Anteroposterior Pelvic Radiographs to Assess Acetabular Retroversion: High Validity of the "Cross-over-Sign"

Amir A. Jamali, Kiril Mladenov, Dominik C. Meyer, Alberto Martinez, Martin Beck, Reinhold Ganz, Michael Leunig

Department of Orthopaedic Surgery, University of Berne, Inselspital, CH-3010 Berne, Switzerland

Received 2 June 2006; accepted 22 December 2006

Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/jor.20380

ABSTRACT: Acetabular retroversion has been proposed to contribute to the development of osteoarthritis of the hip. For the diagnosis of this condition, conventional AP pelvic radiographs may represent a reliable, easily available diagnostic modality as they can be obtained with a reproducible technique allowing the anterior and posterior acetabular rims to be visible for assessment. This study was designed to: (i) determine cranial, central, and caudal anatomic acetabular version (AV) from cadaveric specimens; (ii) establish the validity and reliability of the radiographic measurements of central acetabular anteversion; and (iii) determine the validity and reliability of the radiographic "cross-over-sign" to detect acetabular retroversion. Using 43 desiccated pelvises (86 acetabuli) the anatomic AVs were measured at three different transverse planes (cranially, centrally, and caudally). From these pelvises, standardized AP pelvic radiographs were obtained. To directly measure central AV, a modified radiographic method is introduced for the use of AP pelvic radiographs. The validity and reliability of this radiographic method and of the radiographic cross-over-sign to detect cranial acetabular retroversion were determined. The mean central and caudal anatomic AVs were approximately 20°, and the mean cranial AV was 8°. Cranial retroversion (AV < 0°) was present in 19 of 86 hips (22%). A linear correlation was found between the central and cranial AV. Below 10° of central AV, all acetabuli were cranially retroverted. Between 10° and 20°, 30% of the acetabuli were cranially retroverted, and above 20°, only 1 of 45 acetabuli was cranially retroverted. The radiographic measurement of the central AV (20.3 ± 6.5°) correlated strongly with the anatomic AV (20.1 ± 6.4°). The sensitivity of the cross-over-sign to detect a cranial acetabular anteversion of less than 4° was 96%, its specificity 95%, and the positive predictive and negative predictive values 90% and 98%, respectively. Both the modified radiographic anteversion measurements and the cross-over-sign demonstrated substantial inter- and intraobserver reliability. Retroversion is almost exclusively a problem of the cranial acetabulum. The cranial AV is on average 12° lower than the central AV, with the latter directly measurable from AP pelvic radiographs. A central AV of less than 10° was associated with cranial retroversion. The presence of a positive cross-over-sign is a highly reliable indicator of cranial AV of <4°. © 2007 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res

Keywords: hip; osteoarthritis; femoroacetabular impingement; radiograph; retroversion

INTRODUCTION

Variations in the spatial orientation of the femoral head/neck and acetabulum have been recognized as a predisposing factor for the development of pain and early osteoarthritis in nondysplastic hips.[1–3] With decreased clearance between the femoral head/neck junction and the acetabular rim, these structures can come into contact with relatively small degrees of internal rotation and adduction/abduction particularly during hip flexion.[4–7] The ensuing repetitive impact may provoke local acetabular cartilage damage and subsequent hip pain with progressive degenerative changes of the acetabular rim and its adjacent structures.[8,9] While quantitative methods to assess the femoral head/neck offset have been reported recently,[4,10–13] almost no such measures are available for quantifying acetabular version (AV) using AP pelvic radiographs.

The radiographic assessment of the AV is difficult mainly due to the irregular morphology of the anterior acetabular rim.[14] In addition, insufficient standardization of the radiographic technique, in particular pelvic rotation and tilt, is known to affect the visual definition of the acetabular rim and thus AV quantification.[15–17] Computed tomography (CT), which has been most widely used to determine AV,[3,18–20] faces positioning problems similar to those of

Correspondence to: Michael Leunig, Dept. of Orthopaedics, Schulthess Clinic, Lengghalde 2, CH-8008 Zürich, Switzerland (Telephone: +41-44-385-7312; Fax: +41-44-385-7477; E-mail: michael.leunig@kws.ch)

conventional radiographs. In addition, CT is not used in the primary diagnosis, and it exposes patients to a substantially higher additional dose of radiation.

Because variations of the acetabular AV, in particular cranial retroversion, can predispose patients to femoroacetabular impingement (FAI), its assessment is important in the evaluation and the management of FAI. The "cross-over-sign" (COS) has been associated with acetabular retroversion.[21] It has been described for AP pelvic radiographs and occurs when the most proximal anterior acetabular rim appears lateral to the posterior rim, creating a figure eight, and suggesting acetabular retroversion above this level.[21] This study was designed to: (i) determine the cranial, central, and caudal anatomic AV from cadaveric specimens; (ii) establish the validity and reliability of the radiographic measurements of central acetabular anteversion as described by Meunier et al.[22]; and (iii) determine the validity and reliability of the radiographic COS to detect acetabular retroversion.

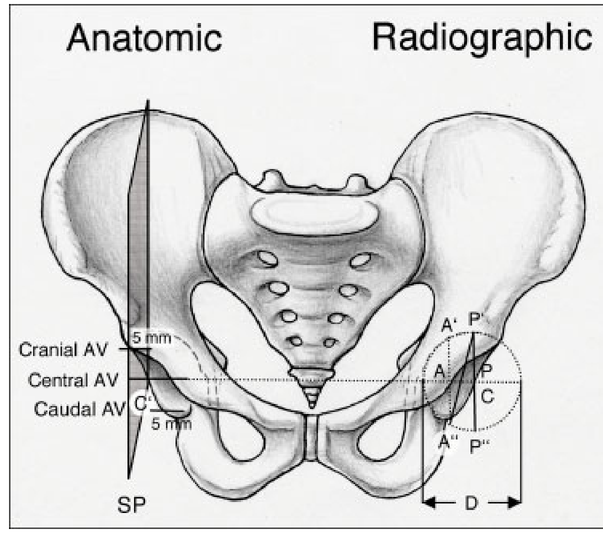

Figure 1. Schematic drawing of a pelvis showing the techniques used for quantifying the anatomic (left side) and radiographic (right side) AV. The anatomic AV [opening of the acetabulum with respect to the sagittal plane (SP)] was quantified at three different transverse planes of the acetabulum. The original method described by Meunier et al.[22] using a standard AP radiograph of the hip was modified for the use of AP pelvic radiographs to quantify the central radiographic AV. [Color figure can be viewed in the online issue, which is available at http://www.interscience.wiley.com.]

METHODS

Pelvic Specimens

Forty-three pelvic specimens (86 hips) including the corresponding femora of the skeletal collection at the Institute for Anthropologic Research, Aesch, Switzerland were examined. These consisted of 30 male and 13 female complete pelvis specimens. The mean age was 47 ± 10 years (range 18–65 years). They were representatives of the Allemanic population that resided in northwestern Switzerland between the 6th and 16th centuries. No institutional review board approval was required for this study.

Anatomic Measurements

The anatomic frontal plane of reference of the pelvis was defined as the plane formed between both anterior superior iliac spine (ASIS) and the pubic symphysis. This plane is oriented vertically during upright standing and walking.[23,24] The pelvic specimens were placed in prone position on a flat table so that both the ASIS and the pubic symphysis rested in a stable position against the table. The table was regarded as the anatomic frontal plane. The AV was quantified at three different transverse sections through the acetabulum as shown in Figure 1: cranial (5 mm distal to the acetabular roof), central (through the longitudinal center of the acetabulum), and caudal (5 mm proximal from the most inferior edge of the acetabular cavity). The distance of 5 mm cranially was used, as most acetabular cartilage damage in femoroacetabular impingement is found anterosuperiorly, close to the anterior inferior iliac spine, which corresponds to a position approximately at the level of or slightly distal (5 mm) to the radiographic acetabular roof (sourcil). Moreover, analysis of a point 5 mm from the acetabular roof allows CT or MR measurements and comparisons for assessing AV.

To determine whether the anterior acetabular rim morphology influences AV measurements, the morphology of the anterior rim was qualitatively categorized into one of four groups (curved, irregular, straight, and angulated), as described recently by Maruyama et al.[14]

Radiographs

Radiographs were taken with a tube-to-film distance of 120 cm. The pelvises were positioned supine with their frontal anatomical plane parallel to the film plate. The central beam was directed to the midpoint between the pubic symphysis and a horizontal line connecting both ASISs. All the radiographs fulfilled the criteria for correct pelvic positioning with regard to the axial and the transverse pelvic rotation. The distance between the sacrococcygeal joint and the superior border of the pubic symphysis measured between 3 and 4 cm.[25]

Radiographic Measurement of AV

The radiographic AV was quantified using a modification of the method described by Meunier et al.[22] for AP radiographs of the hip. The modification was to quantify

 DOI 10.1002/jor

AV using AP pelvic radiographs (instead of AP hip radiographs) (Fig. 1). To measure AV, the centers of both acetabuli (C and C′) and their corresponding diameters were determined. The points of intersection of the bicentric line (CC′) with the contours of the anterior and the posterior acetabular rim were determined and marked as **A** (anterior) and **P** (posterior), respectively. Perpendicular lines were drawn intersecting the horizontal line (CC′), and passing through **A** and **P**. The points **A′**, **A″**, **P′**, and **P″** represent intersections of the vertical lines through the anterior and the posterior acetabular rims with the contour of the acetabular diameter. The angle **A″-P′-P″** represents the AV. To account for an underestimation of acetabular anteversion on AP pelvic radiographs caused by the divergence of the X-ray beam, the correction angles to be added to the X-ray measurements were calculated according to the following equation:

$$\text{correction angle} = \arctan((CC'/2)/120) \qquad (1)$$

where ***C-C′*** is the distance between both centers of rotation.

Intraclass correlation coefficients (ICCs; inter- and intraobserver reliability) of measurements of the radiographic AV (46 randomly selected hips in 23 pelvises) were performed for two observers (K. M. and A. J.) in two sessions at least 2 weeks apart.

To calculate AV based on radiographic linear measurements only, the ratio of the distance of the anterior and posterior rims at the central acetabulum (AP) and the acetabular diameter (D) was used and an AP/D ratio was determined. In addition, the lateral center edge (LCE) angle and the femoral neck/shaft (CCD) angle were measured.

Assessment of the COS

The AP pelvic radiographs were evaluated for the presence of the COS.[21] It was defined as negative when the contours of the anterior and the posterior acetabular rims met proximally exactly at the most lateral point of the acetabular roof, or when the most cranial point of the anterior rim contour was located medial to the corresponding point of the posterior rim contour. The COS was defined as positive whenever the contour of the anterior rim was located lateral to the corresponding point of the posterior rim. The sensitivity [Tp/(Tp + Fn)], specificity [Tn/(Tn + Fp)], positive predictive value [Tp/(Tp + Fp)], and negative predictive value [Tn/(Tn + Fn)] for the COS were calculated (Tp, true positive; Tn, true negative; Fp, false positive; Fn, false negative).

The kappa statistics (inter- and intraobserver reliability) of measurements for the COS were performed for all 86 hips by two observers (K. M. and A. J.) in two sessions at least 2 weeks apart.

Statistics

Data are expressed as mean ± the standard deviation. Statistical significance was set at $p < 0.05$. Statistical comparisons were performed using nonparametric tests (Wilcoxon test, Kruskal-Wallis test, Mann-Whitney test, Spearman rank correlation). To determine the relationship between the anatomical anteversion at different vertical positions and between anatomical and radiographic measures of anteversion, linear regression analysis was performed.

RESULTS

Anatomic AV

The anatomic AV was cranially (8.5 ± 9.1°) significantly smaller than centrally (20.1 ± 6.4°) ($p < 0.0001$, Wilcoxon test). Of the specimens evaluated, 22% (19 of 86, in six pelvises bilaterally, in seven unilaterally) were cranially retroverted (i.e., anatomic AV was ≤0°), while none of the specimens demonstrated centrally acetabular retroversion. No significant difference was found between the central and the caudal AV (19.7 ± 6.2°; $p = 0.1967$, Wilcoxon test). A linear correlation was found between the central and cranial anatomic AV ($R = 0.808$ at $p = 0.01$, Spearman's rho) (Fig. 2).

Below a central AV of 10° (4 of 86), all sockets (four of four) were cranially retroverted (AV ≤ 0°). Between 10 and 20° of central AV (37 of 86), 38%

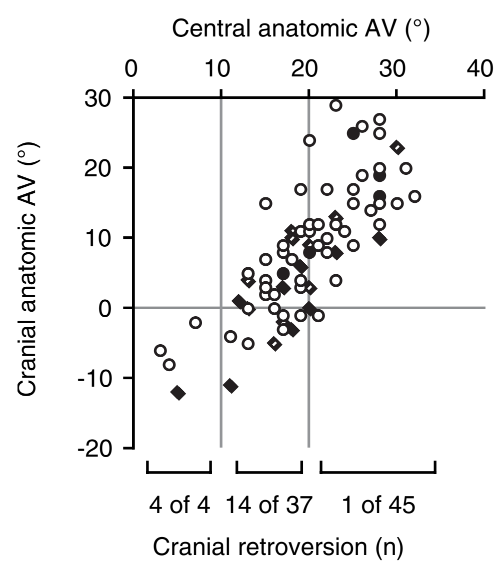

Figure 2. Scatter diagram showing a strong correlation ($R = 0.808$ at $p = 0.01$, Spearman's rho) between the central and cranial anatomic AV. Below a central AV of 10°, all sockets are cranially retroverted (AV ≤ 0°). Between 10° and 20°, 37% of the acetabuli were cranially retroverted (two measurements are overlapping) and above 20° of central AV only one of 45 sockets was retroverted. (○, curved; ●, irregular; ◇, straight; and ◆, angulated).

(14 of 37) of the acetabuli were cranially retroverted, and above 20° of central AV (45 of 86), only 1 of 45 sockets was cranially retroverted. The determination of the contour of the anterior acetabular rims revealed 65% (56/86) curved, 8% (7/86) irregular, 15% (13/86) straight, and 12% (10/86) angulated morphologies. When stratifying for these rim morphologies, a slightly decreased cranial AV ($p = 0.0150$, Kruskal Wallis test) was found for the subgroups revealing curved and angulated acetabular rim morphologies. No significant differences for rim morphologies were found for the central AV ($p = 0.2077$, Kruskal-Wallis test). The femoral shaft/neck angle (CCD, $132 \pm 6°$) and the femoral antetorsion ($10.7 \pm 7.5°$) were in the normal range.

Radiographic Central AV

The radiographic assessment of the central AV (A″-P′-P″) was made using a modification of the method of Meunier et al.[22] for AP pelvic radiographs. The ICC for interobserver reliability for the first session was 0.885 and for the second session was 0.930. The ICC for intraobserver reliability for the first observer was 0.913 and for the second observer was 0.950. The measurement of "radiographic" acetabular version of $20.3 \pm 6.5°$ was almost identical to the central "anatomic" acetabular version of $20.1 \pm 6.4°$. The mean difference between the "anatomic" and "radiographic" AV was $3.1 \pm 3.0°$. Values obtained by both methods showed a highly linear correlation ($R = 0.799$ at $p = 0.01$, Spearman's rho).

A strong linear correlation was also seen for the ratio AP/D representing the distance of the anterior and posterior rims at the level of the bicentric line (CC′) in relation to the acetabular diameter (D) and the "anatomic" AV ($p = 0.0001$, Spearman rank correlation). The lateral center edge angle measured $29 \pm 5°$ but was slightly larger in the subgroup of angulated rim morphology only ($33 \pm 3°$; $p = 0.0182$, Kruskal Wallis test).

COS

In 41 pelvises, the radiographically measured COS was assessable bilaterally (Fig. 3). In two pelvises the COS was measured unilaterally only due to a slightly damaged anterior acetabular rim. Of these 84 hips, 28 were COS-positive (33%) and 56 COS-negative (66%). The kappa-values for the interobserver reliability were 0.628 and 0.698 for the first and second sessions. The kappa-values for the intraobserver reliability were 0.674 for the first observer and 0.698 for the second observer. Based on the standards for the kappa statistic proposed by Landis and Koch[26] our measurements were in substantial agreement (0.41 to 0.60 moderate agreement and 0.61 to 0.81 substantial agreement).

The calculated underestimation of central AV due to the divergence of the X-ray beam was $4.0 \pm 0.2°$ (range: 3.2 to 4.5°). This means an AV of 4° represents the cut-off between COS-positive and COS-negative. Of the 56 COS-negative hips, 54 were measured radiographically. Of these, 48 hips (89%) were from a pelvis that was bilaterally COS-negative and six hips (11%) were from a pelvis that was unilaterally COS-negative, that is, an $AV > 4°$ (Fig. 3). In the 28 hips that were COS-positive, 22 hips (79%) were from a pelvis that was bilaterally COS-positive and six (21%) were from a unilaterally COS-positive pelvis.

The cranial, central, and caudal anatomic AV were significantly lower in COS-positive hips when compared to the COS-negative hips ($p < 0.0001$, Kruskal Wallis test, Mann-Whitney *U*-test, Fig. 4). The CCD was $134 \pm 7°$ in COS-positive and $132 \pm 6°$ in COS-negative ($p = 0.1452$, Mann-Whitney *U*-test), the LCE was $30 \pm 4°$ in COS-positive and $28 \pm 5°$ in COS-negative ($p = 0.3775$, Mann-Whitney *U*-test) and did not significantly differ between both groups.

The validity of the COS with the gold-standard measurement of anatomical cranial version was performed with a cutoff of 4° of anteversion based on our previously described correction for AP pelvic radiographs. Using these criteria, the sensitivity [Tp/(Tp + Fn)], specificity [Tn/(Tn + Fp)], positive predictive value [Tp/(Tp + Fp)], and negative predictive value [Tn/(Tn + Fn)] of a radiographic COS in the determination retroversion were calculated as 96, 95, 90, and 98%, respectively.

DISCUSSION

Abnormalities of AV, in particular retroversion, can be a predisposing factor for pain and degenerative changes of the hip.[1–3,25,27] Measurement of AV has been performed traditionally between the two lines connecting the vertex of the anterior and posterior rims and another one perpendicular to the transverse axis (Fig. 1). AV is called positive or anteverted when this angle opens anteriorly (the anterior acetabular rim lies medial to the posterior rim), and negative or retroverted if it opens posteriorly (the anterior rim lies lateral to the posterior rim). AV measurements through the center of the acetabulum ranging between 15 and 20° (Table 1)

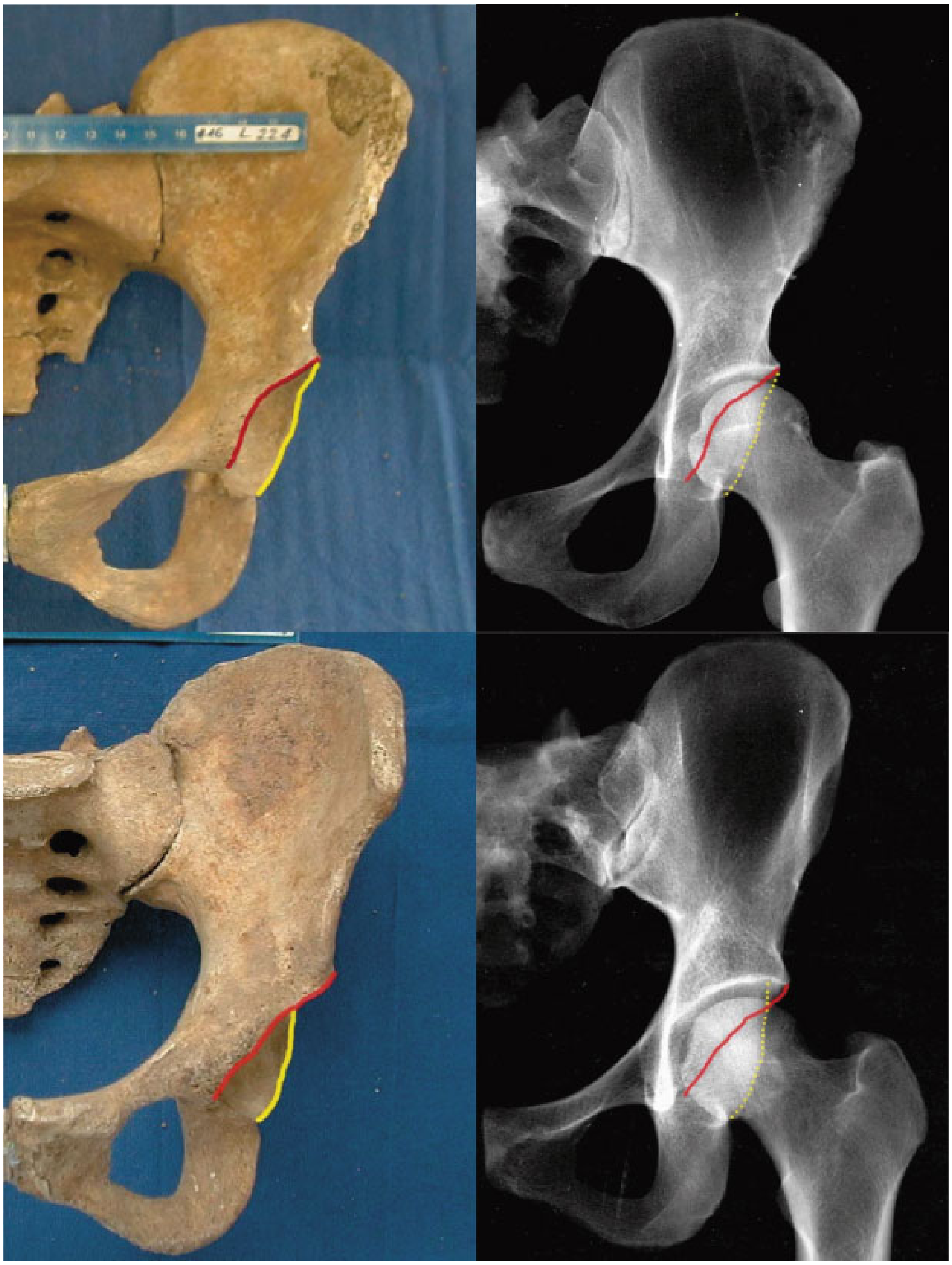

Figure 3. Photograph of a dessicated pelvis (upper left) with cranial anteversion (COS negative) with its corresponding radiograph (upper right). Photograph of a pelvis with cranial retroversion (COS positive) (lower left) and its corresponding radiograph (lower right). The anterior rims are highlighted in red and the posterior in yellow, which do cross (cross-over-sign) in the retroverted hips (lower pictures). [Color figure can be viewed in the online issue, which is available at http://www.interscience.wiley.com.]

are considered normal.[2,3,14,20,21,24,28–30] So far, AV in the cranial aspect has not been determined, although its role in the development of osteoarthritis of the hip has been suggested.[1,3,4,21,25,31] This is partially based on the fact that reliable measures to define AV of the cranial portion of the acetabulum have not been defined.

Using skeletons of the Allemanic population, who resided in northwestern Switzerland between the 6th and 16th centuries, we found anatomic

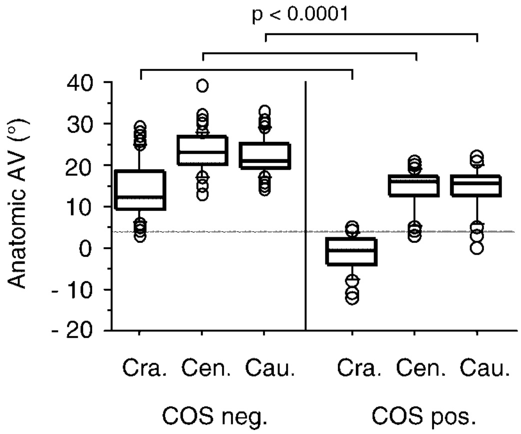

Figure 4. Boxplot showing the cranial, central, and caudal AV in hips revealing a negative (left side) and positive (right side) COS. There was a significantly lower anatomic AV in all portions of the COS-positive hips ($p < 0.0001$, Kruskal-Wallis and Mann-Whitney tests).

values of central AV around 20°, which are quite similar to data reported by Maruyama et al.[14] (19.9 ± 6.6°), who also directly assessed AV in skeletons of 50 males and 50 females amassed between 1912 and 1938. Because cranial retroversion has been suggested to cause FAI, we additionally determined AV in the cranial and caudal portions of the acetabulum. It was found that there is a significantly decreased anatomic AV in the cranial acetabulum relative to the central acetabulum (8.5 ± 9.1° vs. 20.1 ± 6.4°). In 22% of these acetabuli, the anatomic cranial AV was negative, that is, these sockets were retroverted. Our measurements of central AV from an ancient European anthropological collection were in close correlation to those of Maruyama et al.[14] in skeletons from the 20th century collected in the United States (19.9 ± 6.6° vs 20.1 ± 6.5°). If the relationship between central and cranial AV were consistent in both populations, acetabular retroversion appears to be a frequent phenomenon.

Table 1. Published Values on Central Acetabular Anteversion

Author	Year	AV (°)	Method
Visser et al.[24]	1982	16.5	CT
Reikeras et al.[2]	1983	17 ± 6	CT
Hoiseth et al.[20]	1989	19.8 ± 5.7	CT
Jacquemier et al.[28]	1995	13 ± 4	CT
Stanitski et al.[29]	1996	15.7	CT
Kim et al.[30]	1999	18.1	CT
Tönnis and Heinecke[3]	1999	15–20	CT
Reynolds et al.[21]	1999	20	CT
Maruyama et al.[14]	2002	19.9 ± 6.6	Direct
Current study	2005	20.1 ± 6.5	Direct
		20.3 ± 6.4	Standard radiographs

Moreover, this study shows that standardized AP pelvic radiographs[25] represent a reliable tool for the quantification of AV and in particular acetabular retroversion. Correcting for the divergence of the X-ray beam affecting AP pelvic radiographs (4°) allowed us to modify the technique of Meunier et al.[22] originally described for AP radiographs of the hip. Using this method we found a high linear correlation between results obtained anatomically and radiographically, suggesting this modified radiographic method as a valid and reliable tool to measure central AV. The decreased cranial AV (approximately 12° as measured anatomically) moreover allows us to extrapolate from the central AV to the cranial AV. The relationship between these two values is quite constant, with a central AV of less than 10° being highly correlated with a negative cranial AV and a central AV of greater than 20° being associated with a positive value for cranial AV (one exception in 45 hips). Between 10 and 20° central AV, more than one-third of acetabuli have a retroverted cranial AV. Besides this direct quantification of central AV, the COS[21] has been validated and shown to be an extremely reliable qualitative parameter to predict a cranial AV of less than 4°.

A number of studies have suggested the use of CT for the quantification of AV.[2,3,14,20,21,24,28–30] Although CT does provide direct and accurate measurements of the acetabular orientation, this technique also bears several limitations. With only one thin slice of the acetabulum visible on any given image, pelvic positioning cannot be evaluated. This can be a source of error if no standardized reference is used. In addition to the lack of universal availability, CT is expensive and is associated with substantial radiation exposure. In contrast, the AP pelvic radiographs are readily available, inexpensive, can be obtained in a standardized manner, allow a complete view of hip morphology, and can be performed intraoperatively. Methods using multiple serial radiographs with the pelvis in different degrees of rotation or based on the parallax effect of the X-ray beam have previously been described.[32,33] Unfortunately, these also have the inconvenience of high radiation exposure and uncertainty related to exact pelvic orientation. The method described by Meunier et al.[22] is a uniplanar method for direct measurement of the AV initially applicable for AP hip radiographs. In the original reference, this method was verified

 DOI 10.1002/jor

on only one cadaveric specimen using an AP radiograph of the hip and has therefore never been widely accepted.

It remains a matter of discussion how accurately static radiographs reflect functional acetabular coverage. There is clinical and experimental evidence that the supine position oriented in the anatomic frontal plane represents the vertical pelvic orientation in the upright position.[15] Nishihara et al.[16] reported the supine pelvic position to approach the functional position with less than 10° difference in the pelvic flexion angle between the standing and the supine position. The limitations of static radiographs also apply to CT and MR studies in the supine (or prone) position for measurement of AV. Therefore, standardized pelvic radiographs in the supine position provides at least a defined position close to the position during normal gait.

Abnormalities of AV are increasingly considered as a factor for the development of pain and degeneration of the hip. This study: (i) establishes a method to directly quantify anatomic AV from cadaveric specimens; (ii) establishes the validity and reliability of the radiographic measurements of central acetabular anteversion as described by Meunier et al.[22]; and (iii) determines the validity and reliability of the radiographic COS to detect acetabular retroversion.

ACKNOWLEDGMENTS

We thank Dr. B. Kaufmann from the Institute of Anthropology in Aesch, Switzerland, for providing access to the femoral specimen skeletons.

REFERENCES

1. Menke W, Schmitz B, Schild H, et al. 1991. [Transverse skeletal axes of the lower extremity in coxarthrosis]. Z Orthop Ihre Grenzgeb 129:255–259.
2. Reikeras O, Bjerkreim I, Kolbenstvedt A. 1983. Anteversion of the acetabulum and femoral neck in normals and in patients with osteoarthritis of the hip. Acta Orthop Scand 54:18–23.
3. Tonnis D, Heinecke A. 1999. Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. J Bone Joint Surg Am 81:1747–1770.
4. Ito K, Minka MA 2nd, Leunig M, et al. 2001. Femoroacetabular impingement and the cam-effect. A MRI-based quantitative anatomical study of the femoral head-neck offset. J Bone Joint Surg Br 83:171–176.
5. Beck M, Leunig M, Parvizi J, et al. 2004. Anterior femoroacetabular impingement: part II. Midterm results of surgical treatment. Clin Orthop Relat Res 418:67–73.
6. Tanzer M, Noiseux N. 2004. Osseous abnormalities and early osteoarthritis: the role of hip impingement. Clin Orthop Relat Res 429:170–177.
7. Wenger DE, Kendell KR, Miner MR, et al. 2004. Acetabular labral tears rarely occur in the absence of bony abnormalities. Clin Orthop Relat Res 426:145–150.
8. Leunig M, Beck M, Woo A, et al. 2003. Acetabular rim degeneration: a constant finding in the aged hip. Clin Orthop Relat Res 413:201–207.
9. Leunig M, Casillas MM, Hamlet M, et al. 2000. Slipped capital femoral epiphysis: early mechanical damage to the acetabular cartilage by a prominent femoral metaphysis. Acta Orthop Scand 71:370–375.
10. Eijer H, Leunig M, Mahomed MN, et al. 2001. Anterior femoral head-neck off-set: A method for measurement. Hip Int 11:37–41.
11. Mast JW, Brunner RL, Zebrack J. 2004. Recognizing acetabular version in the radiographic presentation of hip dysplasia. Clin Orthop Relat Res 418:48–53.
12. Meyer DC, Beck M, Ellis T, et al. 2006. Comparison of six radiographic projections to assess femoral head/neck asphericity. Clin Orthop Relat Res 445:181–185.
13. Notzli HP, Wyss TF, Stoecklin CH, et al. 2002. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. J Bone Joint Surg Br 84:556–560.
14. Maruyama M, Feinberg JR, Capello WN, et al. 2001. The Frank Stinchfield Award: Morphologic features of the acetabulum and femur: anteversion angle and implant positioning. Clin Orthop Relat Res 393:52–65.
15. Eckman K, Hafez MA, Ed F, et al. 2006. Accuracy of pelvic flexion measurements from lateral radiographs. Clin Orthop Relat Res 451:154–160.
16. Nishihara S, Sugano N, Nishii T, et al. 2003. Measurements of pelvic flexion angle using three-dimensional computed tomography. Clin Orthop Relat Res 411:140–151.
17. Siebenrock KA, Kalbermatten DF, Ganz R. 2003. Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. Clin Orthop Relat Res 407:241–248.
18. Abel MF, Sutherland DH, Wenger DR, et al. 1994. Evaluation of CT scans and 3-D reformatted images for quantitative assessment of the hip. J Pediatr Orthop 14:48–53.
19. Anda S, Svenningsen S, Grontvedt T, et al. 1990. Pelvic inclination and spatial orientation of the acetabulum. A radiographic, computed tomographic and clinical investigation. Acta Radiol 31:389–394.
20. Hoiseth A, Reikeras O, Fonstelien E. 1989. Lack of correlation between femoral neck anteversion and acetabular orientation. Radiography and computed tomography in cadavers and in vivo. Acta Orthop Scand 60:93–96.
21. Reynolds D, Lucas J, Klaue K. 1999. Retroversion of the acetabulum. A cause of hip pain. J Bone Joint Surg Br 81:281–288.
22. Meunier P, Lefevre C, Le Saout J, et al. 1987. [A simple method for measuring anteversion of the acetabulum from a frontal radiograph of the hip]. J Radiol 68:799–804.
23. McKibbin B. 1970. Anatomical factors in the stability of the hip joint in the newborn. J Bone Joint Surg Br 52:148–159.
24. Visser JD, Jonkers A, Hillen B. 1982. Hip joint measurements with computerized tomography. J Pediatr Orthop 2:143–146.

25. Ganz R, Parvizi J, Beck M, et al. 2003. Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res 417:112–120.
26. Landis JR, Koch GG. 1977. The measurement of observer agreement for categorical data. Biometrics 33:159–174.
27. Giori NJ, Trousdale RT. 2003. Acetabular retroversion is associated with osteoarthritis of the hip. Clin Orthop Relat Res 417:263–269.
28. Jacquemier M, Bollini G, Jouve JL, et al. 1995. [Acetabular anteversion in congenital luxation of the hip]. Rev Chir Orthop Reparatrice Appar Mot 80:22–27.
29. Stanitski CL, Woo R, Stanitski DF. 1996. Acetabular version in slipped capital femoral epiphysis: a prospective study. J Pediatr Orthop B 5:77–79.
30. Kim SS, Frick SL, Wenger DR. 1999. Anteversion of the acetabulum in developmental dysplasia of the hip: analysis with computed tomography. J Pediatr Orthop 19:438–442.
31. Harris WH. 1986. Etiology of osteoarthritis of the hip. Clin Orthop Relat Res 213:20–33.
32. Frot B, Duparc J. 1973. [Method for radiologic measurement of acetabulum anteversion, inclinaison and depth in the erect man]. Rev Rhum Mal Osteoartic 40:613–616.
33. Wientroub S, Boyde A, Chrispin AR, et al. 1981. The use of stereophotogrammetry to measure acetabular and femoral anteversion. J Bone Joint Surg Br 63-B:209–213.