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Limitations of Imageless Computer-Assisted Navigation for Total Hip Arthroplasty

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Abstract: We prospectively evaluated acetabular cup placement in total hip arthroplasty with an imageless computer navigation system or using conventional manual technique. The achieved cup orientation in the manual group had substantially larger variances and greater placement error than the navigation cases. The use of navigation was abandoned in 3 cases because of excessive pelvic tilt and unreliable registration of the pelvis. Computer navigation system helped improve the accuracy of the acetabular cup placement for total hip arthroplasty in this study. The variation between the intraoperative navigation readings and the computed tomographic values suggests that relying on palpation of bony landmarks through drapes and tissue is a limitation of this method. Further, the variation in pelvic tilt has an effect on cup placement that requires further studies. **Keywords:** hip arthroplasty, computer assisted navigation.

In addition to achieving long term implant fixation without material failure, a successful outcome of a total hip arthroplasty (THA) should result in a functional range of motion, without impingement or dislocation, and restore appropriate leg length and offset.

The cause for a hip dislocation following a THA is multifactor. Morrey described an incidence in the literature of 2% to 3% [1]. Lewinnek et al [2] proposed a "safe zone" of 40° ± 10° of abduction and 15° ± 10° of anteversion. They found that cups positioned outside a "safety zone" had a 4-fold increase in dislocations with cups below the 5° of anteversion having posterior dislocations and cups above 25° of anteversion tending to have anterior dislocations. Barrack et al [3] indicated that variation in acetabular cup position was a major cause of hip dislocations and advocated positioning cups in 35° to 55° of abduction and 10° to 30° of anteversion. McCollum et al [4] recommended cup positioning inside of 30° to 50° abduction and 20° to 40° of anteversion. Jolles et al [5], in a multivariate analysis of hip dislocations found that combined femoral and acetabular anteversion of less than 40° or greater than 60° was associated with a higher incidence of hip dislocations. Biedermann [6] et al, in a study of 4784 hip replacements, found a 2.4% incidence of dislocation in primary hips and 4.6% in revisions. Using Lewinnek et al's criteria [2], 93% of the stable group was inside the "safe zone" compared to 67% of the dislocation group. Nishii et al [7], in a computed tomographic (CT) study of THA found that cases with posterior dislocation were more frequently positioned with less than 20° of anteversion. Padget et al [8] found increased dislocation rates with 22 mm-heads compared to 26- and 28 mm-heads. Burroughs [9] found a progressive increase in stability with larger head sizes and changes in acetabular anteversion. Increased wear and foreign body lytic changes were seen by Kennedy et al [10] in cups with increased abduction angles although Del Shutte et al [11] did not find an effect from increased anteversion. D'Lima et al [12] described a complex interplay between the orientations of the femoral and acetabular components and head-neck rations on the range of motion, stability and component impingement.

Historically, the posterior approach has been associated with higher dislocation rates [1], which has been reduced by surgical repair of the posterior soft tissues [13] with a meta-analysis by Kwon [14] showing no significant differences in dislocation rates between

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surgical approaches. Malposition of one or both components is responsible for the majority of dislocations, with the acetabular component being the most sensitive variable predisposing to dislocation [15-18]. Of all the factors associated with dislocation, component malposition is the most easily controlled and predictive of a good result [15,18].

The computer assisted hip navigation systems are classified into 3 groups: those based on preoperative CT images, those based on intraoperative fluoroscopic images for planning and registration, and those based on the imageless, intraoperative registration of bony landmarks. All rely on establishing the anterior frontal plane of the pelvis (AFPP) as the neutral plane in a 3-dimensional (3D) coordinate system to determine the acetabular cup orientation (anteversion and abduction). The AFPP is formed by the most prominent bony landmarks of the 2 anterior superior iliac spines (ASIS) and the 2 anterior promontories of the pubic tubercles (PT). With image based computer navigation systems, these points are determined by matching the points at surgery to pre-operative CT scans or fluoroscopic images. Imageless computer assisted navigation systems depend on manual palpation of these bony prominences without the help of radiographs [19,20]. With this reliance on digital palpation through overlying drapes and soft tissue, there is a concern whether the determination of prosthesis alignment, mainly the acetabular orientation, is reliable using imageless computer assisted navigation system [21-23]. Another limitation identified by other authors [24,25] may be the need to incorporate pelvic tilt into the assessment of acetabular cup position.

The hypothesis of the study was that an imageless computer assisted navigation system would be more accurate for acetabular cup placement in THA than conventional methods using manual instruments. To test this hypothesis, cup anteversion and abduction were examined in 2 groups of patients receiving primary THA surgery, one group with the aid of a computer assisted navigation system, and the other, using a traditional manual alignment instrument.

Materials and Methods

Study size was determined with a power analysis based on radiographic readings from previous navigated and manual THA cases where we assumed a similar difference 0.50 in proportion would be observed between the 2 methods. Specifically, we assumed 75% of the navigated cases fell into a target range compared to 25% of the manual cases where with a significance level of $\alpha = .05$, a sample size of 20 in each group would yield a statistical power of 0.97. Considering possible drop-off, 25 participants were included in each group. After institutional review board approval, we approached 64 consecutive patients of which 50 subjects agreed and were randomized into 2 groups of 25 each using either an imageless computer navigation system (CAS) or a conventional manual instrument (MAN). Table 1 summarizes the subject characteristics.

Table 1. Subject Group Characteristics Analyzed in this Study

Characteristic	Group: MAN	Group: CAS	Significance for Group Difference (2-tailed t-test)
Number	25	25	n/a
Male:female	13:12	15:10	0.58
Age (y)	63.5 ± 13.0	62.1 ± 12.0	0.69
Height (cm)	173.5 ± 12.4	174.0 ± 11.2	0.87
Weight (kg)	87.0 ± 20.1	80.3 ± 11.8	0.15
BMI	28.8 ± 5.5	26.5 ± 3.4	0.09
Osteoarthritis	25	25	n/a
Preoperative Harris Hip Score [46]	49.8 ± 10.9	52.1 ± 7.9	0.39
Preoperative WOMAC Score [47]	51.6 ± 15.8	50.3 ± 12.0	0.75

The sample size, sex, age, height, weight, and BMI data, as well as osteoarthritis, preoperative hip score, and preoperative Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Score are given.

The imageless computer assisted navigation system used in this study (Stryker Navigation System, Stryker Corp, Kalamazoo, Mich) relies on "trackers" that attached to the subject and instruments (Fig. 1) to determine the spatial location and orientation of any bony point or implant. Percutaneous pins with trackers, which had multiple infrared light-emitting diodes that transmitted pulses of patterned light signals to 3 cameras, were placed in the femur and pelvis to establish a coordinate system. A digital pointer with similar light-emitting diodes was used to identify various bony landmarks in this coordinate system. A similar tracker was attached to the instruments to determine the position of the cup reamers and implant.

We chose to follow Lewinnek safe zone to determine the goal of the surgery. Lewinnek et al [2] suggested a radiographic definition of a safe zone as 15° ± 10° for anteversion and 40° ± 10° for abduction. Because the computer-assisted navigation system uses an anatomic definition, the values for the middle of Lewinnek's safe zone were transformed using Murray's [26] equations to 42.3° of abduction and 22.6° of anteversion in anatomic description. Therefore, the goal at surgery was to place the cup within a few degrees of these values. Although the anatomic definitions [26] were used in our surgery, all results for cup orientation were converted to radiographic definitions [26] for analysis and comparison to other published studies.

At surgery, the patients were placed in a lateral decubitus position with firm supports for the anterior pelvis, chest, sacrum and dorsal spine to keep the patient in a stable position throughout the surgery. For CAS

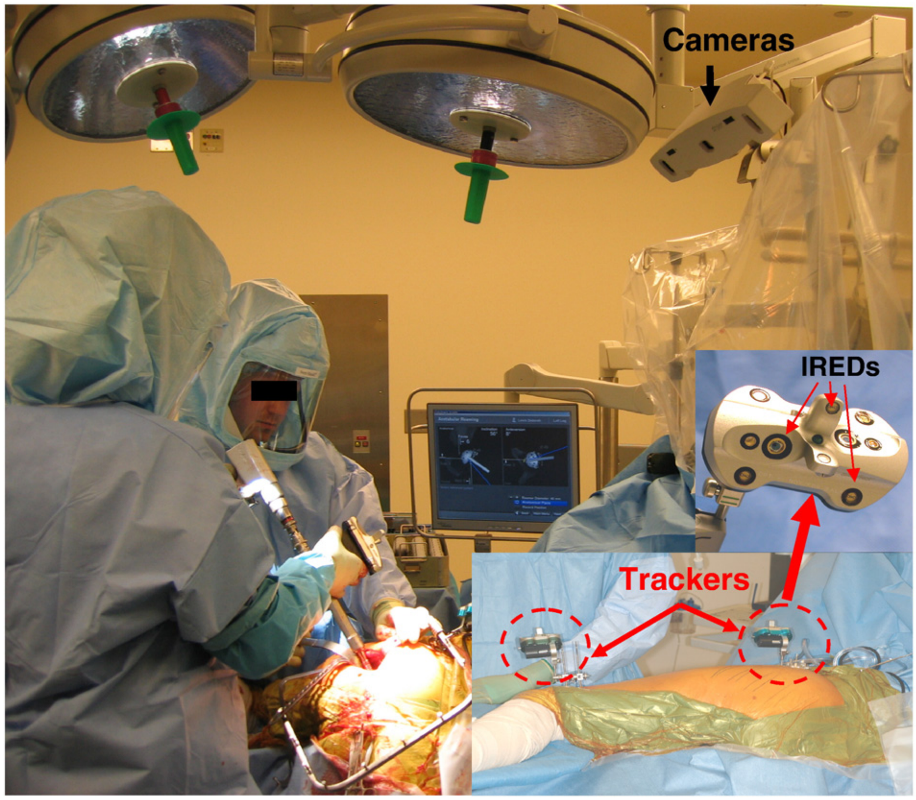

Fig. 1. The use of the imageless computer assisted hip navigation system in a THA surgery. "Trackers" are attached to the subject and communicate with the cameras of the navigation system to determine the spatial location and orientation of any bony points in the 3-dimensional coordinate system. IRED indicates infrared light emitting diode.

group, 2 navigation trackers were placed as described previously. Then the 2 ASISs and center of the pubis were palpated through the drapes and a digitizing pointer used to register their locations with the navigation system.

All surgeries were performed by one of the authors, RLW, using a limited posterior approach of 8 to 12 cm that was begun at the superior posterior corner of the greater trochanter and carried proximally. Following exposure of the acetabulum the acetabular fossa, articular surface and acetabular rim were registered and the acetabulum reamed with navigated guidance, if the patient was in the CAS group. The acetabular cup used in both groups was the Stryker Trident (Stryker Corp), which has a plasma sprayed titanium surface with hydroxylappatite for bone ongrowth. Following impaction, either a cross-linked polyethylene or ceramic liner was inserted.

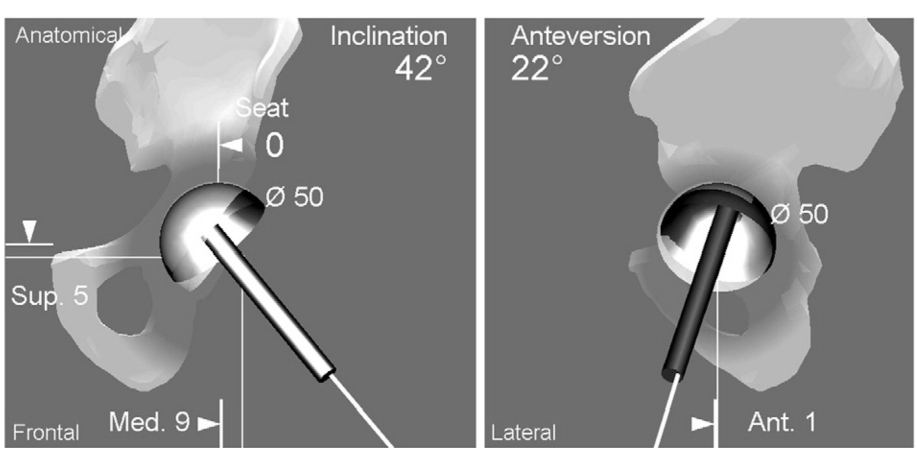

Fig. 2. The screen of the imageless computer assisted navigation displaying in real-time the navigated cup position for abduction (inclination in the image) and anteversion.

In the surgery with navigation, the surgeon used the real-time values for anteversion and abduction provided by the navigation system to decide on the appropriate orientation of the acetabular cup (Fig. 2). For the MAN group, anteversion was based on an estimation of the angle formed by the insertion handle and aligning a 20° attachment with the apparent long axis of the body. Abduction was estimated in relation to the operating table with an insertion handle forming an angle of 40° to 45° to the table and checked with an Innomed angular bubble level (Innomed, Innomed Inc, Savannah, Ga). If palpation of the bony landmarks indicated that the pelvis was tilted in this position, the amount of abduction was adjusted.

The femoral component used in all of the surgeries was a press-fit, bone ingrowth tapered design (Accolade Femoral Implant, Stryker Corp). The largest head diameter available for the implanted cup liner was used.

In a subset of 17 patients to compare to the measurements that had been taken in the lateral position, following standard closure of the wound and application of sterile dressings, the patients were turned supine with the navigation trackers still attached. The pelvic landmarks were palpated and redigitized.

Postoperatively, the subjects were mobilized with gait training and full weight bearing as tolerated. All subjects were begun on resistive exercises that were continued with outpatient physical therapy after discharge. All were given appropriate perioperative and postoperative antibiotics, anticoagulated with Coumadin and followed a dedicated total hip protocol with a clinical pathway that included dislocation precautions for 1 month. All

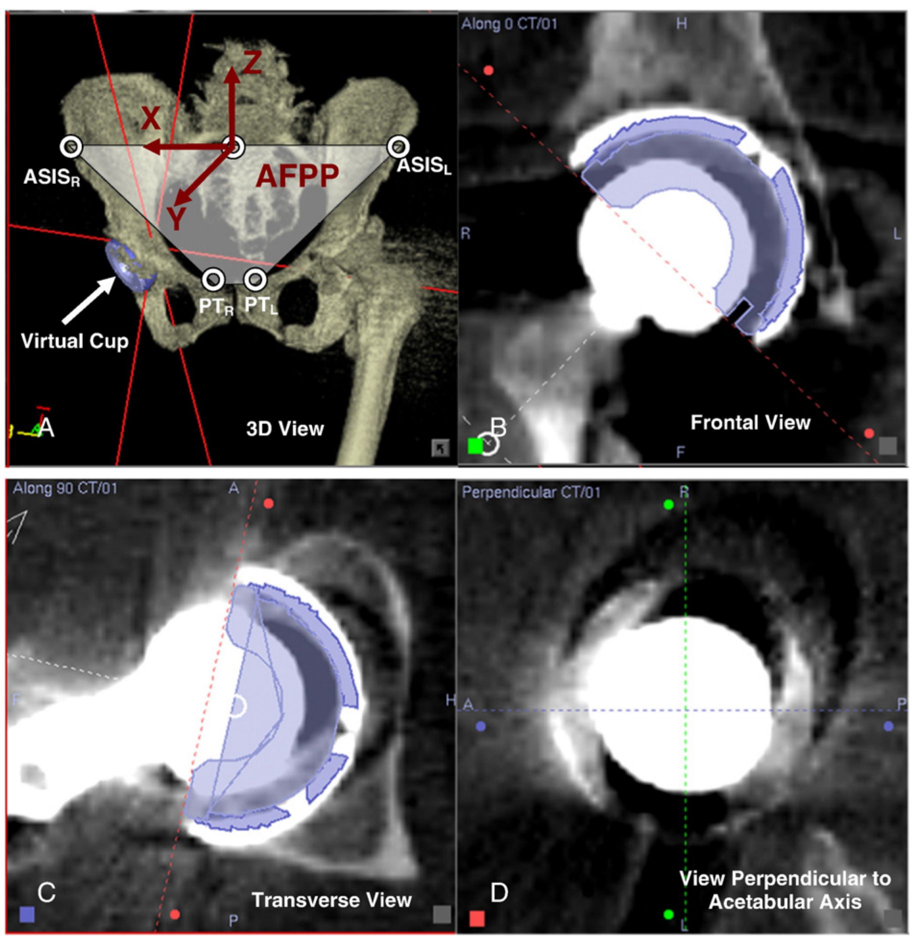

Fig. 3. The method of using a 3D pelvis-prosthesis model and a superimposed virtual acetabular cup to obtain the orientation of the implanted acetabular cup based on CT images. The coordinate system used in this study is also shown. (A) The 3D pelvis-prosthesis model based on CT images and the coordinate system used in this study. The coordinate system takes the origin as the midpoint between the ASISs, with a pelvic plane defined by 2 ASISs and pubic tubercules (AFPP). z-Axis is in the AFPP pointing superiorly, with x-axis pointing to right ASIS and y-axis pointing ventrally perpendicular to AFPP. Superimposed virtual cup is also shown. (B) The frontal view of the CT image of the implanted acetabular cup and the Superimposed virtual cup which is aligned with the implanted cup. (C) The transverse view of the CT image of the implanted acetabular cup and the superimposed virtual cup which is aligned with the implanted cup. (D) A CT image of the implanted acetabular cup and the superimposed virtual cup from a view which is perpendicular to the implanted acetabular cup.

subjects were followed up at 1 month to assess their recovery from the hip procedure at which time radiographs were taken.

On the second postoperative day, all subjects had a CT scan of the pelvis and proximal femur in supine position with 1.25-mm cuts. The CT images were used to create a 3D model for the pelvis and the prosthesis (Fig. 3A) by using software developed for a CT based hip navigation system (CT-Hip System, Stryker Leibinger GmbH and Co KG, Freiburg, Germany). On this model, the pelvic coordinate system (Fig. 3A) was established by defining the AFPP based on bilateral ASISs and PTs. The pelvic coordinate system took the origin at the midpoint between the ASISs, with the z-axis in this plane pointing superiorly, the x-axis pointing to the right ASIS and the y-axis pointing ventrally, perpendicular to the AFPP. A virtual acetabular cup was superimposed over the implanted cup component (Fig. 3). By adjusting the location and tilting angle of the virtual cup in frontal plane (Fig. 3B) and the transverse plane (Fig. 3C), and in a plane perpendicular to cup axis (Fig. 3D), the virtual cup was aligned closely to the implanted cup. Then the reading of anteversion and abduction of the virtual cup was considered to represent that of the implanted cup. This method has been validated in our previous cadaver study [27].

The cup position in the 2 groups was then evaluated by 3 methods. The first was to determine the number of cases that fell into Lewinnek's safe zone [2]. The second method was to compare the absolute variation of the cup position determined by the CT from the target position, which were the mid-points of Lewinnek's safe zone. This variation was defined as placement error. This was done by comparing all the patients who had been randomized to the 2 groups with the intention to use or not use navigation. The same analysis was performed comparing the manual group to the patients where navigation was actually used. Lastly, the recorded navigation position for anteversion and abduction was compared to the values derived from analysis of the CT scans.

From the CT images, the ASIS and pubis were determined and used to calculate the flexion or extension of the AFPP to the CT table with the patient lying in supine.

For statistical analysis a χ^2 was used to compare the number in each group that were inside the Lewinnek's [2] safe zone. The variation of the cup position from mid-points of this zone for each group was compared using independent-sample *t* tests. Paired *t* test compared the variation between the navigated values and CT derived values. Statistical analysis was performed using SPSS Version 16.0 (SPSS Inc, Chicago, Ill) with a significance level of .05.

Results

There were no dislocations or significant complications from the surgery in either group or problems with the use of percutaneous pins in the CAS group. In 3 cases (12%) of the CAS group, placing the cup in the targeted position of anteversion appeared clinically inappropriate and the use of navigation was abandoned with the cup positioned using the manual technique. Fig. 4A and B are scatter plots of comparing the navigated position recorded intraoperatively using the navigation system and that measured by the CT scans. Cases where navigation was abandoned are

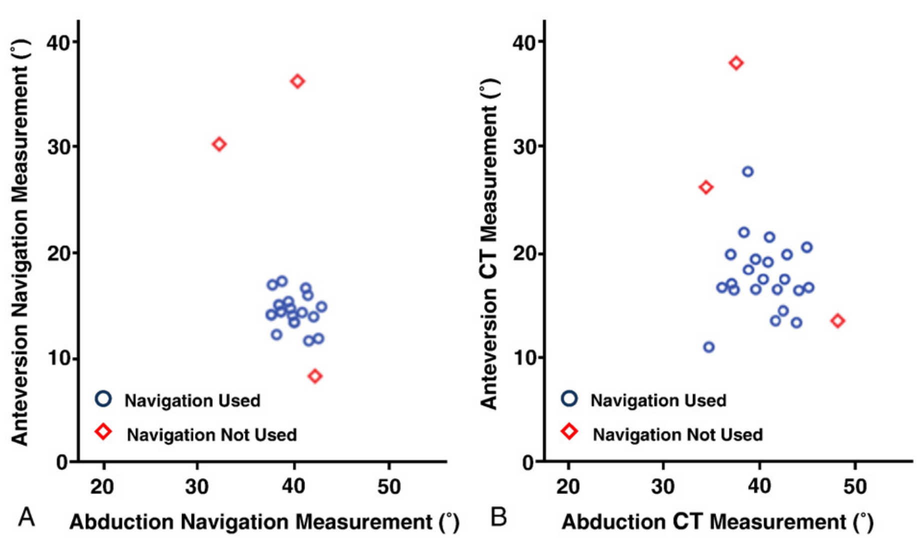

Fig. 4. Scatter plots of the achieved cup orientation for CAS group. The 3 cases where the navigation system was not used are included and indicated using a different marker shape. There is more scatter of the actual values determined from CT than the recorded values of navigation at surgery. A, The scatter plot of the achieved cup orientation from the readings of the navigation system. B, The scatter plot of the achieved cup orientation calculated by CT-model method.

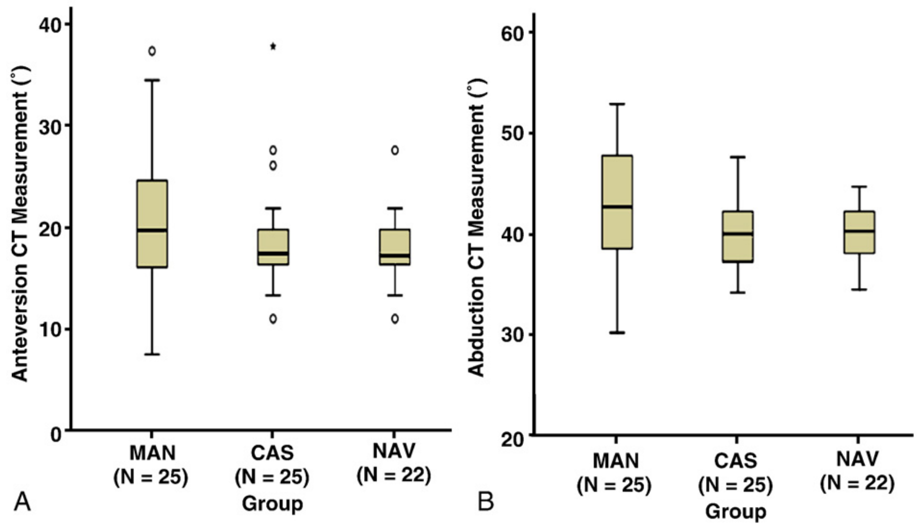

Fig. 5. The box plots of CT-model calculations on cup anteversion (A) and cup abduction (B) for MAN, CAS and NAV groups. The bars represent median, quartiles, and extreme values. The points represent outliers. A, The box plot of the acetabular cup anteversion calculated by CT-model method for MAN, CAS and NAV groups. B, The box plot of the acetabular cup abduction calculated by CT-model method for MAN, CAS and NAV groups.

indicated. Fig. 5A and B are box plots with the cup position, as determined from the CT scans, for the navigated (NAV), the intended to use navigation (CAS) and manual cases (MAN). For cup abduction, 23 of 25 manual cases and 25 or 25 navigated cases were in the safe zone ($P > .05$). For cup anteversion, 19 of 25 manual cases and 22 of 25 CAS cases were in the safe zone ($P > .05$). For the NAV cases, 21 of 22 cases were in this range ($P > .05$).

The mean, standard deviation, minimum and maximum values are shown in Table 2 for cup orientation for the manual group, the CAS group and the NAV group. The accuracy of imageless navigation was assessed by looking at the difference from the anteversion and abduction values determined from the CT scans. The mean anteversion difference was 3.4° ± 3.6° (range-4° to 13°) while the mean abduction difference was 0.0° ± 2.8° (range, 4° to 5°). Abduction was significantly more accurately achieved ($P = .001$).

The placement error for both anteversion and abduction was significantly less for the CAS and NAV groups than the manual cases as seen in Table 2.

For the navigated cases, Fig. 4 shows more scatter of the anteversion and abduction values determined from

Table 2. Acetabular Cup Orientations (mean ± SD) and the Cup Placement Errors Obtained from CT Scan Analysis for CAS (n = 25), NAV (n = 22) and MAN (n = 25) groups

	Navigation System Reading		CT-model Measurement	
Group	Anteversion (range)	Abduction (range)	Anteversion (range)	Abduction (range)
MAN (n = 25)				
Cup orientation			20.3° ± 7.6° (8°-37°)	42.5° ± 6.3° (30°-53°)
Placement error			7.3° ± 5.7° (0-22°)	5.5° ± 3.8° (0-13°)
CAS (n = 25)				
Cup orientation	15.5° ± 5.6° (8-36°)	39.8° ± 2.2° (32-43°)	18.7° ± 5.5° (11-37°)	40.0° ± 3.4° (34-48°)
P^1			.384	.080
Placement error	2.9° ± 4.8° (0-21°)	1.6° ± 1.5° (0-8°)	4.4° ± 4.9° (0-23°)	2.7° ± 1.9° (0-8°)
P^1			.060	**.003**
NAV (n = 22)				
Cup orientation	14.2° ± 1.5° (12°-17°)	40.0° ± 1.6° (38°-43°)	17.7° ± 3.5° (11°-28°)	40.0° ± 2.9° (34°-45°)
P^2			.132	.082
Placement error	1.3° ± 1.0° (0-4°)	1.3° ± 0.9°(0-3°)	3.4° ± 2.7° (0-12°)	2.3° ± 1.5° (0-6°)
P^2			**.006**	**.001**

For CAS and NAV group, data from the navigation system reading are also given. For each data, in addition to mean and standard deviation, the range of the data is also given in the parentheses.

P^1, the significant difference between CAS (n = 25) Group and MAN (n = 25) on data obtained using CT-model measurement.

P^2, the significant difference between NAV (n = 22) Group and MAN (n = 25) on data obtained from CT-model measurement.

Table 3. Difference of the Cup Orientation Relative to Body Position

Cup orientation	Difference (n = 17)	Significance
Abduction		*P* = .903
Lateral	1.2 ± 2.9°	
Supine	1.0 ± 3.4°	
Anteversion		*P* = .570
Lateral	4.4 ± 5.3°	
Supine	4.3 ± 6.6°	

Data (mean ± SD) are given for the difference between digitizing the pelvic bony landmarks in the lateral versus the supine position. Data were from a subset (n = 17) of the NAV group where the navigation system was used.

CT than were recorded by the navigation system. The mean absolute difference for anteversion was 2.1° ± 3.0° (*P* = .003), while the mean absolute difference for abduction was 1.1° ± 1.6° (*P* = .007).

As seen in Table 3 there was no significant difference in the variation from the CT measured cup position between digitizing the pelvic bony landmarks in the lateral position compared to the values that would have been obtained from palpation in the supine position.

From the measurements of pelvic position in the CT scanner, there was anterior tilt (ASIS higher than pubis) of 8.1° ± 5.9° (−6° to 17°) for the manual group and 9.0° ± 10.6° (−4° to 31°) for CAS group ($P > .05$).

For the 3 cases where navigation was abandoned, 2 had increased anterior pelvic tilt of 17° and 14°, while the third case had posterior pelvic tilt of 3°.

There was not a significant correlation between body mass index (BMI) and differences between the navigated cup position values and the CT values (anteversion: r = 0.099, P = .637, abduction: r = 0.324, P = .14). Similarly, comparing groups of patients with BMI <26 and ≥26, there was no difference between them on anteversion (*P* = .74) and abduction (*P* = .73).

The surgical time was recorded from the skin incision (manual group) or the stab wound for placement of the percutaneous pins (CAS group) to application of the wound dressing. The use of navigation resulted in an average additional 21 minutes of surgical time.

Discussion

In this study, although the use of computer assisted surgical navigation for THA resulted in less variance in acetabular cup placement than the manual method, there were limitations to the use of this approach. In 3 of 25 navigation cases, the use of the system was abandoned, representing 12% of the group and suggesting that imageless navigation relying on the AFPP may be limited in reliability. Although the difference between the abduction from the navigation record and the CT measurement was 0.0° ± 2.8°, the difference for anteversion was 3.4° ± 3.6°. The results were further complicated by the finding of a very wide range of pelvic flexion-extension in the entire patient group. This appears to be the reason that in 2 of the cases where navigation was abandoned, the marked pelvic tilt resulted in the appearance of less anteversion based on navigation alone.

The determination of the cup orientation in navigated THA was based on the plane formed by the ASISs and the PTs. Therefore, inaccurate palpation of these landmarks can lead to an error in cup placement [21,28]. Anteversion is affected by changes in the anterior-posterior measurement of the pubis in the sagittal plane. With a relatively short distance from the midpoint between the 2 ASIS points of 91.0 ± 8.0 mm, small differences in the palpation of the height of the pubic area can affect the calculated navigated anteversion values. By similar analysis, it is obvious that abduction is less affected by small variations in the exact points where the 2 ASIS are palpated because there is a relatively large distance between them (229.5 ± 16.6 mm). Wolf et al [18], using a kinematic model, quantified the effect of inaccurate measurements on cup placement.

One of the sources of error is the amount of soft tissue that may be on top of the pubis. With palpation, it is necessary to push the soft tissue away to get as close to the bone as possible. Richolt et al [21] found soft tissue over the pubis to be 5.7 ± 3.4 mm thicker than that over the ASIS, which would result in a mean underestimation of anteversion of 2.8° ± 1.8°. Parratte et al [23] found ultrasound was more reliable than digital palpation. Ybinger et al [22] was able to correlate errors in cup positioning with soft tissue over the bony prominences. Spencer et al [29], in a cadaver study with repeated measures by 8 surgeons, found significant variation between surgeons in the determination of abduction and anteversion. In our study, in one of the cases where navigation was abandoned, the actual position of the cup on CT had 6° more anteversion than suggested by the navigation system. We have attributed this to an error in the accuracy of percutaneous digital palpation.

Kaleitis et al [19,30] described similar improvements in acetabular cup position comparing manual technique to both CT-based and imageless computer assisted navigation methods. Both navigation methods resulted in significantly more cases in the safe zone, with both the navigated mean values were close to the CT findings. In Kaleitis' study, a supine position was used for registration and hip positioning. Although we found no difference between the lateral and supine measurements in a subset of our patients, the use of a lateral position for bony palpation and component positioning in our study may be related to the slightly higher anteversion found with the CT analysis.

Parratte et al [31] have also described the use of an imageless hip navigation system with less variation in cup position than manual techniques. Unlike our study, they found a BMI of >27 affected the accuracy of cup placement which they attributed to the increased soft tissue thickness over the bony landmarks. Although our study found no correlation with BMI, we also found a difference between the navigated values and CT values, especially for anteversion. Parratte et al [31] suggested other methods, such as echographic morphing of the pelvis, could be useful in heavier patients.

Dorr et al [32] described the use of an imageless navigation system with a bias of less than 1° for abduction and anteversion with precision less than 5°. These results were better than those obtained by an experienced surgeon using manual methods. Determination of the proper amount of acetabular anteversion by aligning the acetabular cup parallel to the transverse acetabular ligament (TAL) has been described by Archbold et al [33] and Pearce et al [34]. These authors suggested that incorporation of digitization of the TAL has potential to improve the use of navigation in hip arthroplasty, while study from Mihalko et al [35] found that using TAL did not achieve as accurate a cup alignment as that of using the posterior interspinal line. Hakki et al [36] have described the use of the acetabular center axis with comparable accuracy to measurements from CT scans and superior to those derived from digital palpation of the bony landmarks of the anterior frontal plane.

Postoperative assessment of the pelvic tilt in the supine position from the CT measurements revealed a wide variation in the range of pelvic flexion-extension. Other groups [24,31,37] found a similar wide variation in pelvic position. Lembeck et al [25] suggested that the variation in pelvic tilt made navigation systems referring to the AFPP inaccurate. In the normal standing position, the AFPP was typically parallel to the longitudinal axis of the patient [38]. McCollum et al [4] have shown that this plane might be altered, especially if patients were placed in the lateral position, or if there was hip flexion reducing the normal lumbar lordosis. Pelvic flexion and adduction were virtually unavoidable in the lateral decubitus position, placing greater demands on the surgical technique for a satisfactory outcome.

In our study, the subject's pelvis and trunk were supported by rigid uprights over the bony prominences to minimize tilting of the subject during surgery. With the manual technique, abduction was estimated with the assumption that the subject's ASISs were also parallel to a vertical line. If palpation of the bony landmarks indicated that the pelvis was tilted in this position, the amount of abduction was adjusted. With the navigated method, however, the abduction is based on the pelvis itself and, as seen in these results, a more reproducible placement of the acetabular cup in abduction was achieved.

With the subject lying in the lateral decubitus position, there was no control over the flexion-extension of the pelvis. As the pelvis flexed or extended in the sagittal plane, the AFPP changed compared to the midline of the body or coronal plane. Thus, the navigated values were based on the real AFPP while the manual values were based on coronal plane of the body. However, with CT scan analysis, for subjects from both groups, the coordinate system was based solely on the AFPP. Therefore, the cup placement for the MAN group could be affected by the amount and direction of any pelvic tilt in the sagittal plane. The use of the AFPP, as was done in this study, may not be an appropriate basis for judging cup position [39-41].

The use of computer assisted navigation involves more complexity, the placement of separate pins for the trackers, and the pelvic registration prior to the skin incision. In this study, these added extra operating time by 21 minutes. Kalteis et al described an increase in operating time of 8 minutes [30] and Parratte reported an increase of 12 minutes [31].

The study described in this study as well as the randomized, prospective studies by other authors [22,30,31,42] used CT scans to determine the final cup position. All of the studies showed a greater concentration of cases in the "safe zone" described by Lewinnek et al [2], particularly for anteversion, when navigation was used. Lewinnek's original study [2], which was published 30 years ago, used standardized radiographs and documented a marked decrease in the dislocation rate inside a broad 20° range of cup positioning for both abduction and anteversion. Issues of impingement, effect on range of motion, edge loading and wear could not be addressed at that time. That study showed that acceptable clinical outcomes could be achieved inside a range of cup placement. With modern implant designs and consideration of other issues related to cup malposition, navigation has the potential to help define a new range of safe cup position [12,43,44].

Although this study has addressed limitations of imageless computer-assisted navigation for hip arthroplasty owing to reliance on percutaneous identification of bony landmarks and variation in pelvic posture, the imageless computer assisted navigation for THA still resulted in less outliers and less variation than the manual method. This suggests that there may be a continuing need to seek improvements in the placement of acetabular cups to minimize problems with dislocation, impingement, range of motion, and wear that can be associated with cup malposition. With the additional time, complexity and need for additional fixation pins, assessment of the clinical outcomes and benefit of computer assisted hip navigation is needed to evaluate these issues and the long-term results. Particularly for cup anteversion, this study suggests that other methods beyond imageless techniques relying on digital palpation are needed to accomplish this.

This study has a number of limitations. The main one is that, in 3 cases, navigation was abandoned by the surgeon intraoperatively due to concerns about cup position. Since the intent was to treat the patients with navigation, their results refer to the limitations of navigation as a method. Interpreting the results was then more limited by the lack of precision of the navigation system in predicting the cup anteversion. With the variation in predicted cup position, it would have been useful for all the cases to have been measured with supine as well as lateral techniques. While the variations in pelvic tilt were identified in this group of patients, the study did not have the ability to address the differences in how cup position would have varied if pelvic tilt had been taken into consideration.

A further conclusion of the study is that incorporation of measurements that took into account individual pelvic tilt are needed to improve the use of imageless navigation [25]. Besides registration errors from digital palpation of the pelvis, variations between different patient's anatomy and inherent range of hip motion could be addressed by intraoperative assessment of patient's kinematics [39,45] or reliance on other landmarks such as the transverse acetabular ligament [32,33].

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