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RESEARCH **Open Access**

Cup positioning relative to the acetabular rim planned with three-dimensional computed tomography improves precision in total hip arthroplasty: a randomized controlled trial

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Abstract

Background Accurate acetabular cup positioning is essential for successful total hip arthroplasty (THA) outcomes. The conventional mechanical alignment guide (MAG) method provides moderate accuracy. We developed a novel technique for cup positioning that utilizes preoperative three-dimensional computed tomography (3D-CT) planning based on the native acetabular rim's relative position and compared cup orientation between this method and the MAG technique.

Methods A randomized controlled trial with 120 patients undergoing primary THA via the posterolateral approach targeted cup positions of 40° radiographic inclination (RI) and 20° radiographic anteversion (RA). The control group ($n = 40$) used a MAG for cup placement, while the study group ($n = 80$) utilized preoperative 3D-CT to measure native RI, calculate RA, and determine the cup overhang distance (COD). The cup inclination was positioned relative to the superior rim point and the transverse acetabular notch. The cup anteversion was adjusted to achieve overhang at the posterior or anterior rim point according to the planned COD. Postoperative RI and RA were assessed using tilt-adjusted plain radiographs and CT scans. The percentages of cups positioned within 5° of the target position (RI/RA of 40°/20° ± 5°), and within the Grammatopoulos aiming zone (RI/RA of 40°/20° ± 10°) were compared between the two groups.

Results The mean RI was 41.7° ± 5.4° (range, 33°–59°) in the control group and 39.9° ± 3.2° (range, 33.8°–45.5°) in the study group ($p = 0.019$). The mean RA was 19.5° ± 7.6° (range, 3°–33°) in the control group and 20.2° ± 3.3° (range, 12.9°–28.3°) in the study group ($p = 0.356$). Cup alignment within 5° of the target was achieved in 86.2% (69 hips) of the study group and 32.5% (13 hips) of the control group ($p < 0.001$). The study group had a significantly higher percentage of cups within Grammatopoulos aiming zone (100% vs. 77.5%, $p < 0.001$).

Conclusions 3D-CT-guided cup positioning relative to the acetabular rim can enhance the precision of cup placement in THA to achieve alignment within 5° of the target position.

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Trial registration Thai Clinical Trials Registry (TCTR 20201220001). Registered on 20 December 2020. Prospectively registered.

Keywords Total hip arthroplasty, Acetabular cup positioning, 3D-CT, Randomized controlled trial

Introduction

Accurate acetabular cup positioning is crucial for successful total hip arthroplasty (THA), preventing edge loading, minimizing wear of the polyethylene liner, improving prosthetic longevity, and reducing dislocation rates [1, 2].

Conventional methods using mechanical alignment guides (MAG) or anatomical landmarks achieve 26–71% accuracy within the Lewinnek safe zone (15° ± 10° anteversion and 40° ± 10° inclination) [3, 4]. The MAG method assumes a fixed pelvic position based on standard preoperative pelvic positioning, which does not account for intraoperative changes in pelvic tilt. These variations are particularly evident during surgical hip dislocation or when the retractor is hooked over the anterior rim of the acetabulum and retracts the femur anteriorly, potentially leading to acetabular cup malpositioning.

Accurate cup placement requires surgeons to assess the three-dimensional pelvic position and motion occurring on the operating table during surgery [5]. An anatomically based alignment method has been introduced for positioning the acetabular cup. This method utilizes anatomical landmarks of the acetabulum obtained from three-dimensional computed tomography (3D-CT), which are easily identified during THA and serve as guides for cup alignment [6]. It does not rely on neutral preoperative pelvic positioning and is not affected by intraoperative motion. However, this technique was investigated in a small group of patients, not a randomized clinical trial, and had no control group.

Recently, 3D-CT and surgical simulation have been utilized for preoperative planning to determine the optimal cup size and position relative to the acetabular edge using the HIP-PLAN software. It has shown improved accuracy in restoring cup anteversion and reducing outliers from the Lewinnek safe zone compared to freehand methods [7]. HIP-PLAN provides 3D modeling and virtual preoperative simulation, enabling surgeons to test different implant sizes and orientations before surgery. It enhances planning efficiency by automating measurements and adjustments while minimizing intraoperative guesswork. However, its widespread use is limited by high costs and restricted software access. Additionally, it requires increased radiation exposure to scan from the iliac crest to the subtalar joint. In contrast, a standard low-dose pelvic CT scan is a more widely available, cost-effective, and lower-radiation alternative, though it lacks interactive simulation and automated measurements. To address this, we developed a novel technique using preoperative 3D-CT images and planning based on the acetabular rim's position. This study aimed to compare cup orientation differences and assess the accuracy and precision of the new method in achieving acetabular cup placement within 5° of the target position and within the predefined zones, compared to the conventional MAG method.

Methods

A randomized controlled trial was conducted among 127 patients undergoing primary THA between January 2021 and November 2022 at our tertiary referral hospital. The inclusion criteria consisted of patients over 25 years old with unilateral hip osteoarthritis or femoral neck fractures requiring THA. The exclusion criteria included hip ankylosis (1 hip), previous acetabular fractures (2 hips), Hartofilakidis Type B or C dysplasia (1 hip), and patients lost to follow-up within two years (3 hips). A total of 120 hips were enrolled in the study (Fig. 1).

Surgeries were performed by two experienced surgeons using the posterolateral approach, targeting a cup position of 40° radiographic inclination (RI) and 20° radiographic anteversion (RA), based on Grammatopoulos et al.'s recommended aiming zones of 40° ± 10° RI and 20° ± 10° RA [8], and 20° ± 5° RA for patients with normal spinopelvic motion [9].

Preoperative planning

All patients underwent a preoperative pelvic CT scan using the Philips Ingenuity Core 128 (Cleveland, USA). CT images were processed to separate the femur for better acetabular visualization. Planning included four steps using the picture archiving and communication system.

Step 1 The 3D-CT pelvic image was standardized for rotation and pelvic tilt, aligning the anterior pelvic plane (APP) in a true lateral view. Verification ensured the anterior superior iliac spines (ASIS) were superimposed and vertically aligned with the pubic symphysis. The APP was set parallel to the monitor's vertical border. A transverse diameter line was drawn on the affected acetabulum and calibrated to the templated cup size. A vertical line intersecting the iliac crest was drawn through the diameter line's center, representing the acetabular center axis (ACA). The ACA-to-ASIS distance was measured (Fig. 2).

Step 2 The 3D-CT image was rotated to an antero-posterior (AP) view. An oblique line connected the superior acetabulum edge to the transverse acetabular notch

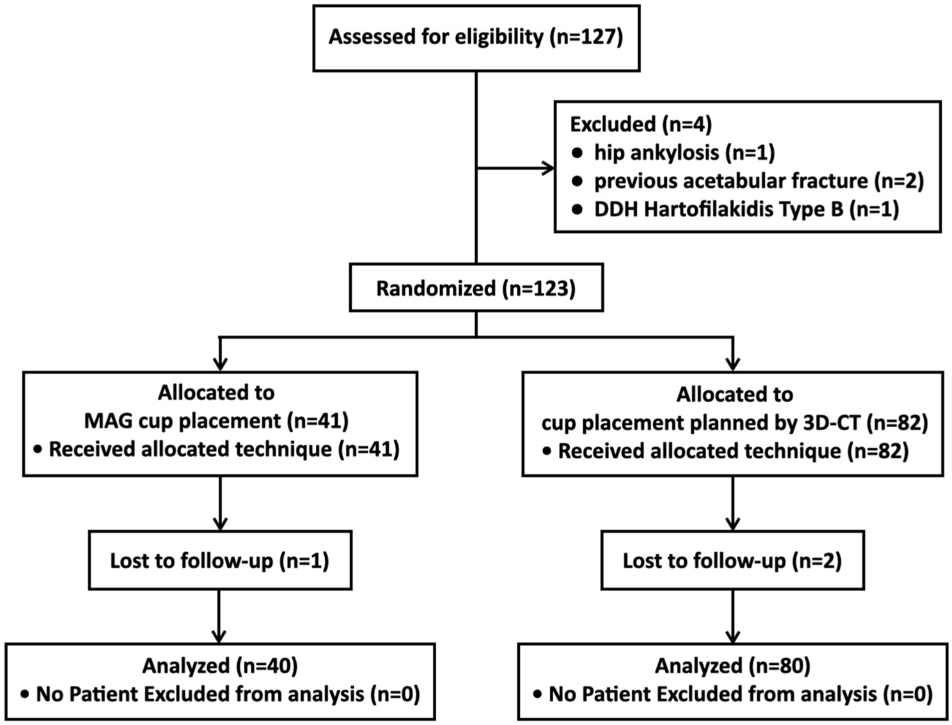

Fig. 1 CONSORT (Consolidated Standards of Reporting Trials) flowchart of the study

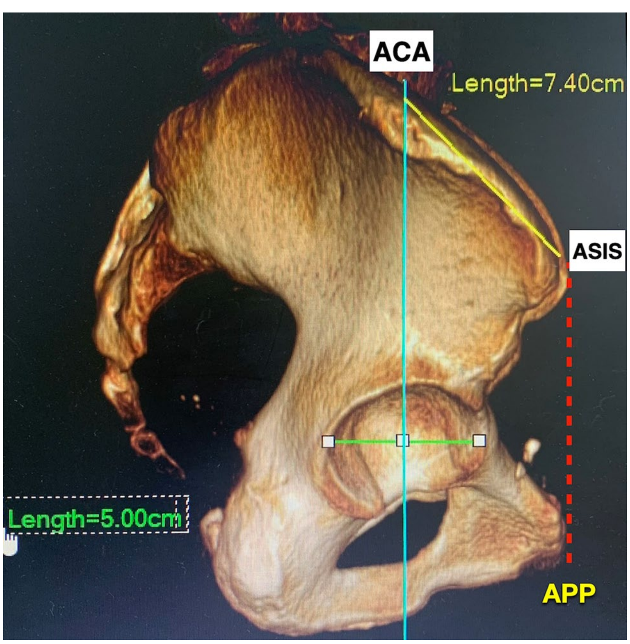

Fig. 2 The 3D-CT pelvic image aligned to the anterior pelvic plane, with a transverse diameter line calibrated to the cup size. A vertical line through the diameter's center represented the acetabular center axis (ACA), and the ACA-to-ASIS distance was measured

Fig. 3 The 3D-CT image was rotated to an antero-posterior view. An oblique line was drawn connecting the superior acetabulum edge to the transverse acetabular notch, and the inter-teardrop line was marked. The angle between these lines was measured as the native radiographic inclination

(TAN), and the inter-teardrop line was drawn. The angle between these lines was recorded as the native RI (Fig. 3).

Step 3 A circle was drawn and resized to the acetabulum's templated cup size. A diameter line, parallel to the acetabular rim's long axis, and a perpendicular short axis were drawn (Fig. 4). Native RA was calculated using the Lewinnek formula [3]: RA = arcsin [short axis/templated cup size].

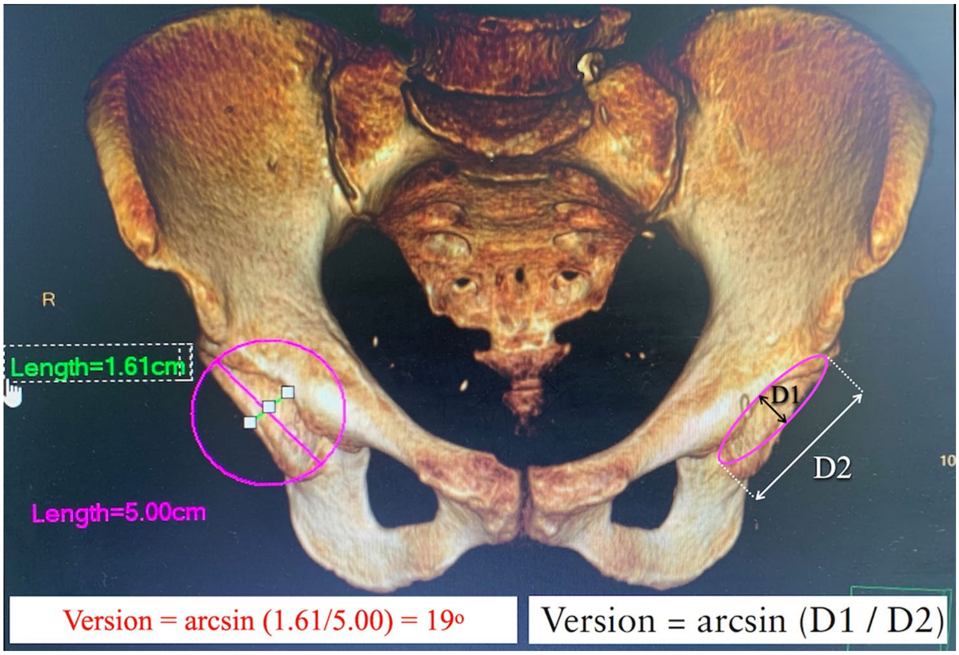

Fig. 4 A circle was drawn around the acetabulum and resized to match the templated cup size. A diameter line, parallel to the acetabular rim's long axis, and a perpendicular short axis were drawn. Native radiographic anteversion was calculated using the formula: arcsin [short axis / long axis]

Step 4 For a hemispherical cup with a 26 mm radius (mean acetabulum diameter 52 mm [10]), circumferential length (2πR = 163 mm) determined that a 1° arc equals 0.5 mm. Assuming the cup aligns flush with the acetabulum, overhanging or underhanging rim points by 0.5 mm alters anteversion by 1°. Target RA (20°) was used to calculate cup overhang distance (COD) via COD = 0.5 × (20 - native RA) mm.

The 3D-CT images and calculated data were printed and sealed. Patients were divided into two groups via block randomization using a computer-generated sequence. The group assignment was sealed in another envelope. In the operating room, the table was set to 0° tilt, and patients were positioned laterally with supports. The second envelope was opened to reveal the group.

Operative techniques

In the control group, acetabular components were placed using a MAG, targeting 37° operative inclination (OI), ensured by a digital protractor, and 25° operative anteversion toward the shoulder for final impaction [11].

In the study group, the first envelope was opened. The skin was prepped, and the iliac crest was marked posterior to the ASIS at the ACA-to-ASIS distance. During exposure, the labrum and transverse acetabular ligament were removed to expose the acetabular rim. Osteophytes were retained as guides per the CT image. Careful reaming is necessary to prevent unintended removal of the acetabular rim. Starting with the smallest-sized reamer, using progressive reaming, ensuring proper surgical exposure, and adequately retracting the femur anteriorly can help mitigate this risk. After reaming to the appropriate size, the reamer was positioned so that one axis of the crossbars aligned with the iliac skin mark, representing the ACA. Rim points were marked using electric cautery (Fig. 5). A T-positioner, made from a 6.5-mm partially threaded screw whose threaded tip had been cut and welded to a stainless nut, connecting it to the threaded bolt at the distal end of the cup positioner, was touched to the superior rim point and the TAN to measure the native OI with a digital protractor (Fig. 6). During cup impaction, the cup positioner was adjusted to 37° plus the difference between the native OI and native RI to achieve 40° RI, verified by a protractor. Simultaneously, the cup face was aligned with the line between the anterior and posterior rim points to achieve the native RA. The cup positioner was tapped horizontally for a press-fit, ensuring a posterior (or anterior) rim overhang equal to the planned COD. After seating, the posterior overhang typically matched the anterior underhang (Fig. 7) if the acetabulum was fully hemispherical. In non-hemispherical cases, where the acetabulum appeared prouder than the cup, the difference between the cup underhang at the posterior rim point and the cup underhang at the anterior rim point should be twice the planned COD.

In both groups, the short external rotators and posterior capsule were repaired. Postoperative antibiotics were administered intravenously for 24 h. Two days postoperatively, a supine pelvic AP radiograph centered on the pubic symphysis was obtained. The X-ray tube was

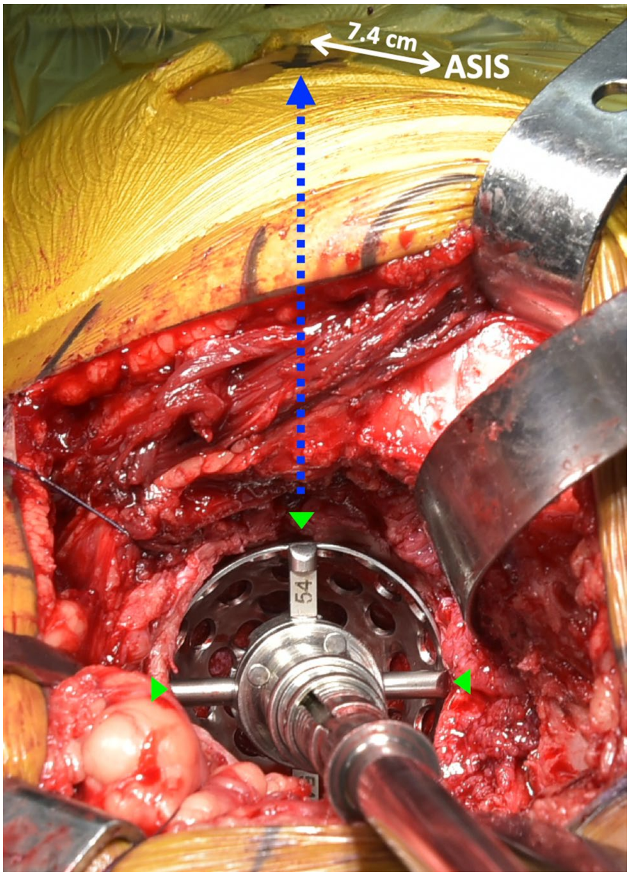

Fig. 5 Before the skin incision, the iliac crest was marked posterior to the ASIS at the ACA-to-ASIS distance. After reaming to the appropriate size, the reamer was positioned with one axis of the crossbars aligned to the iliac skin mark (blue dotted line), representing the ACA, and rim points were marked using electric cautery (green arrowhead)

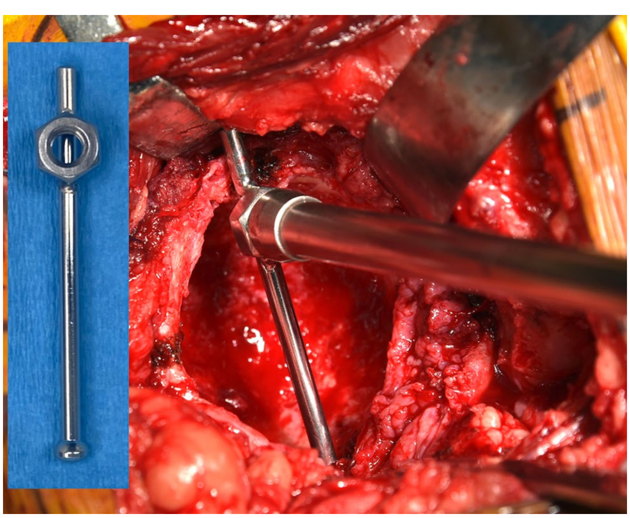

Fig. 6 The native operative inclination was measured using a T-positioner placed on the superior rim point and the transverse acetabular notch with the help of a digital protractor

adjusted vertically to match the coccyx-pubic symphysis relationship from the preoperative 3D-CT image, ensuring perpendicularity to the APP. The cup RI was measured as the angle between the inter-teardrop line and the long axis of the cup opening ellipse. A pelvic CT scan with a 1.5 mm slice thickness was also performed. Pelvic position was standardized by aligning with the APP, as per the preoperative protocol. The pelvis was resliced perpendicular to the APP, and the largest acetabular component section was selected from an axial 2D-CT view. Circles drawn along the acetabular cup and contralateral femoral head margins established hip centers. A line connecting these centers and another perpendicular to it were drawn. A third line extended from the anterior to posterior cup points measured the anatomical anteversion (AA) angle in the APP. AA was converted to RA using Murray's formula [11, 12]: RA = arctan [tan(AA) × sin(RI)]. Radiographic assessments by one resident and one surgeon, blinded to group assignments, were repeated after two weeks. Final cup position was the average of four measurements.

Data analyses

The study parameters included patient demographics, acetabular cup type, operative time, blood loss, dislocation, and infection. The primary outcome was the percentage of cups within 5° of the target position (RI/RA 40°/20° ± 5°), chosen to match computer navigation precision (4.4° inclination, 4.1° anteversion) [13]. Secondary outcomes were the percentage within the Grammatopoulos zone (RI/RA 40°/20° ± 10°). The intra-class correlation coefficients (ICCs) assessed intra-/inter-observer reliability using a two-way random-effects model. Categorical data were compared using the exact probability test, and continuous data with the *t-test*, with $p < 0.05$ statistically significant. Analyses used STATA version 12.1 (StataCorp LLC, USA).

The sample size calculation aimed to detect a difference in the percentage of cups positioned within 5° of the target between two placement methods. A prior study found the MAG method achieved this in 45% of hips [14]. We hypothesized our novel method could reach 80%, similar to computer navigation [13, 15, 16]. Using the two-independent-proportions formula [17], with a 0.01 error level, 90% power, and a 2:1 ratio, we calculated 80 cases for the study group and 40 for the control group. The study received ethical approval (Code 143/63) and was registered (ID: TCTR20201220001).

Results

Baseline characteristics showed no significant differences between groups (Table 1). The most common diagnoses were osteonecrosis (43 hips, 35.8%), femoral neck fracture (37 hips, 30.8%), and hip dysplasia (19 hips, 15.8%).

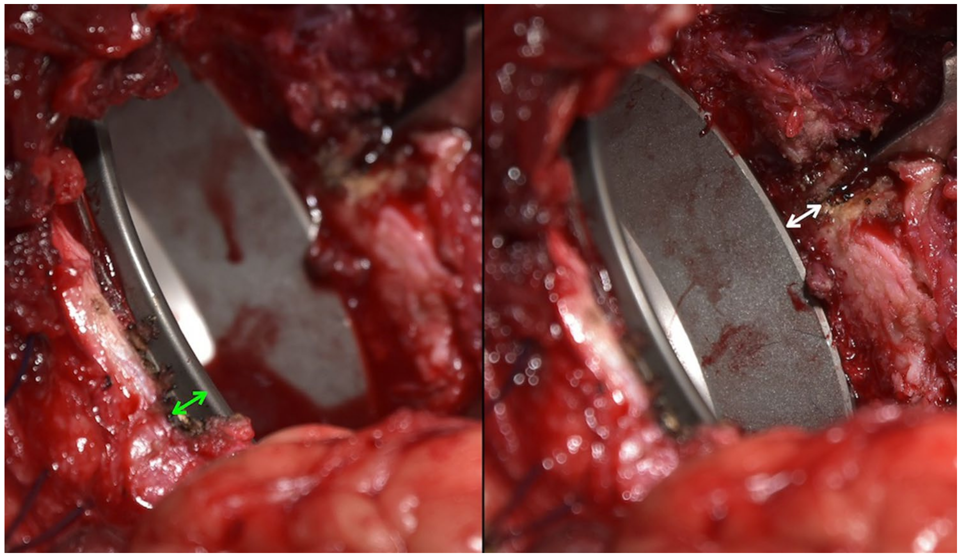

Fig. 7 Cup impaction aimed for a posterior (or anterior) rim overhang equal to the planned cup overhang distance. After final seating, the posterior overhang (green arrow) typically matched the anterior underhang (white arrow)

Table 1 Baseline characteristics and operative data of patients, comparing the two groups ($n = 120$)

Data	Control group ($n = 40$)	Study group ($n = 80$)	*p*-value
Age (yr) mean ± SD	56.3 ± 11.6	59.2 ± 12.4	0.214
range	25–79	26–89	
Gender % (n) women: men	55.0 (22): 45.0 (18)	62.5 (50): 37.5 (30)	0.437
BMI (kg/sqm) mean ± SD	23.1 ± 3.3	22.9 ± 3.9	0.723
range	17.0–29.3	15.8–34.0	
Diagnosis % (n)			
Osteonecrosis of femoral head	40.0 (16)	33.7 (27)	0.911
Femoral neck fracture	25.0 (10)	33.7 (27)	
Hip dysplasia	17.5 (7)	15.0 (12)	
Inflammatory joint disease	5.0 (2)	7.5 (6)	
Primary osteoarthritis	7.5 (3)	6.3 (5)	
Others	5.0 (2)	3.8 (3)	
Cup diameter (mm) mean ± SD	51.8 ± 2.0	51.4 ± 2.2	0.369
range	48–56	48–58	
Cementless cup type % (n)			
Allofit (Zimmer Biomet)	42.5 (17)	47.5 (38)	0.880
Plasmafit (Aesculap)	45.0 (18)	41.2 (33)	
G7 (Zimmer Biomet)	12.5 (5)	10.0 (8)	
Trilogy IT (Zimmer Biomet)	0 (0)	1.3 (1)	
Operative time (min) mean ± SD	114 ± 29	122 ± 28	0.191
range	65–185	65–200	
Total blood loss (ml) mean ± SD	400 ± 153	444 ± 224	0.338
range	200–800	100–950	

Table 2 Radiographic measurements of cup alignment comparing the two groups ($n = 120$)

Data	Control group ($n = 40$)	Study group ($n = 80$)	*p*-value
Inclination angle (°) mean ± SD	41.7 ± 5.4	39.9 ± 3.2	**0.019**
95% CI	40.0–43.5	39.2–40.6	
range	33.0–59.0	33.8–45.5	
Anteversion angle (°) mean ± SD	19.5 ± 7.6	20.2 ± 3.3	0.489
95% CI	17.1–21.9	19.5–20.9	
range	3.0–33.2	12.9–28.3	
Within target RI/RA of 40°/20° ± 5° % (n)	32.5 (13)	86.2 (69)	**< 0.001**
Within Grammatopoulos aiming zone % (n)	77.5 (31)	100 (80)	**< 0.001**

Allofit cups were implanted in 45.9% (55 hips), Plasmafit in 42.5% (51 hips), Allofit in 45.9% (55 hips), G7 in 10.8% (13 hips), and Trilogy IT in 0.8% (1 hip).

The mean RI was 41.7° ± 5.4° (range, 33°–59°) in the control group and 39.9° ± 3.2° (range, 33.8°–45.5°) in the study group ($p = 0.019$). The mean RA was 19.5° ± 7.6° (range, 3°–33°) in the control group and 20.2° ± 3.3° (range, 12.9°–28.3°) in the study group ($p = 0.356$). The control group showed significantly higher standard deviations (SD) for inclination (5.4° vs. 3.2°, $p < 0.001$) and anteversion (7.6° vs. 3.3°, $p < 0.001$) (Table 2; Fig. 8).

Cup alignment within 5° of the target was achieved in 86.2% (69 hips) of the study group and 32.5% (13 hips) of the control group ($p < 0.001$) (Fig. 9). The risk difference for outliers was − 0.5, and the risk ratio was 0.2. In the control group, 28 hips (70%) had an inclination angle within 5° of the target, while 20 hips (50%) had an anteversion angle within the same range. The study group

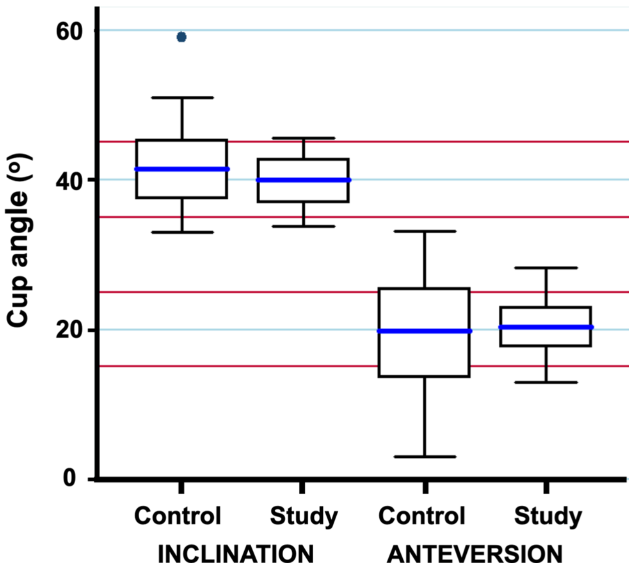

Fig. 8 Radiographic inclination and anteversion angles of the acetabular components, comparing the two groups. The box boundaries represent the 25th and 75th percentiles, with blue horizontal lines indicating the median. Whiskers and large dots denote the maximum and minimum values. Red and light blue horizontal lines outside the boxes represent the target zones for cup placement

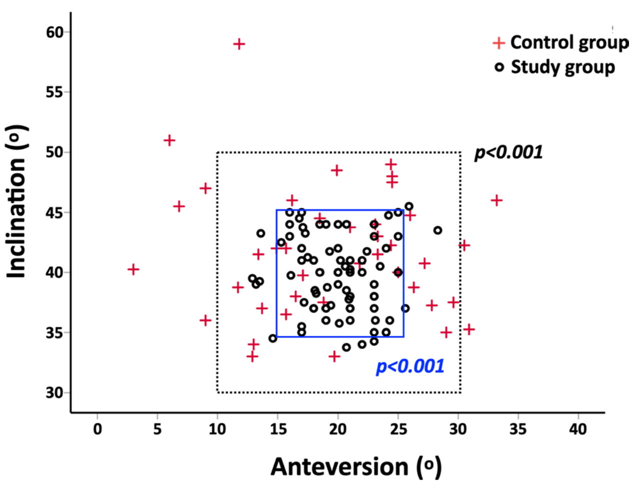

Fig. 9 Distribution of inclination and anteversion angles measured from postoperative radiographs and CT scans, compared between the two groups. The frames represent the zones within 5° of the target position (blue line) and the Grammatopoulos aiming zone (black dotted line)

had a significantly higher percentage of cups within the Grammatopoulos aiming zone (100% vs. 77.5%, $p < 0.001$).

The ICCs for intra-observer and inter-observer reliability were 0.96 and 0.92 for inclination and 0.98 and 0.97 for anteversion measurements. No significant differences were found in operative time ($p = 0.191$) or blood loss ($p = 0.338$) between groups. Follow-up lasted at least two years, with no dislocations or infections recorded.

Discussion

This study found no significant differences in mean anteversion between the traditional MAG technique and the novel 3D-CT-based technique. However, the study group showed a mean inclination angle closer to the target of 40°, reflecting greater accuracy with the novel technique. The significantly lower SD values for inclination and anteversion in the study group suggest the novel technique provides superior precision, minimizing variability in cup alignment and offering more consistent, reliable surgical outcomes. The new technique achieved cup alignment within 5° of the target in 86% of hips, compared to 33% with the MAG technique, reflecting a 53% improvement. These results suggest that the new approach improves precision, potentially preventing incorrect cup placement in about half of THAs. From the patient's perspective, although the CT scan may take additional time, the cost of the pelvic 3D-CT is fully reimbursed by the healthcare system in our country. This novel technique does not increase operative time or result in wound pain at the pin tracker sites, unlike computer navigation or robotic surgery [18].

Some researchers have investigated acetabular component positioning using anatomical landmarks on the acetabular rim. Ha et al. [6] used two reference points for cup inclination: the inferior point at the TAN and the superior point opposite the TAN. For anteversion, they identified the anterior point at the acetabular notch (AAN) and the posterior point opposite the AAN. They proposed that a change of 1 mm in the COD from the TAN or AAN would alter cup inclination or anteversion by 1°. However, we disagree with this assumption. The fulcrum for adjusting cup angles should be the cup's center of rotation (COR), not a bony rim point. Altering the COD at one rim point inevitably changes the COD at the opposite point. We hypothesize that a 0.5 mm change in COD results in a 1° change in the cup angle, which we find more plausible. Additionally, the inferior portion of the cup often obscures the TAN during impaction, making it difficult to observe the parallelism between the cup border and the line joining the superior rim point and TAN. Unlike Ha et al., we did not use the COD from the superior rim point to guide inclination. Instead, we employed a digital protractor on the T-positioner to measure the angle between the floor and the plane connecting the superior rim point and TAN, representing the native OI. This tool's accuracy in aligning cup inclination has been validated [14, 19]. Our technique defines the anterior and posterior rim points at the 3 o'clock and 9 o'clock positions relative to the TAN's inferior margin. These points, 2–3 mm deep to the acetabulum's COR, are parallel to the acetabular face, ensuring the cup is implanted in the patient's native anteversion [20, 21].

Sariali et al. [7] used HIP-PLAN software for preoperative planning and surgical simulation, displaying a 3D image of the cup within the osseous frame. The software allowed measurement of the distances from the cup's edge to the acetabular margins, adjusting the cup orientation to match the 3D planning image. These distances were measured with a flexible ruler and compared to the 3D planning results. The HIP-PLAN method improved cup anteversion accuracy and reduced outliers compared to freehand implantation. However, this software is unavailable in our country. We adopted HIP-PLAN's 3D visualization concept by calculating native acetabular anteversion using the Lewinnek formula. The cup RA was set equal to the native RA when the cup border aligned with the line connecting the acetabular anterior and posterior rim points. Adjustments to anteversion were based on our hypothesis that a 0.5 mm change in COD results in a 1° change in the cup angle. Our method showed an average error of 0.2° in cup anteversion (SD 3.3°, range −7.1°to 8.3°), compared to HIP-PLAN's mean error of -2.7° (SD 5.4°, range −4.8° to -0.5°). Both methods had lower SD values than traditional techniques, with precision comparable to computer navigation (4.1°–4.4°) [13] and robotic-assisted THA (4°) [22].

Conventional cup positioning guided by MAG in this study resulted in only 32.5% of cups placed within 5° of the intended position. This deviation can be attributed to errors in preoperative pelvic positioning, intraoperative pelvic mobility, and manual inaccuracies during surgery [23]. While MAG devices have been used to align the cup with respect to the longitudinal and coronal planes of the patient, they fail to account for individual variations in a patient's anatomy or changes in pelvic orientation during the operation. As a result, high percentages of suboptimal cup orientations outside the desired alignment have been reported in previous studies [3]. Using MAG in this study, 70% of hips had an inclination angle within 5° of the target, while 50% had an anteversion angle within the same range. The higher accuracy in inclination may be attributed to the use of a digital protractor placed on the cup positioner during placement. An inclinometer can provide a mean RI angle closer to the target angle with less variation and outliers when compared with using MAG alone [14, 24]. For anteversion, positioning the cup relative to the bony landmark of the acetabulum, as performed in the study group, may be more beneficial and precise than using MAG, as it does not rely on neutral preoperative pelvic positioning and remains unaffected by intraoperative motion.

This study used the APP for preoperative planning, intraoperative cup orientation, and postoperative evaluation of cup alignment. A 3D-CT image, reformatted during planning, aligned the pelvis with the APP. The ACA was determined in the true lateral view using four pelvic and acetabular landmarks: the iliac crest, superior rim point, acetabular center, and TAN [25]. The ACA runs from the TAN through the acetabular center and parallels the APP. By using the ACA and ASIS distance along with reamer interface crossbars, these landmarks were applied intraoperatively. We believe that this 3D-CT planning concept can be adapted to the functional coronal plane in cases of abnormal spinopelvic motion, allowing optimal cup orientation without computer navigation or fluoroscopy.

Recently, Grammatopoulos et al. proposed an aiming zone for optimal functional cup orientation at an RI/RA of 40°/20° ± 10° [8]. They recommended this zone as the coronal target for cup orientation, with the sagittal target adjusted to achieve an optimal combined sagittal index within 205°–245° in the standing position. Using our technique, 100% of hips achieved cup alignment within this zone. This outstanding result can be attributed to the same target position used in our study but with a range that is twice as wide.

The key strength of our study is aligning preoperative and postoperative CT scans within the same APP, reducing errors in anteversion evaluation due to pelvic orientation. Postoperative CT scans offer more accurate measurements than radiographs. This method ensures RA values are analyzed in the same pelvic position, making preoperative and postoperative comparisons reliable. Additionally, our randomized clinical trial achieved 94% power to detect a difference in the primary outcome. Nevertheless, this study has several limitations. First, it requires preoperative CT scans to measure the acetabular native inclination and anteversion, increasing cost and radiation exposure. Potential improvements to minimize radiation exposure without compromising image quality in pelvic 3D-CT imaging include advanced imaging technologies, iterative reconstruction, artificial intelligence-driven reconstruction techniques, and optimized scan planning [26]. Second, it cannot be applied in cases with difficult-to-identify acetabular rims, such as hip ankylosis, prior fractures, or severe dysplasia. Third, the method is designed for lateral decubitus position and requires specialized equipment, including a digital protractor and a custom T-positioner. Lastly, it demands a strong understanding of acetabular anatomy, CT imaging, pelvic planes, and mathematical calculations, with a learning curve for accurate landmark identification and cup alignment.

Conclusions

3D-CT-guided cup positioning relative to the acetabular rim can improve the precision of cup placement in THA, achieving alignment within 5° of the target position. All cups were placed within the Grammatopoulos aiming zone.

Abbreviations

THA	Total hip arthroplasty
MAG	Mechanical alignment guide
3D-CT	Three-dimensional computed tomography
RI	Radiographic inclination
RA	Radiographic anteversion
OI	Operative inclination
AA	Anatomical anteversion
COD	Cup overhang distance
APP	Anterior pelvic plane
ASIS	Anterior superior iliac spine
ACA	Acetabular center axis
TAN	Transverse acetabular notch
AAN	Anterior point at the acetabular notch
COR	Center of rotation
ICC	Intra-class correlation coefficients
CI	Confidence interval
SD	Standard deviation
kg/sqm	Kilogram per square meter

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05704-4.

Supplementary Material 1

Supplementary Material 2

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None.

Author contributions
AP: conception, data analysis and writing the manuscript. NW: data collection, analysis and data interpretation. RR: data analysis and interpretation.All authors approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The Research Ethics Committee of Lampang Hospital reviewed and approved this study (EC code: 143/63). Written informed consent was obtained from all participants in the study. The procedures were in accordance with the ethical standards of the responsible committee on human experimentation and with the Declaration of Helsinki 2000.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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