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Precision and Bias of Imageless Computer Navigation and Surgeon Estimates for Acetabular Component Position

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Computer navigation has the potential to permit accurate placement of components. We first hypothesized acetabular inclination and anteversion using navigation would be within 5° of postoperative computed tomography scans, then secondly, computer precision would be better than that of surgeons. In the first phase, we obtained postoperative CT scans in 30 hips to ascertain the computer navigation values for inclination and anteversion of the cup. In the second phase, in 99 patients with 101 hips, we determined the surgeon's precision by comparing surgeons' blind estimates for trial cup position with computer navigation values. The navigation precision for inclination was 4.4° with a bias of 0.03° and for anteversion was 4.1° with a bias of 0.73°. The experienced surgeons' precision was 11.5° for inclination and 12.3° for anteversion, whereas the less experienced surgeons' precision was 13.1° for inclination and 13.9° for anteversion. The data supported the first hypothesis as computer navigation had a bias for inclination and anteversion of less than 1° with precision less than 5°. The precision of computer navigation was better than that of surgeons. This imageless computer navigation system allows more accurate acetabular component placement.

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

The position of the acetabular component has historically been judged by the experience of the surgeon without intraoperative knowledge of the true relationship of the acetabulum to the pelvic position.[10] The consequence of clinical judgment alone has been the risk of component malposition associated with impingement of the femoral neck on the cup, which can cause dislocation, pain, accelerated wear, and loosening.[4,6,11,32,40] The surgeon's performance of component implantation has always been measured by plain radiographs, which have been imprecise in comparison to the true position of the cup.[18,33] The advent of computer navigation has revealed the imprecision of plain radiographic measurements and that of surgeons using mechanical guides for implant positioning.[10,19,21,23,28]

The primary function of computer navigation is to provide precise intraoperative knowledge to the surgeon, including acetabular component placement. Orthopaedic surgeons have assumed more accurate placement of components will provide fewer short-term complications and better long-term durability.[6,24,25,39] Previous studies with computer navigation have confirmed its function as an instrument for improved component placement.[10,19,21,23,28] These studies suggest computer navigation-assisted component placement by the surgeon is more predictable and reproducible because there is knowledge of the position of the acetabulum relative to the pelvis. Due to relatively recent use of computer navigation, no studies document its contribution to improved long-term clinical outcomes.

No study has measured and reported the accuracy and precision of the computer navigation system in clinical use. While previous clinical reports suggest reduced deviation from a target number for cup inclination and anteversion when using computer navigation, they have not reported the navigation system's accuracy with precision and bias.[10,19,23,28]

According to the American Society of Testing and Materials,[3] accuracy is the closeness between a test result and an accepted reference value or the true value (computed tomography scan values in this study). This definition states only the words precision and bias should be used as descriptors of accuracy. Precision (randomized error) is

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the closeness of agreement between repeated measurements made under similar conditions and represents reliability and reproducibility of the test. In our study precision was measured initially between computer navigation values and postoperative computed tomography scans and posteriorly between surgeons' estimates and radiographic values against the computer navigation values. Bias (system error) is the consistent difference between a set of measurements and an accepted reference or true value.[20,35]

We first hypothesized the computer navigation system would be accurate within 5° for inclination and anteversion of postoperative computed tomography scan values. We then hypothesized the precision of computer navigation would be superior to the clinical judgment of the surgeon for acetabular component positioning.

MATERIALS AND METHODS

All patients had primary total hip replacement performed using the Navitrak Imageless Computer Hip System (Orthosoft, Montreal, Canada). Institution Review Board approval for computed tomography scans and informed consent for prospective review of data was obtained. Our study focused on the accuracy of computer navigation as intraoperative instrumentation and therefore clinical outcome data were not included.

In the first phase of the study 35 patients were invited to enroll by obtaining a postoperative computer tomography scan. Thirty patients with 30 hips, who agreed to a postoperative computer tomography scan, had a comparison of their computer navigation values and computed tomography (CT) values for cup inclination and anteversion.

Thirty patients were selected for this study because according to the American Standards for Testing and Materials (ASTM) criterion at least 30 cases are required to correctly calculate the values for precision and bias. In this study the sample error of a mean value was 2.4% for inclination and 4.4% for anteversion when the sample size reached 30 hips.

The second phase of the study was a comparison of surgeons' estimates of cup position to the true value of computer navigation. Computer navigation was used as the true value because of its validation in phase 1. In the initial phase, 35 hips (including the 30 with CT scans) had had a surgeon estimate (LDD) for the trial cup position. The surgeon's estimates were not consistently close to the computer values. Therefore, the second phase of the study was designed with a protocol for comparison of estimates of two surgeons (two observers), one experienced (LDD), and one less experienced (a fellow), to the cup position measured by the computer. The surgeon estimated the inclination and anteversion of the trial cup position which was compared to the computer navigation numbers for inclination and anteversion of the trial cup. Surgeons were blinded to the computer navigation numbers. Surgeons' estimates were given simultaneously to the recording nurse. The trial cup position was used because computer navigation values were known to be precise and the final cup could then be placed with computer control to obtain the desired position. One hundred hips were the goal for comparison and 101 hips in 99 patients were included. These were consecutive operations in which a fellow was in attendance with the senior surgeon (LDD). Therefore 88 of 189 hips were excluded with 35 in the preliminary single surgeon estimates, 16 in simultaneous bilateral hips in which the second hip did not have navigation, and 37 in which a fellow was not in attendance at the operation.

The diagnosis of the initial CT scan group was osteoarthritis in 28 hips, dysplasia in one hip, and rheumatoid arthritis in one hip. The diagnosis of the patient group which had surgeon estimates was osteoarthritis in 85 hips, dysplasia in ten, avascular necrosis in three, rheumatoid arthritis in two, and posttraumatic osteoarthritis in one (Table 1). The posterior minimally invasive surgical approach was performed in each patient by one experienced surgeon (LDD).[12,13,17] The instrumentation for computer navigation was calibrated while the patient was prepared for anesthesia. After the patient was anesthetized, a metal base plate for the pelvic tracker was secured with three ⅛-inch threaded pins to the thickest portion of the pelvic brim. With the patient supine, the anterior pelvic plane registration was performed by puncturing the skin to obtain bony contact to both anterior-superior iliac spines and the pubic bone near the pubic tubercles. This is a vital step requiring care to ensure bony contact even in obese patients. In obese patients a scalpel is inserted through the skin to the bone to create a track for the registration pointer. The pubis is identified by palpating the superior border in the midline of the body and the registration pointer is contacted to the bone just distal to this midline border. The patient was then "flipped" to the lateral position and secured with two pelvic supports and two chest supports (Sunmed, Redding, CA). The registration pointer was used to contact the two posterior supports with three points in triangular geometry (Fig 1). The software can then compute the tilt of the pelvis relative to this longitudinal reference plane in the lateral position with this navigation system. The values for pelvis tilt are necessary for calculation of the adjusted inclination and anteversion values which are in the radiographic plane of Murray.[13,27]

Different references were obtained by registration of the native bony acetabulum: (1) center of rotation and diameter of the bony acetabulum; (2) outline of the medial wall; and (3) inclination and anteversion. The qualitative position of the reamer was displayed against the outline of the medial wall. The change in position of the center of rotation during trial and cup place-

TABLE 1. Demographics

Demographic	CT Scan Group	Surgeon Estimate Group
Number of patients (hips)	30 (30)	99 (101)
Age (years)	67.9 (42–89)*	63.7 (33–89)*
Gender (male/female ratio)	17/13	60/41
Height (meters)	1.69 (1.42–1.91)*	1.70 (1.33–1.98)*
Weight (kilograms)	78.1 (50–131)*	84.1 (45–140)*
Body mass index (kg/m^2)	26.8 (20–39)*	28.0 (17–40)*

*Ranges shown in parentheses
CT = computed tomography

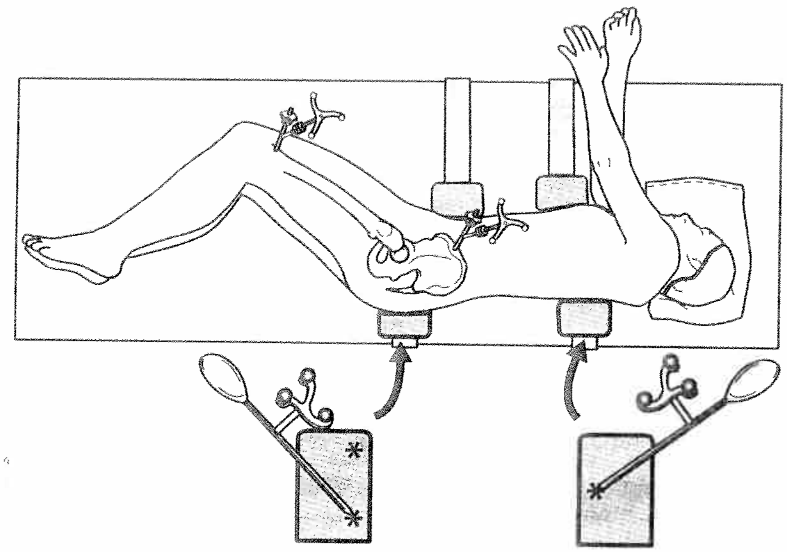

Fig 1. The patient is in the lateral position for the operation and supported by two pelvic and two chest supports. The triangle is formed using the posterior supports of the pelvis and the chest to register the longitudinal axis of the body. This is illustrated with two points on the pelvic support and one on the chest support.

ment was quantified in the cephalocaudad and mediolateral direction. The center of rotation of the cup (as compared to the center of rotation of the bony acetabulum) was used by the software for calculation of hip length after the reconstruction (Fig 2). Inclination and anteversion of the trial cup, and the actual acetabular component, was measured quantitatively.

Based on Murray's definitions,[27] the software of the computer is designed to provide on the computer screen both the anatomic and radiographic plane values of the acetabular component in the pelvis. In this navigation system adjusted inclination and anteversion represent the radiographic inclination and anteversion of Murray.[27] Surgeons who operate in the posterior position visualize the acetabular inclination and anteversion in a similar plane as the radiographic plane when positioning the cup. The radiographic plane position (adjusted position) is also the traditional plane used for data comparison with postoperative radiographs. It was important to us the software be formatted with the numeric component positions with which we were familiar, which is why we determined the pelvic tilt in the lateral position to obtain the adjusted radiographic values.

The final acetabular component was manipulated into the desired inclination, which was targeted between 35° and 45°. A combined anteversion technique of the femoral and acetabular components was used for implant positioning. The femoral stem

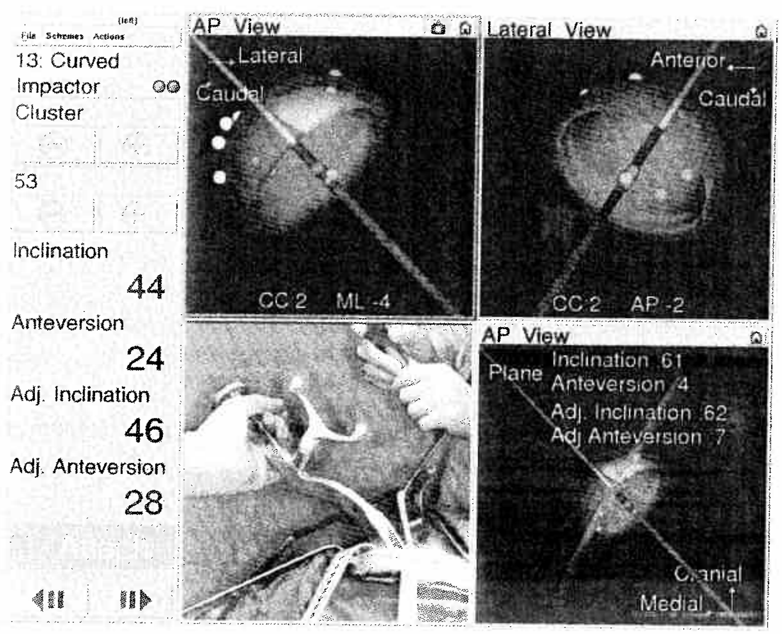

Fig 2. The trial cup implantation is shown in the lower left quadrant. The upper quadrant shows the position of the cup relative to the acetabulum, including the medial wall. The CC, ML, and AP numbers provide the center of rotation superior displacement (CC), medialization (ML), and anteroposterior displacement (AP). The numbers on the left give the numeric inclination anteroposterior anteversion and adjusted inclination and anteversion. The lower right quadrant gives the native acetabulum values, and the gray lines show what portion of the cup would be uncovered.

anteversion was measured using the computer software before the acetabular preparation. The acetabular component anteversion was then determined according to the stem anteversion so there would be a combined anteversion of 30° to 40° for men, and 35° to 45° for women. This concept was similar to that proposed by Widmer and Zurfluh[37] in their finite element study, although we did not use their formula. We based our desired combined anteversion on the clinical experience of Ranawat and Maynard[30] and our previous experience.[12,13]

The numeric position for inclination and anteversion had to also be combined with cup position within the bony socket in order to obtain correct bony coverage. The desired position of the cup was one that avoided lateralization of the metal shell and provided adequate bony coverage. If the anterior-superior portion of the cup was flush with bone, the metal neck would not impinge on the metal cup during flexion and particularly flexion, internal rotation, and adduction. The posterior-superior edge of the cup could project 3 mm lateral to the posterior-superior bone. The inferior-medial edge of the metal shell was placed level with or just superior to the bony edge of the cortical bone of the cotyloid notch (inside the transverse acetabular ligament). The center of rotation of the acetabulum was reamed medially and cephalad sufficiently to ensure this cup coverage. From previous studies, we knew this meant reaming an average of 6 mm medial and 5 mm superior.[12] The reaming was medialized to the cortical bone of the cotyloid notch. The offset of the hip had to be correct to also prevent impingement of the trochanter against the pelvic bone (bone-to-bone impingement).

Movement of the cup can occur with the pounding in of the polyethylene to lock it in place. If the implanted cup moved more than 5° after polyethylene insertion, it was considered an unstable cup and to create stability, the polyethylene would have to be removed and screw fixation added or the cup size changed.[12,13] In this series no cup required repositioning to add screws. Screws were placed in three hips for fixation because the metal shell was not considered stable during its implantation. The final cup position was measured after the polyethylene liner installation because the numbers can change by 1° to 3°. The computer navigation cup plane values obtained by digitizing the metal shell equator after liner installation were the values used to compare with the postoperative computed tomography scans because they were the final measured values.

Thirty patients had postoperative computed axial tomography scans (MX 8000; Phillips, Highland Heights, OH). Each scan was performed at 1.3-mm intervals and 1.3-mm thickness with a field of view of 400 and pitch of 1.250. Four hundred to 450 scans were obtained for each study. This data was measured with the computed tomography-based hip plan module of the Navitrack System (Navitrack Computed Tomography Based Hip Application; Orthosoft). A virtual three-dimensional model of the patient's pelvis, as well as the implanted cup, was reconstructed from the data. The three points defining the anterior pelvic plane were used to establish an anatomic coordinate reference system. A virtual cup was positioned over the reconstructed cup to match its position and orientation. The software then calculated the resulting standardized computer radiographic anteversion and inclination values based on Murray's equations in the anatomic plane.[27] The computed tomography position of the acetabular component was measured by independent examiners experienced in this technique without knowledge of the computer navigation numbers. We validated the accuracy of the computer navigation by the comparison of the postoperative computed tomography scans and the computer navigation measurements of inclination and anteversion from these 30 patients. Postoperative computed tomography scans showed the true value because they have been accepted as the gold standard in the literature for validating cup position.[9,18,20,22,33,35]

The anteroposterior pelvic radiograph was taken in the supine position with the beam centered over the symphysis pubis. Measurement of the radiographic cup inclination was performed using the method of Callaghan et al[5] and anteversion using the modified method of Ackland et al[1] with a correction factor of 4°.[36] The radiographic measurements were evaluated as mean ± standard deviation.

We used the Kolmogorov-Smirnov test for normal distribution before further statistical analysis. For analysis of measurements, the means and standard deviations were calculated. We used one-way analysis of variance to determine the difference in measurements between anteroposterior pelvic tilt. The repeatability between femoral inclination and anteversion of computer navigation and computed tomography scans was calculated using intraclass correlation coefficient using the reliability analysis. A p value of less than or equal to 0.05 was considered different. The surgeons' estimates were evaluated as mean ± standard deviation, precision and bias, and as outliers greater than 5° compared with the computer navigation values. The analysis was performed with SPSS software (SPSS, Inc, Chicago, IL).

The bias and precision were calculated according to the American Society for Testing and Materials definitions.[3] We used the ASTM preferred index of precision.[3] The preferred index was the 95% limit on the difference between the two test results. The ASTM preferred index of precision was calculated as follows:

$$r = 1.96\sqrt{2}\,\mathrm{Sr} \text{ and}$$

$$S_r = \sqrt{\frac{\sum_{j=1}^{c}\sum_{i=1}^{n}(x_{ij}-\bar{X}_j)}{\sum_{j=1}^{c}(n_j-1)}}$$

In the equation, (r) is the 95% repeatability limit[2] and (Sr) is the repeatability standard deviation derived from ASTM E691.[2]

RESULTS

Computer navigation was reproducible and predictable to within 5° of the computed tomography scan with precision being 4.4° for inclination and 4.1° for anteversion. The navigation system had no outliers greater than 5° when compared to postoperative CT scans. On comparing the computer navigation system and CT scans there was a bias

TABLE 2. Accuracy of Computer Navigation for Acetabulum

Measurement	CT Scan Inclination	Navitrack Inclination	CT Scan Anteversion	Navitrack Anteversion
Number of hips studied	30	30	30	30
Mean (degrees)	41.0 ± 4.7	41.0 ± 3.8	27.5 ± 6.3	26.7 ± 6.4
Precision (degrees)	4.4		4.1	
Bias (mean of differences; degrees)	0.03		0.73	
Intraclass correlation coefficient	0.92		0.97	

CT = computed tomography

of less than 1° for both inclination and anteversion (Table 2). The intraclass correlation between the navigation system and CT scans was 0.92 for inclination and 0.97 for anteversion.

Computer navigation for all 101 hips showed a mean adjusted inclination of 39.8° ± 4.7° (range, 27°–54°) and mean adjusted anteversion of 25.1° ± 5.9° (range, 10°–39°). The radiographic mean for 101 hips for inclination was 43.1° ± 4.7° (range, 35°–58°); anteversion was mean 23.2° ± 4.9° (range, 9°–34°). The magnitude of pelvic tilt influences the surgeon's visualization of the bony acetabulum at the operation. The anteroposterior tilt of the pelvis is divided into four categories according to the number of degrees of tilt. Patients with high pelvic tilt values (10°–20°) required a greater adjustment of the anatomic plane to give the equivalent radiographic plane values of inclination and anteversion (Table 3).

The experienced surgeons' mean estimate for cup inclination was similar to that for computer navigation, but anteversion was worse (Table 4). The inexperienced surgeons' mean estimates were different from computer navigation values for both inclination and anteversion (Table 4). Both surgeons' estimates were worse than the computer for precision and bias (Table 5). The intraclass coefficient for the computer for inclination was 0.92 versus 0.084 for the experienced surgeon and 0.087 for inexperienced surgeons; for computer anteversion it was 0.97 versus 0.311 for the experienced surgeon and 0.14 for inexperienced surgeons. Experienced surgeons tended to have fewer outliers beyond both 5° and 10° than did the inexperienced surgeons, but this was not different (Table 6). Outliers beyond 10° are most likely to cause adverse clinical outcomes such as instability or accelerated wear. Experienced surgeons had outliers 10° or more of inclination in 6% of hips and anteversion in 12% of hips.

DISCUSSION

Our study was designed to validate the accuracy of the imageless navigation system to within 5° for inclination and anteversion of the true value. This was confirmed by validation with postoperative computed tomography scans with accuracy of the navigation system being 4.4° precision (0.03° bias) for inclination and 4.1° (0.73° bias) for anteversion with no outliers greater than 5°. Secondly, we compared the precision of computer navigation to the clinical judgment of surgeons for acetabular component positioning. The experienced surgeon's precision was 11.5° versus 4.4° for computer navigation for inclination and 12.3° versus 4.1° computer navigation for anteversion. The experienced surgeon had outliers greater than 10° in 6% of estimates for inclination and 10% of estimates for anteversion while the computer had none. In all studies, inclination is more accurately measured than anteversion by computer navigation and surgeons.[10,18,23,33,38]

The first limitation of this study was the computed tomography scan procedure and reconstruction technique we used was specific for the software of this computer navigation system. The comparison of computed tomography scans values to computer navigation values is based on using the same reference of the anterior pelvic plane for both systems. Murray's definitions[27] are used to develop

TABLE 3. Influence of Anteroposterior Pelvic Tilt on Inclination and Anteversion (N = 101)

Computer Measurement	Posterior Tilt 10°–20°	Posterior Tilt 1°–9°	Anterior Tilt 0°–9°	Anterior Tilt 10°–20°	p Value
Computer inclination	36.8 ± 1.9	39.0 ± 3.7	41.6 ± 3.7	47.0 ± 2.5	0.001
Computer-adjusted inclination	40.7 ± 2.8	40.4 ± 3.9	40.1 ± 3.9	42.0 ± 1.8	0.791
Computer anteversion	18.6 ± 5.5	22.8 ± 4.0	28.7 ± 4.9	37.0 ± 2.7	0.001
Computed-adjusted anteversion	29.1 ± 5.3	26.5 ± 3.6	25.5 ± 4.5	29.6 ± 2.6	0.038

TABLE 4. Computer and Surgeon Measurements of Trial Cup

Measurement 101 hips	Mean ± SD (range) Degrees
Trial cup computer inclination* (1)	39.8 ± 4.7 (27–54)
Trial cup computer anteversion* (2)	25.1 ± 5.9 (10–39)
Experienced surgeons' inclination (3)	40.7 ± 4.2 (33–55)
Experienced surgeons' anteversion (4)	23.0 ± 4.8 (5–35)
Less experienced surgeons' inclination (5)	42.4 ± 4.7 (25–54)
Less experienced surgeons' anteversion (6)	23.2 ± 5.7 (5–36)

*Adjusted for tilt measurement; SD = standard deviation; statistical significance of surgeon estimates versus computer navigation values: (1) versus (3) p = 0.067; (1) versus (5) p = 0.001; (2) versus (4) p = 0.006; (2) versus (6) p = 0.010

TABLE 6. Surgeons' Outliers

Trial Cup Position (total 101 hips)		0°–5°	6°–10°	> 10°	Total Outliers
Inclination*	Exp	70	25	6	31
	Inexp	56	33	12	45
Anteversion†	Exp	62	29	10	39
	Inexp	55	31	15	46

Numbers are in percentage of 101 hips; Outliers = surgeon estimates versus computer navigation value; *no statistically significant difference (p = 0.097); †no statistically significant difference (p = 0.476); exp = experienced surgeon (LDD); inexp = inexperienced surgeons (fellows); 0°–5° = difference from computer; 6°–10° = difference from computer; greater than 10° = difference from computer

the mathematical formulas which determine the anatomic and radiographic values of navigation systems. The application and use of these algorithms may differ between the software of different navigation systems and therefore may not allow direct comparison of results between them. The second limitation is that all patients did not have a postoperative scan, but we purposely limited the number because ASTM recommends 30 scans for precision and bias and the intraclass coefficients were above 0.90. The third limitation of this study was that we compared surgeons' estimates to computer navigation and not to the computed tomography scan because the surgeon estimate was performed with the trial implant. Computer navigation values could be used as the true value for comparison of surgeon estimates because they had been validated in phase I of the study. The fourth limitation is the human factor of the surgeons involved in estimating the cup position, which certainly can vary from surgeon to surgeon. Our results are limited to the experience and ability of the surgeons involved in this study. However, the senior surgeon (LDD) has nearly 30 years of experience with THA, having performed several thousand cases. The surgeons in fellowship did not vary greatly from the experienced surgeon, although their values were different from the computer navigation values for both inclination and anteversion. A fifth limitation was the use of the posterior approach with visualization of cup position in the radiographic plane.[27] Surgeons who operate supine (anterior approach) might vary by visualization of the cup in the anatomic plane. A sixth limitation was the navigation system used. Errors produced by each navigation system are a combination of errors of registration, landmark identification, optical camera and tracking devices, and of the different algorithms used in the software. Therefore, the accuracy of this navigation system cannot be transposed to other navigation systems. A seventh limitation is the necessity of percutaneous pins for this optical-guided navigation. None of 99 patients reported iliac crest pin problems and three of 99 (3.0%) reported continued pain at the distal femoral pin site 6 weeks postoperatively, which subsequently resolved. Currently we are administering local anesthetic to reduce pain at this distal femoral pin site. There were no complications of hematoma or fracture from the pins.

These results validated registration of the anteroposterior plane, the longitudinal axis of the body, and the pelvic tilt measurements. With adjustment for tilt, the inclination values are able to be targeted to a mean of 40° and the anteversion can be adjusted to provide a combined acetabular-femoral anteversion of 30° to 45°. The "flip technique," involving the measurement of the long axis by triangulation on the posterior pelvis and spine supports, provided accurate results with correct adjusted values of cup position. The correlation of the postoperative computed tomography scans to intraoperative computer navigation values means the software calculations of the pelvic position remained accurate even with any pelvic movement during the operation.

We utilize imageless technology because preoperative image-based programs do not account for intraoperative

TABLE 5. Precision of Surgeon Estimates

Surgeon	Precision Inclination	Bias Inclination	ICC	Precision Anteversion	Bias Anteversion	ICC
Experienced surgeon (LDD)	11.5	1.0	0.084	12.3	2.1	0.311
Inexperienced surgeons (fellows)	13.1	2.6	0.087	13.9	1.9	0.14

ICC = intraclass coefficient

deviations of reaming or cup placement from intended targets as was observed with the use of preoperative image-based programs.[9,18] Imageless technology allows real-time intraoperative knowledge of the quantitative reaming direction and depth; adjustment of reaming for variations in bony anatomy to allow correct cup coverage with optimal inclination; and adjustment of cup anteversion for desired combined anteversion when there is knowledge of the fixed femoral anteversion.

One reason for accelerated wear in some cases in clinical series may be the imprecision of the surgeons' intraoperative judgment of cup position, which is magnified by the imprecision of radiographic measurements which surgeons use to confirm their technique of cup placement.[7,8,14–16,34] In studies of implants, there is always a percentage of hips that have excessive and accelerated wear, which often results in osteolysis, but the reasons for this can often not be identified. These cases of accelerated wear have been attributed to 32-mm head size, titanium femoral heads, activity of the patient, or cup design.[7,8,14–16,34] One possibility to explain the cause of accelerated wear is the occurrence of impingement. In the retrieval study of Yamaguchi et al,[40] wear was increased in the cups with impingement. Our data suggest a computer navigation system, validated for accuracy and precision, is the only method currently available to ensure reliability of the component position which can minimize impingement.[11,31,32,37] Component inclination must be no more than 45° to prevent accelerated wear.[29,31] As the computer has a precision of 4.1° for inclination, we target cup inclination at 40°. Combined anteversion of the cup and stem should be 30° to 40° for men and 35° to 45° for women.[12,13,26,30]

The importance of this study is the validation of this computer navigation system to have a precision to within 5°, with a bias less than 1° of the true value while providing better results than the surgeons' judgment alone. These data let the surgeons know they can trust a validated computer-navigated system for cup position. This is important in our evolution of understanding computer navigation benefits, but must be combined with data on precision of leg length and offset for complete validation of the use of these systems in total hip replacement. The contribution of the use of computer navigation to improved clinical outcomes can be learned with randomized studies in a short period of time for intraoperative and early postoperative complications, but will take years for final clinical outcomes. It is fair to say accurate reproducible cup positions that avoid outliers will benefit patient outcome.

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