

Targeting a New Safe Zone: A Step in the Development of Patient-Specific Component Positioning for Total Hip Arthroplasty

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Abstract

Surgeons often target the Lewinnek zone, with its mean (SD) inclination of 40° (10°) and mean (SD) anteversion of 15° (10°), for acetabular orientation during total hip arthroplasty (THA). However, matching native anteversion (20°-25°) may achieve optimal stability.

We conducted a study in a large single-surgeon patient cohort to determine the incidence of early postoperative dislocation with increased acetabular anteversion and the accuracy of imageless navigation in achieving target acetabular position. Soft-tissue repair through a posterolateral approach was performed in 553 THAs that met the inclusion criteria. Mean (SD) target acetabular orientation was 40° (10°) of inclination and 25° (10°) of anteversion. Software was used to measure acetabular positioning on postoperative radiographs. Incidence of dislocation within 6 months after surgery was determined.

Mean (SD) inclination was 42.2° (4.9°), and mean (SD) anteversion was 23.9° (6.5°). Approximately 82% of cups were placed in the target zone. Variation in anteversion accounted for 67.3% of outliers. Only body mass index was associated with inclination outside the target range ($P = .017$), and only female sex was associated with anteversion outside the target range ($P = .030$). Six THAs (1.1%) experienced early dislocation, and 3 (0.54%) of these were revised for multiple dislocations. There was no relationship between dislocation and component placement in either the Lewinnek zone ($P = .224$) or the target zone ($P = .287$).

Postoperative dislocation remains a common complication of primary total hip arthroplasties (THAs), affecting less than 1% to more than 10% in reported series.^{1,2} In large datasets for modern implants, the incidence of dislocation is 2% to 4%.^{3,4} Given that more than 200,000 THAs are performed in

the United States each year,⁵ these low percentages represent a large number of patients. The multiplex patient variables that affect THA stability include age, sex, body mass index (BMI), and comorbid conditions.⁶⁻⁸ Surgical approach, restoration of leg length and femoral offset, femoral head size, and component positioning are also important surgical factors that can increase or decrease the incidence of dislocation.^{3,8,9} In particular, appropriate acetabular component orientation is crucial; surgeons can control this factor and thereby limit the occurrence of dislocation.¹⁰ Furthermore, acetabular malpositioning can increase the risk of liner fractures and accelerate bearing-surface wear.¹¹⁻¹⁴

To minimize the risk of postoperative dislocation, surgeons traditionally have targeted the Lewinnek safe zone, with its mean (SD) inclination of 40° (10°) and mean (SD) anteversion of 15° (10°), for acetabular component orientation.¹⁵ However, the applicability of this target zone to preventing hip instability using modern implant designs, components, and surgical techniques remains unknown. Achieving acetabular orientation based on maximizing range of motion (ROM) before impingement may be optimal, with anteversion from 20° to 30° and inclination from 40° to 45°.^{16,17} Furthermore, mean (SD) native acetabular anteversion ranges from 21.3° (6.2°) for men to 24.6° (6.6°) for women.¹⁸ Placing THA acetabular components near the native range for anteversion may best provide impingement-free ROM and thus optimize THA stability,^{16,19} but this has not been proved in a clinical study.

Early dislocation is typically classified as occurring within 6 months after surgery,⁹ with almost 80% of dislocations occurring within 3 months after surgery.¹⁰ Surgeon-specific factors, such as acetabular component positioning, are thought to have a predominant effect on dislocations in the early postoperative period.¹⁰ Computer-assisted surgery (CAS), such as imageless navigation, is more accurate than conventional methods for acetabular component placement,²⁰⁻²³ but the clinical relevance of improving accuracy for acetabular component placement has not been shown with respect to altering patient outcomes.²³

We conducted a study in a large single-surgeon patient cohort to determine the incidence of early postoperative dislocation with target anteversion increased to 25°, approximating

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mean native acetabular anteversion.^{16,19} In addition, we sought to determine the accuracy of imageless navigation in achieving target acetabular component placement.

Materials and Methods

After obtaining institutional review board approval for this retrospective clinical study, we reviewed 671 consecutive cases of primary THA performed by a single surgeon using an imageless CAS system (AchieveCAS; Smith & Nephew, Memphis, Tennessee) between July 2006 and October 2012. THAs were excluded if a metal-on-metal bearing surface was used, if an adequate 6-week postoperative supine anteroposterior (AP) pelvis radiograph was unavailable, or if 6-month clinical follow-up findings were not available (Figure 1). The quality of AP radiographs was deemed poor if they were not centered on the symphysis pubis and if the sacrococcygeal joint was not centered over the symphysis pubis. After exclusion criteria were applied, 553 arthroplasties (479 patients) with a mean (SD) follow-up of 2.4 (1.4) years remained. Perioperative demographic data and component sizes are listed in Table 1.

During surgery, the anterior pelvic plane, defined by the anterior-superior iliac spines and pubic tubercle, was registered with the CAS system with the patient in the supine position. THA was performed with the patient in the lateral decubitus position using a posterolateral technique. For all patients, the surgeon used a hemispherical acetabular component (R3 Acetabular System; Smith & Nephew); bearings that were either metal on highly cross-linked polyethylene (XLPE) or Oxinium (Smith & Nephew) on XLPE; and neutral XLPE acetabular inserts. The goals for acetabular inclination and anteversion were 40° and 25°, respectively, with ±10° each for the target zone. The CAS system was used to adjust target anteversion for sagittal pelvic tilt.²⁴ Uncemented femoral components were used for all patients, and the goal for femoral component anteversion was 15°. Transosseous repair of the posterior capsule and short external rotators was performed after component implantation.²⁵

On each 6-week postoperative radiograph, acetabular orientation was measured with Ein-Bild-Röntgen-Analyse (EBRA; University of Innsbruck, Austria) software, which provides a validated method for measuring acetabular inclination and anteversion on supine AP pelvis radiographs.^{10,26} Pelvic bound-

aries were delineated with grid lines defining pelvic position. Reference points around the projections of the prosthetic femoral head, the hemispherical cup, and the rim of the cup were marked (Figure 2). EBRA calculated radiographic inclination and anteversion of the acetabular component based on the spatial position of the cup center in relation to the plane of the radiograph and the pelvic position.²⁶

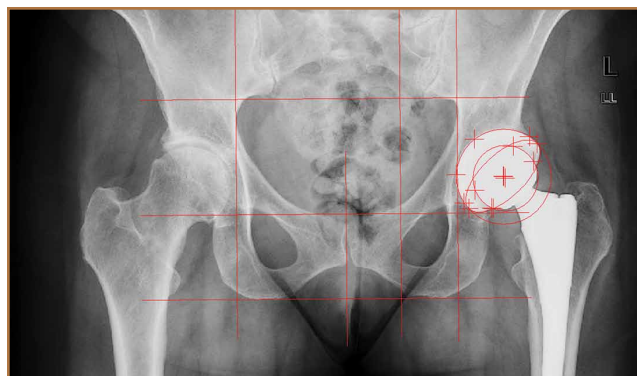


Figure 2. Supine anteroposterior pelvis radiograph with Ein-Bild-Röntgen-Analyse (EBRA; University of Innsbruck, Austria) grid lines and landmarks. As determined by the EBRA software, acetabular component inclination was 42.9°, and anteversion was 25.8°.

Table 1. Study Demographics and Implant Size

	N	%		
Hips	553	100		
Patients	479	100		
Side				
Right	299	54.1		
Left	254	45.9		
Bilateral	74	26.8		
Sex				
Male	226	40.9		
Female	327	59.1		
Primary diagnosis				
Osteoarthritis	460	83.2		
Avascular necrosis	35	6.3		
Childhood hip disease	29	5.2		
Posttraumatic arthritis	14	2.5		
Inflammatory arthropathy	10	1.8		
Acute hip fracture	3	0.5		
Prior arthrodesis	2	0.4		
	Mean	SD	Minimum	Maximum
Age, y	57.7	12.1	16.7	89.5
Body mass index, kg/m ²	29.2	6.4	17.5	59.1
Acetabulum size, mm	52.6	3.0	48	62
Femoral head size, mm	34.9	2.2	28	40

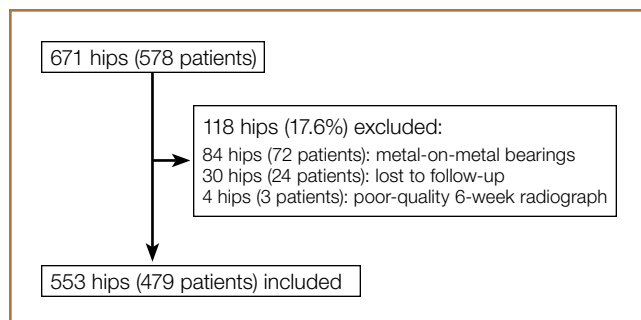


Figure 1. Flowchart for study group formation.

Charts were reviewed to identify patients with early post-operative dislocations, as well as dislocation timing, recurrence, and other characteristics. We defined early dislocation as instability occurring within 6 months after surgery. Revision surgery for instability was also identified.

For the statistical analysis, orientation error was defined as the absolute value of the difference between target orientation (40° inclination, 25° anteversion) and radiographic measurements. Repeated-measures multiple regression with the generalized estimating equations approach was used to identify baseline patient characteristics (age, sex, BMI, primary diagnosis, laterality) associated with component positioning outside of our targeted ranges for inclination and anteversion. Fisher exact tests were used to examine the relationship between dislocation and component placement in either the Lewinnek safe zone or our targeted zone. All tests were 2-sided with a significance level of .05. All analyses were performed with SAS for Windows 9.3 (SAS Institute, Cary, North Carolina).

Results

Mean (SD) acetabular inclination was 42.2° (4.9°) (range, 27.6°-65.0°), with a mean (SD) orientation error of 4.2° (3.4°) (Figure 3A). Mean (SD) anteversion was 23.9° (6.5°) (range,

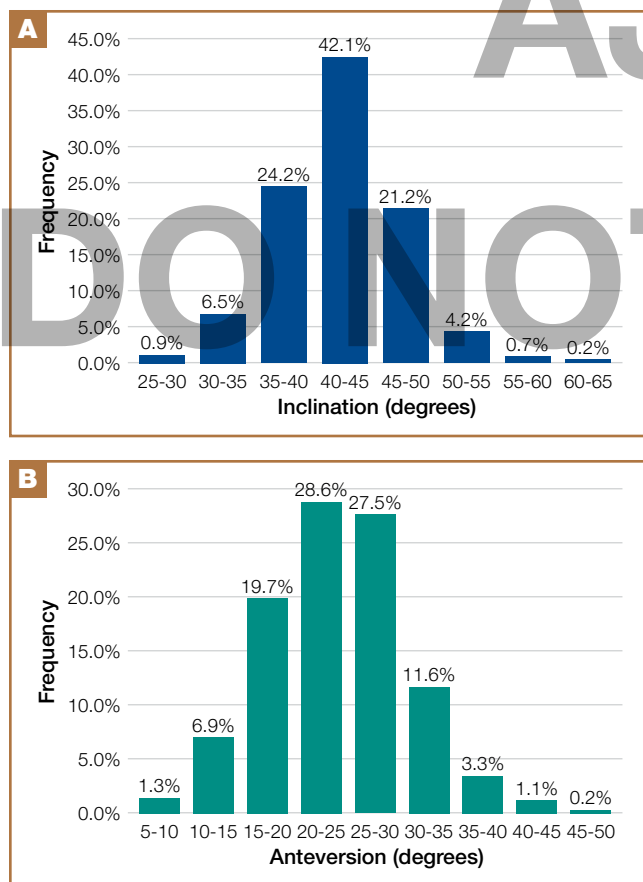


Figure 3. Histograms of acetabular component (A) inclination and (B) anteversion show frequency of components within various degree ranges.

6.2°-48.0°), with a mean (SD) orientation error of 5.2° (4.1°) (Figure 3B). Components were placed outside the Lewinnek safe zone for inclination or anteversion in 46.5% of cases and outside the target zone in 17.7% of cases (Figure 4). Variation in acetabular anteversion alone accounted for 67.3% of target zone outliers (Table 2). Only 0.9% of components were placed outside the target ranges for both inclination and anteversion.

Regression analysis was performed separately for inclination and anteversion to determine the risk factors for placing the acetabular component outside the target orientation ranges. Only higher BMI was associated with malposition with respect to inclination (hazard ratio [HR], 1.059; 95% confidence interval [CI], 1.011-1.111; P = .017). Of obese patients with inclination outside the target range, 90.9% had an inclination angle of more than 50°. Associations between inclination outside the

Table 2. Target Zone Outliers

	Inclination		Anteversion		Total ^a	
	n	%	n	%	N	%
Lewinnek zone outliers	33	6.0	241	43.6	257	46.5
Target zone outliers	33	6.0	70	12.7	98	17.7

^aSeventeen patients were Lewinnek zone outliers for both inclination and anteversion; 5 patients were target zone outliers for both inclination and anteversion.

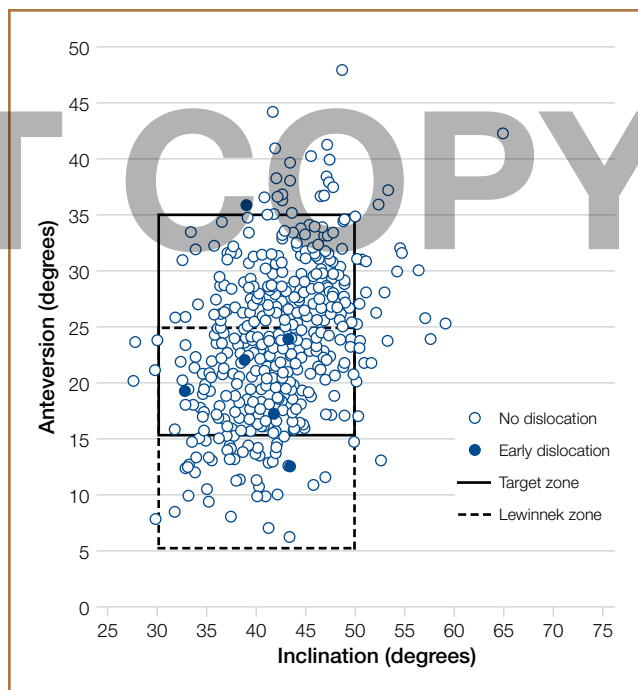


Figure 4. Scatterplot of acetabular component position depicted as anteversion versus inclination values for all patients, including those with early dislocation. Safe range as defined by Lewinnek is delineated by dashed rectangle; our target range is delineated by solid rectangle. There was no relationship between incidence of dislocation and component placement in Lewinnek zone (P = .224) or our target zone (P = .287).

target range and age ($P = .769$), sex ($P = .217$), preoperative diagnosis ($P > .99$), and laterality ($P = .106$) were statistically insignificant. Only female sex was associated with position of the acetabular component outside the target range for anteversion (HR, 1.871; 95% CI, 1.061-3.299; $P = .030$). Of female patients with anteversion outside the target range, 70.0% had anteversion of less than 15° . Associations between anteversion outside the target range and age ($P = .762$), BMI ($P = .583$), preoperative diagnosis ($P > .99$), and laterality ($P = .235$) were statistically insignificant.

Six THAs (1.1%) in 6 patients experienced dislocation

within 6 months after surgery (Table 3); mean (SD) time of dislocation was 58.3 (13.8) days after surgery. There was no relationship between dislocation incidence and component placement in the Lewinnek zone ($P = .224$) or our target zone ($P = .287$). Of the dislocation cases, 50% involved female patients, and 50% involved right hips. Mean (SD) age of these patients was 53.3 (7.6) years. Mean (SD) BMI was 25.4 (0.9) kg/m^2 . Osteoarthritis was the primary diagnosis for all patients with early dislocation; 32- or 36-mm femoral heads were used in these cases. Two patients had acetabular components placed outside of our target zone. One patient, who had abnormal

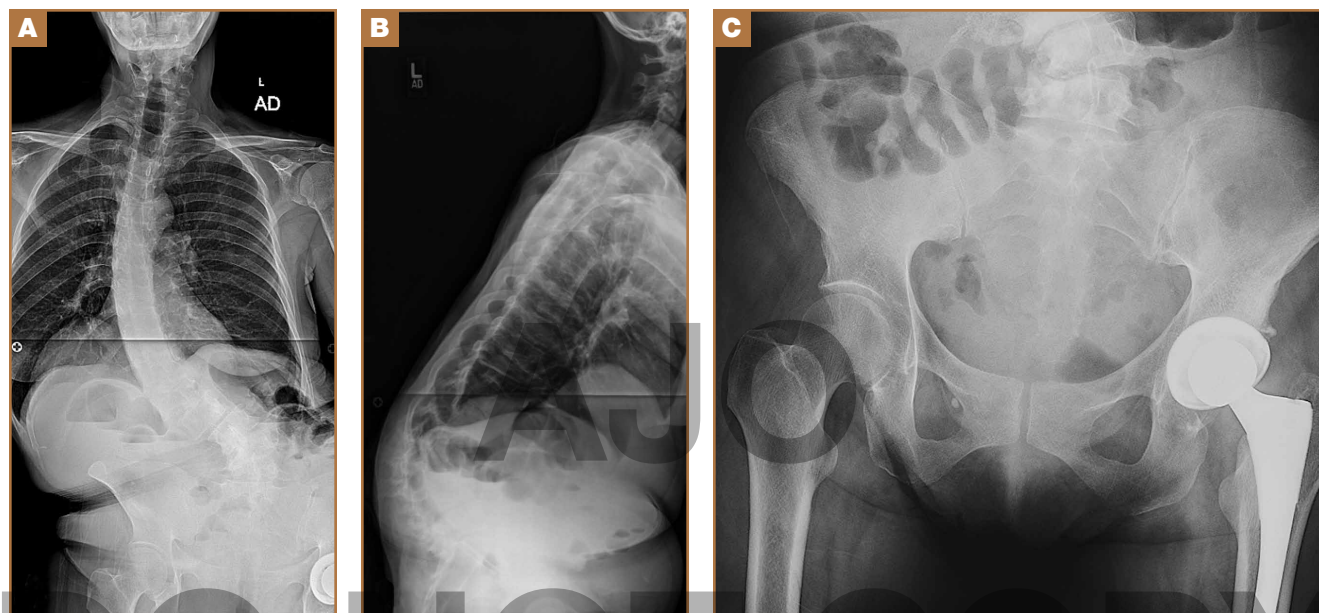


Figure 5. (A) Standing anteroposterior spine radiograph, (B) standing lateral spine radiograph, and (C) supine anteroposterior pelvis radiograph of only patient with dislocation and acetabular placement outside of both target zone and Lewinnek zone, secondary to 36° of acetabular anteversion measured on supine pelvis radiograph. (A, B) There is significant lumbar spine deformity, coronal imbalance, and sagittal imbalance. (A, B) On standing, there is increased posterior pelvic tilt ($\sim 27^\circ$) with consequent increase in apparent acetabular anteversion compared with (C) supine radiograph.

Table 3. Characteristics of Patients With Early Dislocation^a

Pt	Age at Surgery, y	Sex	BMI, kg/m^2	Side	Time to Dislocation, d	Size, mm		Acetabular Inclination, $^\circ$	Acetabular Anteversion, $^\circ$	Within Zone		Risk Factors	Multiple Dislocations	Revision
						Cup	Femoral Head			Target	Lewinnek			
1	62.1	M	26.7	L	81	54	36	43.2	23.9	Y	Y	None	Y	Y
2	48.1	F	25.7	R	65	48	32	38.8	22.1	Y	Y	Trauma	N	N
3	65.8	F	24.6	R	54	52	36	43.4	12.5	N	Y	Trauma	N	N
4	47.5	M	26.0	R	61	54	36	32.8	19.3	Y	Y	Cerebral palsy	Y	Y
5	47.5	M	24.8	L	54	52	36	41.8	17.3	Y	Y	Hyperlaxity	N	N
6	48.9	F	24.3	L	35	50	32	39.0	36.0	N	N	Pelvic obliquity, scoliosis	Y	Y

Abbreviations: BMI, body mass index; Pt, patient.
^aIn each case, the primary diagnosis was osteoarthritis.

pelvic obliquity and sagittal tilt from scoliosis (Figures 5A, 5B), had an acetabular component placed outside both the target zone and the Lewinnek safe zone. Mean (SD) acetabular inclination was 39.8° (3.6°), and mean (SD) anteversion was 21.8° (7.3°) (Figure 5C). Two dislocations resulted from trauma, 1 dislocation was related to hyperlaxity, 1 patient had cerebral palsy, and 1 patient had no evident predisposing risk factors. Three patients (0.54%) had multiple episodes of instability requiring revision during the follow-up period.

Discussion

To our knowledge, this study represents the largest cohort of primary THAs performed with an imageless navigation system. Our results showed that increasing targeted acetabular anteversion to 25° using a posterolateral surgical approach and modern implants resulted in a 1.1% incidence of early dislocation and a 0.54% incidence of recurrent instability requiring reoperation. Of the patients with a dislocation, only 1 did not experience trauma and did not have a risk factor for dislocation. Only 1 patient with a dislocation had acetabular components positioned outside both the target zone and the Lewinnek safe zone. The acetabular component was placed within the target zone in 82.3% of cases in which the imageless navigation system was used. In our cohort, BMI was the only risk factor for placement of the acetabular component outside our target range for inclination, and sex was associated with components outside the target range for anteversion.

Early dislocation after THA is often related to improper implant orientation, inadequate restoration of offset and myofascial tension, and decreased femoral head–neck ratio.⁸ Although dislocation rates in the literature vary widely,^{1,2} Medicare data suggest that the rate for the first 6 months after surgery can be as high as 4.21%.^{3,4} Although use of femoral heads with a diameter of 32 mm or larger may decrease this rate to 2.14%,³ accurate acetabular component orientation helps prevent postoperative dislocation.¹⁰ Using an imageless navigation system to target 25° of anteversion and 40° of inclination resulted in an early-dislocation rate about 49% less than the rate in a Medicare population treated with similar, modern implants.³

Callanan and colleagues¹¹ found that freehand techniques were inaccurate for acetabular positioning in up to 50% of cases, and several studies have demonstrated that imageless navigation systems were more accurate than conventional guides.^{20,21,27-29} Higher BMI has been implicated as a risk factor for acetabular malpositioning in several studies of the accuracy of freehand techniques¹¹ and imageless navigation techniques.^{23,30} Soft-tissue impediment to the component insertion handle poses a risk of increased inclination and inadequate anteversion, regardless of method used (conventional, CAS). When the acetabular component is placed freehand in obese patients, it is difficult to judge the position of the pelvis on the operating room table. For imageless navigation, a larger amount of adipose tissue over bony landmarks may limit the accuracy of anterior pelvic plane registration.³⁰ Sex typically is not cited as a risk factor for inaccurate acetabular component positioning. We speculate that omitted-variable

bias may explain the observed association between female sex and anteversion. For example, changes in postoperative pelvic tilt alter apparent anteversion on plain radiographs,³¹⁻³⁴ but preoperative and postoperative sagittal pelvic tilt was not recorded in this study.

The proper position of the acetabular component has been debated.^{15,16,35,36} Although it is generally agreed that inclination of $40^\circ \pm 10^\circ$ balances ROM, stability, and bearing-surface wear,^{12,13,15,16} proposed targets for anteversion vary widely, from 0° to 40° .^{35,36} Patel and colleagues¹⁶ formulated computer models based on cadaveric specimens to determine that THA impingement was minimized when the acetabular component was placed to match the native anteversion of the acetabulum. In their study model, 20° of anteversion paralleled native acetabular orientation. Tohtz and colleagues¹⁸ reviewed computed tomography scans of 144 female hips and 192 male

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hips and found that mean (SD) anteversion was 24.6° (6.6°) for women and 21.3° (6.2°) for men. Whether native anatomy is a valid reference for acetabular anteversion is controversial,¹⁹ and definitive recommendations for target anteversion cannot be made, as the effect of acetabular anteversion on the wear of various bearing materials is unknown.¹⁴ Yet, as with inclination, ideal anteversion is likely a compromise between maximizing impingement-free ROM and minimizing wear.

The present study had several limitations. A single-surgeon patient series was reviewed retrospectively, and there was no control group. We determined the incidence only of early dislocation, and 5.3% of THAs that were not metal-on-metal were either lost to follow-up or had inadequate radiographs. However, of the patients excluded for inadequate radiographs, none had an early dislocation. The effects of our surgical techniques on long-term outcomes, bearing wear, and dislocation are unknown. We were not able to comment on the direction of dislocation for any of the 6 patients with early dislocation, as all dislocations were reduced at facilities other than our hospital. Therefore, we cannot determine whether increasing acetabular anteversion resulted in a larger number of anterior versus posterior dislocations.¹⁵

We did not use CAS to place any of the femoral components. Therefore, we could not accurately target combined anteversion, defined as the sum of acetabular and femoral version,

which may be an important determinant of THA stability.²⁸ Although restoration of femoral offset and leg length is important in preventing THA dislocation,⁸ the CAS techniques used did not influence these parameters, and they were not measured.

As an imageless navigation system was used, there were no preoperative axial images, which could have been used to assess native acetabular orientation. This limited our assessment with respect to matching each patient's natural anteversion. Imageless navigation, which references only the anterior pelvic plane, may not be reliable in patients with excessive sagittal pelvic tilt.³⁷ Furthermore, changes in the functional position of the pelvis from supine to sitting to standing were not accounted for, and changes in sagittal tilt between these positions can be significant.³⁸ Changes in sagittal pelvic tilt affect measurement of acetabular anteversion on plain radiographs, with anterior tilt reducing apparent anteversion and posterior tilt increasing it.^{32,34} Although postoperative computed tomography is the gold standard for assessing acetabular component orientation, EBRA significantly reduces errors of measurement on plain radiographs.¹⁰ Some variability in measured anteversion may be explained by our surgical technique. In particular, if the cup was uncovered anteriorly, additional anteversion was usually accepted during surgery to minimize anterior impingement and limit the risk of iliopsoas tendonitis.^{16,39}

Our study results suggested that increasing target acetabular anteversion to 25° may reduce the incidence of early postoperative instability relative to rates reported in the literature. Despite the higher accuracy of component placement with an imageless navigation system, dislocations occurred in patients with acetabular components positioned in our target zone and in the historical safe zone. These dislocations support the notion that there likely is no absolute safe range for acetabular component positioning, as THA stability depends on many factors. Ideal targets for implant orientation for acetabulum and femur may be patient-specific.^{16,19} Investigators should prospectively evaluate patient-specific THA component positioning and determine its effect on postoperative dislocation and bearing-surface wear. As specific implant targets are further defined, tools that are more precise and accurate than conventional techniques will be needed to achieve goal component positioning. Our study results confirmed that imageless navigation is an accurate method for achieving acetabular orientation targets.

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