Acetabular Tilt Correlates with Acetabular Version and Coverage in Hip Dysplasia

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Abstract

Background The rotational position of the acetabulum to the pelvis (acetabular tilt) may influence acetabular version and coverage of the femoral head. To date, the pathologic significance of acetabular tilt in hip dysplasia is unknown.

Questions/Purposes We determined whether acetabular tilt in hip dysplasia is different from that in normal hips and whether this correlates with acetabular version and coverage.

Methods We measured the acetabular tilt angle on the lateral view of three-dimensional pelvic CT images of 40 patients (72 hips) with hip dysplasia. Forty normal hips from 40 patients were used as controls. The acetabular sector angle was measured as an index for acetabular coverage of the femoral head.

Results The mean acetabular tilt angle was increased in dysplastic hips compared with controls. In dysplastic hips, a posteriorly rotated acetabulum (increased acetabular tilt) was associated with increased acetabular anteversion and with decreased anterior and anterosuperior acetabular

coverage. No correlation was found in controls. In dysplastic hips with a posterior acetabular deficiency, the acetabulum was rotated anteriorly (decreased acetabular tilt) compared with hips with anterior and lateral deficiencies.

Conclusions We observed a correlation between the rotational position of the acetabulum in the pelvis with acetabular version and coverage in hip dysplasia. Our observations confirmed anterior rotation of the acetabular fragment during periacetabular osteotomies is an anatomically reasonable maneuver for hips with anterolateral acetabular deficiencies, while the maneuver can exacerbate posterior coverage and should be avoided in hips with a posterior acetabular deficiency.

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

Introduction

Developmental dysplasia of the hip (DDH) is a common cause of secondary hip osteoarthritis [11]. Patients with DDH present with morphologic abnormalities, such as insufficient acetabular coverage of the femoral head, a shallow acetabular concavity, and a maloriented acetabulum [6, 14, 26]. These deformities lead to abnormal stress distributions on the articular weightbearing area, elevated joint contact pressures, and shearing stresses on the acetabular rim complex [10, 12, 24]. Thus, these patients often have labral tearing and cartilage degeneration develop at an early age, resulting in premature hip osteoarthritis [18, 26, 30, 37, 38].

Although the majority of patients with DDH present with anterolateral acetabular deficiencies, previous studies have shown the acetabular version and the quantity and location of acetabular deficiencies can vary among

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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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individuals [6, 7, 9, 13, 22, 23, 27]. Thus, when planning periacetabular osteotomies [8, 29], it is important to assess the morphologic features of the hip of each patient three-dimensionally and to customize the correction in accordance with this individual variation [16, 19, 31, 32]. Previous studies suggested suboptimal correction of abnormal acetabular version and coverage can result in inferior clinical results [17, 28, 33].

However, little information has been available regarding the rotational position of the acetabulum to the pelvis in DDH and its pathologic significance. In a study of subjects with normal hips, Köhnelein et al. [20] observed wide variation in “acetabular tilt,” which is an index of rotational position of the acetabulum with reference to the anterior pelvic plane (APP) [21]. As the natural acetabular rim profile is not symmetric but has a regular wavelike contour with three eminences and three depressions [4, 20, 35, 36], the variability in acetabular tilt can be a contributing factor in individual variation of acetabular version and coverage of the femoral head. Appreciating the acetabular tilt of the acetabulum in DDH and its correlation with acetabular version and coverage may be useful when corrective maneuvers such as periacetabular osteotomies are considered for these patients.

We therefore asked whether (1) acetabular tilt in hip dysplasia differs from that in normal hips, (2) acetabular tilt correlates with acetabular version, and (3) acetabular tilt correlates with acetabular coverage of the femoral head.

Patients and Methods

This is an observational study comparing the acetabular tilt angle between patients with DDH and subjects with normal

hips and correlating the angle with acetabular version and coverage of the femoral head. Preliminary data of 10 hips from each group showed a difference in the mean acetabular tilt angle was 4.6° with a SD of 7.0°. A power analysis indicated a sample size of 38 in each group is sufficient to address the questions with a power of 0.80 and a significance level of 0.05. Our institutional review board approved this study.

We reviewed pelvic CT scans from 84 patients (143 hips) with DDH, obtained during their preoperative examinations for a transposition osteotomy of the acetabulum [5] between July 2004 and February 2008. Hips with minimal or no osteoarthritic changes with a lateral center-edge angle of Wiberg (LCE) [38] less than 20° on AP pelvic radiographs were included in this study. Twenty-seven hips with Grade 2 or greater, according to the Tönnis classification [34], were excluded to minimize the effect of osteoarthritic changes on the following measurements. Twenty-four hips with prior surgery or Legg-Calvé-Perthes-like deformities also were excluded. As the majority of patients with DDH are female, we excluded seven male patients (10 hips) to eliminate the effect of morphologic differences between sexes (Table 1). An additional 10 hips were excluded because the edge of the acetabular fossa was unclear on reconstructed three-dimensional (3D) CT images.

Using these criteria, 40 patients (72 hips) were included. The average age of the patients at examination was 39 years (range, 17–58 years). There were 36 right hips and 36 left hips with a mean LCE of 10° (range, −9° to 19°). Eight patients had unilateral dysplasia and 32 had bilateral dysplasia. Fifty-three of 72 hips were symptomatic and 19 hips were asymptomatic at the time of the examination. Forty normal hips from 40 patients with osteoarthritis of the knee

Table 1. Comparison of CT measurement between the DDH and control groups

Parameter	DDH female group (n = 72)	DDH male group (n = 10)	Control group (n = 40)	p value*
Acetabular tilt (°)	25.0 (7.1)	25.7 (7.5)	21.1 (7.3)	0.0166
Acetabular opening angles (°)				
Acetabular anteversion	25.2 (5.9)	21.5 (4.6) [†]	22.1 (6.0)	0.0049
Acetabular inclination	48.3 (3.7)	48.3 (4.9)	36.5 (3.7)	< 0.0001
Cranial anteversion	10.1 (8.6)	9.8 (7.6)	12.8 (10.1)	0.0667
Acetabular coverage (°)				
Anterior ASA	41.3 (7.7)	42.1 (6.0)	60.7 (9.0)	< 0.0001
Anterosuperior ASA	80.3 (13.8)	82.3 (10.5)	106.1 (12.2)	< 0.0001
Superior ASA	100.9 (7.0)	96.9 (8.7)	129.0 (7.1)	< 0.0001
Posterosuperior ASA	100.6 (8.5)	98.3 (6.3)	125.8 (8.8)	< 0.0001
Posterior ASA	91.3 (6.8)	84.4 (6.2) [†]	104.5 (9.3)	< 0.0001

Values are expressed as mean, with SD in parentheses; * DDH female group versus control group; [†]p < 0.05 compared with DDH female group; DDH = developmental dysplasia of the hip; ASA = acetabular sector angle.

who had no history of hip disease were used as control subjects; these subjects were all females with an average age of 73 years (range, 52–79 years). There were 23 right hips and 17 left hips with a mean LCE of 37° (range, $25\text{--}42^\circ$). These pelvic CT images were obtained as part of a preoperative examination for TKA using a CT-based navigation system [25]. Although the control group was older ($p < 0.0001$) than the DDH group, control subjects had no degenerative changes or other hip abnormalities on radiographic and CT examination and were deemed suitable for morphologic examination.

Pelvic CT was performed with patients in a supine position. The images were obtained at 2-mm intervals from the anterior superior iliac spines to the inferior rim of the pelvis. For the control group, CT images were obtained at 2-mm intervals from a 100-mm section of the femoral head, a 200-mm section of the knee, and a 100-mm section of the distal part of the tibia [25]. All CT images, including those for the control group, included the anterior superior iliac spines and pelvic tubercle.

After downloading data from these tomographs in DICOM format, a 3D image of the pelvis without the femur was developed using image processing software (INTAGE Realia; Cybernet Systems Co, Ltd, Tokyo, Japan). The pelvic position was standardized using the APP coordinate system. The acetabular tilt was defined as sagittal rotation of the entire acetabular cup with reference to the APP in this study. Using the lateral view of the 3D image of the pelvis, we determined the acetabular tilt angle as an angle formed by the intersection of the APP and a line connecting the center of the ellipse fitted to the acetabular edge and the midpoint of the acetabular notch (Fig. 1). An increased acetabular tilt angle indicated posterior rotation of the entire acetabular cup relative to the pelvis.

Measurements of acetabular version and coverage were performed on a multiplanar reconstruction image of the pelvis using image processing software (3D template; Japan Medical Materials, Osaka, Japan). Before measurement, the pelvic position was standardized with reference to the APP coordinate system to minimize measurement error caused by varying pelvic positions. Regarding the acetabular opening angle, we measured the acetabular anteversion angle on the axial plane passing through the center of the femoral head (Fig. 2A) and the acetabular inclination angle on the coronal plane passing through the center of the femoral head (Fig. 2B). The cranial anteversion angle [15] was measured on the axial plane 5 mm distal to the acetabular roof to determine the existence of acetabular retroversion (Fig. 2C). Hips with negative cranial anteversion angles were defined as having acetabular retroversion. Acetabular coverage of the femoral head was evaluated by measuring the acetabular sector angle (ASA) in five directions, based on the method described by Anda

Fig. 1 A lateral view 3D CT image of the pelvis shows measurement of acetabular tilt angle. The acetabular tilt angle (Angle a) was measured as an angle formed by the intersection of the APP (Line b) passing through the anterior superior iliac spines and pubic tubercles and a line (Line c) connecting the center of an ellipse fitted to the acetabular rim (black dot) and the midpoint of the acetabular notch (white dot).

et al. and Fujii et al. [1, 7] (Fig. 3). The anterior and posterior ASAs were used to classify patients with DDH into four types: anterior deficiency (anterior ASA $< 50^\circ$ and posterior ASA $\geq 90^\circ$), global deficiency (anterior ASA $< 50^\circ$ and posterior ASA $< 90^\circ$), mild deficiency (anterior ASA $\geq 50^\circ$ and posterior ASA $\geq 90^\circ$), and posterior deficiency (anterior ASA $\geq 50^\circ$ and posterior ASA $< 90^\circ$) [2]. We classified hips with global and mild deficiencies as lateral deficiency [13].

All measurements using CT images were performed by one observer (MF) and were repeated in a blinded manner during two sessions at least 1 month apart. The reliability of measurements on multiplanar reconstructed images has been validated in previous studies [6, 7]. Intraobserver reliability of the measurement of the acetabular tilt angle, evaluated with the use of the intraclass correlation coefficient, was 0.8516. Using the data obtained from CT measurements, we performed the following analyses: (1) comparison of CT measurements between the DDH and control groups; (2) correlation of acetabular tilt with the acetabular opening angle and with acetabular retroversion; and (3) correlation of acetabular tilt with acetabular coverage of the femoral head and with the type of acetabular deficiency. The chi square test and Wilcoxon rank-sum test were used to compare the categorical and continuous parameters between the two groups, respectively. The Wilcoxon signed-rank test was used to

Fig. 2A–C (A) The acetabular anteversion angle (Angle a) was measured as an angle formed by a line connecting the anterior and posterior edges of the acetabulum and a sagittal line on an axial plane passing through the center of the femoral head. (B) The acetabular inclination angle (Angle b) was measured as an angle formed by a line connecting the superior and inferior edges of the acetabulum and a

horizontal line on the coronal section passing through the center of the femoral head. (C) The cranial anteversion angle (Angle c) [15] was measured as an angle formed by a line connecting the anterior and posterior edges of the acetabulum and a sagittal line on the axial plane 5 mm distal to the acetabular roof.

determine the bilateral difference. The Tukey-Kramer honestly significant difference test was used for multiple comparisons. Correlations between two continuous parameters were evaluated using Spearman's rank correlation coefficient. Significant differences were defined as being present when p values were less than 0.05. Statistical analyses were performed using JMP® software (Version 8.0; SAS Institute, Inc, Cary, NC, USA).

Results

Acetabular tilt varied widely in patients with DDH and control subjects (range, 11.0–42.5° and 8.1–37.9°, respectively), with

the mean value greater ($p = 0.0166$) in hips with DDH than in control hips (25.0° versus 21.1°, respectively) (Fig. 4; Table 1). Acetabular anteversion and inclination angles were increased in hips with DDH compared with control hips (Table 1). The incidence of acetabular retroversion was not different ($p = 0.5384$) between the two groups: DDH group, eight hips (11%); and control group, three hips (8%). The ASA was decreased in all directions in the DDH group compared with the control group (Table 1). Based on the measurement value of ASA, 36 hips (50%) were classified as having anterior deficiency, 27 hips (38%) as having global deficiency, three hips (4%) as having mild deficiency, and six hips (8%) as having posterior deficiency. Four of six hips (67%) with a posterior deficiency had acetabular retroversion along with

Fig. 3 A diagram shows the ASA [1, 5]. The ASA was defined as an angle formed by the intersection of a line connecting the femoral head center and the acetabular edge with a horizontal line. The ASA was measured in the (a) anterior, (b) 45° anterosuperior, (c) superior, (d) 45° posterosuperior, and (e) posterior directions.

Fig. 4 Box plots show acetabular tilt angles in patients with DDH and control subjects. The acetabular tilt angle varied widely in both groups (range, 11.0°–42.5° and 8.1°–37.9°, respectively). The mean acetabular tilt angle was increased ($p = 0.0166$) in patients with DDH compared with control subjects (25.0° versus 21.1°, respectively). Box = interquartile range (IQR); whiskers = minimum and maximum data within 1.5 IQR from the end of the box; horizontal line in box = median.

four of 27 hips (15%) with a global deficiency. There was no significant bilateral difference in CT measurements in 32 patients with bilateral DDH (Table 2).

In the DDH group, the acetabular tilt angle was positively correlated with acetabular anteversion and cranial anteversion angles but not with acetabular inclination angle (Table 3). Hips with DDH with acetabular retroversion had lower ($p = 0.0012$) acetabular tilt angles compared with those with acetabular anteversion (17.0° versus 26.0°, respectively). In subjects with normal hips, the acetabular tilt angle was not correlated with acetabular anteversion, cranial anteversion, or inclination angles. There was no

Table 2. Bilateral difference in CT measurement in patients with bilateral DDH ($n = 32$)

Parameter	Difference (right hip – left hip)	p value
Acetabular tilt (°)	–1.5 (–3.4; 0.5)	0.1270
Acetabular opening angles (°)		
Acetabular anteversion	–1.0 (–2.5; 0.6)	0.3353
Acetabular inclination	0.4 (–1.0; 1.7)	0.6408
Cranial anteversion	–1.2 (–3.9; 1.4)	0.3127
Acetabular coverage (°)		
Anterior ASA	1.6 (–0.8; 4.0)	0.1984
Anterosuperior ASA	–1.4 (–5.6; 2.7)	0.4919
Superior ASA	–2.7 (–6.1; 0.7)	0.1792
Posterosuperior ASA	–2.0 (–5.3; 1.4)	0.3388
Posterior ASA	–0.4 (–2.5; 1.6)	0.5095

Values are expressed as mean, with 95% CI in parentheses; DDH = developmental dysplasia of the hip; ASA = acetabular sector angle.

Table 3. Correlation of acetabular tilt angle with acetabular opening angle

Group	Parameter	Correlation coefficient (p value)
DDH	Acetabular anteversion	0.4389 (0.0001)
	Acetabular inclination	0.1227 (0.3082)
	Cranial anteversion	0.4360 (0.0002)
Control	Acetabular anteversion	–0.0037 (0.9821)
	Acetabular inclination	–0.0577 (0.7238)
	Cranial anteversion	–0.0795 (0.6259)

DDH = developmental dysplasia of the hip.

difference ($p = 0.6625$) in the acetabular tilt angle between normal hips with acetabular retroversion and those with acetabular anteversion (19.1° versus 21.3°, respectively).

Regarding acetabular coverage of the femoral head, the acetabular tilt angle was correlated negatively with anterior and anterosuperior ASAs and positively with posterior ASA in hips with DDH (Table 4). In control subjects, we found no correlation between the acetabular tilt angle and ASA in any direction (Table 5). The acetabular anteversion angle was correlated negatively with anterior and anterosuperior ASAs and positively with posterosuperior and posterior ASAs in patients with DDH and control subjects. The acetabular inclination angle was negatively correlated with anterosuperior and superior ASAs in both groups and with anterior and posterosuperior ASAs in the DDH group. When the DDH group was subdivided based on defect location, hips with a posterior acetabular deficiency had decreased acetabular tilt angles compared with the anterior and lateral acetabular deficiency groups (Fig. 5).

Table 4. Correlation of ASAs with acetabular tilt, anteversion, and inclination angles in the DDH group

Parameter	Correlation coefficient (p value)		
	Acetabular tilt	Acetabular anteversion	Acetabular inclination
Anterior ASA	−0.4393 (< 0.0001)	−0.7524 (< 0.0001)	−0.3678 (0.0015)
Anterosuperior ASA	−0.4086 (0.0004)	−0.6046 (< 0.0001)	−0.3844 (0.0009)
Superior ASA	−0.1723 (0.1507)	−0.2044 (0.0850)	−0.7580 (< 0.0001)
Posterosuperior ASA	0.1999 (0.0946)	0.3165 (0.0068)	−0.2832 (0.0159)
Posterior ASA	0.3734 (0.0013)	0.6787 (< 0.0001)	−0.0924 (0.4401)

DDH = developmental dysplasia of the hip; ASA = acetabular sector angle.

Table 5. Correlation of ASAs with acetabular tilt, anteversion, and inclination angles in the control group

Parameter	Correlation coefficient (p value)		
	Acetabular tilt	Acetabular anteversion	Acetabular inclination
Anterior ASA	−0.0433 (0.7910)	−0.6059 (< 0.0001)	−0.3028 (0.0575)
Anterosuperior ASA	−0.1400 (0.5141)	−0.5661 (0.0039)	−0.4436 (0.0299)
Superior ASA	0.0060 (0.9709)	−0.1522 (0.3484)	−0.7029 (< 0.0001)
Posterosuperior ASA	−0.2052 (0.3361)	0.4200 (0.0410)	−0.2140 (0.3154)
Posterior ASA	0.0213 (0.8962)	0.6367 (< 0.0001)	−0.0828 (0.6114)

ASA = acetabular sector angle.

Fig. 5 Box plots show the variance in acetabular tilt angles based on the types of acetabular deficiency. The acetabular tilt angle of hips with a posterior deficiency (mean, 16.0°; range, 11.0°–22.9°) was decreased ($p = 0.0011$ and 0.0108 , respectively) compared with hips with anterior (mean, 26.8°; range, 12.1°–35.6°) and lateral (mean, 24.7°; range, 12.7°–42.5°) deficiencies. Box = interquartile range (IQR); whiskers = minimum and maximum data within 1.5 IQR from the end of the box; horizontal line in box = median.

Discussion

Previous studies have described morphologic alterations in DDH and the existence of individual variation in resulting deformities [6, 7, 9, 13, 22, 23, 27]. However, there has been little information available regarding the rotational position of the acetabulum (acetabular tilt) in DDH and its

pathologic significance. The natural acetabular rim profile is not a hemisphere but has a regular wavelike contour [4, 20, 35, 36], indicating the variability in the rotational position of the acetabulum could be a contributing factor in individual variation in acetabular version and coverage. We therefore asked whether (1) acetabular tilt in hip dysplasia differs from that in normal hips, (2) acetabular tilt correlates with acetabular version, and (3) acetabular tilt correlates with coverage of the femoral head.

There were several limitations to this study. First is the small number of subjects. Second, control subjects were older than the patients with DDH. Subjects with the same age range would be ideal for control; however, it is generally difficult to obtain qualified CT images of normal hips in the young adult population. In this study, we confirmed control subject had neither degenerative change nor other abnormality of the hip based on radiographic and CT examinations. Thus, we considered them qualified to be used as control subjects with normal hips. The third limitation is possible inaccuracy in the measurement method of the acetabular tilt angle. We determined the acetabular tilt angle on the lateral view of the 3D image of the pelvis. Thus, the measurement value could be influenced by the acetabular anteversion and inclination angles. Theoretically, the acetabular tilt angle could correlate negatively with acetabular anteversion and inclination angles. However, these correlations were not observed in our study, and a positive correlation was observed between acetabular tilt angle and acetabular anteversion angle, despite this

possible limitation. Therefore, we assume our results and interpretation of them are appropriate.

The acetabular tilt angle varied widely among individuals in the DDH and control groups in this study. The mean acetabular tilt angle of normal hips (21.1°) was relatively greater in our study than in the study by Köhnlein et al. [20] (18.9°). We assume this discrepancy was caused by differences in measurement methods: Köhnlein et al. [20], using the bony pelvis, measured acetabular tilt as the angle between the APP and the projection of the 180° meridian line on the opening plane. Additionally, we showed the mean acetabular tilt angle was increased in patients with DDH compared with control subjects. This result indicates posterior rotation of the acetabulum to be one of the morphologic variations of DDH.

No studies have correlated the rotational position of the acetabulum to the pelvis with acetabular version and coverage. In normal hips, we did not observe a correlation of acetabular tilt with the acetabular opening angle, the presence of acetabular retroversion, or acetabular coverage. This result suggests the rotational position of the acetabulum to the pelvis has little effect on acetabular version and coverage of the femoral head. However, in patients with DDH, posterior rotation of the acetabulum was associated with increased acetabular anteversion, decreased acetabular coverage in the anterior and anterosuperior directions, and increased posterior acetabular coverage. Additionally, the acetabulum in dysplastic hips with a posterior deficiency was rotated anteriorly compared with those with anterior and lateral deficiencies.

The pathogenesis of this association of acetabular tilt with acetabular version and coverage in patients with DDH is unknown. One possible explanation is that posterior rotation of the acetabulum orients the anteroinferior acetabular depression (acetabular notch) anteriorly, causing increased acetabular anteversion and an anterior acetabular deficiency. This explanation disagrees with our finding that acetabular tilt did not correlate with acetabular version and coverage in normal hips; however, the acetabular rim profile in DDH may vary from the normal hip. Another explanation is that a growth disturbance of the anterior ramus of the lunate surface leads to an anteriorly oriented acetabular notch and resultant increased acetabular tilt angle (Fig. 6). This explanation is consistent with our observation that acetabular tilt was increased in hips with DDH compared with normal hips. We evaluated rotation of the acetabulum based on the position of the acetabular notch; however, the location and degree of the lunate surface deficiency may change the orientation of the acetabular notch in DDH. We assume acetabular tilt angle not only represents the rotational position of the acetabulum but also may be influenced by the dysplastic portion of the acetabulum in DDH. We could not define the causal

Fig. 6 On this lateral view of a 3D CT image of the pelvis in a patient with DDH with an anterior deficiency, the growth disturbance of the anterior ramus of the lunate surface can be observed (black arrow), and the acetabular tilt angle was 35.6° .

relationship in this study, and further investigation is needed to answer this question definitively.

When planning periacetabular osteotomies for patients with DDH, it is important to customize the correction of the acetabular fragment in accordance with individual variability [16, 19, 31, 32]. Anterior rotation, ie, forward tilt or extension, of the acetabular fragment is one of the conventional maneuvers performed during periacetabular osteotomies to correct anterolateral acetabular deficiency. However, previous studies suggested anterior rotation of the acetabulum can aggravate posterior acetabular insufficiency [3, 16]. Our observations confirmed anterior rotation of the acetabular fragment is an anatomically reasonable maneuver for patients with an anterolateral deficiency to enhance the anterior and anterosuperior articulating surfaces on the femoral head. However, the maneuver can be problematic for patients with insufficient posterior acetabular coverage and therefore should be avoided in this subgroup.

This study suggested posterior rotation of the acetabulum as one of the common but not exclusive morphologic variations of DDH. The rotational position of the acetabulum in the pelvis was associated with acetabular version and coverage. Although many hips with DDH had a posteriorly rotated acetabulum (increased acetabular tilt), which is associated with decreased anterior and anterosuperior acetabular coverage of the femoral head, some hips had an anteriorly rotated acetabulum (decreased acetabular tilt), which is associated with posterior acetabular deficiency and acetabular retroversion. These observations

confirmed anterior rotation of the acetabular fragment in periacetabular osteotomies is a rational maneuver for hip dysplasia with an anterolateral deficiency to enhance anterior and anterosuperior acetabular coverage of the femoral head. However, the maneuver can exacerbate posterior acetabular coverage and therefore should be avoided in patients with decreased acetabular tilt and posterior acetabular deficiency.

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