Is Vertical-center-anterior Angle Equivalent to Anterior Coverage of the Hip?

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Received: 11 September 2008 / Accepted: 9 March 2009 / Published online: 26 March 2009
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Abstract We investigated whether the vertical-center-anterior (VCA) angle measured on the false-profile view of the hip represents true anterior coverage by computer simulation using three-dimensional (3-D) computed tomography (CT) in 100 hips without osteoarthritic changes. True anterior coverage angle on the sagittal plane was measured in the pelvic coordinate system. Two types of VCA angle were measured on the digital reconstructed radiographs: the anterior point of the VCA angle was defined as the foremost aspect of the acetabulum, denoted VCA-1, whereas the anterior edge of the dense shadow of the subchondral bone of the acetabulum was defined as VCA-2. In the normal hips, VCA-1 was consistent with anterior coverage angle ($r = 0.88$, Spearman rank test), whereas VCA-2 underestimated the anterior coverage ($r = 0.72$). In the dysplastic hips, VCA-2 did not always indicate true anterior coverage ($r = 0.64$), whereas VCA-1 overestimated the anterior coverage ($r = 0.002$). Although VCA-1 in normal hips shows true anterior coverage, the VCA angle does not

indicate true anterior coverage in dysplastic hips, and VCA angle measurement in dysplastic hips should be used carefully.

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

Introduction

For evaluation of dysplastic hips, lateral coverage is commonly estimated as the Sharp angle [13] or Wiberg's center-edge (CE) angle [15] on plain anteroposterior (AP) radiographs. A CE angle of the hip smaller than 20° is regarded as acetabular dysplasia [15]. Although dysplastic hips with a CE less than 20° or borderline hips with a CE of 20° to 25° are likely to have small anterior coverage, the relationship between the lateral coverage and the anterior coverage is unknown. Lequesne and de Seze [9] reported anterior coverage of the hip can be considered to be represented by the anterior CE angle (vertical-center-anterior margin [VCA]; Fig. 1) on false-profile radiographic views.

The VCA angle has been reported to be useful for geometric evaluation of anterior coverage in normal hips with a CE greater than 25° [2, 4, 12] and radiographic evaluation of early osteoarthritic changes at the anterior portion in patients with osteoarthritis of the hip. However, the VCA angle has not been reported to be useful for quantitative evaluation of anterior coverage in dysplastic hips or borderline hips. Moreover, there are no data regarding whether the VCA angle indicates the anterior coverage on the sagittal plane in normal hips or dysplastic hips, most likely for the following two reasons. First, it is difficult to define and investigate the true anterior coverage on the sagittal plane by radiographs, ie, two-dimensional

One of the authors (KS) has received funding from the Japanese Science and Technology Agency.

Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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projected images. Second, the false-profile radiographs are taken in the standing position at an angle of 65° between the pelvis and the film, and rotation of the pelvis when taking the false-profile view is difficult to establish and may differ among radiographs [10]. To solve these two issues, computer simulation to model the pelvis and femur

Fig. 1 A diagram illustrates the VCA angle on the false-profile view of the hip. The angle is composed of a vertical line through the center of the femoral head (Line VC) and a second line through the center of the hip and the anterior point of the acetabulum (Line CA).

Fig. 2 A flowchart illustrates the methodologic steps used in the study.

Step 1: The anatomic pelvis axis is settled by clicking manually the right and left anterior superior iliac spine and posterior superior iliac spine.

Step 2: The acetabular plane matrix is produced automatically by plotting 25 points around the acetabular rim.

Step 3: The femoral head is sliced using the acetabular plane matrix.

Step 4: The femoral head sphere is produced automatically by plotting 100 points on the femoral head surface. The center of the femoral head sphere is defined as the center of the femoral head.

Step 5: Lateral center-edge angle and Anterior center-edge angle are measured.

Step 6: VCA-1 and VCA-2 are measured on the digital reconstructed radiographs.

can be used. Computer simulation enables measurement of the true anterior coverage on the sagittal plane (lateral aspect of the hip) and rotation of the pelvis position exactly for the VCA angle measurement. If measurement of the VCA angle on the false-profile view indicates the anterior coverage quantitatively, it is useful for investigating the natural history of osteoarthritis of the hip on the basis of anterior coverage of the hip and for preoperative planning and postoperative results of acetabular osteotomy in dysplastic hips. In addition, it may be useful for diagnosis of excessive anterior coverage, as with anterior femoroacetabular impingement [5], in nondysplastic hips. To date, it has not been proven whether the VCA angle on the false-profile view is equivalent to the anterior coverage. Until this relationship is clarified, measurement of the VCA angle should be used carefully in evaluating anterior coverage.

The purpose of this study was to investigate this relationship. We asked whether: (1) lateral and anterior coverage in hips can be correlated; (2) the VCA angle on the false-profile view is equivalent to true or actual anterior coverage as determined from computer simulation using 3-D CT data; and (3) there is a difference in this relationship between normal and dysplastic hips.

Materials and Methods

From among the patients who presented with a chief complaint of symptoms around the hips between January 2005 and January 2008, we enrolled 50 consecutive female

patients (100 consecutive hips) without osteoarthritic changes (joint space narrowing, osteophyte formation, cyst formation, or subluxation) on plain radiographs in the study. Because osteoarthritis of the hip secondary to hip dysplasia occurs in approximately 90% of all cases of hip osteoarthritis in Japan and because hip dysplasia is common, especially in females [14], we selected female patients only. Our institution approved the human protocol for this investigation and all investigations were conducted in conformity with ethical principles of research.

We obtained axial images of the pelvis and femora with a CT scanner (HiSpeed Dx/I; GE Medical Systems, Milwaukee, WI). Patients were placed on the table with the femoral shaft axis parallel to the direction of the scanning table movement. The slice thickness and the pitch were 1 mm. The CT imaging protocol produced images of 1-mm slices from the top of the iliacus to the ischial process, 5-mm slices from the ischial process to the lesser trochanter level, and 5-mm slices for the femoral condyles. We recorded all CT image data as DICOM format data. We reconstructed 3-D pelvis and femur models from DICOM files using original computer software.

The pelvic coordinate system was defined and angles were measured. The anatomic axis was settled according to the definition of the joint coordinate system for the pelvis proposed by the International Society of Biomechanics [16], because this system generally is recommended in biomechanical studies. Namely, the Z-axis was defined as the line parallel to a line connecting the right and left anterior-superior iliac spines (ASIS) and pointing to the right. The X-axis was defined as the line parallel to a line lying in the plane defined by the two ASISs and the midpoint of the two posterior-superior iliac spines (PSISs), orthogonal to the Z-axis, and pointing anteriorly. The Y-axis was defined as the line perpendicular to X and Z pointing cranially. The right and left ASIS and PSIS were digitized manually, by clicking them with a computer mouse.

Around the acetabular rim, we plotted 25 edge points by clicking them with a computer mouse, and the acetabular plane matrix, which is the best-fit opening plane of the acetabulum, was produced automatically on a computer monitor using original computer software (Fig. 2). The standard deviation (SD) of the fit of a plane to each femoral head surface was 0.79 mm (SD, 0.3). This represents the mean distances between the fitted plane and the corresponding points on the acetabular rim for all the points of the 3-D surface models. A 3-D femoral model was sliced using this acetabular plane matrix, and the femoral head surface model in the acetabulum was produced automatically. The 100 points then were plotted by clicking them with a computer mouse on this femoral head surface, and a femoral head sphere was produced automatically using

Fig. 3A–B The true lateral coverage angle (lateral CE angle) was composed of the Y-axis and a second line through Point C and the acetabular edge point on the Y-Z plane (coronal plane). The lateral CE angle was measured on the pelvic coordinate system proposed by the International Society of Biomechanics [16] in (A) normal and (B) dysplastic hips.

original computer software (Fig. 2). The SD of the fit of a sphere to each femoral head surface was 0.75 mm (SD, 0.22). This represents the mean distances between the fitted sphere and the corresponding points on the femoral head

surface for all the points of the 3-D surface models. The SDs of the acetabular plane and the femoral head sphere were less than 0.8 mm, which we considered acceptable. The center of this femoral head sphere was defined as the center of the femoral head (Point C), and the origin of the axis of the pelvis was coincident with the center of the femoral head.

We measured the true lateral coverage angle (lateral CE angle) of the 3-D pelvis and femur models. The angle was composed of the Y-axis and a second line through Point C and the acetabular edge point on the Y-Z plane (coronal plane) in all hips (Fig. 3). A lateral CE angle less than 20° was defined as dysplasia [14]. In all, we classified 54 hips in 29 females in the dysplasia group, whereas the remaining 46 hips in 24 females were normal. There were no major differences in age or body mass index between the dysplasia group and the normal group (Table 1).

We measured the true anterior coverage angle (anterior CE angle) of the 3-D pelvis and femur models. The angle was composed of the Y-axis and a second line through Point C and the acetabular edge point on the X-Y plane (sagittal plane) in the normal and dysplastic hips (Fig. 4).

The VCA angle was measured on the digitally reconstructed radiographs when the 3-D pelvis model was rotated 65° around the Y-axis using the computer simulation in the normal and dysplastic hips (Fig. 5). The angle was composed of the Y-axis and a second line through Point C and the anterior point of the acetabulum (Point A). We measured two types of VCA angles on the digitally reconstructed radiographs using two different points: Point A1 was defined as the foremost aspect of the acetabulum [4] (VCA-1), and Point A2 was defined as the anterior edge of the dense shadow of the subchondral bone of the acetabulum [2, 9] (VCA-2). Two researchers (TS, KS) took two measurements of each hip, and intraobserver and interobserver errors for VCA-1 and VCA-2 were calculated using Spearman rank tests. For VCA-1, intraobserver errors were $r = 0.90$ ($p < 0.0001$) for TS and $r = 0.88$ ($p < 0.0001$) for KS; interobserver error was $r = 0.88$ ($p < 0.0001$). For VCA-2, intraobserver errors were

$r = 0.70$ ($p < 0.0001$) for TS and $r = 0.64$ ($p < 0.0001$) for KS; interobserver error was $r = 0.64$ ($p < 0.0001$).

We performed statistical analysis of outcome between groups using the nonparametric Mann-Whitney U test. The Spearman rank test was performed to identify a potential correlation between lateral CE angle and anterior CE angle and between anterior CE angle and VCA angle. A p value < 0.05 was considered statistically significant.

Results

The lateral CE angle showed strong correlation with the anterior CE angle ($r = 0.85$; $p < 0.0001$) (Table 1). The mean lateral CE angle ($p < 0.001$) and the anterior CE angle ($p < 0.0001$) were larger in the normal group than in the dysplasia group.

Although the VCA angle showed true anterior coverage in the normal hips, it did not always indicate true anterior coverage in the dysplastic hips. Although VCA-1 was consistent with the anterior CE angle in the normal group ($r = 0.88$; $p < 0.0001$), it did not show any correlation with the anterior CE angle in the dysplasia group ($r = 0.002$; $p = 0.2$). Although VCA-2 showed strong correlation with the anterior CE angle in the normal group ($r = 0.84$; $p < 0.0001$), it had weak correlation with the anterior CE angle in the dysplasia group ($r = 0.64$; $p < 0.0001$). The mean VCA-1 and VCA-2 were larger ($p < 0.001$) in the normal group than in the dysplasia group (Table 1).

VCA-1 was equivalent to the anterior CE angle in the normal hips, whereas VCA-1 overestimated the anterior coverage in the dysplastic hips, and VCA-2 was not always equivalent to the true anterior coverage on the sagittal plane in the dysplastic hips. Overestimation and underestimation of the anterior coverage were defined as a difference between the VCA angle and the anterior CE angle greater than 5° (Table 2). In the normal hips, 43 (93.5%) showed the differences between VCA-1 and the anterior CE angle were less than 5°, whereas VCA-2

Table 1. Patients' characteristics and measured angle

Parameter	Normal hips (n = 46 hips)	Dysplastic hips (n = 54 hips)	p Value*
Age (years)	39.3 ± 10.4 (15–59)	34.3 ± 9.9 (15–53)	0.06
Body mass index (kg/m ²)	21.2 ± 3.7 (14.9–34.5)	21.6 ± 2.2 (18.1–26.9)	0.10
Lateral CE angle (°)	29.8 ± 7.7 (20.0–53.0)	7.7 ± 7.6 (–13.0–19.5)	< 0.0001
Anterior CE angle (°)	37.7 ± 6.8 (24.3–53.6)	9.2 ± 17.5 (–59.6–36)	< 0.0001
VCA-1 (°)	37.6 ± 5.3 (28.1–51.4)	31.5 ± 8.2 (2.4–47.2)	0.0001
VCA-2 (°)	35.9 ± 5.9 (21.8–51.4)	6.3 ± 20.4 (–46.2–37.9)	< 0.0001

Values expressed as mean ± standard deviation, with range in parentheses; * Mann-Whitney U test; CE = center edge; VCA = vertical-center-anterior; VCA-1 = Point A1 is the foremost aspect of the acetabulum; VCA-2 = Point A1 is the anterior edge of the dense shadow of the subchondral bone of the acetabulum.

Fig. 4A–B The true anterior coverage angle (anterior CE angle) was composed of the Y-axis and a second line through Point C and the acetabular edge point on the X-Y plane (sagittal plane). The anterior CE angle was measured in (A) normal hips and (B) dysplastic hips.

underestimated anterior coverage in 12 hips (26.1%). In the dysplastic hips, VCA-1 overestimated anterior coverage in 45 hips (83.3%), whereas the difference between VCA-2 and the anterior CE angle was less than 5° in 15 hips (27.8%).

Discussion

We determined whether there was a correlation between the lateral and anterior coverage in hips, whether the VCA angle on the false-profile view was equivalent to true or actual anterior coverage as determined from computer simulation using 3-D CT data, and whether there was a difference in this relationship between normal and dysplastic hips.

This study has several limitations. First, the sample size was small, although this limitation was compensated for by computer simulation and by ensuring accurate digital measurements of angles. Second, the VCA angle originally was measured in a standing position [2, 9]. However, a cadaver study of measurement of the VCA angle using radiographs with the cadaver in a supine position [4] showed results similar to those of previous reports [2, 9]. In normal and dysplastic hips without osteoarthritic changes, the pelvic tilt at the standing position leads to 1° to 6° posterior tilting compared with the pelvic tilt in the supine position [1, 6–8, 11]. We do not believe these small postural changes influence the results of this study. Third, we did not compare the 3-D reconstructed surface models with actual false-profile radiographs but with digitally reconstructed radiographic images. Li and Ganz [10] noted rotation of the pelvis when taking the false-profile view is difficult to establish and may differ among radiographs. We performed well-controlled computer simulation and produced digitally reconstructed radiographic images using exact angle rotation. Nevertheless, additional study may be necessary to compare clinical radiographs in a standing position and true anterior coverage in 3-D CT reconstruction.

We found lateral coverage on the coronal plane strongly correlates with anterior coverage on the sagittal plane in normal and dysplastic hips as determined by 3-D quantitative evaluation. We also found, although the VCA angle indicated true anterior coverage in the normal hips, it did not show true anterior coverage in the dysplastic hips.

We defined and compared two types of anterior points (Point A) in the VCA angle measurement in our study. Crockarell et al. [4] defined Point A as “the foremost aspect of the acetabulum”; this fits our definition of Point A1. However, Chosa and Tajima [2] described Point A as “the anterior edge of the dense shadow of the subchondral bone slightly posterior to the anterior edge of the acetabulum,” which fits our definition of Point A2 and originally was indicated in the first report of the VCA angle by Lequesne and de Seze [9]. In our study, in the normal hips, VCA-1 represented true anterior coverage, whereas VCA-2 underestimated anterior coverage. Because previous studies have indicated a VCA angle greater than 20° is normal [3, 4, 9], in our study, VCA-1 and VCA-2 in the normal hips were similar.

Fig. 5A–D The VCA angle was measured on the digitally reconstructed radiographs when the 3-D pelvis model was rotated 65° around the Y-axis using computer simulation. Two types of VCA angles on the digitally reconstructed radiographs are shown: Point A1 of the VCA angle was defined as the foremost aspect of the acetabulum (VCA-1) and Point A2 was defined as the anterior edge of

the dense shadow of the subchondral bone of the acetabulum (VCA-2). (A) A 3-D pelvis model of the normal hip, (B) digitally reconstructed radiograph of the normal hip, (C) 3-D pelvis model of the dysplastic hip, and (D) digitally reconstructed radiograph of the dysplastic hip are shown.

Table 2. Overestimation and underestimation of the VCA and anterior CE angles

Parameter	Normal hips (n = 46 hips)			Dysplastic hips (n = 54 hips)		
	Overestimation > AntCE + 5°	AntCE ± 5°	Underestimation < AntCE – 5°	Overestimation > AntCE + 5°	AntCE ± 5°	Underestimation < AntCE – 5°
Number of hips estimated by VCA-1	2 (4.3%)	43 (93.5%)	1 (2.2%)	45 (83.3%)	9 (16.7%)	0
Number of hips estimated by VCA-2	1 (2.2%)	33 (71.7%)	12 (26.1%)	16 (29.6%)	15 (27.8%)	23 (42.6%)

VCA = vertical-center-anterior; CE = center edge; AntCE = true anterior coverage angle (anterior CE angle); VCA-1 = Point A1 is the foremost aspect of the acetabulum; VCA-2 = Point A1 is the anterior edge of the dense shadow of the subchondral bone of the acetabulum.

In dysplastic hips, although VCA-2 showed better correlation with the anterior CE angle than VCA-1, which overestimated the anterior coverage, the difference between VCA-2 and anterior coverage was less than 5° in only 27.8%, and VCA-2 was not always equivalent to the true anterior coverage on the sagittal plane. Although Point A1 and Point A2 were close or the same in normal hips, we had difficulty determining Point A2 on the false-profile view in the dysplastic hips, as Li and Ganz [10] noted, because the dysplastic hips showed various anterolateral acetabular deficiencies regarding the direction of the pelvis, ie, rotation angle of the pelvis around the Y-axis. This difficulty may result in inaccuracies when measuring the VCA angle in dysplastic hips.

Therefore, although the false-profile view is useful for radiographic assessment of early osteoarthritic changes at the anterior portion, including joint space narrowing or osteophyte formation in dysplastic hips [9], VCA angle measurement on the false-profile view should be used carefully for quantitative estimation in hips with a CE angle less than 20°. Because there currently is no simple or adequate radiographic estimation method of the anterior coverage of the pelvis in dysplastic hips, we think 3-D CT may be necessary for patients with dysplasia for whom osteotomy is considered in the preoperative planning. On the basis of the data of anterior coverage from 3-D reconstructed models, the natural history of hip dysplasia and the postoperative evaluation of dysplastic hips with surgical intervention can be analyzed. However, VCA-1 represented true anterior coverage in normal hips, and VCA-1 in normal hips is useful for quantitative estimation of anterior coverage, including excessive or large anterior coverage, which may cause femoroacetabular impingement [5].

Acknowledgments We thank Mr. Ryoji Nakao, Dr. Kunihiro Oka, and Dr. Tsuyoshi Murase for technical support. We also thank Dr. Shunsaku Nishihara and Dr. Masaki Takao for helpful advice.

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