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Original Research

Direct Anatomic Registration in Computer-Assisted Total Hip Arthroplasty Improves Accuracy of Acetabular Cup Alignment

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ABSTRACT

Background: Computer-assisted total hip arthroplasty using direct anatomic registration (DAR) with acetabular center axis software is an alternative method to the indirect anterior pelvic plane method. The software maps the center of hip rotation and orientation of the native acetabulum in 3 dimensions. This study aimed to evaluate the accuracy of acetabular cup alignment using DAR navigation combined with a mechanical guide device (MGD).

Methods: This prospective nonrandomized controlled study included 106 patients who underwent primary cementless total hip arthroplasty through the posterolateral approach. Fifty-four patients in the study group underwent DAR combined with MGD, whereas 52 patients underwent MGD only for acetabular cup positioning. Plain radiographs of both hips and computerized tomographic scans were obtained 2 months postoperatively for the evaluation of acetabular cup inclination and anteversion, respectively.

Results: The acetabular cup alignment in the study group was within the Lewinnek safe zone more than that in the control group (81.5% vs 59.6%, $P < .05$). The study group had a mean inclination angle of 43.88°° (standard deviation [SD] 5.38) and anteversion angle of 12.82° (SD 5.99), whereas the control group had 41.10° (SD 6.79) and 12.82° (SD 9.53), respectively. There were no significant differences in estimated blood loss, length of stay, and Harris hip scores at preoperative and 3 and 6 months postoperatively, except for the operative time, which was longer in the study group ($P < .01$). There was 1 posterior hip dislocation in each group.

Conclusions: DAR navigation combined with MGD provides better accuracy for acetabular cup positioning within the Lewinnek safe zone compared with the conventional technique.

Introduction

Acetabular component position is essential to clinical outcome after total hip arthroplasty (THA) because the inaccurate orientation of cup alignment increases dislocation risk, limb-length discrepancy, cup migration, polyethylene wear, and osteolysis [1]. Acetabular component malposition has been reported as a major cause of unstable THA especially in cases of revision THA [2,3]. “Lewinnek safe zone,” which was defined in 1978, for the acetabular cup alignment should be 15° ± 10° of anteversion and 40° ± 10° of inclination; Lewinnek et al. [4] found a dislocation rate of 1.5% when the acetabular cup was within the safe zone compared to 6.1% of those outside the safe zone. For the conventional surgical technique of THA (mechanical alignment guide), Callanan et al. [5] evaluated 1823 patients who underwent THA and reported 79% of anteversion and only 63% of the inclination angle of the acetabular component being within the Lewinnek safe zone. Moreover, Nishii et al. [6] demonstrated that the acetabular cup alignment was changed, with a 1% increase and 41% decrease in inclination and a

Trial Registration: The study was registered in the Thai Clinical Trials Registry (Trial number: TCTR20201212001) in Thailand.

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19% increase and 8% decrease in anteversion, while the acetabular components were inserted using a mechanical alignment guide.

Imageless computer navigation is a noninvasive and safe technique to achieve good orientation of cup alignment for THA. The anterior pelvic plane (APP), which is a widely used technique, estimates the alignment of the acetabulum via anatomic landmarks outside the acetabulum (ie, pubic tubercles and anterior superior iliac spines). Navigated THA with the APP reference was associated with 20% outliers of cup alignment from the Lewinnek safe zone compared to 57% outliers in conventional THA [7]. However, a few studies have suspected the accuracy of this indirect method, particularly with a lateral decubitus position. This is because the technique relies on bony landmarks that may be intervened by the thickness of soft tissue at the registration point, pelvic tilt, and the problem of spinopelvic mobility [8-10]. Additionally, the vertical plane angle of APP has changed more than 5° and 10° in 38% and 13% of patients, respectively, and has also been influenced by spinal factors [11,12].

Direct anatomic registration (DAR) for navigated THA using acetabular center axis (ACA) software is a patient-specific method that registers at the readily accessible anatomy of the acetabular rim and is independent of variations in pelvic position or morphology [13]. The software determines ACA, the orientation of the native acetabulum, and the center of rotation of the hip. The ACA usually coincides with the femoral neck version, and thus, the new hip center guided by this software could provide optimal hip stability. Furthermore, the ACA requires 2 tracker pins placed at the iliac crest, which is versatile for surgeons to perform THA with any surgical approach and patient position. However, limited evidence is currently available regarding the benefit of DAR navigation when combined with a mechanical guide device (MGD) during THA. Hence, this study aimed to evaluate the accuracy of adjunct DAR navigation for placement of the acetabular cup via the posterolateral approach, when compared to those who underwent THA using only the MGD or a conventional surgical technique. We hypothesized that ACA software for computer-assisted THA could provide a more accurate alignment of acetabular cup placement in the Lewinnek safe zone.

Material and methods

This prospective nonrandomized controlled study was conducted with approval from an ethical committee and was registered in the Clinical Trials Registry. All patients who underwent primary cementless THA from 2018 to 2022 were enrolled and divided into 2 groups (Fig. 1), and written informed consent was obtained. In the control group, 52 patients underwent conventional THA using a MGD only for acetabular cup placement. In the study group or DAR combined with the MGD group, 54 patients underwent THA using navigation for acetabular positioning with the anatomic registration technique. Navigation was applied on alternate weeks due to device availability, regardless of patient demographic or pathology. The inclusion criteria were patients who had a diagnosis of primary or secondary osteoarthritis (OA) and osteonecrosis without contraindication to undergo primary THA. Patients who had iliac crest problems that did not allow pin insertion for navigation, severe lumbopelvic deformity, septic hip arthritis, and declined to participate in this study were excluded. All cases were implanted with a cementless stem, Metha or Excia stem (B Braun Aesculap, Tuttlingen, Germany), and a cementless cup, Plasmafit (B Braun Aesculap, Tuttlingen, Germany).

Surgical technique

All THAs were performed by a single surgeon [AP] via a standard posterolateral approach in the true lateral decubitus position. The authors targeted the acetabular component position to 40° of inclination relative to the floor and 20° of anteversion relative to the longitudinal axis of the patient in both groups by applying a mechanical guidance device to the reamer. For the study group, ACA navigation software (OrthoPilot, B Braun Aesculap, Tuttlingen, Germany) was used to assist in the placement of the acetabular component. Two pins were applied at the iliac crest approximately 3 cm from the anterior superior iliac spine for the connected tracker. A standard posterolateral approach was performed in the lateral decubitus position by fixing the pelvis and chest of the patient in a straight line and rectangular to an operative table. After the arthrotomy, the femoral head was dislocated and cut according to preoperative planning. The acetabular landmarks were then registered by touching 3 points on the superior rim, anterior rim, and posterior rim, and 5 points on the deep parts of the teardrop (Fig. 2). The superior center point should be the point of transection of the line from the midpart of the transverse acetabular ligament to the iliac tuberosity [13]. The navigation interpreted these data and mapped out the center of rotation of the hip, orientation of the acetabulum, and cup size. The MGD was subsequently applied to set the acetabular cup alignment at 40° of inclination and 20° of anteversion (our preferred cup position), and information on the cup position relative to the acetabular rim was recorded as guidance for the reaming process (Fig. 3). While reaming the acetabulum, the navigation showed real-time information on the reamer alignment compared to the native acetabular landmarks. The reaming process was continued until the desired acetabular cup alignment regarding inclination, anteversion, hip center, and cup size was achieved (Fig. 4). The cementless acetabular prosthesis was subsequently implanted using a press-fit technique similar to the control group. The position of the prosthesis and new hip center in the study group were shown by navigation (Fig. 5). Subsequently, a cementless femoral stem was applied using the press-fit technique, and the acetabular liner was inserted following the standard procedure.

The control group underwent a standard posterolateral approach in the lateral decubitus position, similar to the study group. Acetabular reaming was performed using only MGD to set the acetabular cup alignment at 40° of inclination and 20° of anteversion. The appropriate depth and size of the reaming were determined by the surgeon,

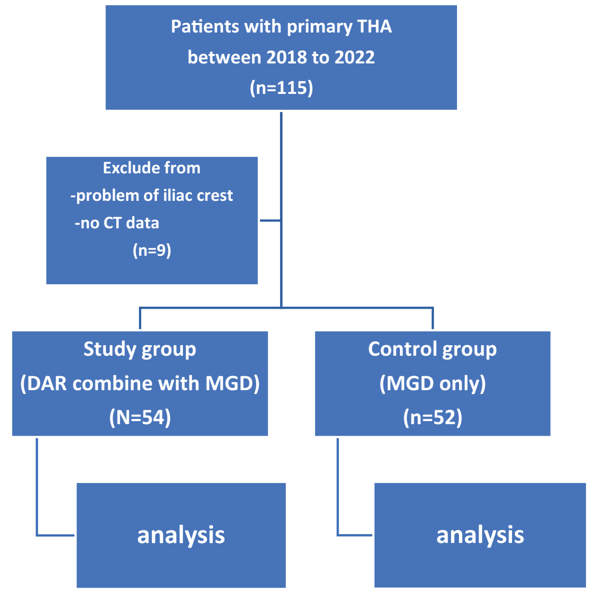

Figure 1. Flowchart of the patient recruitment process. THR, total hip replacement; CT, computerized tomography.

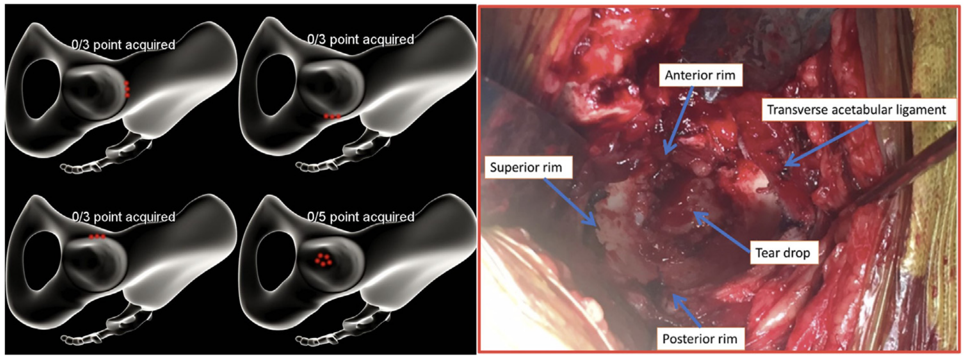

Figure 2. Registration of the acetabular landmarks including the superior rim, anterior rim, posterior rim, and tear drop.

and the acetabular prosthesis was then applied to the aiming position. A femoral stem and liner were also used.

Both groups received identical postoperative protocols, such as antibiotic prophylaxis for 24 hours, no suction drain, and a rehabilitation program. Demographic data were recorded, including age, sex, body mass index, side, American Society of Anesthesiologists physical status classification, and diagnosis for surgery. Standard plain radiographs of both hips were assessed preoperatively and 2 months after the surgery. Patients were placed on a platform 110 cm away from the radiograph machine, and the radiation beam was centered on the pubic symphysis (Fig. 6). The radiographic inclination of the acetabular cup was evaluated using the interteardrop line as a reference. A multislice computerized tomographic scan was also obtained 2 months after the index surgery to measure cup anteversion (Fig. 7), which was then converted to radiographic anteversion using the Murray equation [14]:

"Tan (AA) = Tan (RA)/Sin (RI)" then "AA = Tan^{-1}[Tan (RA)/Sin (RI)]"

(AA, anatomical anteversion [CT scan]; RA, radiographic anteversion; RI, radiographic inclination)

Only adequate imaging was interpreted by 2 orthopaedic surgeons, and the assessment was performed twice, 2 weeks apart. Operative time, estimated blood loss (EBL) using the modified Gross formula [15], length of stay (LOS), Harris hip score (HHS) preoperative and at postoperative 3 and 6 months, and complications were also evaluated.

Statistical analysis

Data analysis was performed using SPSS Statistics, version 17. The normality of data distribution between both groups was assessed using the Kolmogorov−Smirnov and Shapiro−Wilk tests. An independent-sample *t*-test was used to compare the data of acetabular cup inclination, acetabular cup anteversion, age, body mass index, LOS, operative time, EBL, and HHS between both groups. Pearson's chi-square test was used to compare the number of patients who had acetabular alignment within or outside the Lewinnek safe zone between the groups. Intraclass correlation coefficients were used to assess intraobserver and interobserver reliability. The interobserver and intraobserver reliabilities for the inclination angle of the acetabular component were 0.97 (95% confidence interval [CI] 0.96-0.98) and 0.98 (95% CI 0.98-0.99), respectively, and were 0.98 (95% CI 0.97-0.99) and 0.99 (95% CI 0.99-0.99), respectively, for the anteversion angle. The sample size of the control and AR groups had 95.7% power to detect a 5° difference in acetabular cup alignment, with a standard deviation (SD) of 7° and a type I error of 5%.

Results

Of 115 total enrolled patients, 9 were excluded due to iliac crest problems and inadequate CT data; therefore, the study group and the control group included 54 and 52 patients, respectively. The baseline characteristics of the patients were not significantly different between the 2 groups (Table 1). All patients underwent cementless THA using an identical acetabular component (Plasmafit cup) and 2 types of the short, cementless femoral stem (Metha and Excia). Table 2 shows the details of the prostheses, including head size, neck length, and bearing surface.

The study group had a significantly higher mean inclination angle (43.88°, SD 5.38) than that of the control group (41.10°, SD

Figure 3. Setting acetabular cup alignment at 40° inclination, 20° anteversion by using mechanical guide device (MGD) and record the data to compare with orientation of the native acetabulum.

Figure 4. The final position of reaming. The alignment of acetabular cup was set by using the different data from the native and depth to the teardrop (0 mm).

6.79). The mean anteversion angle did not differ between groups (Table 3). The acetabular cup alignment of the study group was more within the Lewinnek safe zone than that of the control group (81.5% vs 59.6%, $P < .05$) (Fig. 8). Both groups had cases of retroversion in cup alignment (2 cases from the study group and 5 cases from the control group), and the mean retroversion was 3.48° (range 0.6°-8.7°). Of the 7 retroverted acetabular components, 4 cases were diagnosed with post-traumatic OA that required an impaction graft, 2 cases had developmental dysplasia of the hip, and 1 case showed osteonecrosis.

No significant differences were observed in EBL, LOS, and HHS at preoperative and 3 and 6 months postoperatively. However, the operative time in the study group was significantly longer than that in the control group (Table 4).

Two patients had posterior hip dislocation; 1 hip dislocation in the study group occurred 1 month after the surgery, whereas the other hip dislocation was in the control group and occurred 2 months postoperatively. All the patients were successfully treated conservatively.

Discussion

Malposition of the acetabular component is one of the most common causes of instability after THA [2,16], and navigation-

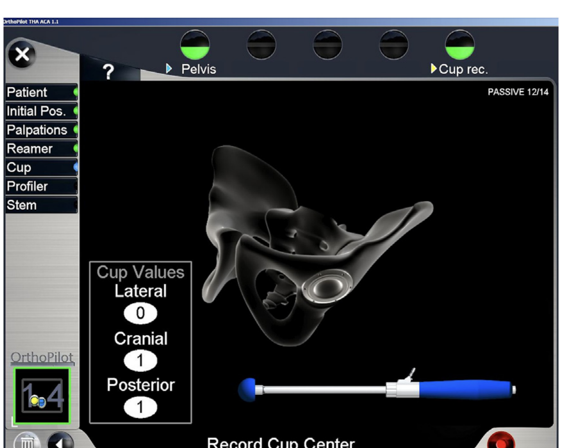

Figure 5. After the acetabular cup was implanted, the navigation showed the new hip center in three dimensions.

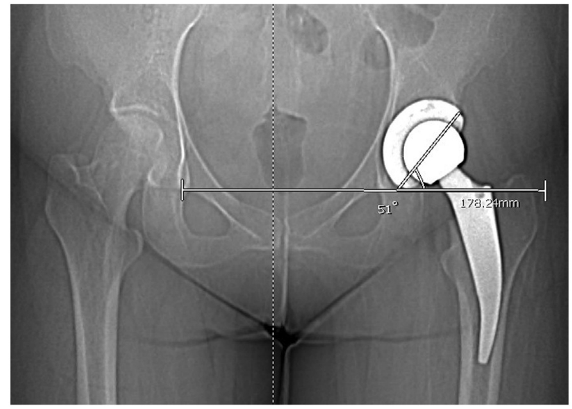

Figure 6. Measurement of acetabular cup inclination from plain radiograph of both hips by using the inter-teardrop line as a reference.

assisted THA has been demonstrated to provide better acetabular cup positioning [17]. However, controversy remains regarding the ideal reference for cup orientation. The present study used ACA software combined with MGD to assist acetabular cup placement through the posterolateral approach. While we found no difference between the groups in terms of EBL, LOS, and HHS, the study group had a significantly lower incidence of the acetabular component positioned outside the Lewinnek safe zone. The inclination angles of the acetabular component in the control and study groups were 41.10° and 43.88°, respectively. The anteversion angle of the control group was 12.82° compared with 12.82° in the study group. There was one case of dislocation in each group due to trauma, even though both acetabular cup alignments were within the Lewinnek safe zone. In accordance, Hakki et al. [13] analyzed data from 135 patients who underwent computer-assisted THA with the ACA software and reported that the ACA software is statistically accurate in determining the inclination and anteversion angle of both the native acetabulum and acetabular implant when compared to CT of the pelvis. They showed that the new hip center of 130 patients was within 2 mm, while only 4 THAs had a new center >4 mm outside the desired center of rotation of the hip. No dislocation was observed in any of the patients during the follow-up for a minimum of 1 year. Moreover, acetabular cup positioning in relation to the acetabular rim may be a preferable technique to reduce overhanging of the acetabular component, which can cause soft-tissue impingement, such as iliopsoas tendinitis [18].

On the other hand, placement of the acetabular cup regarding the acetabular rim may result in deviation of the acetabular cup

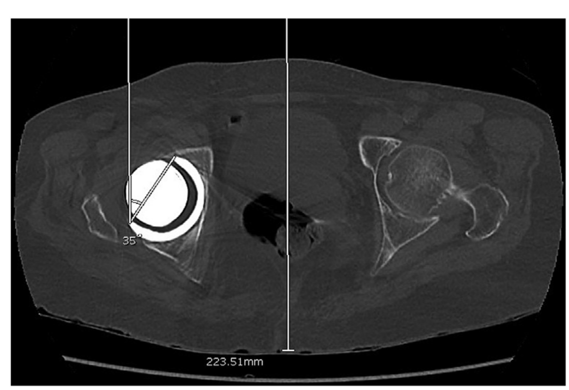

Figure 7. Measurement of acetabular cup anteversion from CT scan of both hips by using vertical line of body.

Table 1
Patient demographics and clinical characteristics.

Patient characteristics	Study group (n = 54)	Control group (n = 52)	*P*-value
Age (y) mean ± SD (range)	56.63 ± 14.27 (18 to 79)	58.21 ± 13.24 (21 to 83)	.09
Female sex, n (%)	31 (57.4%)	28 (53.9%)	.71
Body mass index (kg/m^2), mean ± SD (range)	24.31 ± 4.77 (15.63 to 39.55)	24.54 ± 5.21 (14.17 to 38.83)	.81
Diagnosis, n (%)			.66
ONFH	30 (55.6%)	23 (44.2%)	
DDH	7 (13%)	12 (23.1%)	
Primary OA	10 (18.5%)	9 (17.3%)	
Post-traumatic ON	4 (7.4%)	4 (7.7%)	
Post-traumatic OA	3 (5.5%)	4 (7.7%)	

DDH, developmental dysplasia of hip; OA, osteoarthritis; ON, osteonecrosis; ONFH, osteonecrosis of femoral head; SD, standard deviation.

alignment from the "safe zone" in cases with secondary OA. We found 7 cases of retroversion alignment of the acetabular component; 2 cases were in the study group and 5 cases were in the control group, despite all the cases having no dislocation. Of the 7 retroverted acetabular cups, 2 had developmental dysplasia of the hip and 4 had post-traumatic OA that required impaction or structural bone graft to manage the bony defect. We hypothesized that the deformed acetabular morphology and the presence of bone defects may influence the accuracy of ACA navigation. Nevertheless, Wada et al. [19] who applied the ACA software in cases of secondary OA, including developmental dysplasia of the hip, osteonecrosis, and rheumatoid arthritis, demonstrated that osteophytes of the deformed acetabulum had no influence on radiographic inclination and anteversion measured according to Murray's definition. They also compared the intraoperative values for cup alignment to the values evaluated on postoperative CT and found that the inclination angle from the ACA navigation system was 3.4° ± 5.3° less than those measured from postoperative CT, and the anteversion angle was 1.4° ± 3.1° more than the postoperative CT assessment. Hence, controversy on the influence of either acetabular or pelvic morphologic variation in relation to ACA navigation may require future investigation. For deformed acetabular anatomy, however, the problem may be resolved by preoperative planning based on imaging to determine the desired cup position and calculate the different degrees from the distorted acetabulum. These changes in the acetabular cup could then be evaluated intraoperatively by the ACA software while maintaining the proper new hip center.

Table 2
Implant data.

Patient characteristics	Study group (n = 54)	Control group (n = 52)
Stem, n (%)		
Metha	36	22
Excia	18	30
Plasmafit cup		
Using 2 secured screws	45	47
No screw	9	5
Femoral head		
32 mm	24	15
36 mm	30	37
Bearing		
M-O-P	33	46
C-O-P	11	4
C-O-C	10	2
Neck length		
Short	41	36
Medium	11	14
Long	2	2

C-O-C, ceramic on ceramic; C-O-P, ceramic on polyethylene; M-O-P, metal on polyethylene.

Usually, imageless hip navigation is used with the APP reference to assist acetabular cup positioning. This plane is presumed to be the vertical axis of the pelvis in the standing position, and the registration was conducted based on 2 points of the anterior superior iliac spine and 1 point of the pubic symphysis. Therefore, it is better to set the patient in a supine or semisupine position, which may limit surgeons to performing THA only via the anterior, anterolateral, or direct lateral approach. Systematic review and meta-analysis revealed that this navigation improved the precision of acetabular cup alignment by decreasing the number of outliers from the safe zone and reducing leg length discrepancy for THA [20,21]. However, many studies have suspected that the accuracy of APP reference may be related to the thickness of soft tissue at the registration point, pelvic tilt, and the problem of spinopelvic mobility [8-10]. Barbier et al. [10] used the EOS imaging system to evaluate the acetabular cup position of 44 patients in standing position at 3 months after Navigation-assisted THA with APP plane. They found that the mean cup inclination and anteversion postoperatively were 44.3° and 29.5°, respectively, compared to 41.3° of inclination and 20.9° of anteversion that were reported intraoperatively by navigation. Pinoit et al. [11] showed that the APP plane may be particularly associated with an error of cup anteversion. They found that 38% of patients had anteversion error >5°, and 13% of patients had an error >10° as compared to the vertical plane. Additionally, Babisch et al. [9] reported that each degree of pelvic tilt change brings to acetabular cup anteversion change of 0.8° and inclination change of 0.3°, resulting in the setting of acetabular cup alignment. Other indirect references including the transverse pelvic plane, sacral slope adjustment, and transverse acetabular ligament have been introduced, but they seem to share similar problems related to a registration issue [13]. Hakki et al. [22] conducted a prospective study of 34 THRs to compare the inclination and anteversion angle of the acetabulum and cup implant between the ACA and APP registration as evaluated by postoperative CT images. They found that both ACA and APP registrations were accurate in the inclination angle for cup positioning. The anteversion angle of the acetabular cup was 23.0° for the ACA group and 12.7° for the APP group, compared to 22.97° for the CT measurement. The authors also showed that the APP technique was significantly inferior to the ACA in determining cup anteversion for dysplastic hips. Therefore, the ACA method seems to be more precise in identifying cup anteversion than the APP reference.

Our study had some limitations. First, the number of THA in the present study was sufficient to detect the difference in acetabular cup alignment and outliers from the Lewinnek safe zone; however, it might be limited to evaluating the incidence of hip dislocation after surgery. Second, the present study was a nonrandomized control study, which might be associated with some inherent limitations. Nevertheless, all THAs were performed in the same period by a single surgeon with identical exposure, surgical

Table 3
Comparison of acetabular cup alignment between the study and control group.

Outcome measure	Study group (n = 54)	Control group (n = 52)	95% CI	*P* value
Inclination angle (°), mean ± SD (range)	43.88 ± 5.38 (32.25 to 55.50)	41.10 ± 6.79 (25.75 to 57.00)	0.428 to 5.138	.02[a]
Anteversion angle (°) mean ± SD (range)	12.82 ± 5.99 (−3.6 to 27.7)	12.82 ± 9.53 (−8.7 to 34.8)	−3.051 to 3.088	.99
Within Lewinnek safe zone, n (%)	44 (81.5%)	31 (59.6%)		<.01[a]

CI, confidence interval; SD, standard deviation.
[a] *P* value of < .05 indicates statistical significance.

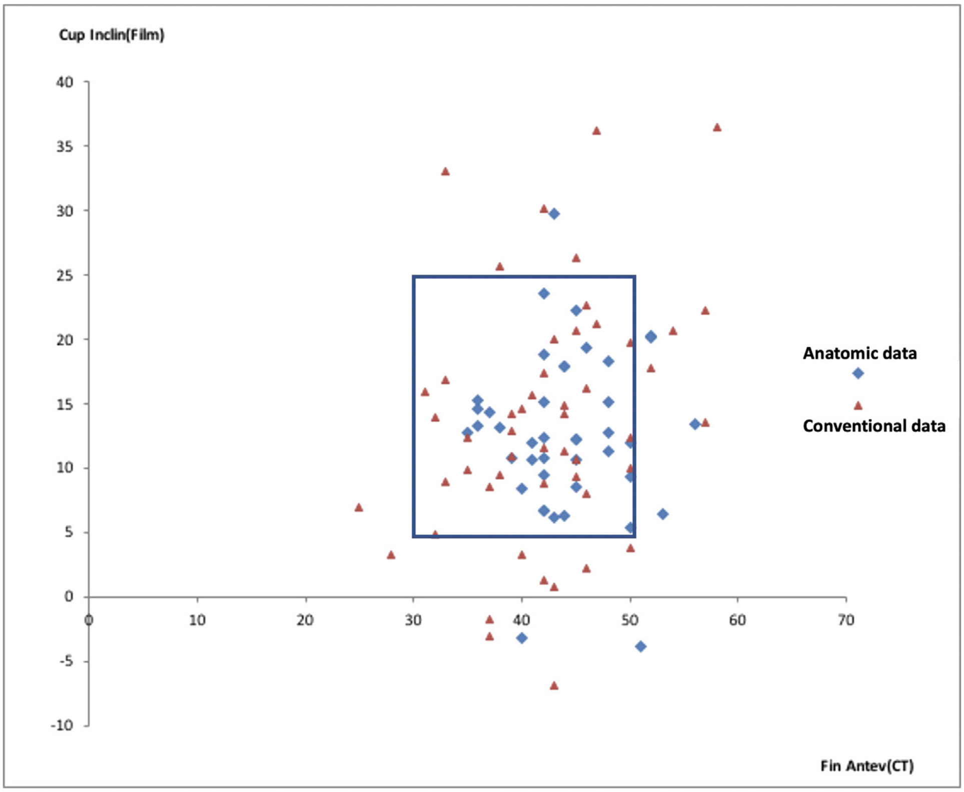

Figure 8. Radiographic cup alignment of the both groups applied to the Lewinnek safe zone. 81.5% of the study group and 59.6% of the control group were within the safe zone.

techniques, and perioperative care, and we found no significant difference in baseline demographic data between both groups. Moreover, we performed >20 computer-assisted THAs with ACA software to pass the learning curve before we started to collect the data. Third, although dysplasia and post-traumatic OA cases, which might be considered outlier cases, were included, there were no statistically significant differences in terms of types of diagnosis. Our results may represent a case typically found in real-life practice. Fourth, changes in the functional position of the pelvis when the patient lies supine for radiography or CT scan might affect the measurement of acetabular cup alignment, especially in patients with complex spinopelvic issues. However, we have already excluded patients with severe lumbopelvic deformity to prevent a potential source of error during measurement. Finally, longer operative time and cost-effectiveness for ACA navigation were not considered.

Conclusions

DAR navigation combined with MGD provides better accuracy for acetabular cup positioning within the Lewinnek safe zone than the conventional technique. Therefore, this navigation system

Table 4
Comparison of secondary outcomes between the study and control group.

Outcome measure	Study group (n = 54)	Control group (n = 52)	95% CI	*P* value
Operative time (min) mean ± SD (range)	103.21 ± 17.23 (55 to 145)	85.52 ± 17.98 (54 to 135)	11.014 to 24.557	<.01[a]
Length of stay (d), mean ± SD (range)	5.19 ± 2.31 (3 to 14)	5.56 ± 3.06 (3 to 16)	−1.416 to 0.671	.48
Estimated blood loss (mL), mean ± SD (range)	412.96 ± 261.74 (100 to 1300)	384.62 ± 318.32 (50 to 1500)	−83.719 to 140.414	.62
HHS (preoperative), mean ± SD (range)	33.09 ± 12.74 (10 to 58)	36.04 ± 10.512 (12 to 54)	−7.453 to 1.561	.20
HHS (3 mo postoperative), mean ± SD (range)	80.83 ± 7.381 (65 to 91)	82.00 ± 6.888 (70 to 91)	−3.919 to 1.586	.40
HHS (6 mo postoperative), mean ± SD (range)	88.78 ± 4.95 (77 to 96)	90.69 ± 3.893 (81 to 96)	−3.634 to 0.195	.39

CI, confidence interval; HHS, Harris hip score; mL, milliliter; SD, standard deviation.
[a] *P* value of <0.05 indicates statistical significance.

could be an adjunct technique to achieve reliable placement of the acetabular component while allowing surgeons to perform THA with their preferred instrument, surgical approach, and patient position.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101148.

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