Hip instability remains one of the most common indications for revision total hip arthroplasty (THA). Approximately 22.5% of revision THAs and 33% of acetabular revisions are due to dislocations. Numerous risk factors, including implant design, surgical approach, and prior hip surgery, have been associated with dislocation. However, incorrect orientation of the acetabular component is the most important factor predisposing patients to hip instability. Acetabular component orientation significantly affects wear and osteolysis, acetabular migration, impingement, and the risk of dislocation in patients undergoing THA.

In 1978, Lewinnek et al introduced a “safe zone” for the optimal orientation of the acetabular component in THA. A dislocation rate of 6.1% occurred for implants outside the safe range (5° to 25° anteversion and 30° to 50° inclination) as opposed to 1.5% for those within range. More recently, Callanan et al suggested a “modified safe zone” (5° to 25° version and 30° to 45° inclination) for cup placement to take into account the use of hard-on-hard bearing surfaces. High angles of inclination and highly anteverted cups have been shown to be correlated with higher rates of anterior and recurrent dislocations. Cup malposition is also linked to higher rates...
of wear debris and aseptic loosening of the prosthesis. In addition to dramatically reducing the risk of dislocation, proper component positioning optimizes forces on the implant and reduces accelerated implant wear.\textsuperscript{11-13}

Placement of an acetabular component in accurate abduction and anteversion angles requires thorough preoperative planning and intraoperative execution. To assess cup position in conventional THA, surgeons use landmarks, including the transverse acetabular ligament (TAL), anterior wall of the native acetabulum, teardrop, and lateral most portion of the native acetabulum.\textsuperscript{14} However, the accuracy of conventional methods, which demonstrate approximately 59\% to 68\% ability to place the cup within the safe zone, have encouraged the development of several new modalities to improve the accuracy of cup position.\textsuperscript{8,15} Robotic- and computer-assisted navigation have been shown to successfully place the acetabular component in the desired position with up to 97\% accuracy.\textsuperscript{16-19} However, these modalities are not readily available or financially feasible for all arthroplasty surgeons. Therefore, it is necessary to have conventions independent of these technologies to confirm precise cup placement.

The current study seeks to use the authors’ experience with 3-dimensional (3D) templating and robotic hip replacement to provide objective data of the value of certain intraoperative anatomic landmarks in confirming accuracy of cup placement. These data may be useful in improving surgical accuracy, reproducibility, and correct positioning of the acetabular cup for non–computer-assisted, conventional surgeries. In the current analysis, the authors addressed the following questions:

1. At 40° inclination and 20° anteversion:
   a. When looking at the anterior wall of the native acetabulum, where is the cup inside the bone (Figure 1)?
   b. When looking at the lateral and posteroinferior native acetabulum, where is the cup uncovered from bone (Figure 1)?
   c. Where on the clock face is the most lateral aspect of the native acetabulum, to correlate cup uncoverage seen on acetate or digital templating of an anteroposterior pelvis radiograph (Figure 2)?
   d. How often is the most inferior aspect of the hip joint above or below the teardrop?
   e. What is the position of the cup compared to the TAL?

This analysis should complement other planning modalities in attaining optimal implantation of the cup and isolating a safe zone for THA. The purpose of this study is to provide an intraoperative reference for surgeons to increase accuracy of component positioning and ultimately to achieve hip joint stability.

**MATeRialS aNd MEtHODS**

This study was a retrospective investigation performed at a single academic center. All cases were performed by a fellowship-trained joint reconstruction surgeon (J.M.V.). The authors identified 93 patients who underwent primary THA from May 2014 to May 2015. All THA procedures were performed using a posterior approach and MAKOplasty Total Hip Application (Stryker, Mahwah, New Jersey). The software uses 3D modeling of the patient’s hip, reconstructed from computed tomography (CT), which allows for preoperative planning, optimization of component position, and real-time adjustments intraoperatively. The use of this software in measuring parameters for THA has been validated in several studies.\textsuperscript{20}

Electronic medical records were used to obtain patients’ baseline characteristics, including gender, laterality, preoperative diagnosis, and surgical procedure. Two cases with inadequate CT images were excluded from the study cohort. The main characteristics of the study cohort are presented in the Table.

Using 3D planning, the authors templated the acetabular component at an inclination of 40° and anteversion of 20°, which are almost at the center of the safe zone and are commonly referred to as the target angles for a THA. It should be emphasized that this study was a CT-based analysis and was not based on intraoperative measurements. The research questions examine previously reviewed crite-
ria that are often used to guide acetabular component placement. Once the cup was positioned at the correct angles, the anterosuperior/anteroinferior and the posteroinferior coverage of the cup by the native acetabular bone was determined. To classify acetabular cup coverage by bone, the acetabulum was used as a clock face, with the center of the TAL as 6 o'clock. Studies suggest that the rate of dislocation can be reduced to 0.6% by using the TAL as a reference for acetabular cup alignment.21,22 The position of the cup was also determined to be anteverted, aligned, or retroverted to the native TAL.

Using the software, 2 lines were created from the center of the cup to the acetabular edge to form a reference for assigning clock values to (1) where the cup was within bone, (2) where the cup was not inside the bone (Figure 2), and (3) where the lateral most aspect of the acetabular was. These measurements were used as an alignment guide for 2 reviewers (A.M.E., N.E.) to independently assign clock values based on visual comparison. All data entries were confirmed by the surgeon to ensure reproducibility and repeatability.

The final criterion examined was whether the most inferior part of the cup was above or below the teardrop. The acetabular teardrop is a radiographic projection of cortical bone of the medial wall of the acetabulum and the superior pubic ramus. It is commonly used as a landmark to guide acetabular component placement during templating for THA. By placing the acetabular component aspect at the same level as the inferior teardrop edge, it is assumed to restore the hip’s center of rotation.23,24 When templating, the position of the acetabular component in a superior/inferior direction dictates the next steps in templating to restore leg length. Categorization (above, below, or same level) was determined based on whether a difference between the position of the most inferior aspect of the cup and the most inferior aspect of the teardrop was possible via the observer’s judgment.

Statistical analysis was performed using Excel software (Microsoft, Redmond, Washington). The number of hips with covered and uncovered cups was calculated at each clock value. Hips were also compared by laterality. For the combined analysis, the values of the left hip were mirrored and added to those of the right hip. A final chart was created to identify the cumulative percentage for each clock value where the acetabular cup was covered and uncovered by bone. These figures were used to make generalized predictors of bony coverage for acceptable cup positioning.

RESULTS
Computed tomography scans for all 93 patients were identified and measured. Seven left and 11 right hips were excluded from this analysis because no portion of the cup was uncovered. In these 18 (19.4%) hips, no anatomic acetabular landmarks were available for component positioning. In the remaining 75 cups, each was examined for coverage at every position using the clock face convention. In right hips, the majority of cups revealed the acetabular component uncovered between 9- to 1-o’clock. In comparison, the majority of left hips were uncovered between 11- to 3-o’clock. After mirroring all left hips onto the right, the authors were able to calculate the percentage of cups with coverage at each clock value (Figures 3-4).

The current analysis revealed that 72% of cups were uncovered between 9- to 1-o’clock for right hips. On the left side, 88% of cups were uncovered between 11- to 3-o’clock. Conversely, 85% of right cups were covered in the range of 2- to 8-o’clock, and 87% of left cups were covered in the range of 4- to 10-o’clock. After the values of left hips were added to right hip data, combined results showed that 80% of cups were uncovered between 9- to 1-o’clock. Finally, combined data

| Table
<p>| Patient Demographics |</p>
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Figure 3: Clock face results for cup uncoverage. Right (A), left (B), and right plus left (C) total hip arthroplasty cup uncoverage.
showed 86% of cups were tucked inside the native acetabular anterior wall in the range of 2- to 8-o’clock.

The authors then measured the clock position of the most lateral aspect of the acetabular cup. Figure 5 details results of these lateral measurements. Across all hips, 74% of cups had a 1-o’clock position at the most lateral aspect—with only 12% at 11-o’clock and 14% at the 12-o’clock position. Figure 6 demonstrates evaluation of the 3D cup template with respect to the teardrop. Analysis revealed that 46% of native acetabular sockets had a teardrop at the same level of the most inferior aspect of the socket, whereas only 37% of cups had a teardrop above the inferior aspect of the socket.

Finally, the authors found that at an inclination of 40° and anteversion of 20°, the acetabular component was aligned with the TAL in 76% of hips, retroverted to the TAL in 16%, and anteverted to the TAL in 8% (Figure 7).

**DISCUSSION**

Acetabular cup positioning is a critical component in THA that affects long-term THA survivorship.25,26 As the number of THAs continues to increase, the importance of improving accuracy of acetabular component positioning needs to be considered. New robotic and computer navigation technology have helped improve the accuracy and consistency for implantation of the acetabular component. However, these modalities are often associated with higher costs and longer surgical duration.27 Therefore, other reliable landmarks and tools must be investigated to help reproduce native cup orientation.

The purpose of this study was to investigate a new method of assessing the hip implant intraoperatively to improve alignment of the acetabular component. There were 5 major findings from the study. First, when doing a THA at 40° inclination and 20° anteversion, the acetabular component should be uncovered between 9- and 1-o’clock in right hips and 11- and 3-o’clock in left hips. Similarly, the cup should be within the native anterior wall and acetabular bone covered between 2- and 8-o’clock in right hips and 4- and 10-o’clock in left hips. Second, the most inferior aspect of the cup should be at (46%) or below (37%) the most inferior aspect of the teardrop. Third, the most inferior aspect of the cup should be at 20° anteversion 76% of the time. Fourth, the TAL aligns to 20° anteversion 76% of the time. Finally, no anatomic acetabular landmarks were available for component positioning in 19.4% of hips, requiring alternative pelvic bony landmarks to be used to accurately position the acetabular component.

**Figure 4:** Right and left total hip arthroplasty cup uncoverage (A) and coverage (B) mirrored onto a right hip as seen by the operative surgeon. Abbreviation: TAL, transverse acetabular ligament.

**Figure 5:** Percentage of hips based on lateral position of cup.

**Figure 6:** Graph showing teardrop results (A), and 3-dimensional template identifying teardrop landmarks (B).

**Figure 7:** Position of cups compared with transverse acetabular ligament.
It is important to remove any curtain osteophytes in these cases to ensure that the true medial wall is identified to adequately expose the acetabulum. To account for individual variations in hip and pelvic anatomy, one must rely on the sciatic notch angle or position of the body—both of which have inaccuracies. In these instances, computer navigation and robotics can be used to help obtain accurate anteversion and inclination angles. To the current authors’ knowledge, this is the first study to utilize such techniques to confirm prior thinking and to provide guidance for intraoperative acetabular component alignment.

Techniques for the alignment of the acetabular component remain controversial. Several studies have shown that freehand positioning of the acetabular cup increases misalignment. Although robotic- and navigation-assisted surgeries have proven to successfully improve cup accuracy, these systems are not readily available to all surgeons. Furthermore, anatomical landmarks are often obscured due to osteophytes or degenerative changes in local pelvic anatomy and differences in pelvic orientation. The need for consistent acetabular placement is an important factor in reducing dislocation rates and the likelihood of revision surgery.

The current results suggest that surgeons can use the clock face values as an intraoperative reference to ensure correct acetabular placement without the need for additional equipment and reliance on anatomical landmarks. However, given the relationship of pelvic tilt and flexible versus rigid spinal deformities, it must also be understood that in these cases the safe zone may not be the appropriate orientation. The presence of hip flexion contracture and adduction deformities may also further complicate the position of the pelvis and subsequent placement of the cup. Furthermore, acetabular dysplasia, heavy osteophytes, or even post-traumatic deformity must be taken into account when anatomic reference points are not available.

The current study has a few limitations. First, there was some interobserver variability in assigning clock values to the 3D templates. Interobserver agreement and validity were analyzed using weighted κ statistics. Mean κ value was 0.89 (0.83-0.94), which represents substantial agreement. Furthermore, any final radiographic disagreements were assessed by the senior author (J.M.V.).

Second, the authors assessed acetabular orientation at 40° inclination and 20° anteversion based on a global coronal plane of the body in a CT scanner. This does not factor in the standing functional pelvic plane, the anterior pelvic plane, or pelvic tilt. Lewinnek et al. created the safe zone using a supine position and a radiograph taken with the patient’s anterior pelvic plane at 0° of pelvic tilt. It has been shown in prior studies that up to 50% of patients have between 5° and 10° of pelvic tilt, with 17% having greater than 10° of pelvic tilt.

Third, this does not factor in subtle changes in anteversion that the surgeon may opt for in anterior or anterolateral approaches to the hip in patients with underlying spinal pathology or pelvic tilt. Fourth, anatomic variations of the proximal femur must also be addressed in the development of hip pathology. Future studies should also aim to find intraoperative techniques to better define the axis of the femoral neck in relationship to the acetabular component.

Finally, although this retrospective study suggests that certain anatomic landmarks can be used as an intraoperative check to cup positioning, a prospective, randomized control study with intraoperative use of the landmarks above would be of significant value in determining the clinical utility of this tool in reducing future dislocations and component wear. A similar study was performed using 3D templating for native anatomical landmarks to help guide acetabular position, helping to increase success of proper positioning of the planned component anteversion and inclination. However, further study is warranted.

**Conclusion**

It is important to consider new methods to ensure greater accuracy for cup positioning. Evidence has already shown that surgeons do not reliably position the cup intraoperatively based on mechanical guides alone. However, the precision of these angles is increased when combined with accurate preoperative planning, correct patient positioning based on pelvic tilt, and ultimately intraoperative execution. This study introduces a useful tool for arthroplasty surgeons to intraoperatively improve accuracy in placing the acetabular cup in the safe zone. However, these suggestions need to be further investigated to observe the clinical benefits for patients in the short- and long-term.

**References**


