Acetabular Center Axis: Is It the Future of Hip Navigation?

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There are 2 distinct methods of cup navigation in total hip arthroplasty. One predicts orientation of the acetabulum through bony landmarks outside the acetabulum (eg, the anterior pelvic plane); its unreliability is well published. The other identifies acetabular center axis (ACA) and is patient-specific method that is independent of pelvic tilt, making it more reliable. Data from readily palpable acetabular registration points were compared with postoperative pelvic computed tomography images in 137 cases. Findings show that ACA software is accurate in determining acetabular/cup version and inclination. Cup center axis should coincide within 4 mm of ACA to minimize impingement and maximize stability without altering preoperative femoral version.

The femoral neck axis normally coincides with the acetabular center axis (ACA), rotating around the center of the acetabulum during range of motion of the hip, producing maximum stability and minimum impingement. The ideal navigation system should be based on that simple fact of reproducing the initial kinematics between femur and acetabulum even in the severely arthritic hips because they usually maintain that relationship.

Currently, total hip arthroplasty (THA) navigation relies on 2 different principles of registration to achieve the desired cup/stem relationship. The first method is the indirect method, which relies on digitalization of bony landmarks outside of the acetabulum that define the frontal pelvic plane by simple palpation or by ultrasound, or aided by a mechanical device (eg, a Tilt-Meter) or by imaging, such as computed tomography (CT). A classic example of the indirect method of registering bony landmarks is palpation of the anterosuperior iliac spines and symphysis pubis, called the anterior pelvic plane (APP). Other examples of indirect registration are (1) palpation of the transverse pelvic plane (TPP), which relies on the posterosuperior iliac spines and the sacral slope adjustment (SSA), which correlates with functional spinal parameters in identifying the APP, and (2) palpation of the transverse acetabular ligament (TAL). However, variation in thickness of subcutaneous tissue, ossification, movement during the registration process, and anatomic variations of acetabular version among healthy individuals have resulted in major errors in cup orientation. Some clinicians resorted to piercing the skin to improve their registration efforts; others resorted to using “adjusted” APP registration in which the APP registration is calculated according to the change of APP with changes of pelvic tilt. Some results showed fairly accurate registration and good prediction of the inclination angle and version of the acetabulum. However, the new hip center could be cranial, caudal, anterior, or posterior in relation to the acetabular center, or it could be medialized by implant design or to gain more stability. These changes made for the new hip center and axis of rotation must be addressed so that the preoperative acetabulum/femur relationship is maintained to avoid impingement and instability.

The direct method of registration has evolved in response to this need. The direct method of registration relies on the ACA, which is patient-specific and
Findings showed ACA software to be comparable with CT in its accuracy in determining the inclination and version angles of the acetabulum and cup implant. The new hip center was >4 mm outside the desired ACA in only 4 of 135 patients; all 4 patients reported impingement symptoms. None of the remaining patients had dislocation or impingement.

**MATeRIALS AND METHODS**

This prospective study compares the ACA registration data with postoperative pelvic CT scan in posterolateral intermuscular minimally-invasive computer-assisted THA. Since March 2007, 137 consecutive patients underwent OrthoPilot navigated press-fit Excia (B. Braun Aesculap, Tuttlingen, Germany) or Metha THA system (B. Braun Aesculap). Two were excluded for lack of complete data. Patient age ranged from 34 to 86 years (mean, 65 years). One hundred sixteen patients had primary osteoarthritis; 14 had avascular necrosis; 5 had rheumatoid arthritis. Mean body mass index was 32.2 kg/m². Dysplastic acetabulum was present in 12% of patients, and protrusio was present in 4%. Patients were followed up for a minimum of 1 year with postoperative radiographs, CT scan, and Harris score assessment.

The ACA registration was done by 3 points of palpation of the superior rim, 3 points of the most anterior rim, and 3 points of the most posterior rim of the acetabulum (Figure 1). The superior point must be chosen consistently. We determined the superior point of the acetabulum as the point of transection of a line from the prominent iliac tubercle to the center of transverse acetabular ligament (acetabular notch) (Figure 2). The software averages the points (Figure 1) and maps out the orientation of the acetabulum and its center, which determines the ACA. This axis guides the surgeon to position the reamer for placement at the center of the acetabulum. The surgeon has the option of choosing the desired acetabular version or inclination angle to accommodate individual patient anatomy while maintaining the center of the acetabulum if possible when reaming. The center of the acetabulum is calculated by the computer program as zero. Any deviation is calculated in millimeters, whether directed medially, anteriorly, posteriorly, caudally, or cranially (Figures 3, 4). We planned to be within 2 mm from the center of acetabular axis (Figure 5). In this way the preoperative version of the neck of the femur could be maintained without fear of impingement or excessive combined version of cup and stem (Figures 4, 6). Stem navigation followed ACA, and a femoral/patella/foot plane was established to ensure proper leg navigation (Figure 7). Here, 3 points are required for leg length and offset: 1 at any marked point (by Bovie or methylene blue) of the greater trochanter, 1 at a marked point at the lateral epicondyle (marker pen or methylene blue), and 1 at a marked point at the ankle. The surgeon may use a small temporary K-wire or just drill a hole in the lateral epicondyle as a point of navigation for leg length with the hip in neutral position.

Preoperative plain pelvis radiographs with anteroposterior and cross-table lateral views were obtained as routine. They
were used to template the expected cup size, depth, and orientation to compare with acetabular anatomy. Postoperative CT measurements of acetabular and cup inclination and version angles were observed independently using special software. Data were compared using the Fisher test and Student t test. The level of significance between CT and the variable should approach 1.0, which means the variable is as good as CT, and when P<0.05, the variable is significantly inferior to CT imaging.

RESULTS
Data for 135 of 137 consecutive patients were eligible for analysis. Mean anatomic acetabular version (ie, control) was 21.2° (SD±4.3°) by CT compared with 20.01° (SD±4.8°) by ACA software. Mean anatomic acetabular inclination was 47.56° (SD±7.0°) by CT compared with 47.4° (SD±8.7°) by ACA software. These results reflect the validity and reliability of ACA software in identifying the version and inclination of the acetabulum. The center of acetabulum was maintained within 2 mm in 130 cases. Six cases were 2 mm off center of the acetabulum; of these, 4 were off center by 4 mm. Cup implant version was 22.97° (SD±5.4°) by CT compared with 23.0° (SD±4.4°) by ACA software. This result reflects the reliability and statistical accuracy of ACA software in identifying the version of the cup implant (P=.98). We then divided the patients into 3 groups according to anatomic variations of the acetabulum: normal, protrusio, and dysplastic. In the first group, the size of the cup closely matched the size of the acetabulum (normal acetabulum). The anatomic cup version was 21.7° (SD±10.2°) by CT compared with 21.4° (SD±8.6°) by ACA software (P=.97).

In the second group, the size of the cup implant was smaller than the acetabulum (as in protrusio hips). The anatomic cup version was 22.0° (SD±9.9°)
by CT compared with 22.8° (SD±9.5°) by ACA software. In the third group, the size of the cup was larger than the acetabulum (as in dysplastic hips or the cup implant was larger by choice). The anatomic version was 26.3° (SD±7.1°) by CT compared with 26.5° (SD±6.4°) by ACA software. The ACA software was as accurate as CT (P=0.96), whereas APP software in a previous study was less accurate (P=.04). As for the inclination angle of the cup implant, the mean anatomic cup inclination angle for all groups was 42.5° (SD±4.2°) by CT compared with 40.5° (SD±3.5°) by ACA software (P=.93).

Similarly, we divided the patients into 3 groups to compare cup inclination. In the first group, the cup matched the acetabulum: the anatomic cup inclination angle was 42.7° (SD±3.6°) by CT compared with 43.1° (SD±4.7°) by ACA software. Again ACA software was accurate (P=.73). In the second group, the cup size was smaller than the acetabulum (representing protrusio). The inclination angle was 42.6° (SD±4.0°) by CT compared with 46.8° (SD±6.6°) by ACA software, which again was accurate (P=.92). In the third group (representing dysplastic), the cup size was larger than the acetabulum, the anatomic cup inclination angle was 46.0° (SD±4.8°) by CT and 42.70 (SD±12.2°) by ACA software (P=.45).

**Clinical Results**

There were no dislocations, and leg length was maintained within <8 mm in all cases. Offset was maintained within 5 mm less than established preoperatively. In 2 cases, offset was allowed to be <5 mm larger.

Impingement pain was noted in range of motion (mainly adduction/extension) in 4 patients. Interestingly, ACA was off by >4 mm in all 4 of these patients. Mean Hospital for Special Surgery scores were 92.5±4.6 with preoperative scores of 36.7±11.2.

When using ACA software methods, the safety zone of Lewinnek was maintained and no serious complications were related to implant or software use.

**DISCUSSION**

The APP has been the cornerstone of image-based hip navigation technologies. Ultrasonography, skin piercing technique, registration with the patient in supine position, and adjusted APP software calculations are examples of attempts to improve the accuracy of APP registration to identify the orientation of the acetabulum (indirectly). Planes other than APP have been introduced, for example, TPP, SSA, and TAL, and they all predict the inclination and version of the acetabulum indirectly and share similar problems in registration through skin and subcutaneous tissue or ossified ligaments. Additionally, they do not identify the ACA nor do they attempt to recreate the relationship of soft tissue envelope tension and direction as the ACA software does. Acetabular center axis identification is a direct method of measurement that is easy to register, with no subcutaneous fat to consider, and it is independent of pelvic and spine positioning.

The reliability of the OrthoPilot navigation system we used has been tested, and special ACA software registration points were developed and the data compared with postoperative CT of the pelvis as a control. Computed tomography of the pelvis revealed significant variation of normal acetabulum version anatomy ranging from 5° to 30° of anteversion, whereas the anatomic CT inclination angle was less variable (47°±8°). This puts the safety zone of Lewinnek in question. For example, a cup version of 29° is outside the safety zone of Lewinnek when one presumes the cup should be 18° of version. One study demonstrated that there is perhaps no ideal position for the cup (45° inclination and 20° anteversion) that can be used for all patients. Because of the wide range of inclination and anteversion figures, half of cases in the study were outside the safety zone recommended by Lewinnek. This is another reason why we believe that patient-specific direct software is superior to other indirect methods of registration, because it determines the orientation of the normal acetabulum and the ACA that is patient-specific.

Is there a limitation to the usefulness of the ACA software if there is a pathologic variation of the acetabular anatomy (protrusio, dysplastic, or large osteophytes)? Will placing the cup implant in the ACA of the acetabulum recreate the original deformity and thus misplace the cup implant? That question was resolved before the study began by obtaining standard pelvis anteroposterior and cross-table lateral radiographs preoperatively. If the acetabulum is determined to be dysplastic or the desired cup is larger than the acetabulum, then templating gives an approximate inclination angle of the acetabulum and the cup. In protrusio, the acetabular inclination angle (<40°) is expected to be smaller than cup inclination angle, whereas in dysplastic cases (>50°), the acetabular inclination angle is expected to be larger than cup inclination angle. The difference in degrees is calculated and used intraoperatively to adjust the computer-navigated ACA measurement to the desired angle while maintaining the proper acetabular/cup center axis. In the extreme rare case of preoperative subluxating hips, we recommend preoperative CT imaging to determine the degree of instability and whether bone augmentation is needed to restore the acetabular center. Adjustment of version of the cup and offset should resolve the instability as long as the preoperative acetabular center is considered. However, when the ACA software reads the final cup position as +1° (Figure 6), then the cup
is 1° inside the acetabulum. If the acetabulum shows protrusio, then the computer readings of inclination should be in the “+ve” (positive) range, which means that the cup will be smaller than the acetabulum. If the acetabulum is dysplastic, then the computer reading of the cup inclination should be in the “−ve” (negative) range (Figure 3), which means that the cup is larger than the acetabulum or that some of the rim of the cup is outside the acetabular superior rim. This enables the surgeon to make the proper adjustment in grossly abnormal acetabula to achieve the ideal cup position specific to each patient. However, no such adjustments are needed for the stem version.

Basically, there are 2 techniques (direct and indirect) for referencing of navigated THA in the lateral position. Our new reference axis (ACA) has the advantage of being patient-specific and independent of variations in anatomy or pelvic position. The system relies on readily accessible anatomic landmarks of the acetabulum, making it significantly attractive for surgeons who use CT-free planning and navigation. Impingement through ACA software is easily predicted by keeping the cup center axis within 4 mm from zero (the normal preoperative ACA) (Figures 3, 4). The stem follows the same version of the neck of the femur as preoperatively; consequently, no change in foot rotation is made. The length and offset is controlled by the modularity of the stem to ensure the femoral neck/implant neck distance is measured from the new hip center that the computer has calculated.

Finally, navigation through identification of ACA may be the future focus of THA navigation because it is capable of reproducing the preoperative relationship between the acetabulum and the femoral head/neck when performing THA. That includes the inclination/version angles of the cup, the offset, and soft tissue tension (length), without altering the version of the stem. Calculated adjustment is also readily made in protrusio and dysplastic hips in ACA software.

REFERENCES