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The John Charnley Award

Risk Factors for Cup Malpositioning

Quality Improvement Through a Joint Registry at a Tertiary Hospital

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Abstract

Background Few studies have examined factors that affect acetabular cup positioning. Since cup positioning has been linked to dislocation and increased bearing surface wear, these factors affecting cup position are important considerations.

Question/purposes We determined the percent of optimally positioned acetabular cups and whether patient and surgical factors affected acetabular component position.

Methods We obtained postoperative AP pelvis and cross-table lateral radiographs on 2061 consecutive patients who received a THA or hip resurfacing from 2004 to 2008. One thousand nine hundred and fifty-two hips had AP pelvic radiographs with correct position of the hip center, and 1823 had both version and abduction angles measured. The AP radiograph was measured using Hip Analysis Suite™ to calculate the cup inclination and version angles, using the lateral film to determine version direction. Acceptable ranges were defined for abduction (30°–45°) and version (5°–25°).

Results From the 1823 hips, 1144 (63%) acetabular cups were within the abduction range, 1441 (79%) were within the version range, and 917 (50%) were within the range for both. Surgical approach, surgeon volume, and obesity (body mass index > 30) independently predicted malpositioned cups. Comparison of low versus high volume surgeons, minimally invasive surgical versus posterolateral approach, and obesity versus all other body mass index groups showed a twofold (1.5–2.8), sixfold (3.5–10.7), and 1.3-fold (1.1–1.7) increased risk for malpositioned cups, respectively.

Conclusions Factors correlated to malpositioned cups included surgical approach, surgeon volume, and body mass index with increased risk of malpositioning for minimally invasive surgical approach, low volume surgeons, and obese patients. Further analyses on patient and surgical factors' influence on cup position at a lower volume medical center would provide a valuable comparison.

Level of Evidence Level II, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Introduction

A variety of patient and surgical factors have been linked to a risk of various postoperative complications following THA. Patient factors influencing an increased rate of dislocation, liner fracture, and increased wear included body mass index (BMI) [46], age [33, 39, 47], gender [33, 47], and primary diagnosis for the THA [10, 47]. Surgical factors influencing these risks include performing surgeon experience [5, 47], surgical approach [2, 9, 13, 28, 34, 47], prosthetic components [3, 18, 20, 22, 33, 35, 47], acetabular cup fixation method [10], and orientation of the acetabular cup [22, 33, 47].

The orientation of the acetabular cup in a primary THA is important to low dislocation rates, liner fracture, and wear. While several studies suggest optimal orientation ranges, most indicate acceptable anteversion from 0° to 30° [23, 26, 54] and acceptable inclination from 30° to 50° [26, 54]. Cup angles that stray outside the optimal ranges are linked to those complications, the most common being dislocation of the prosthesis [1, 4, 20, 23, 26, 33, 42, 54]. Dislocations affect an estimated 1% to 5% of THAs performed [7, 17, 39]. Cup orientations that fall within the acceptable ranges have much lower incidence of all types of dislocations [26]. High angles of inclination (55°–69°) are linked to higher rates of dislocation and recurrent dislocations. Highly anteverted cups correlate with an increased incidence of anterior dislocation while retroverted cups correlate with an increased risk of posterior dislocation [20, 26, 39]. A commonly used range of acceptable angles is the safe zone established by Lewinnek et al. (5°–25° of anteversion and 30°–50° of abduction), which is based on an increased dislocation risk for angles outside of these ranges [26].

Impingement of the prosthetic joint can also be caused by malpositioning of the acetabular cup and can lead to dislocation and liner cracking [1, 50, 54, 56].

Component wear also correlates with the position of the acetabular cup. Higher rates of wear are linked to higher angles of cup abduction, which can cause edge loading [56]. Increased wear debris from the bearing surface can lead to osteolysis and aseptic loosening of the joint [6, 16, 21]. This increased wear can be seen in both hard-on-soft and hard-on-hard bearing surfaces [11, 14, 25, 38]. Importantly, recent reports on metal-on-metal bearings describe an increased risk of tissue reactions around these bearings related to metal debris from edge loading of cups [29, 41]. Increased wear and edge loading have been linked to abduction angles of greater than 45° [25].

There are many ways to calculate cup abduction and version angles. Digital image analysis programs using edge detection such as Martell Hip Analysis Suite™ (HAS, Chicago, IL) have been used to accurately measure wear of polyethylene liners in hip prosthesis by comparing followup AP radiographs back to the postoperative AP radiograph [7, 17]. Since calculating cup orientation is crucial in aligning films from different time points to accurately determine wear, HAS provides an effective way to accurately determine abduction and version angles of the acetabular cup. These angles can be obtained from a single postoperative radiograph.

Several studies have identified factors influencing cup positioning. In a prospective analysis of 200 cups, orthopaedic surgeons and residents were asked to hit goal targets for abduction and version angles [5]. That study concluded the mean inaccuracies of estimation were 4.1° and 6.3° in abduction and 5.2° and 5.7° in version for surgeons and residents, respectively. Using a multivariate analysis the authors concluded the age of the patient and a surgery performed by an orthopaedic surgeon compared to a resident were predictors of inaccuracy in estimation of cup positioning. Variables included in the analysis but not linked to inaccurate estimation were BMI, gender, operated side, acetabular fixation method, cup model, and surgical approach [5]. Another study considered the effect of surgical experience on cup positioning and observed no difference between experienced and inexperienced surgeons for 85 cups [45]. Differences in BMI were compared to acetabular cup angles in 111 patients, resulting in no differences between abduction and version angles for healthy, overweight, and obese patients [53]. Thus, while many studies have linked patient and surgical factors to postoperative complications, none have examined the influence of these factors on the positioning of the acetabular cup in a large population. Clinically, linking these factors to suboptimal cup position will allow surgeons to identify combinations of factors that could increase risk for malpositioning.

We designed this study to determine (1) the number of optimally positioned acetabular cups in a large patient sample at a teaching hospital based on various patient and surgical factors; and (2) independent predictors of malpositioned cups, and to use those predictors to calculate odds ratios for increased risk of malpositioning and construct a table describing the percent chance of a malpositioned cup based on combinations of those prediction factors.

Patients and Methods

Using the local joint registry at Massachusetts General Hospital, we identified all 1750 patients (2061 hips) who underwent a primary THA, Birmingham hip resurfacing, or revision THA from 2004 through 2008. The database was used to obtain patient information from each THA including laterality of operated hip, age, performing surgeon, gender, BMI, femoral head size, acetabular cup outer diameter, acetabular cup fixation method, surgical approach, and preoperative diagnosis. Patients were required to have both a digital postoperative AP pelvic radiograph and a digital shoot-through lateral hip radiograph in DICOM format to be included in the final analysis for both cup abduction and version angles. This study was IRB approved.

Of the 1750 patients (2061 hips) having a THA or resurfacing during the 4 year period, we excluded 99 patients with 109 THAs (5%): 42 did not have a postoperative AP pelvic radiograph and 42 had AP pelvic radiographs that could not be read by HAS; three hips, all operated by the same surgeon, were excluded due to the small sample size for that surgeon; 22 additional hips we excluded because they were fixed using cement, the majority of which were all-polyethylene cups, which cannot be read using HAS. This left 1952 hips for analysis. Of these, we measured the acetabular cup abduction angle using mDesk™ (RSA Biomedical, Umea, Sweden) in 39 (2%) because HAS could not analyze hip resurfacings and was unable to read one film because the angle was too high. An additional 90 (4.6% of 1952 remaining) were missing a shoot-through lateral hip radiograph, which did not allow for a determination of the sign of the version. These 129 hips were only used in the final analysis of abduction angle. Thus, we used 1952 hips in the analysis of abduction, 1823 hips in the version analysis, and 1883 hips when malpositioning was determined using both abduction and version (60 hips were outside of the acceptable abduction range and therefore were considered malpositioned based on abduction and version without knowing the version angle). The 1883 hips qualifying for the combined analysis represented a total of 1719 patients, 858 (50%) of which were female and 861 (50%) of which were male. The mean patient age was 66 ± 12.8 years (range, 21–96 years), and the average BMI was 28.1 ± 5.3 (range, 12.2–77.2).

The AP pelvic radiograph was measured using HAS Version 8.0.4.1 (Martell Hip Analysis Suite™, Chicago, IL) to calculate the cup inclination and version angles. Using only the AP film, HAS is unable to determine whether the cup is anteverted or retroverted. The sign value (positive for anteversion, negative for retroversion) of the version angle was determined from the shoot-through lateral using mDesk™ software (RSA Biomedical Inc, Umea, Sweden).

To determine the accuracy of calculating the abduction angle from mDesk™ compared to HAS, all patients from 2007 (n = 345) had their abduction angles measured in both HAS and mDesk™. Abduction angles from both programs were plotted against each other, and the correlation was determined using the Pearson R. The abduction angles from HAS and mDesk™ correlated (0.992 and a slope of 0.99) with one another. The 95% confidence interval for abduction angles in HAS was ± 1.66°. To ensure accuracy and repeatability of the reader, a set of 20 paired (postoperative, followup) AP pelvic radiographs were each read three times. Repeated readings by the sole reader were entered into a gauge repeatability and reproducibility test. All film pairs were required to be reread until the reader had at least three distinct categories, and all readings were within one SD of the previous readings. All measurements used in the study were completed by a single reader (MC). Acceptable angle ranges were set at 30° to 45° for abduction and 5° to 25° for version based on surgeon consensus and standards from previous studies [12, 25, 26, 54].

For the statistical analyses, ages at surgery were divided into three groups: less than 50 years, 50 to 70 years, and older than 70 years. BMI groups were based on classifications from the World Health Organization with a BMI of less than 18.5 being underweight, between 18.5 and 24.99 normal, greater than or equal to 25 overweight, and greater than or equal to 30 obese. A total of 290 (15%) hips did not have data for BMI and were therefore omitted from the analysis with respect to this variable. Femoral head size was categorized as less than 32 mm, 32 mm, and greater than 32 mm. Acetabular cup outer diameters were analyzed as a continuous variable, and the outer diameters of two hips were unavailable. The acetabular fixation method was divided into groups of press fit without screws or press fit with screws. A total of 21 hips did not have data for their fixation method and were omitted from the analysis with respect to fixation. Four approach categories were used, including the anterolateral, posterolateral, direct lateral, and minimally invasive surgical (MIS) approach (53 hips operated with a two-incision MIS, and 42 operated with muscle-sparing anterolateral MIS). A total of 10 hips did not have information on approach and were omitted from the analysis of this variable. Diagnosis was divided into five groups: avascular necrosis/fracture, osteoarthritis, congenital/developmental dysplasia, revision THA, and other (tumors, inflammatory disease, or metabolic diagnosis). Two surgeons performed the highest volume of the THAs, with one performing 1047 (53.5%) and the second performing 591 (30%). The number of THAs contributed by the remaining five surgeons were 97 (5%), 95 (5%), 47 (2%), 42 (2%), and 33 (1.5%). Surgeons were divided into a high-volume group (two surgeons with 1638 THAs, (84%) and a low-volume group (the remaining five surgeons with 314 THAs, 16%). Surgeons in the low-volume group were all experienced, fellowship-trained surgeons, some of which had been high volume surgeons earlier in their career.

Patient and surgical factors were correlated to acceptable abduction and version angles independently and to malpositioning of the cup based on either an abduction or version angle outside of the acceptable range. A univariate cross-tabulation was used to identify factors that could correlate to malpositioning. Patient and surgeon factors that were independent predictors of unacceptable abduction angles, unacceptable version angles, and malpositioned cups based on both abduction and version angles were determined using a stepwise multivariate logistic regression. An odds ratio for the increased chance of malpositioning was calculated for all factors identified from the multivariate analyses. These ratios indicate the increased risk of malpositioning based on different subcategories within prediction factors. To calculate odds ratios, variables were compared to the most accurate subcategory within each factor. Also, using generalized estimating equations with a binomial distribution and a logistic link function, a chart was created giving the percentage chance that an acetabular cup will be placed with an abduction or version angle outside of the optimal ranges given a certain set of risk factors. Correlations were considered significant when the p value was less than 0.05, and all statistical analyses were performed in SPSS (IBM, Chicago, IL).

Results

For the entire data set of 1952 hips, the average abduction and version angles were 42.2° ± 6.8° and 12.7° ± 7.4°, respectively. Abduction angles ranged from 21.07° to 72.52° and version angles ranged from −16.72° to 43.00°. Ten variables were analyzed for correlation with cup positioning. A breakdown of these variable groups as well as the percentages of each which fell within the window of acceptable ranges for abduction and version is shown (Table 1). There were 1213 (62%) acetabular cups that fell within the 30° to 45° optimal abduction range, and 1441 cups (79%) within the 5° to 25° optimal version range. A total of 13 hips (0.7%) had retroverted acetabular cups. There were 917 hips (47% of 1883) that had both inclination and version angles that fell within the set optimal range. The number of hips in each abduction and version angle range showed a nearly normal distribution, with a slight skew toward anteversion in the version data (Table 2). A scatter plot of abduction and version angles with a window indicating the boundary of the optimal cup angles shows each hip's position (Fig. 1). A similar plot for revisions shows that 57% of the cups were optimally positioned (Fig. 2). Scatter plots for posterolateral (Fig. 3), anterolateral (Fig. 4), and MIS approaches (Fig. 5) clearly show the differences in accuracy of the different approaches and the trend toward high abduction and low version angles with the anterolateral and MIS approaches.

Surgical approach and BMI were the only variables that were indicators for malpositioning of abduction, version, and combined abduction and version in the multivariate analyses (Table 3). Head size and surgeon volume were also variables identified in the multivariate analyses. Independent predictors for malpositioning in abduction only or in abduction and version combined were BMI (categorized as obese versus not obese), surgical approach, and surgeon volume. For version alone, head size replaced surgeon volume as an independent indicator of angles outside the acceptable range. The most accurate subcategories within each independent predictor used to create odds ratios were not obese for BMI, less than 32 mm for head size, high volume for surgeon volume, and posterolateral for approach. The odds ratios are the increased risk of malpositioning in abduction, version, or both based on the category of that prediction factor

Table 1. Univariate analysis of 10 possible prediction factors based on hips falling within the window of acceptable abduction and version angles

Factor	Number of hips		
	Total (n = 1883)	Within window (n = 917, 48.7%)	Malpositioned (n = 966, 51.3%)
Age group			
< 50 years	201	86 (42.8%)	115 (57.2%)
50–70 years	912	441 (48.4%)	471 (51.6%)
> 70 years	770	390 (50.6%)	380 (49.4%)
Gender			
Female	941	467 (49.6%)	474 (50.4%)
Male	942	450 (47.8%)	492 (52.2%)
Body mass index (n = 1603)			
Underweight	32	19 (59.4%)	13 (40.6%)
Normal	403	197 (48.9%)	206 (51.1%)
Overweight	681	346 (50.8%)	335 (49.2%)
Obese	487	217 (44.6%)	270 (55.4%)
Head size			
< 32 mm	366	210 (57.4%)	156 (42.6%)
32 mm	1308	632 (48.3%)	676 (51.7%)
> 32 mm	209	75 (35.9%)	134 (64.1%)
Outer diameter	1881	916 (48.7%)	965 (51.3%)
Fixation (n = 1862)			
Screws	1253	596 (47.6%)	657 (52.4%)
Press-fit	609	309 (50.7%)	300 (49.3%)
Approach (n = 1873)			
Posterolateral	1170	670 (57.3%)	500 (42.7%)
Anterolateral	560	207 (37.0%)	353 (63.0%)
Direct Lateral	50	16 (32.0%)	34 (68.0%)
Minimally invasive surgical	93	18 (19.4%)	75 (80.6%)
Diagnosis			
Osteoarthritis	1432	690 (48.2%)	742 (51.8%)
Dysplasia	229	109 (47.6%)	120 (52.4%)
Fracture/ avascular necrosis	91	47 (51.6%)	44 (48.4%)
Revision	99	54 (54.5%)	45 (45.5%)
Other	32	17 (53.1%)	15 (46.9%)
Type			
Primary	1709	820 (48.0%)	889 (52.0%)
Revision	174	97 (55.7%)	77 (44.3%)
Surgeon volume			
High	1619	827 (51.1%)	792 (48.9%)
Low	264	90 (34.1%)	174 (65.9%)

Table 2. Hips falling within ranges of abduction and version angles

Angle ranges	Number of hips	% of total
Abduction		
20°–25°	8	0.4
25°–30°	66	3.4
30°–35°	200	10.2
35°–40°	443	22.7
40°–45°	570	29.2
45°–50°	422	21.6
50°–55°	192	9.8
55°–60°	43	2.2
60°–65°	4	0.2
65°–70°	3	0.2
70°–75°	1	0.1
Version		
−20° to −10°	7	0.4
−10° to 0°	6	0.3
0°–5°	237	13.0
5°–10°	477	26.2
10°–15°	494	27.1
15°–20°	305	16.7
20°–25°	165	9.1
25°–30°	91	5.0
30°–35°	34	1,9
35°–40°	6	0.3
40°–45°	1	0.1

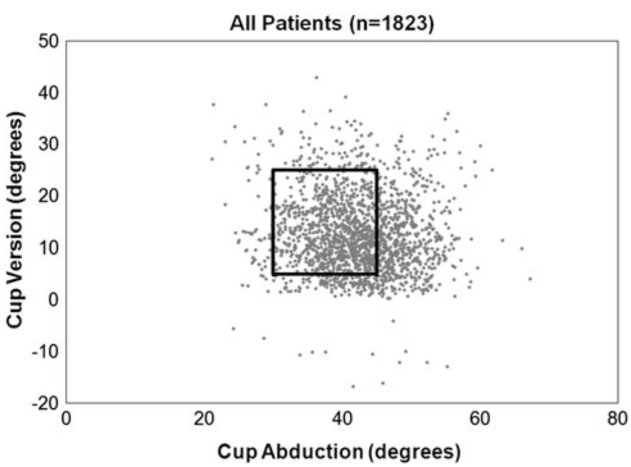

Fig. 1 A scatter plot of each hip's abduction and version angles with a window of acceptable angles shows a tendency toward higher abduction angles and anteverted cups.

(Table 4). Using the three variables of BMI, surgical approach, and surgeon volume from the combined abduction and version analysis, we examined the percent chance of malpositioning for every possible combination of these three variables' subcategories (Table 5).

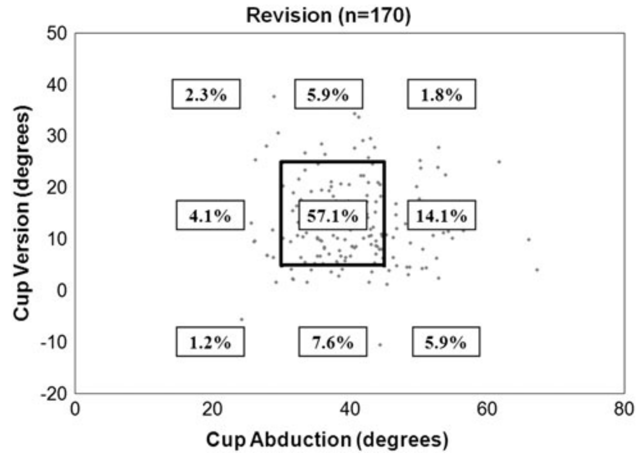

Fig. 2 A scatter plot of abduction and version angles with a window of acceptable ranges and percentages of hips falling in each region for revision procedures showing that 57% of cups were optimally placed.

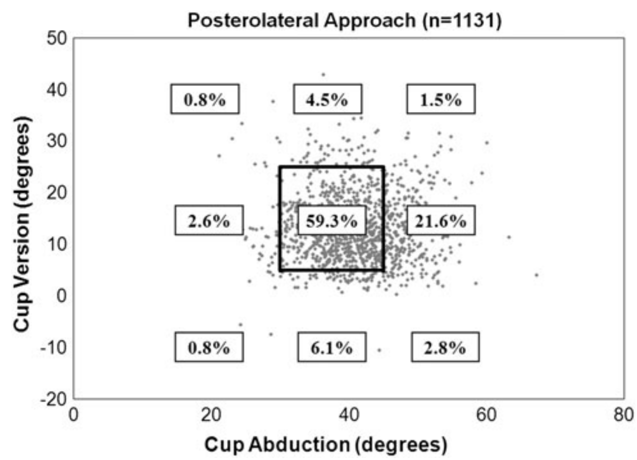

Fig. 3 A scatter plot of abduction and version angles with a window of acceptable ranges and percentages of hips falling in each region for patients operated with the most accurate posterolateral approach shows excellent accuracy of 59.3% and a trend towards higher abduction angles.

Discussion

Malpositioning of the acetabular cup has been linked to an increased rate of dislocation, liner fracture, and increased wear. The increased dislocation risk has been well established [20, 23, 26, 54], and implant wear is greater for malpositioned cups with metal-on-polyethylene, metal-on-metal, and ceramic-on-ceramic bearings [11, 14, 25]. Specifically, one study showed surgical technique factors such as abduction angle of the cup were the most predictive of polyethylene wear [14]. This is possibly more important with hard-on-hard bearings due to the increased effects of edge loading in a rigid construct. Metal-on-metal and ceramic-on-ceramic bearings have wear rates 10 to 30 times as high when acetabular cup angles exceeded 55°,

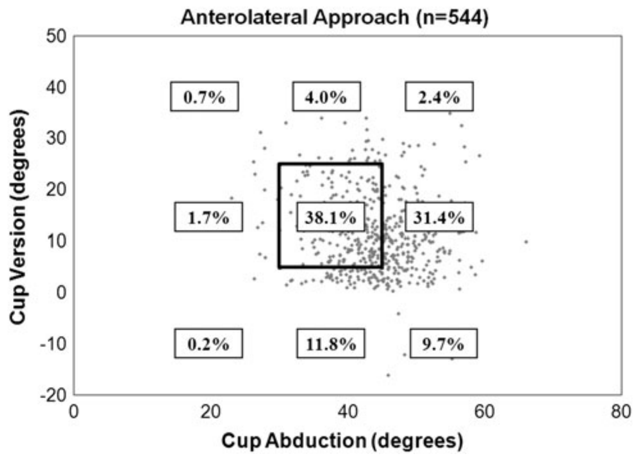

Fig. 4 A scatter plot of abduction and version angles with a window of acceptable ranges and percentages of hips falling in each region for patients operated with the anterolateral approach shows decreased accuracy compared to the posterolateral approach and trends towards a higher abduction angles and lower version angles.

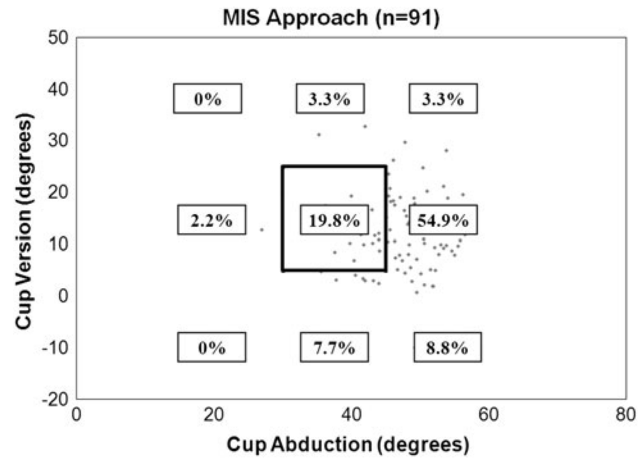

Fig. 5 A scatter plot of abduction and version angles with a window of acceptable ranges and percentages of hips falling in each region for patients operated with the least accurate MIS approaches shows a very poor accuracy of 20% and the majority of hips with high abduction angles.

Table 3. Results of the univariate and multivariate analyses correlating the 10 prediction values to abduction, version, and abduction and version combined

Variable	Univariate analysis: Pearson chi-square p value			Multivariate analysis: stepwise binary logistic regression p value		
	Abduction	Version	Abduction and version	Abduction	Version	Abduction and version
Age	0.497	0.086	0.133	0.495	0.117	0.321
Gender	0.472	0.479	0.420	0.644	0.622	0.778
Body mass index t(obese versus others)	0.103	0.192	0.111	0.011	0.030	0.008
Head size	0.003	0.001	0.000	0.629	0.038	0.111
Cup outer diameter	0.586	0.849	0.937	0.845	0.502	0.283
Fixation	0.241	0.000	0.199	0.294	0.121	0.187
Surgical approach	0.000	0.000	0.000	0.000	0.000	0.000
Diagnosis	0.932	0.527	0.702	0.512	0.416	0.215
Primary/revision	0.040	0.207	0.051	0.302	0.946	0.101
High/low volume surgeon	0.021	0.029	0.000	0.015	0.560	0.000

measured in vitro on simulators and in vivo by serum ion levels and implant retrieval studies [11, 32]. While the effects of cup positioning on complications are well understood, a comprehensive analysis of patient and surgical factors contributing to poor implant positioning is lacking, with the exception of the study by Bosker et al. [5], which is limited by its relatively small sample size. We determined percentages of optimally positioned acetabular cups based on various patient and surgical factors, and then determined which of those factors, if any, correlated to the orientation of the acetabular cup in a large group of THA patients.

There are several limitations to our study. First is the use of a computer software program to obtain inclination and version angles without accounting for pelvic tilt, which could influence the calculated angles. Recent studies show CT scans measure acetabular version more accurately than radiographs [15] and the combination of CT scans and radiographic information is the most effective tool to accurately measure cup position [31, 43, 51, 57]. Second, we did not measure the rotational position of the femoral stem in the femoral canal. This is relevant because cups that are outside the limits of the acceptable version ranges may have been purposely placed there to align with the

Table 4. Odds ratios for increased risk of malpositioning

Factor	Odds ratio (95% confidence interval)		
	Abduction	Version	Abduction and version
Body mass index (obese versus not obese)	1.33 (1.1–1.6)	1.35 (1.0–1.8)	1.35 (1.1–1.7)
Head size			
32 mm versus > 32 mm		*	
< 32 mm versus > 32 mm		†	
Approach			
Anterolateral versus posterolateral	1.81 (1.5–2.3)	2.05 (1.5–2.7)	2.02 (1.6–2.5)
Direct lateral versus posterolateral	*	2.17 (1.0–4.7)	†
Minimally invasive surgical versus posterolateral	4.81 (3.0–7.7)	1.76 (1.0–3.0)	6.10 (3.5–10.7)
Surgeon volume (low versus high)	1.41 (1.1–1.9)		2.07 (1.5–2.8)

* Comparison not significant ($p > 0.70$); †comparison not significant ($p > 0.07$); variable not significant.

Table 5. Percentage chance of malalignment in abduction or version for every combination of the predictors from the multivariate analysis

Weight category	Surgeon volume	Surgical approach	% chance of misalignment
Normal/overweight (body mass index < 30)	High	Posterolateral	39.1
		Direct lateral	54.2
		Anterolateral	56.5
		Minimally invasive surgical	79.8
	Low	Posterolateral	57.1
		Direct lateral	71.0
		Anterolateral	72.9
		Minimally invasive surgical	89.1
Obese (body mass index ≥ 30)	High	Posterolateral	46.5
		Direct lateral	61.5
		Anterolateral	63.7
		Minimally invasive surgical	84.2
	Low	Posterolateral	64.3
		Direct lateral	76.8
		Anterolateral	78.4
		Minimally invasive surgical	91.7

femoral component, especially in revision cases. Third, the study was conducted at a single, high-volume teaching hospital. Since surgery volume has been correlated to cup positioning, our observations could differ at a smaller, lower-volume hospital. Fourth, the optimal ranges we used were based on literature [23, 54] and surgeon input. Many studies cite 50° as the upper limit for optimal cup abduction. The upper limit for this study was set at 45° based on a recent study indicating increased wear in cups with hard-on-hard bearings placed with abduction angles greater than 45° [25]. Also, to combine readings of cup abduction from mDesk™ and HAS, a correlation between a test set of readings was performed. The average difference of 1.66° is a clinically acceptable variation, and a Pearson R of 0.99 showed both programs can be used interchangeably to determine angles. This justified the inclusion of the 39 hips that could only be read using mDesk™. Finally, we did not examine the long-term clinical implications of our observations.

Average abduction and version angles of 42.2° and 12.7° were similar to those reported in the literature which range from 37.5° to 49.7° for abduction and 10.7° to 27.3° for version (Table 6) [5, 24, 36, 44, 45, 48, 53]. The literature inconsistently reports acceptable angle ranges for optimally positioned cups, and the percentage of acceptably placed cups in both abduction and version using the most widely used acceptable range (the Lewinnek range [26]) varies from 70.5% [5] to 25.7% [48]. We found that 47% of cups were properly positioned in both, which is slightly lower than the best accuracy presented in the literature, however, we used a slightly tighter abduction range criteria (30–45°) compared to the Lewinnek range (30–50°). We found a similar percentage of acetabular cups within the ranges for abduction (62%) and version (79%) alone compared to the most accurate study in the literature with 85% and 83% optimally positioned in abduction and version respectively [5].

Surgical approach was the only factor indicating cup malpositioning in every analysis. This is in direct contrast to two previously published studies [5, 36] which show no link between surgical approach and cup positioning. In this study, the posterolateral approach was the most used and was 20% more accurate than all other approaches. It is possible some confounding factors contributed to this finding in the univariate analyses because the posterolateral approach was used predominantly by the highest-volume surgeon. However, the second high-volume surgeon did not use the posterolateral approach, and our findings that

Table 6. Comparison of results to recent literature

Authors	Number of hips	Average abduction angle	Average version angle	% of optimally positioned cups	Factors affecting position	Factors NOT affecting position
Bosker et al. [5]	200	49.7° ± 6.7°	16 ± 8.1	85.2% (30–50° abduction criteria), 82.7% (5–25° anteversion criteria), 70.5% combined, 21.5% (± 5°)	Surgeons versus residents (abduction only)	BMI, gender, (un)cemented fixation, surgical approach
Leichtle et al. [24]	950	48.7° ± 7° (28°–75°)	18.6 ± 9 (−9–50)	22.7% (45 ± 5° abduction, 20 ± 5° version), 65.5% (± 10°)		Surgeon qualifications, implanted model, operated side
Myers et al. [36]	64 (BHR)	37.5° (56°–50°) for posterior approach 43° (30°–56°) for lateral approach				Surgical approach
Pirard and DeLint [44]	323					BMI
Reize et al. [45]	85			41% (30–50° abduction, 5–25° abduction criteria)		Surgical experience
Saxler et al. [48]	105	45.8° ± 10.1° (23°–71.5°)	27.3° ± 15 (−23.5°–59°)	25.7% (30–50° abduction, 5–25° abduction criteria)		
Todkar [53]	111	44.5°, 46.8°, 44° for healthy, overweight, obese	11.6°, 12.2°, 10.7° for healthy, overweight, obese			BMI
Callanan et al. [current study]	1952	42.2° ± 6.8° (21°–73°)	12.7° ± 7.4° (−17°–43°)	62% (30–45° abduction), 79% (5–25° version), 47% combined	BMI, surgeon volume, surgical approach, head size (version alone)	Age, gender, cup outer diameter, (un)cemented fixation, diagnosis, primary/revision

surgical approach was an independent predictor in the multivariate model indicated that even among high volume surgeons, surgical approach still affects cup malpositioning. The binary logistic regression used in the multivariate approach accounts for other variables, including surgeon volume. The less invasive MIS approach was the least accurate, with anterolateral and posterolateral approaches having similar accuracies. The inaccuracies of the MIS approach could be caused by a more constrained working space and decreased direct vision associated with MIS, making the accurate assessment of anatomy and placement of the acetabular cup more difficult compared to other approaches. The volume of surgeries performed was another indicator of malpositioning in abduction and abduction or version combined. Three previous studies examined the effect of surgical volume and experience on cup positioning, two of which reported no affect of surgical experience [24, 45] while one found a substantial difference between surgeons compared to their residents [5]. Two of these studies were limited by a small sample size [5, 36], and the third examined only surgeon qualifications, implanted model, and side [24]. For surgeon volume in our study, the high-volume surgeons who performed an average of 164 THAs per year were 16% more accurate than the low-volume surgeons who performed an average of 13 THA's per year. This indicates that a lower-volume surgeon would benefit the most from additional training or the use of some form of navigational assistance. Previous studies have established a link between surgeon volume and infection, dislocation, revision, or complications [30, 49, 52]; therefore, the link between proper cup positioning and surgeon volume is not unexpected. Also, while we found an independent link between surgeon volume and cup positioning in abduction and version combined, the surgeon experience could prove even more important if these experienced surgeons were performing more difficult procedures on more complex patients. Surgeon volume was not an independent indicator of attaining an acceptable version angle. This suggests a lower-volume surgeon's greater risk of cup malpositioning is due to a lack of accuracy in cup abduction, not cup version. This discrepancy could be due to the use of the lateral patient position for all surgeries except for those using the two-incision MIS approach, resulting in a higher variation in pelvic tilt and lower variation in pelvic flexion. A previously mentioned study of acetabular cup placement by orthopaedic surgeons and residents found a difference between intended and actual angles for abduction but not for version [5]. This supports our finding that performing a greater volume of surgeries can increase accuracy of cup placement in abduction but not necessarily in version. BMI was another indicator for increased risk of cup malpositioning. More specifically, obesity had a greater risk of malpositioning than the other BMI categories of underweight to overweight. This contradicts three previous studies indicating no relationship between cup position and BMI, but those studies were also limited by their small sample size [5, 44, 53]. A possible explanation for the decreased accuracy found in positioning cups in obese patients is the relatively smaller field for a given incision size due to the increased amount of adipose tissue. The excess tissue can also make it more difficult to locate anatomic landmarks. The link between obesity and malpositioning of the acetabular cup established in this study could explain some of the increased incidence of post-THA prosthesis dislocation found in obese populations in other studies [27, 46]. In addition to surgeon volume, surgical approach, and BMI, which were indicators in multiple analyses, femoral head size was an independent indicator of cup malpositioning for version alone. Head size was also a predictor of implant malpositioning in abduction and version when other variables were not taken into account. There are currently no studies comparing head size or cup outer diameter to positioning of the cup. Cups paired with femoral head sizes smaller than 32 mm were more accurately placed, with 9% greater accuracy than 32-mm heads and 22% greater accuracy than large heads. Since most surgeons are aware a larger head size allows for greater ROM and a decreased risk of impingement and dislocation, extra attention to acetabular cup positioning could be lacking when larger head sizes are used. Because of this, surgeons should be particularly aware of this tendency.

As a result of this study, we are currently reporting cup positioning back to surgeons on a regular basis. This monthly analysis of each surgeon's cup abduction and version angles has the potential to increase cup position accuracy, allowing them to continuously correct for tendencies to over- or under rotate their cups. Regular feedback is facilitated by the presence of a registry and the ability to consistently evaluate cup positioning using a database of radiographs and associated patient factors. With the ultimate goal of increasing the accuracy of acetabular cup position to reduce the risk of complications, we identified the main factors contributing to malpositioning of the cup, namely volume of surgeries performed, surgical approach, and obesity. Related to surgical approach, special consideration should be taken when positioning and fixing the patient on the operating table. Navigational assistance increases the accuracy of acetabular cup positioning regardless of surgical experience or approach [8, 19, 37, 40, 55]. The use of navigation could have a positive impact on patients, especially for surgeons who perform fewer THAs per year or use a MIS approach, indicating a need for less expensive, more accessible navigation options. Our data suggest special care should be taken when positioning cups in obese patients, especially when the surgery is being performed by a low-volume surgeon using the MIS approach. Further analyses on patient and surgical factors' influence on cup position at a lower volume medical center would provide a valuable comparison.

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