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A Comparison Between Imageless Navigated and Manual Freehand Technique Acetabular Cup Placement in Total Hip Arthroplasty

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Abstract: The purpose of this study was to compare acetabular component positioning using an imageless system to a matched control group using conventional techniques. Thirty procedures were performed using navigation. A multislice computed tomographic scan was used to assess cup position. There was no significant difference between mean inclination (*P* = .11) and anteversion (*P* = .24) but a statistical significant difference for mean deviation from the desired position for inclination (*P* = .003) and anteversion (*P* = .007). There was a significant difference in the percentages of correctly placed cups with inclination (*P* = .046) and with anteversion (*P* = .006). Combining both anteversion and inclination, there was a significant difference (*P* = .01). We demonstrated a significant increase in accuracy of placement of acetabular cups within the desired position and safe zone using imageless navigation. **Keywords:** hip arthroplasty, imageless navigation, cup placement, freehand technique, CT measurements, case-control study.

Acetabular cup orientation has been shown to be an important factor in determining outcome in patients undergoing total hip arthroplasty (THA) [1-3]. Malpositioning can result in a higher dislocation rate, increased wear, early loosening, and impingement [1,4].

Various authors have reported on optimal cup orientation [5-7]. For example, Lewinnek et al [7] defined a "safe zone" with an inclination of 40° ± 10° and anteversion of 15° ± 10°. Freehand techniques rely on manual guides or the surgeon's ability to estimate the cup orientation in relation to the patient's position on the operating table [2,3,8]. Using conventional techniques, placement within the safe zone, as described by Lewinnek et al [7], remains a challenge even for experienced surgeons [1-3,8,9]. Previous studies [1-3,9] have demonstrated that when using conventional techniques, 22% to 58% of acetabular components were placed outside the safe zone.

Several researchers [1,10-12] have reported that imageless navigation is a safe and reliable technique and results in more consistent cup placement compared to conventional manual techniques. However, imageless navigation relies on accurate digitization of bone landmarks (ie, anterior superior iliac spine [ASIS], pubic tubercle, pelvic rim, or acetabulum) using a metal pointer [13,14]. The navigation system uses the acquired landmarks to calculate an anterior pelvic reference plane [13,14], yet overlying soft tissues—especially in obese patients—can obscure these landmarks [4,15,16] and potentially introduce systematic error resulting in a tilting of the reference plane.

As a consequence, imageless navigation may not result in a significantly more precise cup placement compared to manual techniques. Therefore, the purpose of this study was to compare acetabular component positioning using an imageless navigation system to a matched control group using conventional freehand techniques. We hypothesized that navigation would significantly increase cup placement within the targeted safe zone and, in doing so, significantly reduce outliers.

Methods

Patient Selection

Between June 2005 and December 2007, 121 patients underwent primary hip joint arthroplasty. Thirty of the

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procedures were performed using an imageless navigation system (Stryker, Kalamazoo, Mich). During this period, the navigation system with the hip navigation software loaded was supplied by Stryker on a regular but random basis. Navigated THA was, thus, performed during periods when the Stryker software was available. If the software was not available, conventional manual techniques were used. Patients who underwent THA were matched with subjects from the group of patients who underwent conventional arthroplasty during this period.

Navigated Group

The average patient age was 66.5 years (range, 28-87 years). Twenty-three noncemented and 9 cemented acetabular cups were implanted. The average size of the noncemented cup was 53 mm (46-60 mm) and averaged 54 mm (50-58 mm) for the cemented cup. The main indication was primary osteoarthritis (n = 25), osteonecrosis (n = 5), displaced neck of femur fracture (n = 1), and failed screw fixation with head collapse after neck of femur fracture (n = 1). In 17 subjects, hip arthroplasty was performed on the right hip, and 15 subjects had a left THA. Surgery was performed by a single surgeon who was an experienced user of the imageless navigation system.

Control Group

The average age was 67.8 years (range, 34-84 years). Nineteen noncemented and 11 cemented acetabular cups were implanted. The average size of the noncemented cup was 56 mm (52-58 mm) and averaged 53 mm (44-56 mm) for the cemented cup. The main indication was primary osteoarthritis (n = 26), osteonecrosis (n = 3), and displaced neck of femur fracture (n = 1). In 13 subjects, hip arthroplasty was performed on the right hip, and 17 subjects had a left THA. Surgery was performed by the same surgeon who was performing the navigated procedures. The average size, height, and body mass index (BMI) of both the navigated and matched conventional group are documented in Table 1.

Sequence of Navigation

A Schanz screw was inserted into the ipsilateral ASIS through a stab incision. The pelvic navigation tracker was attached to the screw. Bony landmarks (ASIS and pubic tubercle) were determined and digitalized with a metal pointer. Once the frontal plane was defined by the computer, the hip was moved through a range of motion to determine the center of rotation. Before dislocation and resection of the femoral head, the piriformis fossa was digitalized. The acetabular fossa and rim were then digitalized. Once the landmarks were defined, the computer determined the inclination and anteversion of the acetabulum.

Table 1. Average Size, Height, and BMI of Both the Navigated and Matched Conventional Group

	Navigated Group	Freehand Group
Mean age (y) (range)	66.5 (28-87)	67.8 (34-84)
Mean height (range)	169 cm (153-186)	167 cm (155-180)
Mean weight (range)	85.6 kg (57-112)	86.2 kg (68-100)
Mean BMI (kg/m^2) (range)	30.04	30.66

Surgical Technique

All procedures were performed supine with a lateral Hardinge approach in all cases. Cup orientation was aimed at 45° of inclination and 15° of anteversion in both groups. In the navigated group, reaming, trial cup position, and final cup position were performed navigated. The cemented contemporary Exeter cup (Stryker) or an uncemented press-fit Trident cup (Stryker) was used based on the patient's age and activity and selected by the surgeon. The cemented cup was selected if the patient's activity was restricted to the house or home environment but included unassisted walks outside the home of less than 1 km. In addition, if poor bone stock was encountered intraoperatively or if the trial cup could not be seated firmly, a cemented cup was selected. When cementing the cup, subchondral bone was retained, multiple anchor holes were drilled into the acetabulum, pulsed lavage was used, and the acetabulum was dried with an adrenalin-soaked sponge. The cement was molded into the acetabulum and pressurized. The cup was inserted, and pressure was maintained in the desired position until the cement had completely cured.

Postoperative Computed Tomography

Postoperatively, a multislice computed tomographic (CT) scan was obtained on day 1 post surgery using a helical CT scanner (Somatom; Siemens, Munich, Germany). All CT scans were performed by the same radiology technician to a preestablished protocol. Two-millimeter slices were obtained in all cases. The position of the pelvis was standardized by reformatting the images to the frontal plane defined by both ASISs and the pubic tubercle. The largest cup diameter on the coronal plane was identified, and the inclination was measured. Similar anteversion was measured by identifying the largest cup diameter on an axial plane. All measurements were performed 3 times and averaged.

Statistical Analysis

To determine sample size, a power calculation was performed. The study was designed to detect a 2° difference of cup placement for both anteversion and inclination with a mean SD of 10% (4.5° for inclination and 1.5° for anteversion) from the desired position. The sample size calculation using standard assumptions of α = .05 and power of 90% indicated that 27 patients were needed in each subject group.

Means and SDs of the physiologic characteristics and dependent variables derived from the CT assessment for

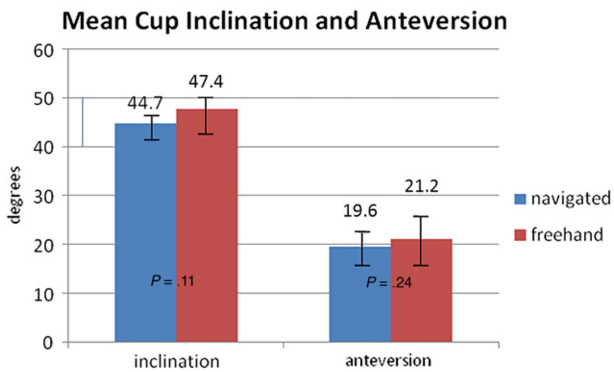

Fig. 1. The mean cup inclination and anteversion angle for both the navigated and freehand group is demonstrated.

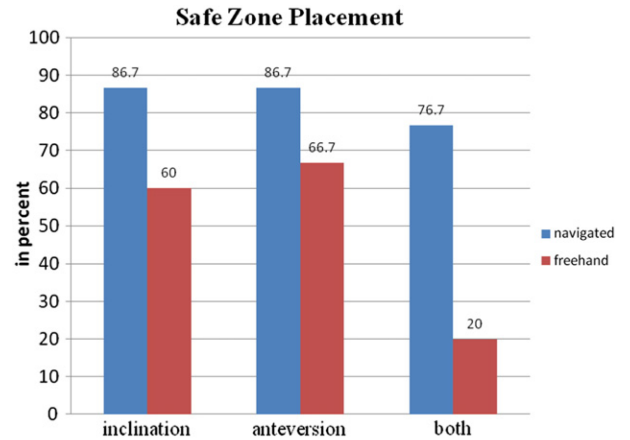

Fig. 3. The percentage of safe zone placement for inclination, anteversion, and both inclination and anteversion combined for the navigated and freehand group is demonstrated.

each subject group were calculated. A series of independent-sample *t* tests were then used to compare each of the continuous variables between subject groups. The proportion of cup placements (inclination, anteversion, and combined inclination and anteversion) within the safe zone for each subject group was compared using Mann-Whitney *U* tests. An α level of $P < .05$ was selected as the level of significance in all analyses. All analyses were performed using SPSS, version 15.0.1 (SPSS, Chicago, IL) for Windows.

Results

Navigated Group

Mean cup placement for inclination was 44.7° ± 4.6° (37.9°-51.8°) (Fig. 1). The mean deviation from 45° inclination was 3.42° ± 2.16° (0.2°-6.8°). According to the criteria of Lewinnek et al [7], 26 (86.7%) from 30 cups were placed within the safe zone for inclination. Mean cup placement for anteversion was 19.6° ± 6.8° (2°-29.7°). The mean deviation from 15° anteversion was 5.5° ± 3.95° (0.2°-14.7°) (Fig. 2). According to the criteria of Lewinnek et al [7], 26 (86.7%) from 30 cups were placed within the safe zone for anteversion. Taking both inclination and anteversion into consideration, 23 (76.7%) from 30 cups were placed within the safe zone (Fig. 3).

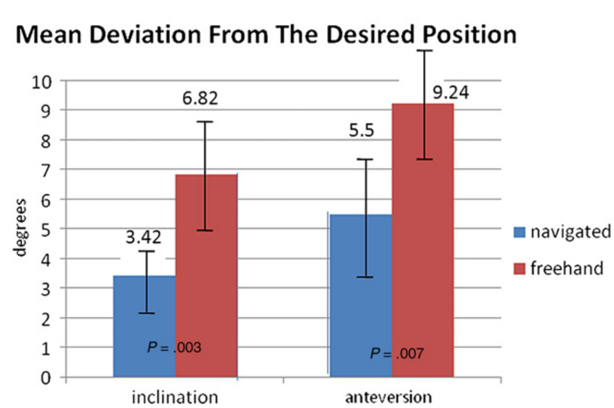

Fig. 2. The mean deviation from the desired cup position for inclination and anteversion angles for both the navigated and freehand group is demonstrated.

Control Group

Mean cup placement for inclination was 47.7° ± 7.5° (33°-57.5°). The mean deviation from 45° inclination was 6.82° ± 3.7° (0.4°-12.2°). According to the criteria of Lewinnek et al [7], 18 (60.0%) from 30 cups were placed within the safe zone for inclination. Mean cup placement for anteversion was 21.2° ± 9.8° (5.5°-37.2°). The mean deviation from 15° anteversion was 9.24° ±

Table 2. Overview of Results

	Navigated Group	Freehand Group	*P*
Mean inclination and anteversion			
Inclination	44.7	47.7	.11
STDEV	4.6	7.5	
Range (95% CI)	37.9-51.8	33-57.5	
95% CI	42.9-46.5	43.9-51.5	
Anteversion	19.6	21.2	.24
STDEV	6.8	9.8	
Range (95% CI)	2-29.7	5.5-32.7	
95% CI	17-22.2	16.2-26.2	
Mean deviation from the desired position			
Inclination	3.42	6.82	.003
STDEV	2.16	3.7	
Range	0.2-6.8	0.4-12.2	
95% CI	2.59-4.25	4.95-8.69	
Anteversion	5.5	9.24	.007
STDEV	3.95	8.97	
Range	0.2-14.7	1.6-28.8	
95% CI	3.99-7.01	4.71-13.77	
Placement within safe zone			
Inclination	26 (86.7%)	18 (60%)	.046
Anteversion	26 (86.7%)	20 (66.7%)	.006
Inclination and anteversion	23 (76.7%)	6 (20%)	.01

STDEV indicates standard deviation; CI, confidence interval.

8.97° (1.6°-28.8°). According to the criteria of Lewinnek et al [7], 20 (66.7%) from 30 cups were placed within the safe zone for anteversion. Taking both inclination and anteversion into consideration, only 6 (20.0%) from 30 cups were placed within the safe zone. Table 2 shows means, SDs, range, and confidence intervals of both the navigation and freehand group.

Analysis

Statistical analysis revealed that there was no significant difference between mean inclination (P = .11) and anteversion (P = .24) between both groups. There was a statistical significant difference for mean deviation from the desired position for inclination (P = .003) and anteversion (P = .007) between the navigated and freehand group. Mann-Whitney U tests revealed significant differences in the proportion of correctly placed cups for cup inclination (P = .046; 86.7% navigated and 60% freehand), anteversion (P = .006; 86.7% navigated and 66.7% freehand), and combined inclination (P = .01; 76.7% navigated and 20% freehand) between the navigated and freehand groups.

Discussion

Computer navigation for total joint arthroplasty is only helpful to the surgeon if it increases precision and reliability of component placement while demonstrating a significant reduction in variation compared to freehand techniques. Our results demonstrate that imageless navigation significantly increases the percentage of correctly placed cups within the safe zone. Overall placement for navigated cups for both inclination and anteversion increased to 76.6% compared to only 20% with freehand techniques. Based on these observations, our hypothesis that navigation significantly increases cup placement within the targeted safe zone is, therefore, supported.

The high degree of inaccuracy associated with freehand techniques has been described by various authors [1,3,9]. For example, Saxler et al [3] reported that only 27 (25.7%) from 105 cups were implanted within the safe zone using freehand techniques. Digioia et al [1] used a mechanical alignment guide, but only 22% of the cups were placed within the safe zone of Lewinnek et al [7]. Hassan et al [9] demonstrated in his study that 42% of the cups were placed outside the safe zone. Unfortunately, freehand positioning is not described uniformly in the orthopedic literature [2]. Definitions include the use of mechanical alignment guides or "eyeballed" placement without any mechanical guides. Bosker et al [2] reported a 70.5% safe zone placement in 194 patients. The authors believe that the high rate of accuracy is the result of a distinctive setup; however, the findings of this should be interpreted with caution given the use of conventional radiographs rather than CT-based outcome analysis [1,17].

Consistent with our results, other authors [10,12,18,19] have reported a significant increase in accurate cup placement with the use of imageless navigation systems. In this respect, Kalteis et al [10] demonstrated that safe zone positioning increased from 14 of 30 acetabular cups with conventional to 28 of 30 cups with imageless navigation. In a prospective study, Parratte and Argenson [18] demonstrated a significant reduction in outliers with respect to the defined safe zone, where 57% of the freehand placed cups and 20% of the navigated cups were placed outside the safe zone. Similarly, Haaker et al [12] compared 69 subjects in a retrospective study using CT-based navigated cup placement to conventional positioning and demonstrated a significant improvement in accuracy with navigation. Furthermore, Najarian et al [19] showed a significant reduction in variation from the desired range with imageless navigation. The authors also demonstrated that a learning curve existed for accuracy, estimated blood loss, and operating time. Nogler et al [14] investigated the Stryker imageless navigation system used in our research in a cadaver study comparing conventional to navigated placement and showed a more consistent placement with navigation.

The current evidence was summarized by Beckmann et al [20] and Gandhi et al [21] in a meta-analysis. Beckmann et al [20] concluded that there is a clear advantage of navigated cup orientation over conventional freehand cup orientation in THA, leading to a reduction in the incidence of outliers. However, the analysis was limited given that few properly designed studies have been performed and that those studies that were included failed to assess long-term outcomes of the surgery. Furthermore, Gandhi et al [21] concluded that navigation decreases the number of outliers and improves the surgeon's ability to place the cup within the desired position.

Although this project was designed as a case-control study, it has also clearly demonstrated an advantage of using computer navigation for acetabular cup placement. Computer navigation can substantially reduce the influence of the pelvic position and tilt, which cannot be adequately determined during implantation [22]. The registration of bony landmarks is a critical step for accuracy of cup placement, given that variation in the registration points of each bony landmark can dramatically affect cup inclination and anteversion angles [23]. Indeed, Ohashi et al [23] investigated intrasurgeon and intersurgeon variability in image-free navigation and demonstrated an increase in intraclass correlation coefficient (ICC) with registration in the supine position (ICC, 0.85-0.95) compared to an ICC of 0.59 to 0.81 in the lateral position. Surgeons who prefer the lateral decubitus position may, therefore, prefer to register landmarks supine and position the patient into the desired lateral position later.

Potential limitations of this clinical study are that it represents the experience of a single surgeon and that it is limited to 1 surgical approach and position on the operating table. The surgeon was an experienced user of the system, and the precision of cup placements can be influenced by the surgeon's experience [11,19]. Hence, the findings of our study may not be applicable to less experienced surgeons. Dorr et al [11] demonstrated that there was a difference of the surgeon's estimate of cup position in trial cup placement between experienced and less experienced surgeons.

We have not controlled for overlying soft tissue thickness. This is important because Parratte and Argenson [18] reported an increase in measurement error with imageless navigation when patients had a BMI greater than 27 kg/m^2. Ybinger et al [24] could demonstrate a significant and moderate correlation between soft tissues overlying the iliac spines and pelvic tubercles. Ryan et al [4] could not demonstrate a correlation between BMI and accuracy. In contrast to Ybinger et al [24] and Parratte and Argenson [18], his study cohort had a mean BMI of less than 27 kg/m^2. With an average BMI of 30.04 kg/m^2 in the navigation group, measurement bias could have potentially been introduced. However, it could be postulated that, in subjects with less overlying soft tissue, navigation would have been even more precise.

In conclusion, this study demonstrated a significant increase in the placement of acetabular cups within the desired position and safe zone using imageless navigation compared to a more traditional freehand technique, supporting our hypothesis.

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