New Radiographic Index for Evaluating Acetabular Version

Hiroshi Koyama MD, Hironobu Hoshino MD, PhD,
Daisuke Suzuki MD, Shoichi Nishikino MD,
Yukihiro Matsuyama MD, PhD

Received: 28 June 2012 / Accepted: 10 December 2012 / Published online: 22 December 2012
© The Association of Bone and Joint Surgeons® 2012

Abstract

Background Several qualitative radiographic signs have been described to assess acetabular retroversion. However, quantitative assessment of acetabular version would be useful for more rigorous research purposes and perhaps to diagnose and treat hip disorders.

Questions/purposes We developed a new quantitative index for acetabular version (p/a ratio). We determined the average p/a, compared it with previous radiographic signs for acetabular retroversion, and evaluated its relationship with anatomic acetabular version.

Methods We calculated the p/a ratio by measuring p (distance from acetabular articular surface to posterior wall) and a (distance from acetabular articular surface to anterior wall) on plain hip AP radiographs and dividing p

by a. P and a were assessed on the perpendicular bisector of the line between the teardrop and the lateral edge of the acetabulum. Using 185 hip radiographs from patients with suspected idiopathic osteonecrosis, we measured p/a and compared it with previous qualitative signs for acetabular retroversion. Using 62 hip CT images from patients with no osteoarthritis, we measured the anatomic anteversion at the height of the central femoral head and investigated its relationship with p/a.

Results The average p/a was 2.05 in 185 hips, and most patients with a p/a greater than 2.05 had a negative qualitative retroversion sign. A correlation was observed between central anteversion and p/a ($r = 0.84$).

Conclusions We believe this ratio can be considered a simple quantitative parameter to assess acetabular version using plain AP radiographs.

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

Each author certifies that he or she, or a member of his or her immediate family, has no funding or commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request.

Clinical Orthopaedics and Related Research neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA approval status, of any drug or device before clinical use.

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.

H. Koyama (✉), H. Hoshino, D. Suzuki, S. Nishikino,
Y. Matsuyama
Department of Orthopaedic Surgery, Hamamatsu University
School of Medicine, 1-20-1 Handayama, Higashi-Ku,
Hamamatsu 431-3192, Japan
e-mail: hiromania27@hotmail.com

Introduction

Acetabular retroversion reportedly is related to pincer-type femoroacetabular impingement (FAI) and development of osteoarthritis of the hip [5, 6, 22]. A retroverted acetabulum with excessive anterior coverage increases the risk for impingement of the anterolateral femoral neck against the acetabular rim. The prevalence of radiographic acetabular retroversion was 20% among patients with idiopathic hip osteoarthritis, compared with 5% among the general population, and the appearance of the retroversion was created by deficiency of the posterior wall of the acetabulum [3, 6]. To identify the presence of acetabular retroversion, some authors have proposed radiographic signs, such as the

crossover sign (COS) [22], the posterior wall sign (PWS) [22], and the prominence of the ischial spine sign (PRISS) [10]. However, these signs do not assess acetabular version quantitatively. Quantitative assessment of acetabular version would be useful for more rigorous research study designs and might prove useful to diagnose and treat hip disorders. Some authors reported that excessive anterolateral rotation of the acetabulum caused pincer-type FAI or deficiency of the posterior acetabular coverage in an acetabular reorientation procedure [18, 25, 26]. An accurate and reliable quantitative assessment could determine the amount of acetabular rotation preoperatively and intraoperatively. The postoperative clinical symptoms might depend on the amount of acetabular version.

To quantify acetabular version, CT with an axial plane is commonly used [1, 8, 9, 21, 30]. However, as with conventional radiographs, CT is not used repetitively because of higher doses of radiation and higher cost. Conventional radiographs remain the essential, easiest, fastest, and most cost-effective imaging modality. Jamali et al. [9] introduced a quantitative method for measuring acetabular version on AP radiographs. They showed a highly linear correlation between their method and anatomic acetabular anteversion. However, their method for measuring acetabular version was too elaborate to be used easily. We propose a new radiographic index for quantitative evaluation of acetabular version, the p/a ratio (p = distance from acetabular articular surface to posterior wall and a = distance from acetabular articular surface to anterior wall).

In this study we (1) determined the average and SD of p/a, (2) compared p/a with previous radiographic signs for acetabular retroversion, (3) examined the intraobserver and interobserver variabilities of p/a, and (4) evaluated the relationship between p/a and anatomic acetabular version (anteversion).

Patients and Methods

To establish the index, we reviewed the AP radiographs of 123 patients (185 hips) with suspected idiopathic osteonecrosis of the femoral head from 2002 to 2010. During the study period, we treated a total of 192 hips with idiopathic osteonecrosis. The inclusion criteria were (1) no hip complaints and (2) noncollapsed osteonecrosis of the femoral head (Stages 1–2 [27]) because we presumed the morphologic features of the acetabulum were not influenced by the pathologic changes of osteonecrosis. We excluded seven hips because the edge of acetabular walls could not be recognized owing to sclerotic change of the femoral head by osteonecrosis. No patient had a history of previous hip disorders or complaints. There were 56 male patients and 67 female patients, with an average age of 49 years (range, 17–81 years). To examine the intraobserver and interobserver

variabilities of the index, 60 randomized, blinded AP hip radiographs were chosen from those of the 185 hips by the random numbers table in Excel (Microsoft Excel; Microsoft Corp, Redmond, WA, USA).

To compare the index with the anatomic acetabular anteversion, we reviewed the CT scans of 49 patients (62 hips) who had CT images taken for their treatment from 2010 to 2011. During the study time, we treated a total of 65 patients with various hip problems who had radiographs and CT scans. The inclusion criteria were (1) no complaints of hip disorders and (2) no previous history of hip disorders. We excluded hips in which we could not recognize the edge of the acetabular walls owing to sclerotic change of the femoral head by osteonecrosis or osteoarthritic change. There were 13 male patients and 36 female patients, with an average age of 58 years (range, 17–84 years). None of the acetabula had osteoarthritic changes of Grades 1 to 3 according to Tönnis grade [29]. Among the 62 hips, there were 11 hips in eight patients with idiopathic osteonecrosis of the femoral head (Stages 1–3a [27]), nine hips in nine patients with developmental dysplasia (defined by Sharp angle [23] greater than 45° or lateral center-edge angle less than 20° [31], one hip was the contralateral hip of the patient with a labral tear), 15 contralateral hips in 15 patients with osteoarthritis, eight hips in six patients without traumatic acetabular changes of fracture or dislocation, one hip in one patient with a labral tear, and 18 hips in 11 patients scheduled for TKAs (CT scans of the hip were obtained to establish the femoral functional axis for planning the TKA). The 11 hips with osteonecrosis evaluated by CT were not included in the 185 hips used in the above radiographic investigation.

We calculated p/a by measuring p and a on plain AP radiographs of the hip and dividing p by a (Fig. 1A). Both

Fig. 1A–B (A) Our index, the p/a ratio, is calculated by dividing p (distance from the acetabular articular surface to the edge of the posterior wall) by a (distance from the acetabular articular surface to the edge of the anterior wall). Both are assessed on the perpendicular bisector of the line between the most inferior point of the teardrop and the lateral edge of the acetabulum. (B) When this perpendicular bisector is located at the acetabular fossa, the acetabular articular surface is used to describe a perfect circle while the acetabular fossa is ignored. The intersection point between the circle line and the bisector line is used as the proximal point of p and a .

were assessed on the perpendicular bisector of a line between the most inferior point of the teardrop and the lateral edge of the acetabulum. The perpendicular bisector usually crosses over the acetabular articular surface, but when this perpendicular bisector was located at the acetabular fossa the acetabular articular surface was used to describe a perfect circle while the acetabular fossa was ignored. The intersection point between the circle line and the bisector line was used as the proximal point of p and a (Fig. 1B). As p becomes longer compared with a, the acetabular anteversion becomes greater and p/a becomes larger. A larger p/a indicates acetabular anteversion and a smaller p/a indicates acetabular retroversion (Fig. 1).

Radiographs were taken with a tube-to-film distance of 120 cm by a computed digital radiographic system. The patients were positioned supine with their frontal anatomic plane parallel to the film. The central beam was directed to the upper point of the pubic symphysis. The radiographic evaluation was performed on the monitor using the measurement tool in the digital radiographic system. In the cases in which the edge of the acetabular wall was initially unclear, it always could be observed clearly by changing the brightness or sharpness of the images on the monitor.

To compare p/a with previous radiographic signs for acetabular retroversion [10, 22], we chose three signs: the COS, the PWS, and the PRISS (Fig. 2). Compared with a normal hip (Fig. 2A), the COS was positive when the contour of the anterior acetabular rim was located lateral to the corresponding point of the posterior rim (Fig. 2B) [22]. The PWS was positive when the outline of the posterior rim was more medial than the center of the femoral head, indicating relatively small posterior coverage (Fig. 2C) [22]. The PRISS focused on the presence of the ischial spine projection into the pelvic foramen, indicating a retroverted acetabulum [10] (Fig. 2D). We measured these signs on the 185 AP hip radiographs and compared them with p/a.

The interobserver reliability and intraobserver reproducibility of p/a was investigated in 60 randomized, blinded AP hip radiographs. For intraobserver reliability, one hip surgeon (HK) measured each radiograph three times, with an interval of at least 1 month between measurements. For interobserver reliability, three hip surgeons (HK, HH, SN), blinded to the clinical data and details of radiology reports, measured each radiograph. The measurements were compared using the intraclass correlation coefficient (ICC).

CT images were taken with the patient in the supine position (AquilionTM TS; Toshiba Medical Systems, Tochigi, Japan). Continuous 1-mm slices with the axial section through both anterior superior iliac spines (ASIS), hips to femoral condyles, were obtained in the helical

Fig. 2A–D (A) A normal hip is shown. (B) The COS is defined as positive when the contour of the anterior acetabular rim is located laterally to the corresponding point of the posterior rim. (C) The PWS is defined as positive when the outline of the posterior rim is more medial than the center of the femoral head, indicating a relatively small posterior coverage. (D) The PRISS focuses on the presence of the ischial spine projection into the pelvic foramen, indicating a retroverted acetabulum.

mode. Analysis of the CT images was performed using software for THA preoperative three-dimensional (3-D) planning (Zed Hip; LEXI Corp, Ltd, Tokyo, Japan). By using DICOM data from CT images, this software can create a virtual 3-D bone model and display multiplanar reconstruction (MPR) images and digitally reconstructed radiographic images (DRR), substituting for plain radiographs (Fig. 3). This software can be used not only for THA planning but also for various measurements around the hip. After manual input of the reference points (anatomic landmarks, such as the ASIS, pubic symphysis), a voluntary plane is defined as the reference plane for the measurement. The first visual bone point is as a reference. (For example, we recognized the first visual small bone point as the ASIS in the coronal plane of the CT image, when we viewed the coronal plane from the anterior to posterior direction.) Therefore, the measurement error was considered within 1 mm theoretically. In this CT image investigation, we defined the tabletop plane (TTP), which is parallel to the tabletop and contains both ASIS (= functional pelvic plane [20]), as a reference plane.

Fig. 3 The Zed Hip software can create a virtual 3-D model and display MPR and DRR images to substitute for plain radiographs. Acetabular anteversion was measured at three transverse planes on the plane perpendicular to the TTP: central anteversion (AV), AV1, and AV2). The p/a was measured on coronal images on the TPP, using the DRR.

Using 62 hip CT images, we measured p/a on precise DRR coronal images of the software in the TTP. Zed Hip also was used to measure anatomic acetabular anteversion on the precise MPR axial image in the TTP. Anteversion was measured at three different transverse planes on MPR axial images in the TTP. We divided the upper part of the femoral head into three equal parts and then measured central, caudal (AV1), and cranial (AV2) anteversion (Fig. 3). Central anteversion was at the height of the center of the femoral head. To determine which anteversion on a transverse section influenced p/a, we investigated the relationship between p/a and each of the three anteversion measures (central anteversion, AV1, and AV2).

The data are expressed as mean $\pm$ SD. We determined the differences of the average p/a between the positive group and the negative group of each qualitative radiographic sign for acetabular retroversion using Mann-Whitney U tests. We determined the differences in proportions of hips with a positive (or negative) qualitative retroversion sign between the group with greater and group with less than the average p/a using the chi-square test.

Results

The average p/a calculated from the 185 plain hip radiographs was 2.05 ± 0.56 (range, 1.04–4.16).

The average p/a in the COS-positive group (36 hips) was smaller ($p < 0.001$) than that in the COS-negative group

(1.63 versus 2.15, respectively). The average p/a in the PWS-positive group (47 hips) was smaller ($p < 0.001$) than that in the PWS-negative (1.68 versus 2.18, respectively). The average p/a in the PRISS-positive group (37 hips) was smaller ($p < 0.001$) than that in the PRISS-negative group (1.62 versus 2.16, respectively). In the hips with a p/a greater than 2.05 (average p/a of the 185 hips), fewer ($p < 0.001$) hips had a retroversion sign than did hips with a p/a less than 2.05. In contrast to hips with a p/a greater than 2.05, the hips with a p/a less than 2.05, we found a mix of hips with positive and negative retroversion signs (Fig. 4).

The ICC of the interobserver reliability for p/a was 0.67 (95% CI, 0.55–0.78). The ICC of the intraobserver reproducibility for p/a was 0.71 (95% CI, 0.60–0.80).

Among the 62 CT hip images, p/a correlated with each measure of anteversion (central anteversion: $r = 0.84$, $p < 0.001$ [Fig. 5A]; AV1: $r = 0.80$, $p < 0.001$ [Fig. 5B]; AV2: $r = 0.74$, $p < 0.001$ [Fig. 5C]). In particular, p/a correlated with the central anteversion, and the regression formula was central anteversion = $9.6 \times \text{p/a} - 0.3^\circ$ with a regression analysis (Fig. 5A).

Discussion

Compared with lateral coverage of the acetabulum, acetabular version or torsion has not been focused on morphologic features of the pelvis as a cause of osteoarthritis of the hip. Acetabular retroversion has been reported

Fig. 4 A graph shows the frequency distribution of the retroversion signs. Fewer hips with retroversion signs had a p/a greater than 2.05 ($p < 0.001$), which was the average of the 185 hip radiographs. However, in the hips with a p/a less than 2.05, hips with positive and negative retroversion signs were intermixed.

Fig. 5A–C The graphs show the relationships between p/a and (A) central anteversion, (B) AV1, and (C) AV2. A correlation between the p/a and each anteversion was observed (central anteversion: $r = 0.84$, $p < 0.001$; AV1: $r = 0.80$, $p < 0.001$; AV2: $r = 0.74$, $p < 0.001$). Using regression analysis, we found the following regression formula for p/a and central anteversion: central anteversion = $9.6 \times p/a - 0.3^\circ$.

[5, 6, 22] to cause pincer-type FAI and development of osteoarthritis of the hip. To clarify these disorders related to acetabular retroversion, some radiographic indices have been reported [10, 22]. However, these signs do not assess acetabular version quantitatively. We therefore developed a new quantitative index for acetabular version called the p/a ratio. We (1) determined the average and SD of p/a, (2) compared p/a with previous radiographic signs for acetabular retroversion, (3) examined the intraobserver and interobserver variabilities of p/a, and (4) evaluated the relationship between p/a and anatomic acetabular version.

Readers should be aware of limitations to our study. First, we did not validate the accuracy of the measurement on DRR images using the software. A radiograph was

based on cone beam projection of x-ray source, while DRR image was based on x-ray-traced projection. Although the quality and appearance of a DRR image are theoretically different from those of film or digital radiographs, use of the vertical image projections provided precise definition of true AP images. Furthermore, p/a is not a distance but a ratio. Therefore, we believe our result was less influenced by the difference between both images. Second, the plane in which the distances for p/a are measured is different from the plane in which anatomic acetabular anteversion is measured [11]. Some errors derived from the difference between both planes are unavoidable. However, considering the definition for anteversion of the acetabular cup in THA [13, 17], p/a indicates radiographic anteversion and

central anteversion indicates anatomic anteversion. Therefore, it had been expected p/a would correlate with central anteversion. Third, developmentally dysplastic hips were included in this investigation using CT images. Although it generally is believed that anteversion of the acetabulum is associated with developmental dysplasia of the hip, there has been controversy regarding whether this actually is seen. Several studies have shown some dysplastic hips tend to be retroverted [4, 14, 15, 19]. It remains unclear whether developmentally dysplastic hips should be discussed separately.

Some quantitative radiographic indices for acetabular retroversion have been reported [7, 9, 19, 24, 30]. Nehme et al. [19], focusing on the crossover point, observed the anterior wall crossing the posterior wall, and calculated a ratio of the distance between the acetabular lateral edge and the crossover point divided by the total length of the acetabulum. This ratio was easily measured, but it depended on the morphologic features of the anterolateral acetabular rim because of use of the crossover point. It does not show retroversion of the entire acetabulum, but retroversion of the focal (more cranial) acetabulum. Jamali et al. [9] introduced a quantitative method for measuring acetabular version on AP radiographs. They showed one could represent central anteversion using the centers of both acetabula, the acetabular rim, and the contour of the acetabular diameter. Values obtained by their method and central anteversion showed a highly linear correlation ($r = 0.799$, $p = 0.01$). However, their method for measuring acetabular version was too complex and elaborate to be used easily. Our new quantitative index, the p/a ratio, for acetabular version uses distances from the acetabular articular surface to the edge of the anterior and posterior walls at the maximum diameter of the acetabulum on an AP radiograph. Our index is simpler to measure and we believe more intuitively related to acetabular version compared with the method of Jamali et al. [9]. The p/a has the advantage of being measureable on radiographs, which are inexpensive and readily available. We found the average p/a was 2.05 in 185 healthy acetabula, indicating the distance p to the posterior wall is approximately twice as long as the distance a to the anterior wall in normal hips. However, another investigation will be required to establish the normal range and clinical importance of p/a.

Werner et al. [30] reported the relationship between the qualitative signs (COS, PWS, and PRISS) and the quantitative index (COS ratio) for acetabular retroversion. All qualitative signs were associated with each other and with the COS ratio. Similarly, the average p/a in the positive qualitative sign group was smaller than that in the negative group in our study. Considering the relationship between p/a and the qualitative signs, fewer hips with the retroversion sign had a p/a greater than 2.05, the average p/a in 185 hip

radiographs. This result means a p/a greater than 2.05 might indicate that the acetabulum is not retroverted, even in cases where the presence of the qualitative retroversion sign is difficult to judge owing to unclear images. However, hips with and without retroversion signs were intermixed with p/a values less than 2.05. It might be impossible to determine the presence of qualitative signs if the p/a value in the acetabulum is less than 2.05.

In our study, the ICC of the interobserver reliability for p/a was 0.67 and that of the intraobserver reproducibility was 0.71. Some authors have reported on reliability and agreement of measures used in radiographic evaluation of the adult hip [2, 9, 16, 28]. In these studies, the interobserver reliability was lower than the intraobserver reproducibility, and the ICC/kappa values for the parameters were various. We believe the interobserver and interobserver reliability (ICC values) of p/a were reasonable, similar to those of the COS of Tannast et al. [28] (interobserver: kappa = 0.60; intraobserver: kappa = 0.73–0.77).

We found a correlation between p/a and central anteversion. Acetabular anteversion generally became smaller cranially [9, 12, 21, 22]. Reynolds et al. [22] described the acetabular mouth opening as spiraling gradually into increasing anteversion distal to the roof edge in normal hips. Jamali et al. [9] investigated anteversion at three different transverse planes of the acetabulum (cranial, central, and caudal). The anteversion was cranially much smaller than it was centrally, and a linear correlation was found between central and cranial anteversion ($r = 0.81$, $p = 0.01$). The value of anteversion depends on the transverse plane of the acetabulum to be measured. A stronger correlation was observed between p/a and central anteversion, compared with those between p/a and AV1 or AV2. We assume this is because these two values are measured in the same largest dimension of the acetabulum.

The p/a ratio is a simple and easily applicable quantitative method to assess acetabular version using only a plain AP radiograph. The average p/a was 2.05 in normal hips, and most hips with a p/a greater than 2.05 had negative qualitative retroversion signs. Furthermore, p/a on the coronal plane correlated with central anatomic anteversion on the axial plane.

Acknowledgments We thank Daisuke Togawa PhD for assistance with preparation of this manuscript.

References

1. Anda S, Svendsen S, Grontvedt T, Benum P. Pelvic inclination and spatial orientation of the acetabulum: a radiographic, computed tomographic and clinical investigation. *Acta Radiol.* 1990;31:389–394.

2. Clohisy JC, Carlisle JC, Trousdale R, Kim YJ, Beaulé PE, Morgan P, Steger-May K, Schoeneker PL, Millis M. Radiographic evaluation of the hip has limited reliability. *Clin Orthop Relat Res.* 2009;467:666–675.
3. Ezoe M, Naito M, Inoue T. The prevalence of acetabular retroversion among various disorders of the hip. *J Bone Joint Surg Am.* 2006;88:372–379.
4. Fujii M, Nakashima Y, Yamamoto T, Mawatari T, Motomura G, Matsushita A, Matsuda S, Jingushi S, Iwamoto Y. Acetabular retroversion in developmental dysplasia of the hip. *J Bone Joint Surg Am.* 2010;92:895–903.
5. Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res.* 2003;417:112–120.
6. Giori NJ, Trousdale RT. Acetabular retroversion is associated with osteoarthritis of the hip. *Clin Orthop Relat Res.* 2003;417:263–269.
7. Hansen BJ, Harris MD, Anderson LA, Peters CL, Weiss JA, Anderson AE. Correlation between radiographic measures of acetabular morphology with 3D femoral head coverage in patients with acetabular retroversion. *Acta Orthop.* 2012;83:233–239.
8. Hapa O, Yüksel HY, Muratlı HH, Akşahin E, Gülçek S, Çelebi L, Biçimoğlu A. Axial plane coverage and torsion measurements in primary osteoarthritis of the hip with good frontal plane coverage and spherical femoral head. *Arch Orthop Trauma Surg.* 2010;130:1305–1310.
9. Jamali AA, Mladenov K, Meyer DC, Martinez A, Beck M, Ganz R, Leunig M. Anteroposterior pelvic radiographs to assess acetabular retroversion: high validity of the “cross-over-sign.” *J Orthop Res.* 2007;25:758–765.
10. Kalberer F, Sierra RJ, Madan SS, Ganz R, Leunig M. Ischial spine projection into the pelvis: a new sign for acetabular retroversion. *Clin Orthop Relat Res.* 2008;466:677–683.
11. Klaue K, Wallin A, Ganz R. CT evaluation of coverage and congruency of the hip prior to osteotomy. *Clin Orthop Relat Res.* 1988;232:15–25.
12. Köhlein W, Ganz R, Impellizzeri FM, Leunig M. Acetabular morphology: implications for joint-preserving surgery. *Clin Orthop Relat Res.* 2009;467:682–691.
13. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am.* 1978;60:217–220.
14. Li PL, Ganz R. Morphologic features of congenital acetabular dysplasia: one in six is retroverted. *Clin Orthop Relat Res.* 2003;416:245–253.
15. Mast JW, Brunner RL, Zebrack J. Recognizing acetabular version in the radiographic presentation of hip dysplasia. *Clin Orthop Relat Res.* 2004;418:48–53.
16. Mast NH, Impellizzeri F, Keller S, Leunig M. Reliability and agreement of measures used in radiographic evaluation of the adult hip. *Clin Orthop Relat Res.* 2011;469:188–199.
17. Murray DW. The definition and measurement of acetabular orientation. *J Bone Joint Surg Br.* 1993;75:228–232.
18. Myers SR, Eijer H, Ganz R. Anterior femoroacetabular impingement after periacetabular osteotomy. *Clin Orthop Relat Res.* 1999;363:93–99.
19. Nehme A, Trousdale R, Tannous Z, Maalouf G, Puget J, Telmont N. Developmental dysplasia of the hip: is acetabular anteversion a crucial factor? *Orthop Traumatol Surg Res.* 2009;95:511–519.
20. Nishihara S, Sugano N, Nishii T, Ohzono K, Yoshikawa H. Measurement of pelvic flexion angle using three-dimensional computed tomography. *Clin Orthop Relat Res.* 2003;411:140–151.
21. Perreira AC, Hunter JC, Laird T, Jamali AA. Multilevel measurement of acetabular version using 3-D CT-generated models: implications for hip preservation surgery. *Clin Orthop Relat Res.* 2011;469:552–561.
22. Reynolds D, Lucas J, Klaue K. Retroversion of the acetabulum: a cause of hip pain. *J Bone Joint Surg Br.* 1999;81:281–288.
23. Sharp IK. Acetabular dysplasia: the acetabular angle. *J Bone Joint Surg Br.* 1961;43:268–272.
24. 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.
25. Siebenrock KA, Schoeniger R, Ganz R. Anterior femoroacetabular impingement due to acetabular retroversion: treatment with periacetabular osteotomy. *J Bone Joint Surg Am.* 2003;85:278–286.
26. Steppacher SD, Tannast M, Ganz R, Siebenrock KA. Mean 20-year follow up of Bernese periacetabular osteotomy. *Clin Orthop Relat Res.* 2008;466:1633–1644.
27. Sugano N, Kubo T, Takaoka K, Ohzono K, Hotokebuchi T, Matsumoto T, Igarashi H, Ninomiya S. Diagnostic criteria for non-traumatic osteonecrosis of the femoral head: a multicentre study. *J Bone Joint Surg Br.* 1999;81:590–595.
28. 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.
29. Tönnes G. *Congenital Dysplasia and Dislocation of the Hip in Children and Adults.* New York, NY: Springer; 1987.
30. Werner CM, Copeland CE, Ruckstuhl T, Stromberg J, Turen CH, Kalberer F, Zingg PO. Radiographic markers of acetabular retroversion: correlation of the cross-over sign, ischial spine sign and posterior wall sign. *Acta Orthop Belg.* 2010;76:166–173.
31. Wiberg G. Studies on dysplastic acetabular and congenital subluxation of the hip joint: with special reference to the complication of osteoarthritis. *Acta Chir Scand.* 1939;83(suppl 58):7–83.