maximum deviations that had been detected in

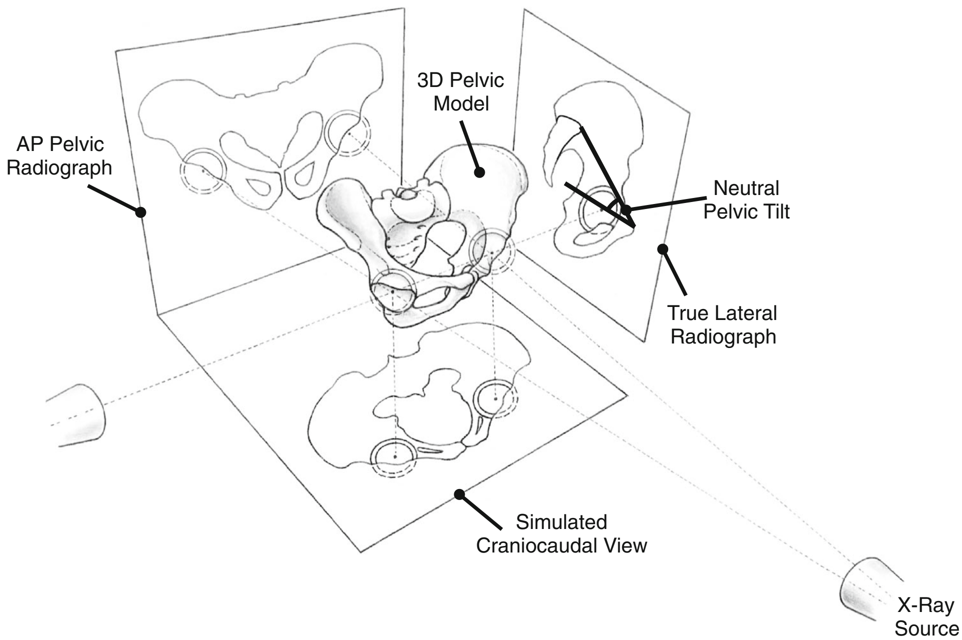


**Fig. 2** Validated and commercially available software Hip$^2$Norm (University of Bern, Bern, Switzerland) [18, 22, 26] was used to calculate the radiographic parameters corrected for pelvic malorientation. This required an AP and true lateral pelvic radiograph. This allowed to correct the radiographic parameters to the pelvic neutral position and to compute acetabular coverage of the femoral head in craniocaudal and anteroposterior direction. Reprinted with permission from John Wiley and Sons: Tannast M, Mistry S, Steppacher SD, Reichenbach S, Langlotz F, Siebenrock KA, Zheng G. Radiographic analysis of femoroacetabular impingement with Hip2Norm-reliable and validated. *J Orthop Res.* 2008;26:1199–1205, Figure 1. Copyright © 2008 Orthopaedic Research Society. 3D = three-dimensional.

both the clinical series of this study (Table 1) and the literature [2, 13, 17]. The calculated values for each of the evaluated 11 radiographic hip parameters were compared between nine positions of pelvic rotation and 17 positions of pelvic tilt. In addition, the maximum deviation for each radiographic parameter was calculated depending on pelvic rotation or tilt.

The relevance of the deviations of radiographic parameters depending on the pelvic orientation was determined based both on the clinical and experimental parts of the study. In the clinical part, changes in radiographic hip parameters were considered "clinically relevant" if the difference between nonnormalized and normalized values (effect of normalization) was significantly greater than the interobserver difference at the $p < 0.05$ level. In the experimental part of the study, changes in radiographic hip parameters were considered "experimentally relevant" if the maximum range depending on the virtual pelvic rotation or tilt significantly exceeded 1 SD of interobserver variability at the $p < 0.05$ level. Eventually, the deviation of a parameter was considered "ultimately relevant" if either the clinical and/or the experimental relevance was given.

Interobserver differences were determined in the clinical setup and showed a mean difference ranging from −0.2° to 1.5° for the angular measurements with a maximum difference of 17° found for the acetabular index (Table 3). The mean interobserver difference for the relative units/acetabular coverage ranged from 0.3% to 4.8% with the maximum difference of 43% found for the retroversion index (Table 3). The interobserver difference in the prevalence of a positive crossover and posterior wall sign was 6% and 5%, respectively (Table 3).

Normal distribution was determined with the Kolmogorov-Smirnov test. For the clinical part, nonnormalized and normalized values of the 11 radiographic parameters were compared using the paired Student's t-test for continuous data and the Fisher's exact test for binominal data. Interobserver difference was calculated as the difference between the measurements of the two observers. Unpaired Student's t-test was used to compare the effect of normalization of each parameter with the interobserver difference. For the experimental part, differences of each radiographic parameter depending on pelvic rotation and tilt were analyzed using repeated-measures analysis of variance.

## Results

In the clinical part of the study, all radiographic parameters apart from the ACM angle [6] and the craniocaudal acetabular coverage changed when being normalized to the neutral pelvic orientation (Table 3). All of the nine

**Table 2.** Definitions of the investigated radiographic hip parameters (see Fig. 3 for schematic illustration)

| Parameter | Definition |
|---|---|
| Lateral center-edge angle [24] | Angle formed by a line parallel to the longitudinal pelvic axis and a line connecting the center of the femoral head with the lateral edge of the acetabulum |
| Acetabular index [23] | Angle formed by a horizontal line and a line through the most medial point of the sclerotic zone of the acetabular roof and the lateral edge of the acetabulum |
| Extrusion index [12] | Percentage of uncovered femoral head (A) in comparison to the total horizontal head diameter (A + B) |
| ACM angle [6] | Angle constructed by the following points: (A) lateral edge of the acetabulum, (M) midpoint of a line connecting the lateral and the inferior acetabular edge, (C) point of the bony acetabulum intersecting the perpendicular line relative to line AM through point M |
| Anterior coverage | The percentage of femoral head covered by the anterior acetabular rim in AP direction |
| Posterior coverage | The percentage of femoral head covered by the posterior acetabular rim in the AP direction |
| Craniocaudal coverage | The percentage of femoral head covered by the acetabulum in the craniocaudal direction |
| Sharp angle | Angled formed by a horizontal line and a line through the caudal tip of the teardrop and the lateral edge of the acetabulum |
| Crossover sign [14] | Positive if the projected anterior wall crosses the posterior wall |
| Retroversion index [21] | Ratio of length of retroverted acetabular opening (E) to the entire length of the lateral acetabular opening (E + F) |
| Posterior wall sign [14] | Positive if the posterior acetabular rim is projected medial of the center of the hip |

parameters that changed decreased except the LCE angle, posterior acetabular coverage, and retroversion index (Table 3). The mean effect of normalization ranged from −0.6° to 0.4° (maximum difference of 5°) for the angular measurements and from −16.2% to 3.8% for the relative units/acetabular coverage (maximum difference of 45% for the retroversion index; Table 3). The effect of normalization of a positive crossover or posterior wall sign was 37% and 15%, respectively (Table 3).

In the experimental part of the study, the following five parameters did not change when the pelvis was being virtually rotated and tilted: LCE, extrusion index, ACM angle, Sharp angle, and craniocaudal coverage (Fig. 5). The remaining six parameters changed as a result of pelvic tilt and/or rotation (Table 4). The acetabular index showed a maximum range of 4.6° depending on pelvic tilt (Table 4). Anterior and posterior acetabular coverage changed with both pelvic tilt and rotation with a maximum range of 13% to 27% (Table 4). The prevalence of a positive crossover and posterior wall sign showed a maximum range of 85% to 97% depending on pelvic orientation (Table 4). The retroversion index showed a maximum change of 62% and 55% depending on pelvic rotation and tilt, respectively (Table 4).

In both the clinical and experimental parts of the study, the anterior and posterior acetabular coverage, the prevalence of a positive crossover and posterior wall sign, and the retroversion index met our threshold of being "ultimately relevant," defined as given clinical and/or experimental relevance (Table 5). For example, the retroversion index showed ultimately relevant changes as a result of a mean effect of normalization of 16% exceeding a mean interobserver difference of 5° ("clinically relevant"; Table 3) or a maximum range of 62% depending on pelvic orientation exceeding 1 SD of interobserver difference of 10° ("experimentally relevant"; Table 4). The remaining six parameters did not show ultimately relevant changes as a result of pelvic rotation and tilt (Table 5) in that any changes noted in those parameters were either less than the interobserver difference for the clinical portion of the study or less than 1 SD of the interobserver difference for the experimental part.

## Discussion

The projected anatomy of the acetabulum and the corresponding radiographic parameters on an AP pelvic radiograph depend directly on pelvic tilt and rotation during acquisition of the radiograph. Novel computerized methods allow correcting radiographic parameters for pelvic malpositioning. Despite some reports on individual parameters in the literature (Table 6), before this study, it was not known which radiographic parameters are affected by malpositioning of the pelvis to a clinically relevant extent. Therefore, we asked (1) which radiographic parameters obtained in a clinical setting change when being normalized; (2) what is the maximum change of each parameter when the pelvis is virtually tilted and rotated using an experimental model; and (3) which of those changes are relevant in clinical practice, where relevance was defined in relationship to an interobserver difference of measurement.

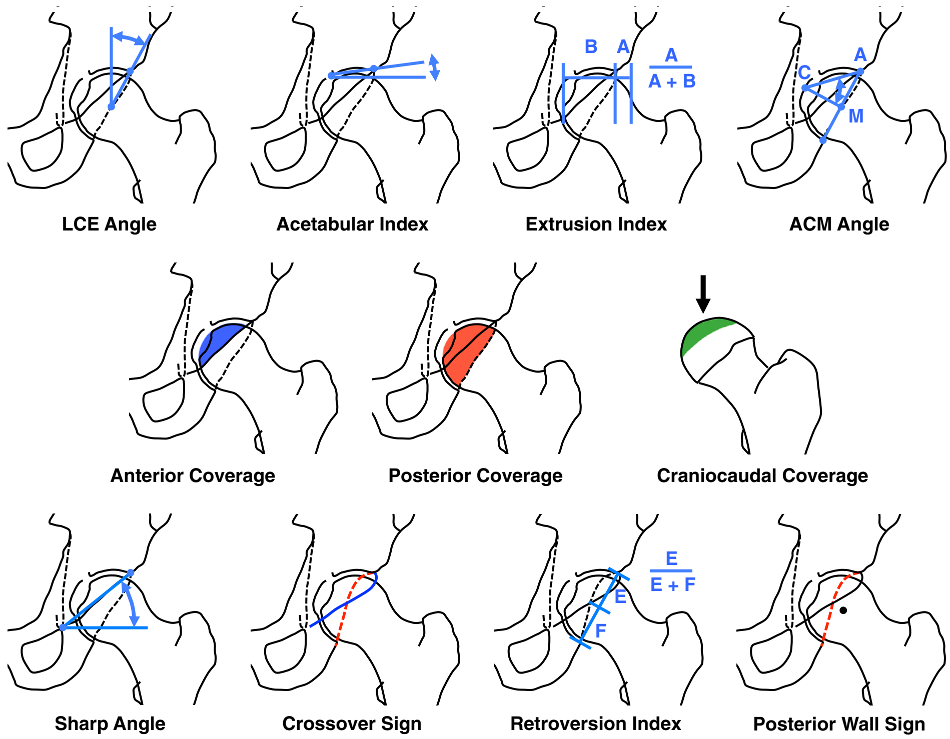


**Fig. 3** Schematic illustration shows the 11 investigated radiographic parameters (see Table 2 for definitions).

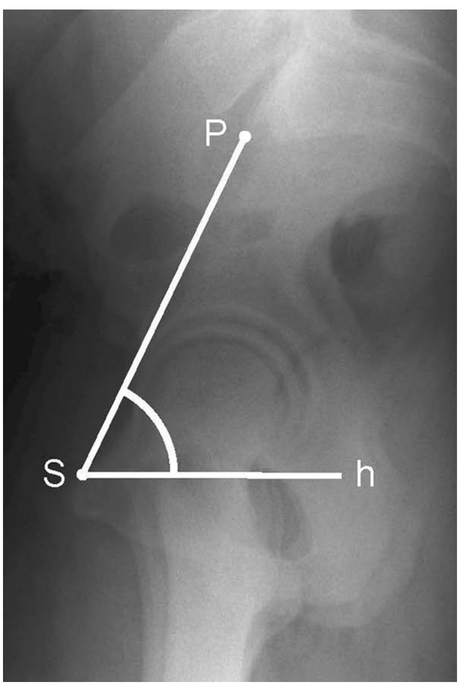


**Fig. 4** Pelvic inclination was measured on the true lateral pelvic radiograph and was defined as the angle formed by a horizontal line (h) and a line connecting the upper boarder of the symphysis (S) with the sacral promontory (P) [21].

This study has several limitations. First, the simulation of the virtual range of each radiographic parameter was based on a more or less spherical configuration of the femoral head and acetabulum. We cannot extrapolate our results for more severely deformed hips. Second, our analysis is based on radiographs with a predefined center of the xray beam. This has become the standard setup for AP pelvic radiographs in joint-preserving hip surgery [20, 21]; it may not apply to radiographs obtained in other ways. Specifically, we did not analyze the influence of variations of the xray centering and film focus distance, which has already been done by others [10]. Our conclusions are therefore not directly transferable to AP radiographs centered on the hip.

When we evaluated radiographs obtained clinically and corrected them for pelvic position using image-analysis software, nine of 11 parameters change when being normalized to an anatomically defined neutral pelvic orientation (Table 3). However, the magnitude and the clinical importance of these differences require further clarification. The changes of four statistically significant parameters were clinically unimportant, including the LCE angle, the acetabular index, extrusion index, and Sharp angle. As an example for the LCE angle, 95% of all hips showed an effect of normalization of less than 4.5°. This is

**Table 3.** Results of the clinical part of the study with comparison of nonnormalized and normalized values of the radiographic parameters*

| Parameter | Nonnormalized values | Normalized values | p value† | Effect of normalization‡ | Interobserver difference | p value§ | 'Clinical relevance' |
|---|---|---|---|---|---|---|---|
| Lateral center-edge angle (degrees) | 30.4 ± 6.1 (16–49) | 31.1 ± 6.4 (17–48) | < 0.001 | −0.6 ± 1.1 (−5 to 3) | 1.5 ± 3.6 (−11 to 9) | 0.014 | No |
| Acetabular index (degrees) | 4.8 ± 5.0 (−7 to 19) | 4.5 ± 5.2 (−7 to 19) | 0.029 | 0.3 ± 1.4 (−5 to 4) | 0.2 ± 5.4 (−16 to 17) | 0.908 | No |
| Extrusion index (percent) | 19.2 ± 6.0 (5–34) | 18.6 ± 6.0 (5–33) | < 0.001 | 0.5 ± 0.7 (−1 to 3) | 0.3 ± 3.5 (−12 to 11) | 0.473 | No |
| ACM angle (degrees) | 44.5 ± 2.9 (39–51) | 44.1 ± 2.8 (39–52) | 0.649 | 0.4 ± 0.5 (−1 to 3) | −0.2 ± 8.0 (−16 to 14) | 0.415 | No |
| Sharp angle (degrees) | 38.9 ± 3.1 (29–47) | 38.6 ± 3.2 (30–47) | < 0.001 | 0.3 ± 0.7 (−2 to 3) | 1.5 ± 3.4 (−11 to 9) | < 0.001 | No |
| Craniocaudal coverage (percent) | 82.4 ± 7.3 (62–100) | 82.2 ± 7.1 (67–97) | 0.608 | 0.2 ± 3.5 (−12 to 9) | 1.2 ± 5.4 (−16 to 15) | 0.122 | No |
| Anterior acetabular coverage (percent) | 27.3 ± 6.5 (13–47) | 23.5 ± 7.3 (7–46) | < 0.001 | 3.8 ± 4.7 (−9 to 15) | 0.3 ± 6.1 (−11 to 27) | < 0.001 | Yes |
| Posterior acetabular coverage (percent) | 42.0 ± 7.1 (25–65) | 45.5 ± 7.3 (27–66) | < 0.001 | −3.4 ± 4.5 (−13 to 7) | 0.6 ± 3.5 (−7 to 11) | < 0.001 | Yes |
| Crossover sign (percent positive) | 56 | 20 | < 0.001 | 37 | 6 | < 0.001 | Yes |
| Retroversion index (percent)‖ | 16.0 ± 17.3 (0–44) | 32.6 ± 9.3 (6–47) | < 0.001 | −16.2 ± 21.3 (−45 to 22) | 4.8 ± 9.9 (−43 to 23) | 0.006 | Yes |
| Posterior wall sign (percent positive) | 86 | 71 | 0.002 | 15 | 5 | 0.005 | Yes |

Values of continuous parameters are expressed as mean ± SD with range in parentheses; *"Clinical relevance" was given if the difference between nonstandardized and standardized values (effect of normalization) exceeded significantly the interobserver difference; †p value for difference between nonnormalized and normalized values; ‡the effect of normalization was defined as the difference between nonnormalized and normalized values; §p value for difference between interobserver difference and effect of normalization; ‖only in hips with a positive crossover sign.

far less than the classical reported normal range for the LCE angle from 25° to 40° [1, 3]. This is the result of the unrealistically high range of pelvic tilt and rotation chosen in experimental studies [3] in the literature. In addition, it seems questionable if a mean change of the LCE angle of less than 1° (Table 3) is likely to change the diagnosis and indication for possible surgical therapies. In contrast, the changes of all five parameters that describe the AP coverage and acetabular orientation (anterior and posterior coverage, crossover and posterior wall sign, retroversion index) are clinically important. As an example, for anterior coverage, 95% of all hips showed an effect of normalization of more than 18% exceeding the reported normal range of 11% [16]. It is important to note that these results do not justify improper patient positioning or incorrect acquisition of xrays regarding film focus distance and centering of the xray beam. Interestingly, only one study described the influence of correcting for pelvic tilt on radiographic hip values in the literature [9]. They found no difference for total acetabular coverage, which is in accordance with our results. In contrast to our findings, the anterior and posterior acetabular coverage did not change depending on correction for pelvic tilt. The reason for this discrepancy is most likely the result of the indirect determination of pelvic tilt using the height-to-width ratio of the obturator foramen on the AP pelvic radiograph. This method, however, reportedly correlates poorly with the actual pelvic tilt [19].

When we evaluated the magnitude of changes in acetabular measurements in an experimental model with image analysis software and cadaver pelves, we found that five parameters do not change when being repositioned through the entire chosen range of tilt and rotation (LCE, extrusion index, ACM angle, Sharp angle, and craniocaudal coverage; Table 4). In the literature, several studies evaluated the influence of pelvic malpositioning on radiographic hip parameters (Table 6). The results are contradictory for many parameters (Table 6). Although some authors reported an inert behavior of the LCE angle [3, 10], others found variability depending on pelvic positioning [5, 7, 11]. Similar inconsistencies are reported for the total femoral coverage, acetabular index, and the Sharp angle (Table 6). The heterogeneity of these results might be related to the use of different imaging modalities, anatomical reference coordinate systems, and arbitrary ranges of tilt/rotation (Table 6). In our study, we try to provide a comprehensive analysis of the most commonly used radiographic hip parameters. This implies a relatively large number of cadaver hips, a large range for both tilt and rotation, and small increments of 3°.

It is important to note that not all changes that can be detected statistically are clinically important. We defined

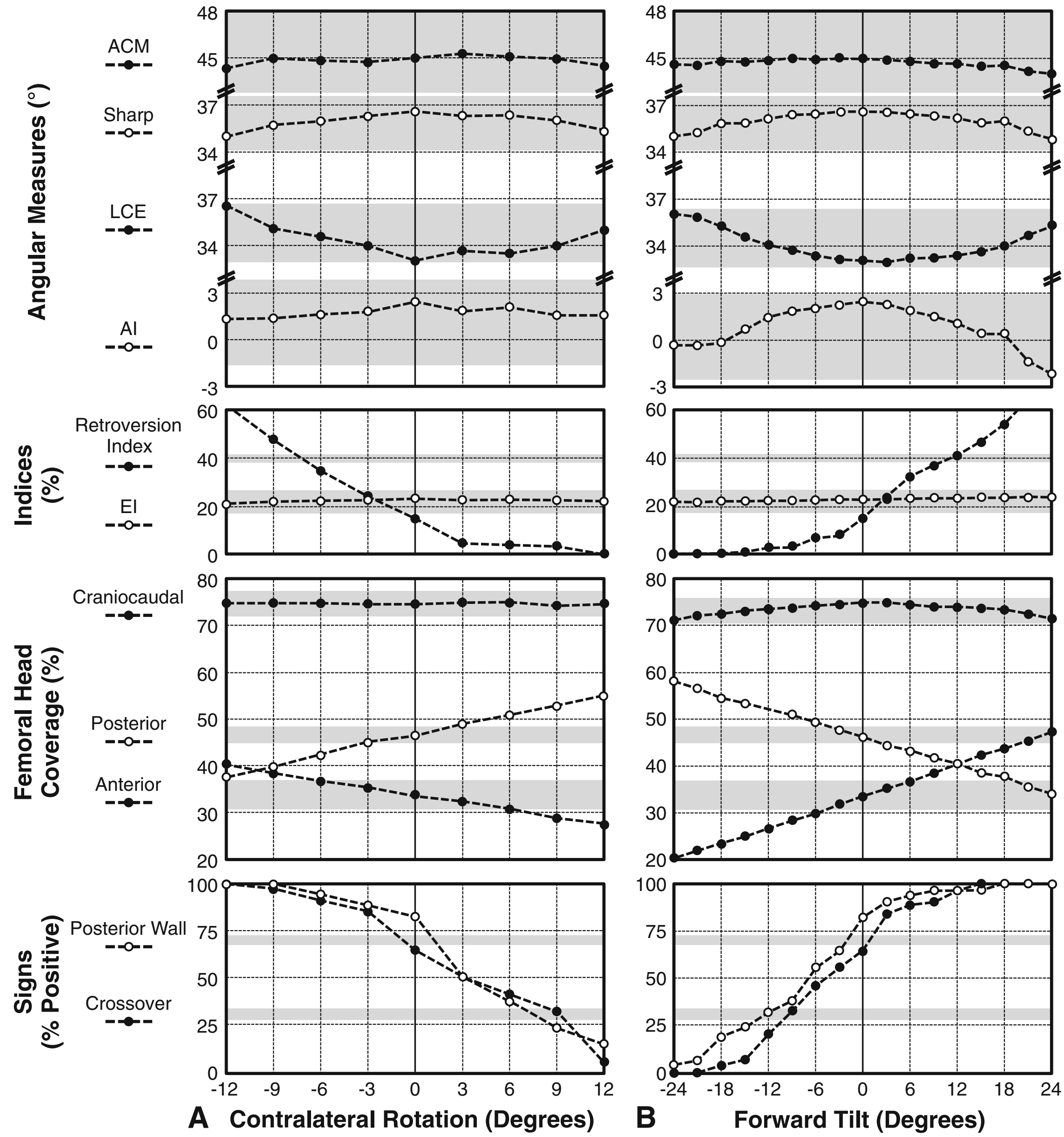


**Fig. 5A–B** Each of the 11 radiographic parameters is computed for (**A**) a pelvic rotation ranging from −12° to 12° and (**B**) a pelvic tilt ranging from −24° to 24°. The gray areas represent 1 SD of interobserver variability for each parameter. "Experimental relevance" was considered given if the maximum range of a parameter depending on rotation and tilt of the pelvis exceeded 1 SD of interobserver variability.

a change as relevant if it was greater than the error in interobserver difference. To our knowledge, no thresholds to distinguish between relevant and not relevant changes have been reported. We chose the threshold of interobserver variability as a result of the fact that if a difference depending on pelvic orientation is less than the interobserver variability, then it could not be consistently detected in a clinical routine setup. Using our standard for relevant changes, five of the 11 parameters changed. By contrast, six of the 11 parameters did not change in a clinically relevant way when being standardized to an anatomically neutral pelvic orientation. That is, for these radiographic parameters, the effect of standardization was lower than the actual interobserver difference, meaning that even if there was a statistically detectable difference of standardization, it is unlikely that this difference would be detected by different observers. For example, the computed effect of standardization was 0.3° for the Sharp angle, which is lower than the mean interobserver difference of 1.5° (Table 3). Analogously, the same six

**Table 4.** Results of the experimental part of the study with the maximum range of each radiographic parameter depending on the virtually rotated (range, −12° to 12°) and tilted (−24° to 24°) pelvis*

| Parameter | Experimental part | | | | | | Overall | |
|---|---|---|---|---|---|---|---|---|
| | Maximum range (pelvic rotation) | p value† (pelvic rotation) | Maximum range (pelvic tilt) | p value† (pelvic tilt) | One SD of interobserver variability‡ | 'Experimental relevance' | 'Clinical relevance' | 'Ultimate relevance' |
| Lateral center-edge angle (degrees) | 3.5 | 0.700 | 3.0 | 0.849 | 3.6 | No | No | No |
| Acetabular index (degrees) | 1.0 | 0.997 | 4.6 | 0.009 | 5.4 | No | No | No |
| Extrusion index (percent) | 1.9 | 0.904 | 2.2 | 0.704 | 3.5 | No | No | No |
| ACM angle (degrees) | 0.9 | 0.990 | 1.3 | 0.981 | 8.0 | No | No | No |
| Sharp angle (degrees) | 1.6 | 0.817 | 1.7 | 0.734 | 3.4 | No | No | No |
| Craniocaudal coverage (percent) | 0.8 | 1.000 | 3.9 | 0.064 | 5.4 | No | No | No |
| Anterior acetabular coverage (percent) | 12.8 | < 0.001 | 27.1 | < 0.001 | 6.1 | Yes | Yes | Yes |
| Posterior acetabular coverage (percent) | 17.1 | < 0.001 | 24.0 | < 0.001 | 3.5 | Yes | Yes | Yes |
| Crossover sign (% positive) | 95 | < 0.001 | 97 | < 0.001 | 6 | Yes | Yes | Yes |
| Retroversion index (percent) | 62.0 | < 0.001 | 54.9 | < 0.001 | 9.9 | Yes | Yes | Yes |
| Posterior wall sign (% positive) | 85 | < 0.001 | 97 | < 0.001 | 5 | Yes | Yes | Yes |

* In addition, significance of changes for both pelvic rotation and tilt are summarized for each radiographic parameter. "Experimental relevance" was given if the maximum range resulting from pelvic rotation or tilt exceeded 1 SD of intraobserver variability. The ultimate relevance was based on both the clinical and experimental part of the study; †p value for comparison of all position of pelvic rotation or tilt; ‡from the clinical part of the study (see Table 3).

**Table 5.** Radiographic hip parameters that are inert to pelvic rotation and tilt compared with those that change relevantly with pelvic malposition

| Radiographic hip parameters that are inert to pelvic rotation and tilt | Radiographic hip parameters that change relevantly with pelvic rotation and tilt |
|---|---|
| Lateral center-edge angle | Anterior acetabular coverage |
| Acetabular index | Posterior acetabular coverage |
| Extrusion index | Crossover sign |
| ACM angle | Retroversion index |
| Sharp angle | Posterior wall sign |
| Craniocaudal coverage | |

radiographic parameters did not change in an "experimentally relevant" way (Table 4). For these parameters, the maximal possible experimental range is smaller than the interobserver SD. It is therefore unlikely that different observers can detect the potential effect of pelvic malpositioning on these six parameters, even with a large deviation of pelvic tilt and rotation. For example, total femoral head coverage changes maximally by 3.9°, which is less than the interobserver variability of 5.4° (Table 4). Combining the "clinical" and the "experimental" relevance, we found six parameters that are inert to pelvic tilt and rotation in a clinically routine setup (Table 5). All five parameters characterizing the orientation of the acetabulum (including the relationship of anterior to posterior coverage) change relevantly with tilt and rotation (Table 5).

In summary, we conclude that the LCE angle, acetabular index, extrusion index, ACM angle, Sharp angle, and the craniocaudal coverage if acquired in a standardized manner to minimize pelvic malorientation can be measured on an AP pelvic radiograph without relevant restrictions. In contrast, anterior and posterior acetabular coverage, the crossover sign, retroversion index, and posterior wall sign can vary to a clinically meaningful extent even when acquired in a clinical routine setup. These parameters call for specific efforts that address individual pelvic orientation such as computer-assisted evaluation of radiographs. These differences resulting from pelvic orientation have the potential to alter the decision-making and execution of joint-preserving surgery of the acetabulum.

**Table 6.** Selected literature on radiographic parameters and their changes depending on pelvic tilt and rotation

| Author (year) | Method | Number of specimens (hips) | Reference pelvic neutral position | Range of pelvic rotation | Range of pelvic tilt | Number of positions | Results |
|---|---|---|---|---|---|---|---|
| Henebry and Gaskill [5] (2013) | Fluoroscopy (cadaver) | 8 | APP | NA | −15° to 15° (5° increments) | 7 | Significant changes of LCE angle, AI, and crossover sign for pelvic tilt; no changes for Sharp angle |
| Monazzam et al. [11] (2013) | EOS® (EOS Imaging, Paris, France) (cadaver) | 4 | APP | −15° to 15° (5° increments) | −15° to 15° (5° increments) | 13 | Significant changes for all parameters (LCE angle, AI, Sharp angle, crossover sign, retroversion index) with rotation; tilt affected all parameters except AI |
| Lee et al. [10] (2011) | 3D CT (clinical data) | 36 | APP | NA | −20° to 20 (20° increments) | 3 | LCE angle and Sharp angle did not show significant differences for pelvic tilt |
| Konishi and Mieno [9] (1993) | Conventional radiography with computer simulation (clinical data) | 286 | Height-to-width of obturator foramen | NA | −15° to 20° (5° increments) | 8 | No changes for total acetabular coverage |
| Siebenrock et al. [15] (2003) | Conventional radiography (cadaver) | 8 | Size of the obturator foramen | NA | −12° to 9° (3° increments) | 8 | Crossover sign, posterior wall sign, and retroversion index change with pelvic tilt |
| Kakaty et al. [8] (2010) | Conventional radiography (clinical and cadaver) | 129 (clinical); 40 (cadaver) | Coccygeal-symphyseal distance | −9° to 9° (3° increments) | −12° to 12° (3° increments) | 16 | Prevalence of positive ischial spine sign significantly changes with pelvic rotation and tilt |
| Dandachli et al. [4] (2009) | 3D CT (clinical) | 93 | APP | NA | −20° to 20° (5° increments) | 9 | Total, anterior, and posterior tilt changed depending on pelvic tilt with the most pronounced effect in dysplastic hips followed by normal and retroverted hips |
| Jacobsen et al. [7] (2005) | Conventional radiography (cadaver) | 2 | Size of the obturator foramen | −12° to 12° (3° increments) | −21° to 21° (3° increments) | 23 | LCE angle and Sharp angle significantly changed with pelvic rotation or tilt; extrusion index was not affected by rotation and by tilt for female hips only |
| Brückl et al. [3] (1986) | Conventional radiography (cadaver) | 2 | NA | −20° to 20° (4° increments) | −16° to 14° (2° or 4° increments) | 19 | ACM angle is depending on rotation and tilt, whereas LCE angle is only minimally affected by pelvic rotation or tilt |

**Table 6.** continued

| Author (year) | Method | Number of specimens (hips) | Reference pelvic neutral position | Range of pelvic rotation | Range of pelvic tilt | Number of positions | Results |
|---|---|---|---|---|---|---|---|
| Current study | Conventional radiography with computer simulation (clinical and cadaver data) | 126 (clinical) 40 (cadaver) | Pelvic inclination | −12° to 12° (3° increments) | −24° to 24° (3° increments) | 25 | Significant changes of anterior and posterior coverage, crossover sign, posterior wall sign, and retroversion index; no changes for ACM, Sharp, LCE angle, AI, extrusion index, and total acetabular coverage |

3D = three-dimensional; NA = not applicable; APP = anterior pelvic plane; LCE = lateral center-edge; AI = acetabular index.

## References


1. Anderson LA, Gililland J, Pelt C, Linford S, Stoddard GJ, Peters CL. Center edge angle measurement for hip preservation surgery: technique and caveats. *Orthopedics.* 2011;34:86.
2. Babisch JW, Layher F, Amiot LP. The rationale for tilt-adjusted acetabular cup navigation. *J Bone Joint Surg Am.* 2008;90:357–365.
3. Brückl R, Plitz W, Rosemeyer B, Schier E, Broos P, Miserez M, Bormans G, De Roo M. [Projection-induced differences in planimetric measuring quantities in the full-size radiogram of the pelvis] [in German]. *Orthop Praxis.* 1986;12:949–955.
4. Dandachli W, Islam SU, Liu M, Richards R, Hall-Craggs M, Witt J. Three-dimensional CT analysis to determine acetabular retroversion and the implications for the management of femoro-acetabular impingement. *J Bone Joint Surg Br.* 2009;91:1031–1036.
5. Henebry A, Gaskill T. The effect of pelvic tilt on radiographic markers of acetabular coverage. *Am J Sports Med.* 2013;41:2599–2603.
6. Idelberger K, Frank A. [A new method for determination of the angle of the pevic acetabulum in child and in adult] [in German]. *Z Orthop Ihre Grenzgeb.* 1952;82:571–577.
7. Jacobsen S, Sonne-Holm S, Soballe K, Gebuhr P, Lund B. Hip dysplasia and osteoarthrosis: a survey of 4151 subjects from the Osteoarthrosis Substudy of the Copenhagen City Heart Study. *Acta Orthop.* 2005;76:149–158.
8. Kakaty DK, Fischer AF, Hosalkar HS, Siebenrock KA, Tannast M. The ischial spine sign: does pelvic tilt and rotation matter? *Clin Orthop Relat Res.* 2010;468:769–774.
9. Konishi N, Mieno T. Determination of acetabular coverage of the femoral head with use of a single anteroposterior radiograph. A new computerized technique. *J Bone Joint Surg Am.* 1993;75:1318–1333.
10. Lee YK, Chung CY, Koo KH, Lee KM, Kwon DG, Park MS. Measuring acetabular dysplasia in plain radiographs. *Arch Orthop Trauma Surg.* 2011;131:1219–1226.
11. Monazzam S, Agashe M, Hosalkar HS. Reliability of overcoverage parameters with varying morphologic pincer features: comparison of EOS® and radiography. *Clin Orthop Relat Res.* 2013;471:2578–2585.
12. Murphy SB, Ganz R, Muller ME. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. *J Bone Joint Surg Am.* 1995;77:985–989.
13. Murphy WS, Klingenstein G, Murphy SB, Zheng G. Pelvic tilt is minimally changed by total hip arthroplasty. *Clin Orthop Relat Res.* 2013;471:417–421.
14. Reynolds D, Lucas J, Klaue K. Retroversion of the acetabulum. A cause of hip pain. *J Bone Joint Surg Br.* 1999;81:281–288.
15. Siebenrock KA, Kalbermatten DF, Ganz R. Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. *Clin Orthop Relat Res.* 2003;407:241–248.
16. Tannast M, Albers CE, Steppacher SD, K Siebenrock. Hip pain in the young adult. In: Bentley G, ed. *European Instructional Lectures.* Vol 11. Heidelberg, Germany: Springer; 2011:141–154.
17. Tannast M, Langlotz U, Siebenrock KA, Wiese M, Bernsmann K, Langlotz F. Anatomic referencing of cup orientation in total hip arthroplasty. *Clin Orthop Relat Res.* 2005;436:144–150.
18. Tannast M, Mistry S, Steppacher SD, Reichenbach S, Langlotz F, Siebenrock KA, Zheng G. Radiographic analysis of femoroacetabular impingement with Hip2Norm-reliable and validated. *J Orthop Res.* 2008;26:1199–1205.
19. Tannast M, Murphy SB, Langlotz F, Anderson SE, Siebenrock KA. Estimation of pelvic tilt on anteroposterior X-rays—a comparison of six parameters. *Skeletal Radiol.* 2006;35:149–155.

20. Tannast M, Siebenrock KA. Conventional radiographs to assess femoroacetabular impingement. *Instr Course Lect.* 2009;58:203–212.
21. Tannast M, Siebenrock KA, Anderson SE. Femoroacetabular impingement: radiographic diagnosis—what the radiologist should know. *AJR Am J Roentgenol.* 2007;188:1540–1552.
22. Tannast M, Zheng G, Anderegg C, Burckhardt K, Langlotz F, Ganz R, Siebenrock KA. Tilt and rotation correction of acetabular version on pelvic radiographs. *Clin Orthop Relat Res.* 2005;438:182–190.
23. Tönnis D, Heinecke A. Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Joint Surg Am.* 1999;81:1747–1770.
24. Wiberg G. The anatomy and roentgenographic appearance of a normal hip joint. *Acta Chir Scand.* 1939;83:7–38.
25. Williams PL. The skeleton of the lower limb. In: Williams PL, Warkick R, Dyson M, Bannister LH, eds. *Gray's Anatomy.* Edinburgh, UK: Churchill Livingstone; 1989:422–446.
26. Zheng G, Tannast M, Anderegg C, Siebenrock KA, Langlotz F. Hip2Norm: an object-oriented cross-platform program for 3D analysis of hip joint morphology using 2D pelvic radiographs. *Comput Methods Programs Biomed.* 2007;87:36–45.