Computer Navigation with Posterior MIS Total Hip Arthroplasty

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The majority of literature on computer-assisted surgery of the hip shows how navigation assists the surgeon in more accurate component placement as compared with techniques that use mechanical guides or are freehand [1–5]. Our work has been with imageless navigation technology, which allows real-time intraoperative knowledge of the quantitative direction and depth of reaming; adjustment during reaming for variations in the bony anatomy to allow for correct cup coverage with optimal inclination; and adjustment of the anteversion of a cup to a desired combined anteversion through knowledge of the fixed femoral anteversion [6].

We have validated the results of the imageless computer navigation by comparison with postoperative computed tomography (CT) scans, which are considered the gold standard. We also compared the precision of the computer with postoperative radiographs and with the surgeons' estimates of cup position.

Methods

The institutional review board approval and proper informed consent for prospective review of data was obtained from 60 consecutive patients with 66 total hip replacements performed between July 2005 and March 2006. The Navitrack Imageless Computer Hip System (Orthosoft/Zimmer, Montreal, Canada) was used for each of these hip replacements. Data was collected during

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the operation. The operation for total hip replacement used was the posterior minimally invasive incision [6, 7]. The preoperative diagnosis for surgery was primary osteoarthritis in 56 cases (85 %), congenital hip dysplasia in 7 cases (11 %), rheumatoid arthritis in 2 cases (3 %), and idiopathic necrosis of the femoral head in 1 case (1 %). The demographics of the patients studied are listed in Table 1.

Posterior MIS Technique

The operative technique for the total hip replacement was the posterior minimally invasive surgery (MIS) operation, which was performed by one experienced hip surgeon (LDD) [7–9]. Components used were the porous coated Converge cup (Zimmer, Warsaw, IN) and Anatomic Porous Replacement (APR) stem (Zimmer), which were implanted cementless.

Table 1 Demographics of 60 patients with 66 total hip replacements performed between July 2005 and March 2006

Patients (hips)	60 (66)
Age (years)	64 (33–89)
Sex (M/F)	40 (60 %)/26 (40 %)
Height (in.)	68.4 (54–78)
Weight (pounds)	186.1 (100–300)
Body mass index (BMI)	27.6 (17–40)

Computer Registration

For tracking, we used baseplates secured on the pelvis and femur with three threaded 1/8″ pins to the bone. An optical tracker was attached to the baseplate. The anterior pelvic plane (APP) was registered with the patient in the supine position by percutaneous (puncturing the skin and ensuring firm bony contact) digitization of both anterosuperior iliac spines and the pubis near the tubercles (Fig. 1). The femoral baseplate was attached to the anterior lateral femur 8 cm cephalad from the superior pole of the patella and anterior to the anterior edge of the iliotibial band. The patient was then turned to the lateral position for the operation. The longitudinal axis of the patient was registered by using the posterior body supports – the flip technique (Fig. 2). The pelvic tilt with the patient in the lateral position was calculated by computer software relative to the APP. The acetabular component position was displayed on the screen as adjusted inclination and anteversion, being adjusted for the pelvic tilt. This adjustment changed the inclination and anteversion from the anatomic plane to the

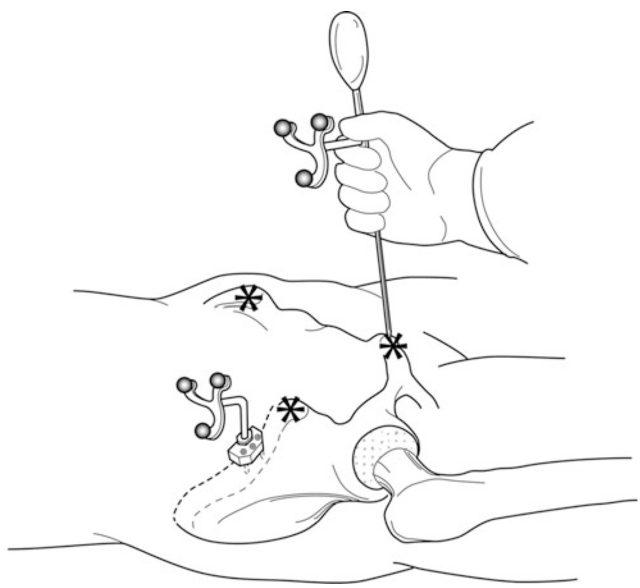


Fig. 1 The pelvic base antenna is pinned to the iliac crest. The two anterosuperior iliac spines and symphysis pubis are touched by the pointer guide. Percutaneous incisions are made to ensure that the guide obtains bony contact through the skin

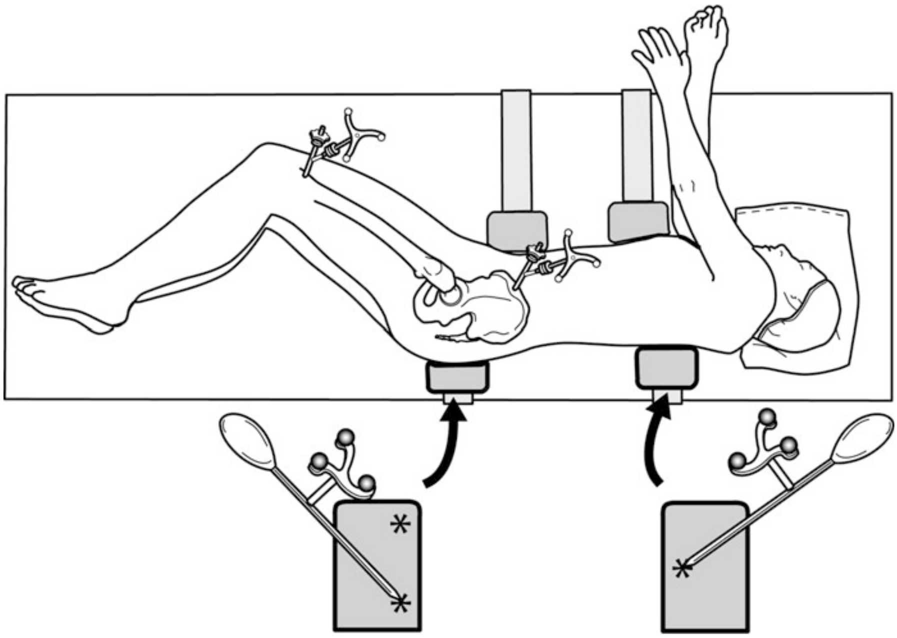


Fig. 2 In the flip technique, once the patient is changed to a lateral decubitus position, a triangle is formed using the posterior supports of the pelvis and chest to register the longitudinal axis of the body. Pelvic tilt in the lateral position relative to the longitudinal axis is also obtained

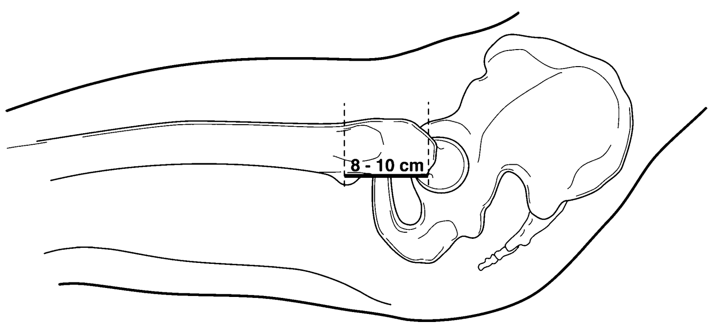


Fig. 3 Schematic representation of cut 1. The incision must be made along the posterior border of the greater trochanter. The average length of the incision is 8–10 cm

radiographic plane as defined by Murray [10]. The longitudinal plane of the leg was registered from the two femoral condyles and ankle malleoli.

Posterior Approach

The incision is made over the posterior 1/3 of the trochanter and extends proximally from the level of the vastus tubercle for 8–10 cm cephalad (Fig. 3). The first incision into hip tissue is done in the gluteus maximus muscle, which is incised for 6–8 cm along the posterior border of the greater trochanter. The second is through the small external rotators and the posterior capsule with the leg held in internal rotation. It is made as a single flap from the proximal edge of the quadratus femoris muscle to the piriformis tendon and then directed posteriorly parallel to the tendon to the edge of the acetabulum (it is important not to go beyond the acetabular edge to protect the sciatic nerve). Thereafter, the hip is dislocated and the neck is cut at the level preoperatively templated to best restore leg length and offset if the hip center

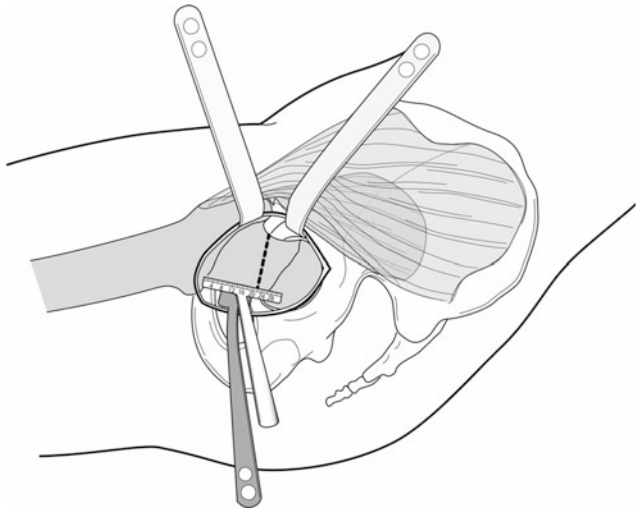


Fig. 4 The neck cut that has been templated preoperatively is validated for hip and leg length measurement. A ruler is used to measure the cut from the distal edge of the femoral head because the lesser trochanter is not visible because the quadratus is not incised

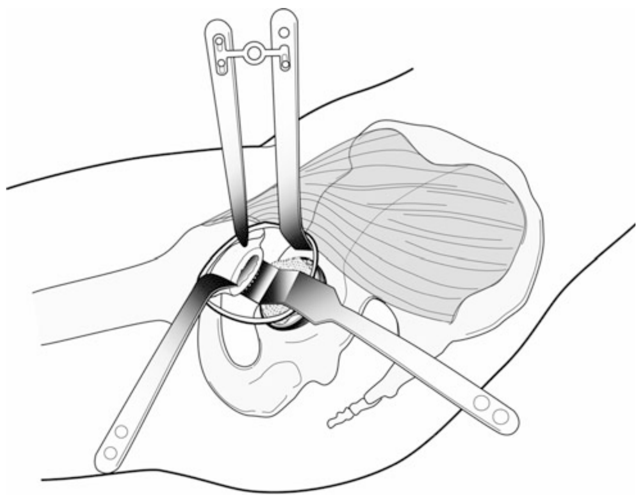


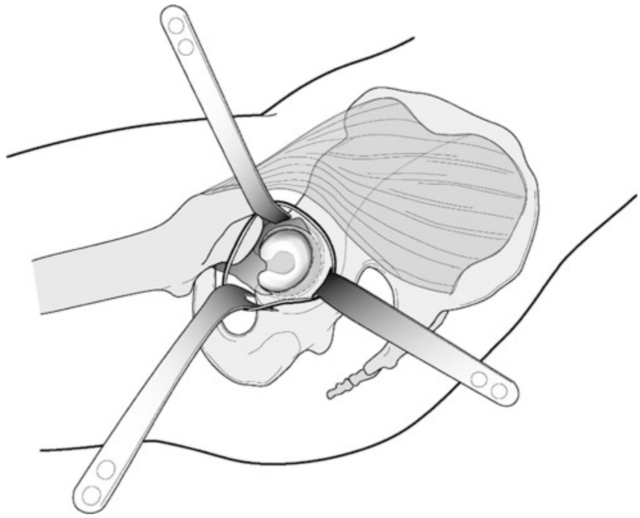
Fig. 5 Femoral exposure: the femur is presented through the wound posteriorly with the aid of the special long retractors. The anterior retractors separate the greater trochanter and the gluteus medius tendon. The posterior retractor inferiorly is placed retracting the quadratus muscle and either the big or baby jaw retractor is under the anterior femoral neck

of rotation is restored (Fig. 4). The third incision is of the inferior medial capsule, which is incised from the anterior femur to the acetabulum through the transverse acetabular ligament.

Femoral Preparation

The preparation of the femur was performed first so that the anteversion of the femur was known prior to the preparation and implantation of the acetabulum. The femur is presented through the wound by the positioning of special long-handled retractors (Zimmer and Innomed) as shown in Fig. 5. Femoral preparation was done by reaming and broaching. The intramedullary canal of the femur was registered by inserting the tool into the opened intramedullary canal and registering five points of the intramedullary canal into the software. The software could then determine the position of the implants in the femoral bone by calculating the intramedullary canal relative to the plane of the leg. The anteversion of the broach (and subsequently the stem) was computed as it was implanted into the bone (Fig. 6). Femoral anteversion can also be estimated by the surgeon by judging it against the axis of the femur. After 15–20 cases the surgeon's precision should be

Fig. 6 Acetabular exposure: the snake retractor is placed anteriorly on the ilium through an incision made on the anterosuperior acetabulum and retracts the greater trochanter anteriorly. The anterior-superior acetabular wall is thus visualized. The number 7 inferior retractor is placed with its tip on the cotyloid notch and the paddle on the ischium. The number 4 retractor is placed posterosuperiorly and the whole acetabulum can be visualized



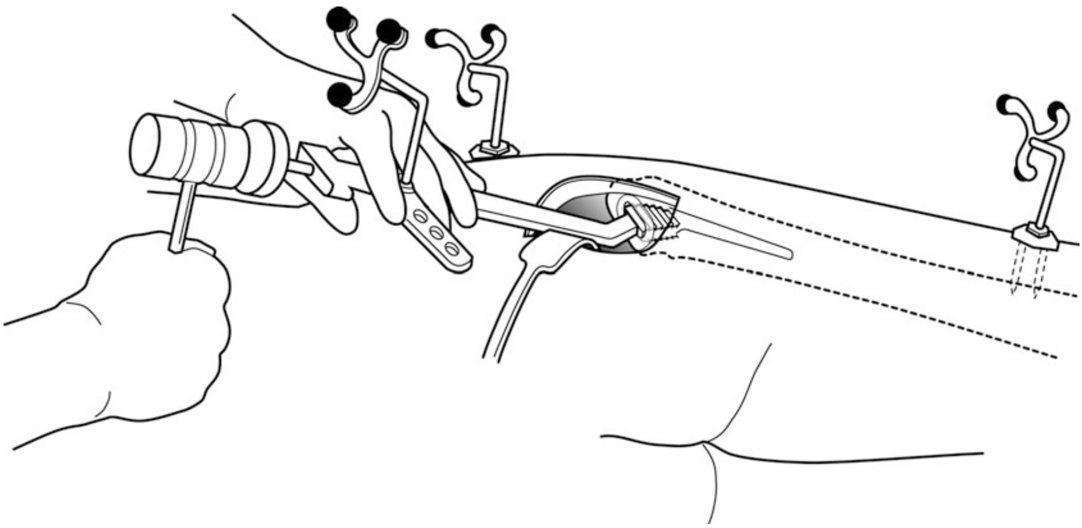


Fig. 7 The broach is inserted into the femur, and the light-emitting diode (*LED*) on the broach handle allows the computer to recognize the broach position in the intramedullary canal. The anteversion of the femur is thus obtained from this broach so that the combined anteversion can be obtained for acetabular cup placement

within 5°. Knowledge of the femoral anteversion permits customized placement of the cup to provide a combined anteversion of stem and cup of 35 ± 5° [11]. This technique of initially preparing the femur and determining femoral anteversion with subsequent cup implantation and positioning is a paradigm shift in the performance of the total hip replacement operation.

Acetabular Preparation

Once again, specialized long-handled retractors are placed to obtain correct exposure of the acetabulum (Fig. 7). Three registrations of the acetabulum are done prior to acetabular preparation: (1) center of rotation (COR) and diameter of the bony

Table 2 Accuracy of computer navigation for acetabulum

	CT inclination	Navitrack inclination	CT anteversion	Navitrack anteversion
N hips	14	14	14	14
Mean value (°)	41.8 ± 4.6	41.2 ± 4.7	24.4 ± 6.3	22.8 ± 8.9
Precision (°)	3.6		4.4	
Mean of differences (bias) (°)	0.64		0.5	
Intraclass correlation coefficient	0.88		0.97	

N hips = the number of hips studied

acetabulum; the acetabulum is digitized 16 times to obtain these values; (2) three to four points on the cortical bone on the cotyloid notch to digitize the medial wall; and (3) inclination and anteversion of the native acetabulum is registered by touching the periphery of the acetabular bone 6 times, which is displayed on the computer screen as both anatomic and adjusted values. The surgeon can control the depth of reaming in both the medial and superior directions while visualizing the change in the COR position on the computer screen. This is important because it allows the surgeon to obtain the correct depth that permits adequate coverage of the cup with an inclination between 35 and 45°, and it gives the surgeon the ability to keep the COR within 3 mm of the original native COR.

Postoperative CT Scans

Postoperatively, 14 patients had a CT scan of their pelvis for comparison of the inclination and anteversion of the cup on the CT scan to that measured by computer navigation. The CT scan value was considered the true value and the accuracy of the computer navigation value was determined by comparison with this CT scan true value. We defined the absolute difference of values of more than 5° between the CT scan and the computer navigator to be an outlier.

The computed axial tomography scans were obtained in the radiology department (MX8000, Philips, Highland Heights, OH). The CT data was analyzed by the hip plan module of the CT-based Navitrack system (Navitrack computed tomography-based hip application, Orthosoft, Montreal, Canada). By means of this software, a virtual three-dimensional model of the patient's pelvis, as well as the implanted cup, was reconstructed using the CT data. The APP was 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 [10].

Radiographic Measurements

Six-week postoperative anterior-posterior radiographs were taken with the patient supine and the beam centered over the symphysis pubis. These radiographs were measured using a digitized program with cup inclination by the method of Callaghan et al. [12] and anteversion by a method previously described by us [13]. By our method, a correction factor of 4° was added to the anteversion measurement obtained on the AP pelvis radiograph. Precision of the radiographs was calculated by comparison of the radiographic measurements with the final cup position by computer navigation. Computer navigation was known to be accurate within 1° (Table 2), so the precision of the radiographs was a consequence of greater measurement errors associated with the radiographic technique [14]. We defined the absolute difference of values of more than 5° for inclination and/or anteversion between the computer navigator and postoperative X-rays to be an outlier.

Surgeon's Estimates

The computer navigation technique is valuable to the surgeon only if it is better than the surgeon in precision of cup placement. We measured the ability of both an experienced surgeon and surgeons in fellowship training to correctly judge the cup position of inclination and anteversion. The trial acetabular cup was placed into the acetabulum using the mechanical holder with a tracking guide, and the computer screen was blinded to the surgeons. The cup holder was removed and the two surgeons estimated the position of the cup within the acetabular bone. These estimates were then compared with the adjusted numbers for inclination and anteversion displayed on the computer screen. The mean precision found for computer values allowed us to use it as the true value (Table 2). We defined the absolute difference of values of more than 5° for inclination and/or anteversion between the computer navigator and surgeon's estimates to be an outlier. The percentage of outliers for inclination and anteversion was then determined.

Statistics

The statistical analysis was performed with SPSS software (SPSS Inc., Chicago, IL). The Kolmogorov-Smirnov test for normal distribution was used before further statistical analysis was conducted. For analysis of measurements, the means and standard deviations were calculated. One-way analysis of variance (ANOVA) was used to determine statistical difference in measurements between anteroposterior pelvic tilt. The repeatability between femoral anteversion of computer navigation and CT scan results was calculated using intraclass correlation coefficient by the reliability analysis. The bias and precision were calculated according to the American Society for Testing and Materials (ASTM) definitions. A p value of less than or equal to 0.05 was considered significant.

Results

The accuracy and precision of computer measurements for inclination and anteversion compared with postoperative CT scans were excellent and are shown in Table 2. We defined the absolute difference of values of more than 5° between the CT scan and the computer navigator to be an outlier and found no outliers for inclination nor for anteversion with computer navigation.

Table 3 Computer, surgeon, and radiographic measurements: means and standard deviations

	Mean ± SD, in degrees (range)
Computer navigation-adjusted inclination	40.3 ± 3.8 (31–59)
Computer navigation-adjusted anteversion	25.9 ± 5.4 (3–39)
X-ray inclination	44.4 ± 4.9 (35–58)
X-ray anteversion	23.6 ± 5.2 (9–33)
Experienced surgeon's inclination	40.6 ± 3.9 (33–50)
Experienced surgeon's anteversion	23.2 ± 4.7 (14–35)
Less experienced surgeon's inclination	42.7 ± 5.1 (25–54)
Less experienced surgeon's anteversion	23.0 ± 5.7 (5–36)

Numbers are in degrees. Adjusted numbers are not adjusted for tilt. Radiographic measurements are included to compare with computer numbers

The mean values of the surgeons' estimates and of postoperative X-rays for inclination and anteversion are compared with those of computer navigation in Table 3. The precision of the radiographic measurements and the surgeons' estimates for inclination and anteversion are listed in Table 4. There was a statistically significant difference between computer values and experienced doctors for anteversion ($p = 0.009$) and inexperienced doctors for inclination ($p = 0.007$) and anteversion ($p = 0.011$).

Experienced surgeons had 27 % outliers for inclination and 35 % for anteversion; less experienced surgeons had 49 % outliers for inclination and 46 % for anteversion. Experienced surgeons are more precise than less experienced surgeons for inclination ($p = 0.004$), but there is no statistical difference for anteversion ($p = 0.852$).

The precision measurements mean that a surgeon can be as much as 11–15° wrong in the position of inclination that he/she thinks the position of inclination or anteversion of the cup is in. Therefore, even though the surgeon has a mean inclination and anteversion very near that determined by the computer, the data shows that anywhere from 30 % to 50 % of the time the surgeon is wrong by 5° or more and can be wrong by as much as 15°.

There was also a statistically significant difference between computer values and postoperative X-ray values for inclination ($p = 0.000$) and anteversion ($p = 0.006$). Radiographic outliers were 22 (33 %) of 66 for inclination and 19 of (29 %) 66 for anteversion. Our results for the X-rays compared with the computer show that they are wrong by more than 5° approximately 33 % of the time for inclination and 29 % for anteversion, with the most inaccurate reading of up to 20°.

Table 4 Computer measurements compared with surgeon and radiographic measurements: precision and bias

	Precision (degrees)	Bias (degrees)	*P* value
X-ray inclination	9.1	3.9	0.000
X-ray anteversion	11.5	2.1	0.006
Experienced surgeon's inclination	11.4	0.4	0.56
Experienced surgeon's anteversion	12.3	2.1	0.009
Less experienced surgeon's inclination	14.6	2.6	0.007
Less experienced surgeon's anteversion	13.6	2.2	0.011

Precision is the reproducibility of results of surgeons and X-rays compared with the computer navigator
Bias is the error compared with the computer
Statistical significance is achieved when *P* £ 0.05

Pelvic Tilt

The influence of tilt on inclination and anteversion is shown in Table 5, which has a comparison of the adjusted and unadjusted measurements. Unadjusted measurements are statistically related to pelvic tilt, whereas, when the anteversion is adjusted for tilt, the values are the same.

Discussion

Posterior single-incision MIS total hip replacement is a safe and effective operation that benefits patients [7, 8, 15–18]. Clinical data has demonstrated the favorable outcomes with the posterior MIS operation technique and shows that it achieves the goal of better function early for patients [7]. The posterior MIS total hip replacement is a more difficult operation to perform than a traditional incision and requires specialized training and instruments. It can be easily learned by those surgeons who perform a traditional posterior approach by gradually reducing the length of the incision and using the instruments we have described [9] (as manufactured by Zimmer or Innomed).

Until recently, the ability to reproducibly position a cup to any target numbers had depended greatly on a surgeon's experience and intuition. However, even the accuracy of experienced surgeons varies at different surgeries, and it is impossible to say that at every surgery the desired cup position can be obtained [1, 2, 4, 5]. Studies have shown that the use of mechanical guides based on

Table 5 Influence of anterior-posterior pelvic tilt on inclination and anteversion

Computer measurement	Posterior tilt 10–20°	Posterior tilt 1–9°	Anterior tilt 0–9°	Anterior tilt 10–20°	*P* value
Computer inclination[a]	36.7 ± 1.4	38.7 ± 2.8	42.4 ± 5.5	45.0 ± 2.8	0.001
Computer-adjusted inclination	40.3 ± 1.6	40.0 ± 2.7	41.2 ± 5.5	40.0 ± 1.4	0.752
Computer anteversion[a]	18.5 ± 1.7	22.0 ± 5.6	27.8 ± 5.5	39.0 ± 4.2	0.000
Computed-adjusted anteversion	28.2 ± 2.1	25.5 ± 5.4	25.2 ± 6.1	31.0 ± 2.8	0.337

Numbers in degrees. The anteroposterior tilt of the pelvis is divided into four categories according to the number of degrees of tilt. The effect of adjustment by pelvic tilt is shown by the difference in unadjusted computer inclination and anteversion values compared with the similarity of adjusted inclination and adjusted anteversion values
[a]The number of degrees of anterior-posterior pelvic tilt is statistically related to these measurements

Table 6 Accuracy of computer navigation for femoral anteversion

Statistics	CT anteversion	Navitrack anteversion
N hips	9	9
Mean value (°)	9 ± 6.2	6.8 ± 4.5
t-Test	$P = 0.07$	
Mean of differences (bias)	2.2	
95 % CI of differences	−0.23 to 4.67	
Intraclass correlation coefficient	0.906	

N hips = the number of hips studied
95 % CI is the confidence interval

the body axis for alignment are inferior to the computer with its knowledge of tilt and position of the acetabulum in space in relation to the APP [2, 5, 15].

When associated with minimally invasive surgery, computer navigation can reduce errors in cup placement and help restore the COR, despite the decreased vision with smaller incisions. The ability of the surgeon to have real-time information of the components' position significantly increases the accuracy of implantation [8, 16]. Our accuracy with the computer was within 1° of the values on postoperative CT scans. The precision (reproducibility) of the computer values was always within 5° of the measured component position, whereas surgeons' precisions varied from 11 to 15° and resulted in outliers of cup position beyond 5° in 27–49 % of cases for inclination and/or anteversion.

A second advantage of computer navigation is to customize the cup position rather than target it. By preparing the femur first and knowing the anteversion of the femoral component, the cup can be anteverted the correct degrees to provide a combined anteversion of 35 ± 5°. The inclination can be customized by controlling the depth of reaming to maintain the COR within 3 mm of the original bony acetabular COR and yet permit inclination to be 40° ± 5° with correct coverage of the cup.

In this study, we learned that with certain design femoral components, the stem anteversion is not the 10–15° that laboratory studies have used (Table 6) [19]. Indeed, with fit and fill stems (and this includes the Zweymuller tapered stem because of its enlarged proximal medial-lateral dimension) we found up to 30 % of the femoral stems were relatively retroverted (5° of anteversion or less). With this design non-cemented stem, the mean femoral anteversion was 7°, and was greater by 4° in women than men, which confirmed the cadaver study of Maruyama et al. [20]. Furthermore, it was difficult to change the anteversion of these type designs, and therefore the stem anteversion was a variable over which the surgeon had little control. However, this limitation is not so confining when using a tapered stem. We have learned by using a tapered stem (Total Joint Orthopedics, Salt Lake City, UT) rather than a fit and fill stem (APR, Zimmer, Warsaw, IN), that anteversion can be 10–20° most of the time. The surgeon can also increase stem anteversion up to 10° by broaching without the risk of fracturing the femur. With a tapered stem anteversion is 0–5° no more than 10 % of the time. A stem should not be left in place if the anteversion is less than 5°, and if increased anteversion cannot be safely achieved by alteration of the broaching, the choices to gain anteversion are a modular stem or to cement the stem.

It is important to customize the cup for each patient's anatomy. By preparing the femur first, and judging the femoral anteversion, the surgeon can adapt the acetabular anteversion to provide a combined anteversion of 35 ± 5°. This technique requires a paradigm shift of femoral preparation prior to acetabular preparation.

In this study group of patients, the mean superior displacement of COR was 1.56 ± 3.3 mm and medialization was 5.19 ± 5.4 mm, which is well within accepted limits of reconstruction of the COR [21, 22].

More than 25 years has passed since Lewinnek et al. [23] described the safe zone for acetabular component positioning as 30–50° for inclination and 5–25° for anteversion. We propose that the safe zone for inclination should be narrowed to 35–45° and for anteversion changed to 15–25°. Surgeons who operate on patients with an anterior approach often state that a cup position of 10–15° anteversion is optimal [24]. However, we suspect that surgeons who operate with the anterior approach, and particularly with the patient in the supine position, visualize the cup position by the anatomic plane and not the radiographic plane. Certainly, patients with posterior tilt of the pelvis on the operating table can have an anatomic anteversion of 10–15° which is equivalent to the functional anteversion of 15–25°. Surgeons who operate through the posterior approach visualize the cup more with the radiographic plane. This may account for differences in the numbers quoted by surgeons. If we take impingement or wear as endpoints, it does not seem reasonable that different numbers should be used for different surgical approaches; however, the numbers may be equivalent if they are being measured in different planes.

The inclination of the cup should not exceed 45° to optimize the wear of the articulation surface [25]. The optimal number for inclination within its safe zone of 35–45° is now known to be related to the spine and pelvis morphology and dynamics [26]. The morphology of the spine/pelvis/hip relationship is the pelvic incidence, and with a low pelvic incidence (PI), the femoral heads are stationed more directly under the spine, while with a high PI the femoral heads are more anterior to the spine. This relationship is important in the standing to sitting postural change because with sitting the pelvis has to tilt posteriorly and the spine is straightened from its standing lordotic position, and this dynamic change of the pelvis allows the hips to clear with sitting. In addition to the pelvis tilting posteriorly, the acetabulum has increased inclination and increased anteversion to again provide clearance for the femoral head and neck without impingement. If we take the patient who has a low PI (below 49°) and a stiff spine [sacral tilt (ST) change from standing to sitting of $<13°$], we have a patient whose pelvis does not tilt posteriorly when the patient sits. With this stiffness of the spine/pelvis construct in a patient with the femoral heads located beneath the spine (low PI) the hip necessarily has to flex more for the patient to sit. So it is understandable why these patients statistically have a higher risk for dislocation. In total hip replacement, to allow the femur to clear with sitting, the cup inclination must be 45°, and in an older patient who does not need longevity of the hip, 50° would be even better. Likewise, the combined anteversion must approach 35° or even 40°. If the cup has inclination of 35° in this group of patients, the sacro-acetabular angle (SAA) can be near 50° which also guarantees impingement. The SAA in all patients should be 60–65° and is often 70–80° in patients with normal and flexible spines and particularly in those with a high PI.

Hips with a low PI but normal or flexible functional dynamics of the pelvis and spine (normal ST) will have a posterior tilt of the pelvis with sitting that is near 25° which allows the hip to clear during sitting. In these patients a cup position of 40° inclination and 15–20° anteversion (combined anteversion of $35\pm5°$) clears the hip easily with sitting. Total hip replacements have done so well through the years because the majority of patients do not have a low PI and stiff spine combination. The majority of patients have a normal or flexible PI with stiff spine or with low, normal, or high PI have a normal or flexible spine. Any of these combinations allow more flexibility in the cup position. The lowest inclination of 35° is tolerated in patients with a normal PI with a flexible spine (ST change) greater than 25° (or flexible PI greater than 59°) with normal or flexible dynamics. Cup inclination as low as 35° should be reserved for these patients with the majority of patients having inclination of 40° and the patients with stiff spines and particularly stiff spine with low PI having high inclination of 45° or even 50°. The use of constrained implants such as a dual mobility articulation is really only needed in patients with a low PI and stiff spine, and the use of dual mobility in these patients is a good choice.

We take a lateral standing spine/pelvic/hip/femur X-ray on every preoperative patient we operate and use the anatomy of that patient at their surgery to make decisions on positions of the cup [26]. Computer navigation allows us to achieve the desired cup position with precision.

Navigation is a great source of data for correlating component position with impingement, to thereby reduce its prevalence. We found that lateralized cup positions had a much higher prevalence of impingement of the metal neck on the metal shell. Cups with a mean 3.2 ± 3.5 mm of medialization had greater impingement ($p = 0.03$) versus those cups medialized on average 5.8 ± 4.9 mm. We have learned that in hips with a low anteversion of the femoral stem (<10°), the greater trochanter can impinge against the ilium with flexion and internal rotation of the hip above 90°. In hips with low anteversion of the femoral stem, a high offset stem should be used even if it increases the offset more than 5 mm. Secondly, the surgeon must be absolutely certain the hip has not been shortened in length either. Shortening of the hip in length or offset with low anteversion of the stem almost assures bony impingement and increased risk of dislocation. This is especially important if a small femoral head is used, such as a 28- or 32-mm head. By using this technique, it also allows the avoidance of dislocation precautions for these patients because impingement has been prevented.

The benefit to patients of the avoidance of outliers and customization of the cup to femoral anatomy is better mating of the femoral head into the cup. The more medial (and the less vertical) the vector of load is into the cup, the lower the linear rate of wear will be. In a study of hips operated with computer navigation at a 10-year follow-up, we measured linear wear of highly cross-linked polyethylene of 0.015 mm p/year. In the images of their hips, as measured on a standing and sitting lateral spine/pelvic/hip X-ray, the femoral head was centered in the cup with the patient seated. When these positions can be achieved every time at surgery (and with computer navigation the surgeon can avoid all outliers), and when these positions are determined to balance the spine/pelvis/hip construct, then the durability of the operation can be projected to have been optimized. When these component positions are combined with correct soft tissue balance (hip length and offset) and excellent head-neck ratios, dislocation will become rare.

Precision measurements confirmed prior observations that that radiographs are not as accurate as the computer. The imprecision of 10° is caused by variable flexion of the pelvis on the X-ray table, the rotation of radiographs, and the variations from the direction of the X-ray beams [5, 14, 27]. The most basic element that orthopedic surgeons have relied on for postoperative control of most orthopedic procedures, the X-ray, is not as reliable as we surgeons have thought, and the computer is superior to them.

Our results show that computer navigation affords a more precise (reproducible) acetabular component reconstruction, with more accuracy than achieved by even the most experienced surgeons. We have validated with CT scans that the computer is a tool that surgeons can rely on during surgery. The computer has permitted us to explore new techniques that customize hip reconstructions to accommodate a patient's individual anatomy. Outcomes of this more accurate hip reconstruction for decreased complication rates and requirements for revision, and improve longevity, are being measured by us in our patient population.

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