

Acetabular Component Positioning in Primary THA via an Anterior, Posterolateral, or Posterolateral-navigated Surgical Technique

DENIS NAM, MD; PETER K. SCULCO, MD; EDWIN P. SU, MD; MICHAEL M. ALEXIADES, MD; MARK P. FIGGIE, MD; DAVID J. MAYMAN, MD

abstract

Full article available online at Healio.com/Orthopedics. Search: 20131120-10

The purpose of this study was to compare the acetabular component alignment in patients undergoing primary total hip arthroplasty (THA) via 3 surgical techniques: direct anterior using intraoperative fluoroscopy, posterolateral using an external alignment guide (posterolateral conventional), and posterolateral using computer navigation (posterolateral navigated). Two surgeons performed the direct, anterior THAs; 2 surgeons performed the posterolateral-conventional THAs; and 1 surgeon performed the posterolateral-navigated THAs. The most recent 110 THAs performed using each approach were reviewed, and Einsel-Bild-Roentgen analysis software was used to measure the acetabular component abduction and anteversion. One-way analysis of variance showed the anterior cohort to have a more horizontal alignment of the acetabular component ($P < .001$); 90.9% of the acetabular components in the posterolateral-navigated cohort were within $40^\circ \pm 10^\circ$ and $15^\circ \pm 10^\circ$ for both acetabular abduction and anteversion, respectively, vs 70% in the posterolateral-conventional ($P < .001$), and 68.2% in the anterior cohort ($P < .001$). The anterior technique using intraoperative fluoroscopy does not improve acetabular positioning compared with the conventional, posterolateral technique.

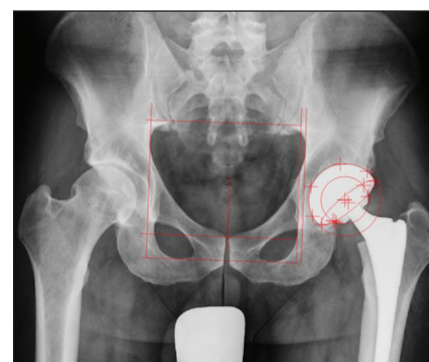


Figure: Postoperative anteroposterior radiograph showing placement of the pelvic gridlines and referencing of the femoral head, acetabular component, and inner rim for Einsel-Bild-Roentgen analysis.

The authors are from Joint Preservation, Resurfacing and Replacement Service (DN), Washington University Orthopedics, Barnes Jewish Hospital, St Louis, Missouri; and the Department of Orthopedics (PKS, EPS, MMA, MPF, DJM), Hospital for Special Surgery, New York, New York.

Dr Nam has stock options in OrthAlign Inc. Drs Sculco and Figgie have no relevant financial relationships to disclose. Dr Su is on the speakers bureau for Smith & Nephew, is a paid consultant for Smith & Nephew, and receives research support from Smith & Nephew and Cool Systems Inc. Dr Alexiades is a paid consultant for Biomet. Dr Mayman is on the speakers bureau and is a paid consultant for Smith & Nephew and has stock options in OrthAlign Inc.

Correspondence should be addressed to: Denis Nam, MD, Joint Preservation, Resurfacing and Replacement Service, Washington University Orthopedics, Barnes Jewish Hospital, 660 S Euclid Ave, Campus Box 8233, St Louis, MO 63310 (namd@wudosis.wustl.edu).

Received: April 15, 2013; Accepted: July 16, 2013; Posted: December 13, 2013.

doi: 10.3928/01477447-20131120-10

Despite the clinical success of primary total hip arthroplasty (THA), postoperative dislocation remains a common complication, with a reported incidence ranging from less than 1% to almost 10%.¹⁻⁵ Although numerous patient and surgical variables influence the overall risk of dislocation, including patient age, sex, body mass index, and surgical approach, appropriate acetabular component orientation has been proven to be critical in limiting this complication.⁴⁻¹⁰ In addition, malpositioning of the acetabular component can increase the risk of linear fractures and the rate of bearing surface wear.⁷ Several studies have suggested an optimal acetabular alignment based on maximizing the range of motion before impingement, with an acceptable anteversion from 0° to 30° and an acceptable abduction from 30° to 50°.^{11,12} Most commonly, the safe zone (anteversion between 5° and 25° and abduction between 30° and 50°) proposed by Lewinnek et al¹³ is targeted intraoperatively based on the increased dislocation risk noted with cup alignment angles outside of this range.

The goal of improving the accuracy of acetabular component positioning has led to the development of computer-assisted surgical (CAS) techniques for THA, and several studies have shown improved results when compared with conventional methods.¹⁴⁻¹⁹ In a cadaveric study in which 150 cups were placed using either a CAS or freehand method, Jolles et al¹⁹ showed a mean error in alignment of 1.5° of abduction and 2.5° of anteversion using a CAS technique vs 10° and 3.5° when using a freehand technique.

Recently, the use of the direct anterior approach to THA has increased, with proposed benefits being, but not limited to, improvements in acetabular component positioning, leg-length equalization, and offset restoration through the use of intraoperative fluoroscopy.²⁰ However, to the current authors' knowledge, no study has compared the results of acetabular component positioning between the direct

anterior, posterolateral, or posterolateral techniques using computer navigation. The purpose of this study was to compare the acetabular component alignment in patients undergoing primary THA via 3 surgical techniques: anterior, posterolateral (posterolateral conventional), and posterolateral using computer navigation (posterolateral navigated). The primary hypothesis of the current authors was that the direct, anterior technique with intraoperative fluoroscopy will improve the accuracy of acetabular component positioning compared with the posterolateral-conventional technique but be less accurate than the posterolateral-navigated technique.

MATERIALS AND METHODS

This study is a retrospective review of the radiographic results from an institutional review board–approved database. One hundred ten patients who received a direct, anterior THA and met the inclusion criteria were available for review. The most recent 110 patients who received a posterolateral-conventional and posterolateral-navigated THA and met the inclusion criteria were included for comparison cohorts. Two surgeons performed the direct, anterior THAs; 2 surgeons performed the posterolateral-conventional THAs; and 1 surgeon performed the posterolateral-navigated THAs. In both the anterior and posterolateral-conventional cohorts, 1 surgeon performed 70 of the THAs, whereas the other surgeon performed 40 of the THAs. In the anterior cohort, the surgeon who contributed 70 THAs has performed over 200 THAs annually using the anterior approach since 2009, whereas the surgeon who contributed 40 THAs had previously performed over 50 THAs using the anterior approach. Two surgeons were included in these cohorts to avoid analyzing the results of a single surgeon's technique. Only 1 surgeon was included in the posterolateral-navigated cohort because there is only 1 surgeon who consistently performs computer-navigated THAs at our institution. All surgeons included in

this database are high-volume, fellowship-trained arthroplasty surgeons who perform greater than 200 THAs annually using their respective, surgical technique.

Inclusion criteria for this study were patients with a primary diagnosis of osteoarthritis, rheumatoid arthritis, post-traumatic arthritis, avascular necrosis, or developmental dysplasia of the hip (Crowe I or II)²¹ who underwent primary, unilateral THA. Exclusion criteria included patients undergoing revision THA, patients with significant scoliotic deformities, and patients with developmental dysplasia of the hip (Crowe III or IV). Scoliotic deformities were assessed on lumbar radiographs in patients with a history of lower back pain or a prior lumbar surgery. If a patient possessed a deformity in which the center sacral vertical line did not pass between the pedicles of the apex of the lumbar curve,²² they were excluded from the study.

The anterior approach cohort consisted of 39 men and 71 women (56 right and 54 left), the posterolateral-conventional cohort consisted of 45 men and 65 women (62 right and 48 left), and the posterolateral-navigated cohort consisted of 56 men and 54 women (49 left and 61 right). The primary diagnoses for each cohort are presented in the **Table**. All patients in both the anterior and posterolateral-navigated cohorts had cementless fixation of both the acetabular and femoral components, whereas 14 patients in the posterolateral-conventional cohort had cement fixation of the femur. All patients received cementless fixation of the acetabular component using 1 of 3 different acetabular designs (R3; Smith & Nephew, Memphis, Tennessee; Trilogy; Zimmer, Inc, Warsaw, Indiana; and RingLoc; Biomet, Inc, Warsaw, Indiana).

For all patients in each cohort, preoperative templating of the femoral and acetabular components was performed as described by Della Valle et al.²³ In the anterior approach cohort, both surgeons used the same surgical technique. The pa-

tient was placed supine on the operating room table with the table parallel to the operating room floor, and both legs were sterilely prepared and draped. A conventional, radiolucent table was used for each surgery. A straight incision beginning approximately 2 cm posterior and 1 cm distal to the anterior superior iliac spine and extending distal and slightly posterior for a total of 10 cm was made. The interval between the tensor fascia latae and the sartorius was developed superficially, and a cobra retractor was placed over the superolateral aspect of the femoral neck. The sartorius and underlying rectus femoris were retracted medially using a Hibbs retractor, and the iliopsoas and the reflected head of the rectus femoris were elevated off the anterior capsule.

Hemostasis, including cauterization of the lateral femoral circumflex vessels, was obtained, and an anterior capsulotomy was created for exposure of the femoral head and neck. Using intraoperative fluoroscopy, the neck resection was performed at the templated location with the femoral head still located in the acetabulum. A second resection was performed at the subcapital region of the femoral head, and the interposed femoral neck and head were removed separately using a threaded Steinmann pin. Intraoperative, anteroposterior (AP) fluoroscopy was used during acetabular preparation to determine the appropriate alignment and medialization of the acetabular reamer. No external alignment guides were used to determine the acetabular alignment other than the insertion handle's position relative to the floor in the sagittal plane (operative anteversion) and the handle's position relative to the horizontal axis in the coronal plane (operative abduction).⁹ During impaction of the trial and final acetabular implants, AP fluoroscopy was again used to assess alignment and medialization of the component. At the surgeon's discretion, fluoroscopic views were printed and transparent templates were overlaid as a secondary check to confirm appropriate acetabular alignment.

Table			
Primary Diagnosis of Patients Undergoing Total Hip Arthroplasty in Each Cohort			
Primary Diagnosis	No.		
	Direct Anterior	Posterolateral Conventional	Posterolateral-navigated
Osteoarthritis	106	104	95
Rheumatoid arthritis	1	2	4
Developmental dysplasia of the hip	2	3	4
Avascular necrosis	1	1	6
Prior femoral neck or intertrochanteric fracture	0	0	1

In the posterolateral-conventional cohort, the patient was placed in the lateral decubitus position, with both surgeons using the same surgical technique and external alignment guide. During positioning of the patient, care was taken to ensure that the pelvis and torso were aligned perpendicular to the operating room table and floor. Acetabular preparation was performed in the standard fashion, with reaming performed in the intended direction of acetabular abduction and anteversion. During placement of the trial and final acetabular implants, an X-bar-type, external alignment guide was used to assist with positioning of the component (**Figure 1**). Alignment of the longitudinal axis of the X-bar with the longitudinal axis of the patient assists with setting the operative anteversion of the acetabular component (if aligned, the operative anteversion is 20°). In addition, the relationship between the longitudinal axis of the X-bar with the operating room table assists with setting the operative abduction of the acetabular component (if parallel, the operative abduction is 45°). At their discretion, each surgeon used intraoperative anatomic landmarks, such as the transverse acetabular ligament, pubis, and amount of lateral under- or overcoverage of the acetabular component (based on preoperative templating), to guide acetabular alignment.

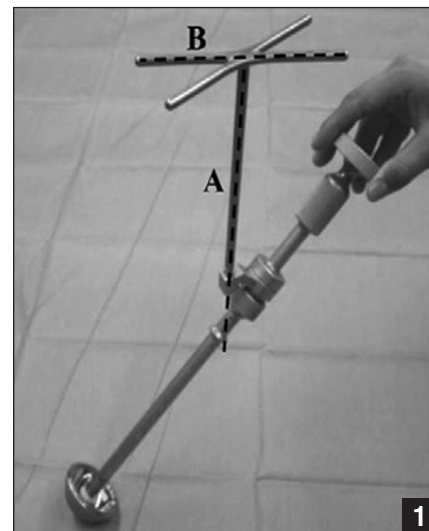


Figure 1: Photograph of an X-bar type, external alignment guide used for positioning of the acetabular component in the conventional posterolateral cohort. Alignment of the longitudinal axis of the X-bar (line B) with the longitudinal axis of the patient sets the acetabular component anteversion to 20°. (Reprinted from *Journal of Arthroplasty*, 25[6], Minoda Y, Ohzono K, Aihara M, et al. Are acetabular component alignment guides for total hip arthroplasty accurate? 986-989, Copyright 2010, with permission from Elsevier.)

In the posterolateral-navigated cohort, an imageless computer-assisted surgery system (AchieveCAS, Smith & Nephew Inc) was used intraoperatively in all patients. Before positioning the patient in the lateral decubitus position, 2 Steinmann

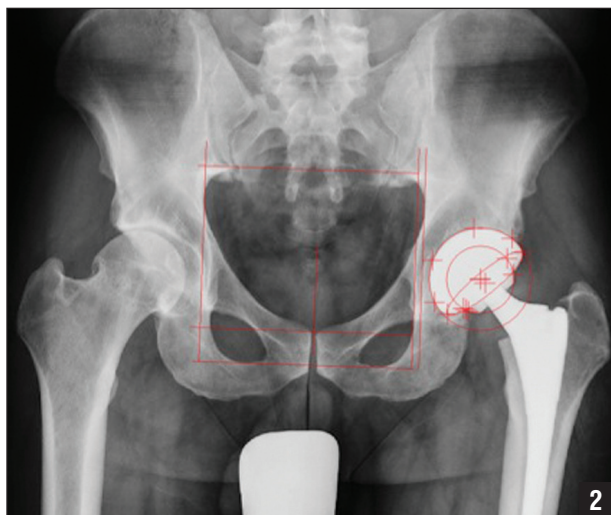


Figure 2: Postoperative anteroposterior radiograph showing placement of the pelvic gridlines and referencing of the femoral head, acetabular component, and inner rim for Einsel-Bild-Roentgen analysis.

pins were placed in the iliac crest for the placement of a pelvic array, and landmark registration of the anterior pelvic plane was performed (both the anterior superior iliac spine and the pubic symphysis). The patient was then placed in the lateral decubitus position to perform a standard, posterolateral exposure. Before acetabular preparation, the articular surface of the acetabulum was registered using the tracking pointer to determine the native acetabular center and native alignment. During acetabular preparation and placement of the final acetabular implant, a tracking array was placed on the insertion handle, enabling the navigation system to register and display the acetabular abduction and anteversion based on the anterior pelvic plane. The surgeon used the adjusted anteversion function, accounting for pelvic tilt, to guide alignment of the acetabular component. Intraoperative radiographs or fluoroscopy were not used in any of the patients in the posterolateral-navigated or posterolateral-conventional cohorts.

For each patient, the postoperative radiographic abduction and anteversion of the acetabular component as defined by Murray⁹ were assessed using AP radiographs of the pelvis (PACS; Sectra Imtec AB, Linköping, Sweden). These

spherical femoral head and the elliptical cup are marked using 4 reference points for the femoral head, 4 reference points for the outer surface of the cup, and 3 reference points for the inner rim of the cup (**Figure 2**). Accounting for the femoral head and acetabular component sizes, EBRA then calculates the spatial position of the center of the cup in relation to the plane of the radiograph and the pelvic position.² The radiographic abduction and anteversion are then reported. Although initially developed to measure the migration of acetabular components, Stockl et al²⁴ previously validated the accuracy of measurement of anteversion and abduction of the acetabular component on a single radiograph using EBRA analysis. All radiographic measurements were independently measured by 2 observers blinded to the treatment arms, and the results were assessed for interobserver reliability. Although the specific goal for acetabular alignment varied among the surgeons based on each patient's native anatomy and surgical approach, all acetabular components were implanted with the intent of being within the safe zone described by Lewinnek et al¹³ ($40^{\circ} \pm 10^{\circ}$ of radiographic abduction and $15^{\circ} \pm 10^{\circ}$ of

radiographs were obtained at each patient's first postoperative clinic visit (typically 6 weeks postoperatively). Einsel-Bild-Roentgen analysis (EBRA) was used to measure the acetabular component abduction and anteversion as previously described by Biedermann et al.² The contours of the pelvis are first marked using defined grid lines to calculate the pelvic position at the time of radiograph exposure. Sequentially, the projection of the

radiographic anteversion). Surgeons using the posterolateral surgical technique also considered the concept of combined femoral and acetabular version during acetabular positioning, but, again, all acetabular components were implanted with the goal of being within Lewinnek's safe zone.

All data were collected and analyzed using Microsoft Excel software (Microsoft Corporation, Redmond, Washington). Statistical comparisons between the 3 cohorts were performed using 1-way analysis of variance with statistical significance set at *P* less than .05.

The number of outliers in each cohort, with respect to acetabular abduction and anteversion, were determined. An outlier was defined as an acetabular component having either an abduction or anteversion alignment outside its respective safe zone. Fisher's exact test was used to compare the number of abduction and anteversion outliers in each cohort, with statistical significance set at a *P* value less than .05. Furthermore, Fisher's exact test was used to compare the number of outliers for each of the 2 surgeons in both the anterior and posterolateral-conventional cohorts. This was done to determine if 1 surgeon was accountable for more outliers than the other in each respective cohort.

Interclass correlation coefficients for postoperative radiographic measurements were graded using previously described semiquantitative criteria: excellent for $.9 \leq P \leq 1.0$, good for $.7 \leq P \leq .89$, fair/moderate for $.5 \leq P \leq .69$, low for $.25 \leq P \leq .49$, and poor for $.0 \leq P \leq .24$.²⁵

Because 110 patients were available for review in each cohort, a post hoc power analysis showed that the minimal effect size detectable with appropriate power (beta level=0.80, alpha level=0.05) was a 14% difference in the number of outliers for both acetabular abduction and anteversion between the cohorts.

RESULTS

The mean age of the patients in the posterolateral-navigated cohort was sig-

nificantly younger than in the anterior or posterolateral-conventional cohorts, with a mean age of 58.6 ± 11.7 years vs 66.7 ± 11.9 years and 66.8 ± 11.1 years, respectively ($P \leq .01$). No statistically significant difference was appreciated in the mean body mass index of the 3 cohorts (29.8 ± 6.5 kg/m², 28.3 ± 5.8 kg/m², and 27.4 ± 5.9 kg/m², respectively; $P = .1$).

The mean acetabular abduction was $39.2 \pm 6.6^\circ$ in the anterior cohort, which was significantly less than the posterolateral-conventional ($44.1 \pm 5.1^\circ$) and posterolateral-navigated ($44.5 \pm 3.9^\circ$) cohorts ($P < .001$); 95.5% of acetabular components were within the safe zone for acetabular abduction in the posterolateral-navigated cohort vs 86.4% in the posterolateral-conventional and 89.1% in the anterior cohorts. Fisher's exact test revealed a statistically significant difference in the number of outliers for acetabular abduction between the posterolateral-navigated and posterolateral-conventional cohorts ($P = .03$), but not between the posterolateral-navigated and anterior ($P = .12$) or posterolateral-conventional and anterior cohorts ($P = .68$).

Mean acetabular anteversion was $21.4 \pm 5.8^\circ$ in the anterior, $20.3 \pm 6.1^\circ$ in the posterolateral-conventional, and $20.0 \pm 3.3^\circ$ in the posterolateral-navigated cohorts ($P = .11$); 95.5% of acetabular components were within the safe zone for acetabular anteversion in the posterolateral-navigated cohort vs 79.1% in both the posterolateral-conventional and anterior cohorts. Fisher's exact test revealed a statistically significant improvement in the number of outliers for acetabular anteversion in the posterolateral-navigated cohort when compared with both the posterolateral-conventional and anterior cohorts ($P \leq .001$ and $P \leq .001$, respectively). However, no significant difference in outliers for acetabular anteversion was seen between the posterolateral-conventional and anterior cohorts ($P = 1.0$).

In the posterolateral-navigated cohort, 90.9% of acetabular components were within the safe zone for both acetabular

abduction and acetabular anteversion vs 70.0% in the posterolateral-conventional and 68.2% in the anterior cohort. Fisher exact tests revealed a statistically significant improvement in the number of outliers for either abduction or anteversion in the posterolateral-navigated cohort vs both the posterolateral-conventional and anterior cohorts ($P \leq .001$ and $P \leq .001$, respectively). However, no significant difference was observed between the posterolateral-conventional and anterior cohorts ($P = .88$).

No significant difference existed in the proportion of outliers between the 2 surgeons in the anterior cohort for either acetabular abduction or anteversion ($P = .6$ to 1.0). Similarly, there was no significant difference in the proportion of outliers between the 2 surgeons in the posterolateral-conventional cohort for either acetabular abduction or anteversion ($P = .14$ to $.30$). The interobserver correlation for acetabular abduction was excellent with a value of 0.91, whereas the correlation for acetabular anteversion was good with a value of 0.86.

DISCUSSION

The orientation of the acetabular component in THA has significant effects on the clinical outcome because acetabular component malpositioning can increase the rate of bearing surface wear and predispose a patient to instability.^{2,4,26-28} Most commonly, external alignment guides are used to aid with component positioning. However, Callanan et al⁷ showed in a series of 1823 THAs performed at a tertiary care facility that 50% of the components were within the safe zone for both acetabular abduction and anteversion. The desire for increased alignment accuracy stimulated the development of computer-assisted techniques, which have shown superior results.^{14,15,17,19,29,30} Recently, it has been suggested that the anterior approach to THA may also improve acetabular component alignment because intraoperative fluoroscopy is used to aid

with component placement. However, this study shows that the use of intraoperative fluoroscopy with the anterior approach does not improve acetabular component alignment when compared with the conventional, posterolateral technique, whereas computer-assisted navigation remains the most accurate method.

Matta et al²⁰ previously reported a series of 494 primary THAs performed via the direct anterior approach using intraoperative fluoroscopy. Radiographic analysis showed a mean abduction angle of 42° with 96% between 35° and 50° and a mean anteversion angle of 19° with 93% within the target range of 10° to 25° . In this study, the anterior approach technique was unable to reproduce these results, with 89.1% of components having an abduction angle between 30° and 50° and 79.1% of components having an anteversion angle between 5° and 25° .

Each surgical technique described is subject to sources of error and technical obstacles. With the anterior approach, the use of intraoperative fluoroscopy can be subject to error because subtle rotations of the pelvis can affect the fluoroscopic views obtained, and it may be difficult to obtain a single fluoroscopic view of the entire pelvis to assess component orientation. Regarding the use of computer navigation, this technique depends on the appropriate registration of anatomic landmarks (which may be more difficult in obese patients) and thus is subject to variability. Lastly, external alignment guides (as with the posterolateral-conventional technique) are also susceptible to error because they rely on appropriate patient positioning, and intraoperative pelvic and body motion can affect their accuracy. However, despite these limitations, overall the results achieved in all 3 cohorts in this study were comparable or superior to those reported by Callanan et al,⁷ who noted only 63% of acetabular cups to be within the abduction range and 79% of acetabular cups to be within the anteversion range.

However, there are several limitations to this study. First, although all acetabular components were placed with the intent of being within the safe zone for both abduction and anteversion, each surgeon may intraoperatively decide to adjust his/her intraoperative goal for alignment on a case-by-case basis. Unfortunately, each surgeon's intraoperative goal for alignment was not recorded although each surgeon did intend for each acetabular component to be within Lewinnek's safe zone.¹³ A second limitation is that only 2 surgeons were included in both the anterior and posterolateral-conventional cohorts, and 1 surgeon was included in the posterior-navigated cohort. Therefore, given the limited number of surgeons included in this study, the results obtained can be affected by each surgeon's technique.

All surgeons included in this study specialize in adult reconstruction and have a significant amount of clinical experience using their respective surgical techniques. Therefore, comparing the results of these high-volume arthroplasty surgeons may indicate whether a difference in accuracy in acetabular component alignment truly exists. Furthermore, there was no significant difference in the proportion of outliers contributed by each surgeon in the anterior and posterolateral-conventional techniques, indicating that each surgeon obtained a similar degree of accuracy. Lastly, all measurements were performed using AP pelvis radiographs and EBRA analysis. Although this is a validated method for measuring both acetabular abduction and anteversion, 3-dimensional analysis using computed tomography might provide more precise results.² However, despite these limitations, this study shows that the use of intraoperative fluoroscopy with the anterior approach does not decrease the incidence of outliers in component alignment compared with the conventional, posterolateral technique, whereas the use of computer navigation significantly improves the accuracy of acetabular component positioning. ■

REFERENCES

1. McCollum DE, Gray WJ. Dislocation after total hip arthroplasty. Causes and prevention. *Clin Orthop Relat Res.* 1990; 261:159-170.
2. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stockl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. *J Bone Joint Surg Br.* 2005; 87:762-769.
3. Fackler CD, Poss R. Dislocation in total hip arthroplasties. *Clin Orthop Relat Res.* 1980; 151:169-178.
4. Morrey BF. Instability after total hip arthroplasty. *Orthop Clin North Am.* 1992; 23:237-248.
5. Morrey BF. Difficult complications after hip joint replacement. Dislocation. *Clin Orthop Relat Res.* 1997; (344):179-187.
6. Sadr Azodi O, Adami J, Lindstrom D, Eriksson KO, Wladis A, Bellocco R. High body mass index is associated with increased risk of implant dislocation following primary total hip replacement: 2,106 patients followed for up to 8 years. *Acta Orthop.* 2008; 79:141-147.
7. Callanan MC, Jarrett B, Bragdon CR, et al. The John Charnley Award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. *Clin Orthop Relat Res.* 2011; 469:319-329.
8. Sanchez-Sotelo J, Berry DJ. Epidemiology of instability after total hip replacement. *Orthop Clin North Am.* 2001; 32:543-52, vii.
9. Murray DW. The definition and measurement of acetabular orientation. *J Bone Joint Surg Br.* 1993; 75:228-232.
10. Conroy JL, Whitehouse SL, Graves SE, Pratt NL, Ryan P, Crawford RW. Risk factors for revision for early dislocation in total hip arthroplasty. *J Arthroplasty.* 2008; 23:867-872.
11. Kummer FJ, Shah S, Iyer S, DiCesare PE. The effect of acetabular cup orientations on limiting hip rotation. *J Arthroplasty.* 1999; 14:509-513.
12. Widmer KH, Zurfluh B. Compliant positioning of total hip components for optimal range of motion. *J Orthop Res.* 2004; 22:815-821.
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. Sendtner E, Schuster T, Worner M, Kalteis T, Grifka J, Renkawitz T. Accuracy of acetabular cup placement in computer-assisted, minimally-invasive THR in a lateral decubitus position. *Int Orthop.* 2011; 35:809-815.
15. Nogler M, Kessler O, Prassl A, et al. Reduced variability of acetabular cup positioning with use of an imageless navigation system. *Clin Orthop Relat Res.* 2004; 426:159-163.
16. Wixson RL, MacDonald MA. Total hip arthroplasty through a minimal posterior approach using imageless computer-assisted hip navigation. *J Arthroplasty.* 2005; 20:51-56.
17. Bosker BH, Verheyen CC, Horstmann WG, Tulp NJ. Poor accuracy of freehand cup positioning during total hip arthroplasty. *Arch Orthop Trauma Surg.* 2007; 127:375-379.
18. Jaramaz B, DiGioia AM III, Blackwell M, Nikou C. Computer assisted measurement of cup placement in total hip replacement. *Clin Orthop Relat Res.* 1998; 354:70-81.
19. Jolles BM, Genoud P, Hoffmeyer P. Computer-assisted cup placement techniques in total hip arthroplasty improve accuracy of placement. *Clin Orthop Relat Res.* 2004; 426:174-179.
20. Matta JM, Shahrardar C, Ferguson T. Single-incision anterior approach for total hip arthroplasty on an orthopaedic table. *Clin Orthop Relat Res.* 2005; 441:115-124.
21. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. *J Bone Joint Surg Am.* 1979; 61:15-23.
22. Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am.* 2001; 83:1169-1181.
23. Della Valle AG, Padgett DE, Salvati EA. Preoperative planning for primary total hip arthroplasty. *J Am Acad Orthop Surg.* 2005; 13:455-462.
24. Stockl B, Biedermann R, Auckenthaler T. Ante- and retroversion measurements of cups by EBRA. *J Bone Joint Surg Br.* 2001; 83(suppl 2):179.
25. Munro BH. Correlation. In: *Statistical Methods for Healthcare Research.* 3rd ed. Philadelphia, PA: Lippincott-Raven; 1997:224-245.
26. Ali Khan MA, Brakenbury PH, Reynolds IS. Dislocation following total hip replacement. *J Bone Joint Surg Br.* 1981; 63:214-218.
27. Dorr LD. Acetabular cup position: the imperative of getting it right. *Orthopedics.* 2008; 31:898-899.
28. McCollum DE, Gray WJ. Dislocation after total hip arthroplasty. Causes and prevention. *Clin Orthop Relat Res.* 1990; 261:159-170.
29. Nogler M, Mayr E, Krismer M, Thaler M. Reduced variability in cup positioning: the direct anterior surgical approach using navigation. *Acta Orthop.* 2008; 79:789-793.
30. Broers H, Jansing N. How precise is navigation for minimally invasive surgery? *Int Orthop.* 2007; 31(suppl 1):S39-S42.