Comparison of Conventional Versus Computer-Navigated Acetabular Component Insertion

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Abstract: This retrospective study compared the efficacy of computer navigation and conventional freehand techniques to place acetabular component orientation in the target position of acetabular cup inclination of 45° and anteversion of 20°. We selected 69 patients who had undergone total hip arthroplasty with freehand cup insertion who had computed tomography (CT) to plan for acetabular cup placement of the contralateral side. This group was compared with 98 patients who underwent CT-based cup insertion, and all had postoperative CT. After CT-based cup placement, average cup position was 43° inclination (95% confidence interval [CI], 0.97; range, 30°-58°) and 22.2° anteversion (95% CI, 1.72; range, 5°-38°). For freehand, average cup position was 45.7° inclination (95% CI, 2.63; range, 26°-64°) and 28.5° anteversion (95% CI, 3.80; range, 9°-53°). F ratio was 5.56 for inclination and 3.67 for anteversion ($P < .0001$). This study demonstrated substantial statistical improvement in accuracy of cup placement using CT-based navigation compared with freehand methods. Key words: acetabulum, navigation, anteversion, inclination, total hip arthroplasty, computer-assisted surgery, alignment.

Achieving optimal acetabular component orientation in total hip arthroplasty is a complex 3-dimensional (3D) problem. Component malposition can lead to increased wear, instability, and increased revision for both wear and instability. Recent publications have demonstrated a connection between the positioning of the prosthesis and the frequency of dislocation [1-7]. Lewinnek et al [8] noted an increase of the hip dislocation rate from 1.5% to 6.1% if a safe range of 15° ± 10° radiographic anteversion or 40° ± 10° acetabular inclination were exceeded. Recent computer simulations have studied range of motion and concluded that the greatest range of motion was noted with acetabular anteversion of 20° to 25°, acetabular inclination of 45°, and femoral stem anteversion of 15° [1,9,10].

The positioning of the acetabular component during surgery is dependent on the position of the patient’s pelvis on the operating table during acetabular component insertion. Hassan et al [11] and McCollum and Gray [12] have stated that patient positioning is not always reproducible in the lateral decubitus position and often leads to pelvic malalignment, with resultant improper cup placement. Pelvic flexion and adduction are virtually unavoidable in this position, placing greater demands on the surgical technique for satisfactory...
outcome. Therefore, improvement in cup implantation will occur if either the pelvis position can be standardized or if the orientation of the pelvis at the time a cup placement can be accurately determined.

Computed navigation techniques use sophisticated computer algorithms and tracking systems to allow the surgeon to determine 3D placement of instruments and prosthetic components during surgery [13-17]. In total hip arthroplasty, several reports have cited the accuracy with which implants can be placed using computer-assisted robotic devices or surgical navigation [16-22]. We proposed a retrospective computed tomographic (CT) analysis to compare the placement of acetabular components using either CT-based navigation or conventional freehand techniques. This was done by selecting a group of patients who had previously undergone primary total hip arthroplasty with conventional freehand techniques who then underwent a preoperative CT for surgical planning total hip arthroplasty on the contralateral side. A second group of patients were selected who had undergone CT-based navigation of cup placement. Both groups were then analyzed postoperatively using the same CT protocol and measurements. Our null hypothesis was that computer navigation was no more accurate than conventional techniques using extramedullary guides, anatomical landmarks, or body positioning.

**Methods**

A group of 69 patients underwent CT for preoperative computer planning of surgical navigation for contralateral total hip arthroplasty after a previously placed conventional total hip arthroplasty. Each CT scan was taken through the pelvis with 3-mm slices. The cohort of the conventional implanted group was aged 63.4 years (range, 46.5-76.8 years). There were 43 women and 26 men, who had been implanted with 41 pressfit cups and 28 screw-in cups. All patients had reached at least 12 months of follow-up at the time of radiographic study. We assessed acetabular implant position of the conventionally placed implants against the anterior pelvic plane that we established in the computer model. A second selected group of 98 patients underwent total hip arthroplasty using a computer-assisted navigation system where the acetabular component had been inserted using preoperative CT guided indexes. In the CT-based computer-navigated cohort, we found an average age of 66.9 years (range, 42.4-81.0 years). There were 63 women and 35 men, who had been implanted with 64 screw-in cups, 26 pressfit cups, and 8 cemented cups. The surgical approach was anterolateral in all cases. A postoperative CT was then done in this group to make the same computer comparison of cup position with the anterior pelvic plane (Figs. 1 and 2).

Retrospective analysis of all postoperative CT studies was done using the SurgiGATE Data.
Analysis software module (Medivision, Oberdorf, Switzerland), which allows for accurate interpretation of implanted acetabular components [21-23]. Computer hardware used was an Ultra 10 Sun Microsystems workstation (Sun Microsystems, Schwerzenbach, Switzerland). This was a multistep process requiring each CT scan to be loaded into SurgiGATE software module. The computer then created a 3D model of the pelvis. From this model, the anterior pelvic plane was determined by identifying the locations of the superior iliac spines and the pubic tubercles. The scans demonstrating the implanted cups were brought into view using the computer touch screen. Using a library of computer-aided design models of each specific acetabular component, the appropriately sized and positioned virtual images were then overlaid to the implanted devices (Fig. 3). As demonstrated, no difficulty was encountered with metal image scatter, and suitable analysis was possible in all cases. After DiGioia et al [16] and Jaramaz et al [17], we described acetabular inclination and anteversion of each implanted device in the study. Specifically, the acetabular inclination was defined as the angle of the polar axis of the cup projected onto the coronal plane, and the anteversion angle was defined as the angle of the polar axis of the cup projected onto the axial plane.

In patients undergoing computer navigation of the acetabular components, a preoperative analysis and planning was required. The CT studies were loaded into the SurgiGATE software program, and the 3D model was then created. The femoral head and the pelvis were separated, and the anterior pelvic plane was determined using the same method (Fig. 4). Seven primary landmarks were identified to be used at the time of surgery for paired-point matching. These included the anterior superior iliac spines (2), the anterior acetabular rim (2), the cotyloid notch (2), and the deep lateral wall of the quadrilateral plate. The final step allowed positioning of a virtual acetabular component into the pelvis at the chosen position of 45° acetabular inclination and 20° acetabular anteversion with respect to the anterior pelvic plane. The surgeon had the ability in this planning step to deepen or medialize the cup position and preferentially position the cup more anteriorly or posteriorly. Final cup position was demonstrated in the 3 planes and also on the 3D pelvic model that had the femoral head extracted (Fig. 5).

Fig. 3. Computer screen view demonstrates 3 postoperative views (sagittal, axial, and frontal) through the center of the acetabulum from the CT scans, followed by a 3D model of the pelvis. Note the calculated acetabular inclination of 39° and anteversion of 28°.
The computer navigation system consisted of an infrared camera (Optotrak 3020; Northern Digital, Waterloo, Ontario, Canada) on an overhead boom, the SurgiGATE system including the video with monitor, and the Unix Ultra 10 workstation with appropriate SurgiGATE software [23] (Fig. 6). A dynamic reference base (DRB), an instrument equipped with infrared transducers, was securely fastened to the pelvic skeleton of the patient. This was done by using a Steinman pin attached approximately 2 cm cranial of the acetabular rim or, alternatively, fixed to the anterior superior iliac spine depending on the surgical exposure. A special pointer was used to indicate landmarks defined in preoperative planning phase and now used for referencing those points in the patient’s acetabulum. The pointer was also used to initiate certain computer functions by activating or tapping designated areas on a virtual keyboard. The conventional instruments for the implantation of hip endoprostheses were equipped with infrared transducers or light-emitting diodes. With these optoelectronic markers, the position of all instruments were tracked in space by the optical camera and transmitted to the computer system.

The intraoperative navigation was divided in 2 major steps, registration and surgical implantation [22,23]. First, the instruments and the reference base were checked for positional error, which is typically less than 0.5 mm. After this step, paired-point matching was done, which identified and registered the same 7 landmarks as determined during preoperative planning phase (Fig. 7A). These points must be picked as precisely as possible, matching the anatomical point in the patient to the same point chosen on the computer’s virtual pelvis. Subsequently, surface matching was done, in which a cloud of points consisting of at least 16 separate points were randomly picked on the lateral surface of the pelvis. Preferred areas were the anterior superior iliac spines (2), ilium lateral to the anterior superior iliac spine (2), ilium cranial to the acetabular dome (3), posterior acetabular wall (3), anterior acetabular rim (1), inferior acetabular fossa (1), and origin of the ligamentum teres (1) (Fig. 7B). With this registration process, the SurgiGATE software attempted to find a “best fit” between the demonstrated points and the 3D pelvic model generated in the preoperative planning phase. The final step in registration was a mathematical verification step, during which the software sought the best solution to “align the virtual and actual pelvis.” The computer generated a “quality index” that defined the precision of which the
patient’s pelvis can be matched to that of the virtual pelvis. The objective was to create a comparison as close to zero as possible. The manufacturer of the system required a maximum allowed quality index value of 7 after the paired-point matching, and this was further reduced to lesser than 2 after the surface point matching. The surgeon identified a known point on the pelvis, and this point must precisely match the point identified on the virtual pelvic model. A known confidence point was selected by the surgeon that could be rechecked during the procedure to reverify the system. At this point, the surgeon was then capable of navigating both the milling process and the subsequent cup implantation. Both of the instruments used for this process, including the reamer and the cup inserter, were instrumented with a light-emitting diode, which allowed for precise positioning in the acetabulum. The surgeon used visual cues and numerical positional data displayed on the computer screen to determine exact reamer and

Fig. 5. In this preoperative planning step, the cup implant in size, design, and position is added to the 3D model of the pelvic bone. The position is defined by the anteversion (25°), the inclination (45°), and the depth of the implant.

Fig. 6. Operating room setup demonstrating computer platform with boom containing cameras noting orientation toward the operative field DRB.
cup position compared with the preoperative planning position. For all patients with acetabular navigation in this study, we recorded the final cup position as indicated on the screen at the conclusion of the procedure.

**Data Analysis**

Both cohorts were by defined by descriptive statistics followed by the F test to compare variances of the 2 groups. We assessed both groups in comparison to the "safe zone," as recommended by Fontes et al [2], which was acetabular anteversion of less than 11° or greater than 35°.

**Results**

From retrospective analysis of the postoperative CT scans, the average acetabular inclination for computer navigation was 43.0° (SD, 4.6; 95% confidence interval [CI], 1.0; range, 30°-58°), and for acetabular anteversion, the average was 22.2° (SD, 7.4; 95% CI, 1.7; range, 5°-38°). For the freehand group, the average acetabular inclination was 45.7° (SD, 9.1; 95% CI, 2.6°; range, 26°-64°). The average acetabular anteversion was 28.5° (SD, 10.3; 95% CI, 3.8°; range 9°-53°).

The average last-saved SurgiGATE computer-navigated acetabular inclination was 43.1° (95% CI, 0.9°; range 42.2°-44°) and the acetabular anteversion was 22.4°(95% CI, 1.5°; range 20.9°-23.9°).

Using the F test for comparing the difference in the amount of variation between the 2 surgical methods, the ratio was 5.56 for abduction (P < .0001) and 3.67 for anteversion (P < .0001), indicating that the variation could not be attributed to chance for either variable and that computer navigation was significantly more accurate than freehand conventional methods. The F ratio for the last SurgiGATE computer-navigated acetabular inclination position compared with the CT control was 0.30, and that for acetabular anteversion was 1.55, not reaching statistical significance.

Comparing both groups with the anteversion "safe zone" described by Fontes et al [2], we found
that 28% of the freehand cups were placed outside 11° to 35° anteversion, 4.7% were placed with less than 11° of anteversion, and 23.4% have been implanted with an anteversion exceeding 35°. In the computer-navigated group, 7% were outside the parameters of 11° to 35° anteversion, 4.7% of the cups were implanted with an anteversion of less than 11°, and 2.5% exceeded 35° of anteversion.

**Discussion**

Acetabular component placement in total hip arthroplasty can be difficult, with optimal placement required to prevent chronic instability, accelerated wear, and implant migration [1,3-5,7,24,25]. Recent investigators have sought to define the radiographic analysis of cup position in the clinical setting, prosthetic issues such as range of motion and component impingement, and technical issues at the time of surgery such as body position and how to place the prosthesis in the desired location [1,6,9,10,26-31]. Computer navigation represents a new technology that can be used to deal with all of these problems [13,14,22,33].

The spatial orientation of the natural acetabulum and prosthetic components placed at surgery is a complex 3D problem [31-33]. Anteversion occurs when the acetabular component is internally rotated about a line through the acetabulum, which is parallel to the longitudinal axis of the patient. The anatomical measurement is made by determining the angulation of the cup compared with the sagittal plane by looking at the axial section CT scan [16,17,30]. We used this method for anteverision measurements and have found no other variations in recent publications concerning computer navigation.

McKibbin [34] was the first author to describe the anterior pelvic plane and noted that the average anteversion of an adult was 16.5°. In the normal standing position, this frontal plane is usually parallel to the longitudinal axis of the patient [8]. Lewinnek et al [8] used a crude device with 3 legs and a bubble level applied to the pelvic crests and pubis to make certain that the anterior pelvic plane was parallel to the plane of the table before taking their anterior posterior radiographs of the pelvis for anteverision measurement [8]. McCollum and Gray [12] have shown that this plane may be altered, especially if patients are placed in the lateral decubitus position or if there is hip flexion, reducing the normal lumbar lordosis. An important step in the registration procedure for computer navigation is to define the anterior pelvic plane using the same identical landmarks each time for generating the standardized pelvic position [16,17].

Optimum acetabular component orientation has been a subject of much debate, but most recent investigations conclude that the approximate position of 45° abduction or inclination and 20° radiographic anteversion is a satisfactory target. Retrospective studies such as those of Lewinnek et al [8] and Fontes et al [2] define a “safe” envelope or range of these angles about which hip stability after arthroplasty is much greater [8]. Barrack et al have used a complex 3D computer analysis to optimize the above parameters and have shown that certain positions such as cup abduction lesser than 25° or cup anteverision lesser than 0° are clearly unsatisfactory for positions such as sitting or stooping [9]. The average cup position after navigation in our study was acetabular inclination of 43° and cup anteverision of 22°, closely approximating the target position in the majority of cases.

Acetabular component positioning in the current study can be related to a number of variables. Certain cups such as screw-in devices can be very difficult to alter once insertion has been initiated and the optimal target position may not have been possible. There was a significant difference in the 2 groups as 57% of the cups were pressfit in the conventional group, whereas 28% were pressfit in the CT-navigated group. If the screw-in cups were more difficult to insert with precision, this study could have been biased, with better results favoring the conventional group. We do not know how the different cup compositions of the 2 groups could have affected the outcome of this study.

Several surgeons were involved in this early study, and it could be stated that each surgeon may have had a different concept for final cup positioning. For example, the thrust plate femoral component used in some cases will not allow the acetabular anteverision to exceed 10° to 15°. There may have been a tendency to improve posterior stability in conventional cups by increasing anteverision. The surgeons performing the conventional technique did not have the advantage of learning a more precise positioning that may have occurred after computer navigation was introduced. Therefore, results of a controlled single blinded protocol may have been different.

We are aware of technical difficulties that may occur limiting the repeatability of cup insertion. For example, pressfit cups can bind on one side, causing the final position to shift from the desired target. While performing CT navigation, we were impressed with the significant alteration in the numerical cup position that resulted from a minor...
shift in direction of the inserter. There may have been errors that occurred with navigated cup insertion if the DRB moved, which could explain certain outliers. Finally, all cases of navigation were studied, including cases that could be considered in the learning curve of certain surgeons. We would point out that an important verification of our cup navigation was the close duplication found from the final overall computer reading for cup position to the postoperative CT evaluation. Other navigation studies that we have reviewed have documented a similar range of outliers, which could be expected, but the reduced number of outliers and the increased accuracy to the target range are clearly favored in the computer-navigated grouping [35-37].

Acetabular stability and impingement relates not only to component position but also to prosthetic design dimensions, relation of the anterior pelvic plane to the spine and longitudinal axis of the body, medialization of the cup, and the offset and orientation of the femoral prosthesis [9,26]. DiGioia et al [33] used a computer navigation system similar to the method we used to study the problems of mechanical alignment in the conventional operative setting with the lateral decubitus position and with the use of typical freehand alignment guides. They found that the mean pelvic position was close to the desired anterior pelvic plane before dislocation, but after dislocation, the pelvis tilted anteriorly, causing a shift of the mean anteverision of the pelvis to 18°. Of 74 cups placed by freehand guides, 58 were placed outside the desired anteverision of 20° ± 10°, whereas only 1 cup was outside the desired inclination of 45° ± 10° [33]. In another study, they were able to determine that postoperative radiographs produced variable and inaccurate results compared with their precise intraoperative computer-generated measurements [17].

The importance of our study is that we have compared our early experience with computer-assisted navigation with freehand conventional methods of acetabular component positioning using a validated methodology that required a postoperative CT study of all patients. Acquisition of data from CT is highly reproducible, and our computer resolution allowed for unimpaired determination of cup position despite the presence of some metal image distortion. We were able to show a significant improvement in the desired surgical result with computer navigation in total hip arthroplasty. We believe this technological advance will allow surgeons to more accurately relate implant alignment to dislocation rates, prosthetic wear, implant loosening, and patient outcomes.

References


