Arthroplasty Today 28 (2024) 101461

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original Research

# Robotic Arm–Assisted System Improved Accuracy of Cup Position and Orientation in Cementless Total Hip Arthroplasty for Dysplastic Hips: A Comparison Among Groups With Manual Placement, Computed Tomography–Based Navigation, and Robotic Surgery

Toshiki Konishi, MD, Taishi Sato, MD, PhD*, Satoshi Hamai, MD, PhD, Shinya Kawahara, MD, PhD, Daisuke Hara, MD, PhD, Yasuharu Nakashima, MD, PhD

*Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan*

A R T I C L E I N F O

*Article history:*
Received 20 December 2023
Received in revised form
5 April 2024
Accepted 9 June 2024

*Keywords:*
Total hip arthroplasty
Computed tomography (CT)–based navigation
Robotic arm–assisted system

A B S T R A C T

*Background:* Accurate cup placement in total hip arthroplasty (THA) for patients with dysplasia is challenging due to the distinctive bone deformities. This study aimed to compare the accuracy of cup placement position and orientation across robotic arm–assisted systems (R-THA), computed tomography–based navigation (N-THA), and manual procedure (M-THA) in THA for osteoarthritis secondary to dysplasia.

*Methods:* A total of 167 patients (197 hips), including 88 R-THAs, 45 N-THAs, and 46 M-THAs, were analyzed. Propensity score matching was performed to align the patient backgrounds. Horizontal and vertical centers of rotation were measured for cup position, whereas radiographic inclination and anteversion were measured for cup orientation. The proportion of cases with cup placement within 3 mm and 5° from the target was compared.

*Results:* R-THA had a significantly higher percentage of cup placement within 3 mm of the target compared to N-THA (78% vs 49%; $P = .0041$) and M-THA (78% vs 53%; $P = .013$). Similarly, R-THA was significantly more successful in placing the cup within 5° of the target compared to N-THA (84% vs 58%; $P = .0049$) and M-THA (91% vs 20%; $P < .0001$). Moreover, N-THA was significantly better at placing the cup within 5° of the target compared to M-THA (62% vs 14%; $P < .0001$), whereas there was no significant difference in the percentage of cup placement within 3 mm of the target (51% vs 51%; $P = 1.0$).

*Conclusions:* Robotic arm–assisted system and computed tomography–based navigation improved accuracy in cup orientation compared to the manual procedure. Additionally, the robotic arm–assisted system further improved cup position accuracy.



## Introduction

In total hip arthroplasty (THA), positive clinical outcomes and long-term survival have been achieved through innovations in surgical technique, implant design, and materials [1]. Nevertheless, implant malposition is associated with increased rates of impingement, bearing surface wear, dislocation, and revision surgery [2,3]. Various devices have been developed to improve the accuracy of implant placement [4]. Computed tomography (CT)–based navigation systems have enabled 3-dimensional (3D) visualization of planning and actual cup orientation in real-time during surgery [5]. The robotic arm–assisted system, such as the Mako system (Stryker, Kalamazoo, MI, US), has been further developed to enhance the reproducibility of the acetabular reaming and installation via semi-automatic guidance based on the surgical plan.

Determining and reproducing the appropriate target point for acetabular reaming and cup insertion is challenging, especially for

Funding: This work was supported by the Japan Society for the Promotion of Science KAKENHI (Grant Numbers FAG3K08654).

* Corresponding author. Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, 3-1-1, Maidashi, Higashi-ku, Fukuoka, 812-8582, Japan. Tel.: +81 92 642 5488.

*E-mail address:* taishi5963@gmail.com

https://doi.org/10.1016/j.artd.2024.101461
2352-3441/


**Figure 1.** An example case of developmental dysplasia of the hip (Crowe type II). The presence of distinctive deformities, such as a shallow and steep acetabulum, double floor, and osteophytes was seen.

secondary osteoarthritis (OA) of the hip caused by dysplasia due to the presence of distinctive deformities, such as a shallow and steep acetabulum, double floor, and osteophytes at the acetabular margin (Fig. 1) [6,7].

Although there have been several reports investigating the accuracy of cup orientation and position in THA for patients with dysplasia through robotic-arm assisted THA (R-THA), CT-based navigated THA (N-THA), and manual THA (M-THA), [8-10] only a limited number of studies have compared the accuracy of the 3 procedures.

This study aimed to compare the accuracy of cup placement position and orientation among robotic arm–assisted systems, CT-based navigation, and manual procedure in THA for osteoarthritis secondary to dysplasia.

## Material and methods

### *Patients*

This study was approved by the institutional review board of the authors' affiliate institution (reference number 2021-210). We reviewed the cases of patients who underwent primary THA for hip OA secondary to dysplasia. The procedures were performed by 10 surgeons at a single institution between September 2019 and December 2022. All surgeries utilized the same implants: Trident HA cup (Stryker, Mahwah, NJ, USA) and Accolade II femoral hip stem (Stryker, Mahwah, NJ, USA). Dysplastic hips were defined as hips with lateral center edge angle (LCEA) $<25^\circ$ on a plain anteroposterior radiograph of the hip joint [11,12].

During the study period, primary THA for OA secondary to dysplasia was performed in 211 patients. Of these, 14 were excluded due to a lack of postoperative CT data. Fourteen R-THA and 4 N-THA cases were excluded because of intraoperative conversion to the manual procedure. Ultimately, 88, 45, and 46 patients who underwent R-THA, N-THA, and M-THA, respectively, were included in the analysis (Fig. 2). There were no significant differences in age, sex, or body mass index among the 3 groups. Regarding the Crowe classification [13], remarkable differences were observed among the 3 groups (Table 1). Multiple comparisons showed that the R-THA group had significantly more patients with Crowe type 2–4 than the M-THA group (17% vs 2.2%; $P = .011$).

### *Preoperative planning and placement target*

Each surgeon conducted preoperative planning with use of the CT images which were routinely performed in our hospital. Planning with CT images was performed using the built-in 3D planning system of the Mako system in the R-THA group and the ZedHip (Lexi, Tokyo, Japan) and 3D Template (Kyocera, Kyoto, Japan) in the N-THA and M-THA groups, respectively. Two-dimensional planning was performed using radiographs in the 5 hips in the M-THA group due to surgeon's preference.

The cup position was aimed at the true acetabulum; however, in cases where the procedure was challenging due to bone defects, the cup was planned such that bony coverage could be obtained (cup center edge angle $\geq 0^\circ$) [14]. The cup center edge angle was defined as the angle created by the intersection of the line connecting the hip center and lateral edge of the host bone and the line perpendicular to the interteardrop line [15].

Cup orientation was determined based on the radiographic definition [16]. The radiographic inclination (RI) was targeted at 40° in all cases. The target angle for radiographic anteversion (RA) was determined intraoperatively so that the sum of the stem anteversion and cup RA was 40° to 60° based on the intraoperative measurement, in accordance with the literature [17,18].

### *Surgical procedure*

All THAs were performed using the posterior approach with a cementless hemispheric cup and stem. To determine the target RA, the stem was placed before the cup [18]. The surgical procedure (R-THA, N-THA, or M-THA) was selected at the discretion of the surgeons and the patient's wishes. For R-THA and N-THA, the Mako system and CT-based hip navigation (version 1.3, Stryker, Leibinger, Freiburg, Germany) were used, respectively. In M-THAs, a conventional mechanical guide was used for cup placement. In all cases, intraoperative anteroposterior radiographs were taken. In cases where the placement significantly deviated from the target, the cups were replaced during surgery. There were no cases requiring revision during surgery in N-THA or R-THA.

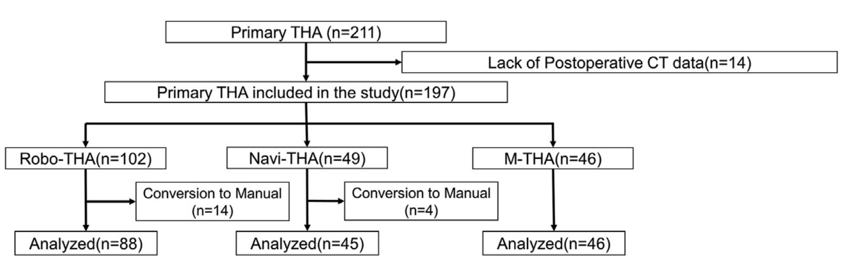


**Figure 2.** Patient flow diagram. M-THA, manual total hip arthroplasty; N-THA, computed tomography–based navigated total hip arthroplasty; R-THA, robotic arm–assisted total hip arthroplasty.

**Table 1**
Patient demographics before matching.

| | R-THA | N-THA | M-THA | *P* value |
|---|---|---|---|---|
| Number of cases | 88 | 45 | 46 | |
| Age (y) | 64 ± 9 | 66 ± 9 | 67 ± 9 | .12 |
| Sex (women/men) | 78/10 | 38/7 | 37/9 | .43 |
| Body mass index (kg/m$^2$) | 24.2 ± 3.8 | 24.5 ± 3.9 | 26.2 ± 5.6 | .081 |
| Crowe type | | | | .030 |
| I | 73 (83.0%) | 41 (91.1%) | 45 (97.8%) | |
| II | 10 (11.4%) | 3 (6.7%) | 1 (2.2%) | |
| III | 2 (2.3%) | 1 (2.2%) | 0 | |
| IV | 3 (3.4%) | 0 | 0 | |

Data are presented as mean ± standard deviation.
M-THA, manual total hip arthroplasty; N-THA, computed tomography−based navigated total hip arthroplasty; R-THA, robotic arm−assisted total hip arthroplasty.

### *Measurement*

The center of rotation (COR) was used to evaluate the location of cup placement [19]. Radiographic measurements, including those of horizontal and vertical center of rotation (HCOR and VCOR, respectively), were performed. Preoperative digitally reconstructed radiographic images obtained from 3D planning and postoperative anteroposterior radiographs were used for radiographic measurements. HCOR was defined as the horizontal distance from the cup center to the teardrop on the surgical side, which is parallel to the interteardrop line. Similarly, VCOR was defined as the vertical distance from the center of the cup to the interteardrop line (Fig. 3a). The COR was defined as the center of the cup to eliminate the effects of the liner and ball offset [20].

CT image measurements, including those of RI and RA, were performed to evaluate the cup orientation. For the CT image measurements, the preoperative functional pelvic plane was used as the pelvic coordinate system. Briefly, the axial and coronal planes were connected to the bilateral anterosuperior iliac spine, and the sagittal plane was based on the tabletop plane. All measurements were performed using ZedHip. The ZedHip software has built-in data on various cups, and by overlaying this information on the actual cup installation position, the software can automatically calculate the cup orientation (both RI and RA) relative to the preoperative functional pelvic plane (Fig. 3b) [21]. The difference between the placement target and postoperative measurement values for each group was calculated as the error. To examine the accuracy of the cup position, the absolute errors of the HCOR and VCOR and the proportion of hips within 3 mm of the target were compared [22,23]. For cup orientation, we compared the absolute errors of RI and RA, as well as the proportion of hips within 5° of the target [24,25]. All measurements were conducted by the first author (T.K.), and 20 randomly chosen cases were examined to determine the interobserver and intraobserver reproducibility to evaluate the reliability of the cup position and cup alignment data. The intrarater and inter-rater reliabilities for these 20 cases were calculated after each evaluation was performed twice by 2 distinct observers (T.K. and T.S.) who were each blinded to the findings given by the other. The intrarater and inter-rater reliabilities for

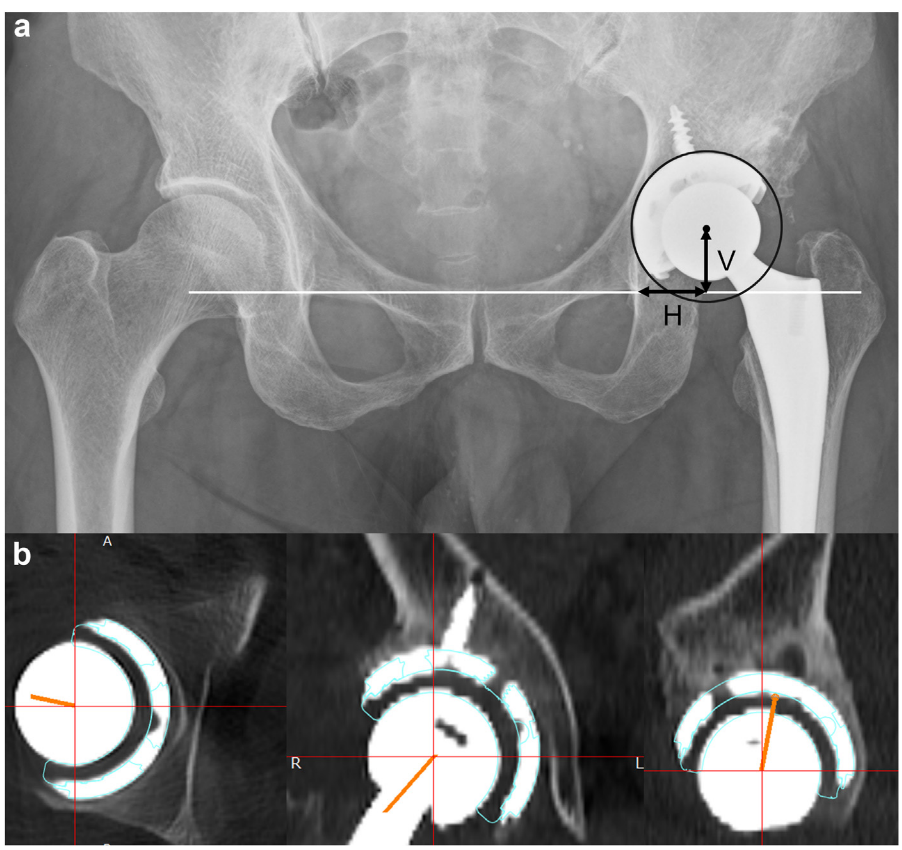


**Figure 3.** Measurement of cup position and orientation (a) cup position White line, Interteardrop line; H, horizontal center of rotation (HCOR); V, vertical center of rotation (VCOR). (b) cup orientation Radiographic inclination (RI) and radiographic anteversion (RA) were automatically measured when the installed implant is placed in the actual cup placement position via ZedHip.

**Table 2**
Reliability of measurement.

| Parameter | Intrarater reliability | Inter-rater reliability |
|---|---|---|
| HCOR (planning) | 0.93 | 0.88 |
| VCOR (planning) | 0.93 | 0.93 |
| HCOR (post operative) | 0.97 | 0.97 |
| VCOR (post operative) | 0.82 | 0.83 |
| RI | 0.91 | 0.94 |
| RA | 0.94 | 0.92 |

HCOR, horizontal center of rotation; RA, radiographic anteversion; RI, radiographic inclination; VCOR, vertical center of rotation.

measurement were in an almost-perfect agreement (0.82-0.96, Table 2).

### Statistical analysis

Statistical analyses were performed using the JMP software (version 16.0; SAS Institute, Cary, NC, USA). The Kruskal—Wallis test was used for continuous variables, whereas Fisher's exact test was used for categorical variables. Propensity score matching (PSM) was performed to reduce differences between the groups. We matched patients using the nearest-neighbor technique with a caliper set at 0.2 standard deviations of the logit of the propensity score. PSM was performed to compare R-THA to N-THA, R-THA to M-THA, and N-THA to M-THA. The matching process accounted for age, sex, body mass index, and the Crowe type.

Outcomes were compared between the R-THA and N-THA, R-THA and M-THA, and N-THA and M-THA cohorts. Comparisons between the study groups were performed using the Student's t-test for continuous variables and Fisher's exact test for categorical variables. All tests were two-sided, and $P < .05$ was considered significant. In accordance with the Bonferroni correction, $P < .017$ was considered significant for multiple comparisons among the 3 groups [26]. The difference in absolute error in cup orientation between N-THA and R-THA, where the discrepancy is small, was approximately $1.5^{\circ} \pm 2.0^{\circ}$ based on previous study [8]. The required sample size to detect this difference was 30 cases per group. This study met the required sample size.

**Table 3**
Patient demographics and error from preoperative planning after matching (R-THA vs N-THA).

| | R-THA | N-THA | *P* value |
|---|---|---|---|
| Number of cases | 45 | 45 | |
| Age (years) | 66 ± 10 | 66 ± 9.3 | .82 |
| Sex (women/men) | 38/7 | 38/7 | 1.0 |
| Body mass index (kg/m$^2$) | 24.7 ± 3.5 | 24.5 ± 3.9 | .79 |
| Crowe type (I / II / III) | 41 / 3 / 1 | 41 / 2 / 2 | .77 |
| The error in COR | | | |
| ΔHCOR (mm) | −0.6 ± 2.0 | −0.8 ± 2.9 | .71 |
| ΔVCOR (mm) | 0.2 ± 1.8 | −0.0 ± 2.9 | .66 |
| The absolute error in COR | | | |
| \|ΔHCOR\| (mm) | 1.6 ± 1.3 | 2.5 ± 1.7 | .013 |
| \|ΔVCOR\| (mm) | 1.4 ± 1.2 | 2.2 ± 1.9 | .019 |
| The error in orientation | | | |
| ΔRI (°) | 0.1 ± 2.1 | 0.1 ± 4.9 | .97 |
| ΔRA (°) | −0.8 ± 2.9 | −1.1 ± 4.7 | .76 |
| The absolute error in orientation | | | |
| \|ΔRI\| (°) | 1.4 ± 1.4 | 3.6 ± 3.3 | .0002 |
| \|ΔRA\| (°) | 2.1 ± 2.1 | 3.8 ± 2.9 | .0028 |

Data are presented as mean ± standard deviation.
R-THA, robotic-arm assisted total hip arthroplasty; N-THA, CT-based navigated total hip arthroplasty; HCOR, horizontal center of rotation; VCOR, vertical center of rotation; RI, radiographic inclination; RA, radiographic anteversion.

## Results

### Cup position

The R-THA group showed a smaller absolute error for HCOR and VCOR than the N-THA ($P = .01$, $P = .02$) and M-THA ($P < .0001$, $P = .11$) (Tables 3 and 4) groups. There was no difference in the absolute errors of HCOR and VCOR between the N-THA and M-THA ($P = .20$, $P = .75$) (Table 5) groups. The proportion of hips placed within 3 mm of the target was significantly higher in the R-THA group than in the N-THA (78% vs 49%; $P = .0041$) and M-THA (78% vs 53%; $P = .013$) (Figs. 4a and 5a) groups. Meanwhile, no significant difference in the proportion of hips placed within 3 mm of the target was observed between the N-THA and M-THA groups (51% vs 51%; $P = 1.0$) (Fig. 6a).

### Cup orientation

The absolute errors for RI and RA were significantly smaller in the R-THA group than in the N-THA group ($P = .0002$, $P = .0028$) and significantly smaller in the N-THA group than in the M-THA group ($P = .095$, $P = .0003$) (Table 3 and 5).

The proportion of cases with cups placed within 5° of the target was significantly higher in the R-THA group than in the N-THA group (84% vs 58%; $P = .0049$) and significantly higher in the N-THA group than in the M-THA group (62% vs 14%; $P < .0001$) (Figs. 4b and 6b).

### Complications

In a survey of complications, including the cases that were not matched, dislocation was observed in 1 case (1.1%) for R-THA, 1 case (2.2%) for N-THA, and 0 cases (0%) for M-THA. All cases of dislocation did not require reoperation. One case of deep infection was observed in both R-THA and N-THA, and both cases required reoperation. There were no significant differences in dislocation and infection rates between groups ($P = .60$, $P = .86$).

**Table 4**
Patient demographics and error from preoperative planning after matching (R-THA vs M-THA).

| | R-THA | M-THA | *P*-value |
|---|---|---|---|
| Number of cases | 45 | 45 | |
| Age (years) | 68 ± 8 | 68 ± 8 | .98 |
| Sex (women/men) | 38/7 | 37/8 | .71 |
| Body mass index (kg/m$^2$) | 25.8 ± 3.5 | 25.6 ± 3.8 | .77 |
| Crowe type (I / II / III) | 44 / 1 | 44 / 1 | 1.0 |
| The error in COR | | | |
| ΔHCOR (mm) | −0.2 ± 1.8 | −1.7 ± 3.2 | .005 |
| ΔVCOR (mm) | 0.1 ± 2.0 | 1.2 ± 2.9 | .015 |
| The absolute error in COR | | | |
| \|ΔHCOR\| (mm) | 1.4 ± 1.1 | 2.9 ± 2.1 | .0006 |
| \|ΔVCOR\| (mm) | 1.6 ± 1.3 | 2.4 ± 2.0 | .11 |
| The error in orientation | | | |
| ΔRI (°) | 0.2 ± 1.9 | −2.3 ± 5.7 | .0065 |
| ΔRA (°) | −0.3 ± 2.5 | 3.7 ± 7.7 | <.0001 |
| The absolute error in orientation | | | |
| \|ΔRI\| (°) | 1.3 ± 1.4 | 4.9 ± 3.6 | <.0001 |
| \|ΔRA\| (°) | 1.7 ± 1.8 | 7.0 ± 4.8 | <.0001 |

Data are presented as mean ± standard deviation.
HCOR, horizontal center of rotation; M-THA, manual total hip arthroplasty; N-THA, computed tomography—based navigated total hip arthroplasty; RA, radiographic anteversion; RI, radiographic inclination; R-THA, robotic arm—assisted total hip arthroplasty; VCOR, vertical center of rotation.

**Table 5**
Patient demographics and error from preoperative planning after matching (N-THA vs M-THA).

| | N-THA | M-THA | *P* value |
|---|---|---|---|
| Number of cases | 37 | 37 | |
| Age (y) | 67 ± 9 | 67 ± 8 | .87 |
| Sex (women/men) | 32/5 | 29/8 | .54 |
| Body mass index (kg/m$^2$) | 24.8 ± 4.0 | 25.0 ± 3.5 | .85 |
| Crowe type (I / II) | 36 / 1 | 36 / 1 | 1.0 |
| The error in COR | | | |
| ΔHCOR (mm) | −0.9 ± 2.8 | −2.0 ± 3.3 | .14 |
| ΔVCOR (mm) | −0.1 ± 3.0 | 1.3 ± 2.9 | .040 |
| The absolute error in COR | | | |
| \|ΔHCOR\| (mm) | 2.4 ± 1.6 | 3.0 ± 2.3 | .20 |
| \|ΔVCOR\| (mm) | 2.3 ± 1.9 | 2.4 ± 2.1 | .75 |
| The error in orientation | | | |
| ΔRI (°) | 0.4 ± 5.1 | −2.4 ± 6.0 | .031 |
| ΔRA (°) | −1.2 ± 4.7 | 3.3 ± 8.2 | .0046 |
| The absolute error in orientation | | | |
| \|ΔRI\| (°) | 3.7 ± 3.4 | 5.2 ± 3.8 | .095 |
| \|ΔRA\| (°) | 3.7 ± 3.0 | 7.3 ± 4.9 | .0003 |

Data are presented as mean ± standard deviation.
HCOR, horizontal center of rotation; M-THA, manual total hip arthroplasty; N-THA, computed tomography−based navigated total hip arthroplasty; RA, radiographic anteversion; RI, radiographic inclination; R-THA, robotic arm−assisted total hip arthroplasty; VCOR, vertical center of rotation.

## Discussion

This study compared the installation accuracy in 3 groups of patients that utilized different techniques to clarify the advantages of robotic-arm assisted systems and CT-based navigation over manual placement for OA secondary to dysplasia. The use of robotic-arm assisted system improved the accuracy of cup placement position and orientation, whereas the use of CT-based navigation increased the accuracy of only the cup orientation.

Regarding cup position, the robotic arm−assisted system achieved a higher accuracy than manual placement and CT-based navigation, whereas there was no difference between the 2 latter procedures. In a comparative study of robotic-arm assisted procedure and manual procedure, Coulomb et al. found that the use of a robotic arm−assisted system was associated with fewer outliers in cup position [27]. Comparing the use of robotic arm−assisted system and CT-based navigation, Ando et al. [8] reported that the absolute error in VCOR was smaller when the former was used [8]. These reports support the findings of our study. In CT-based navigated procedures, the cup can be monitored in real-time while reaming and cup placement are performed by the surgeon. Therefore, there is still a risk of human error, such as excessive or insufficient reaming. Consequently, there may not be a remarkable

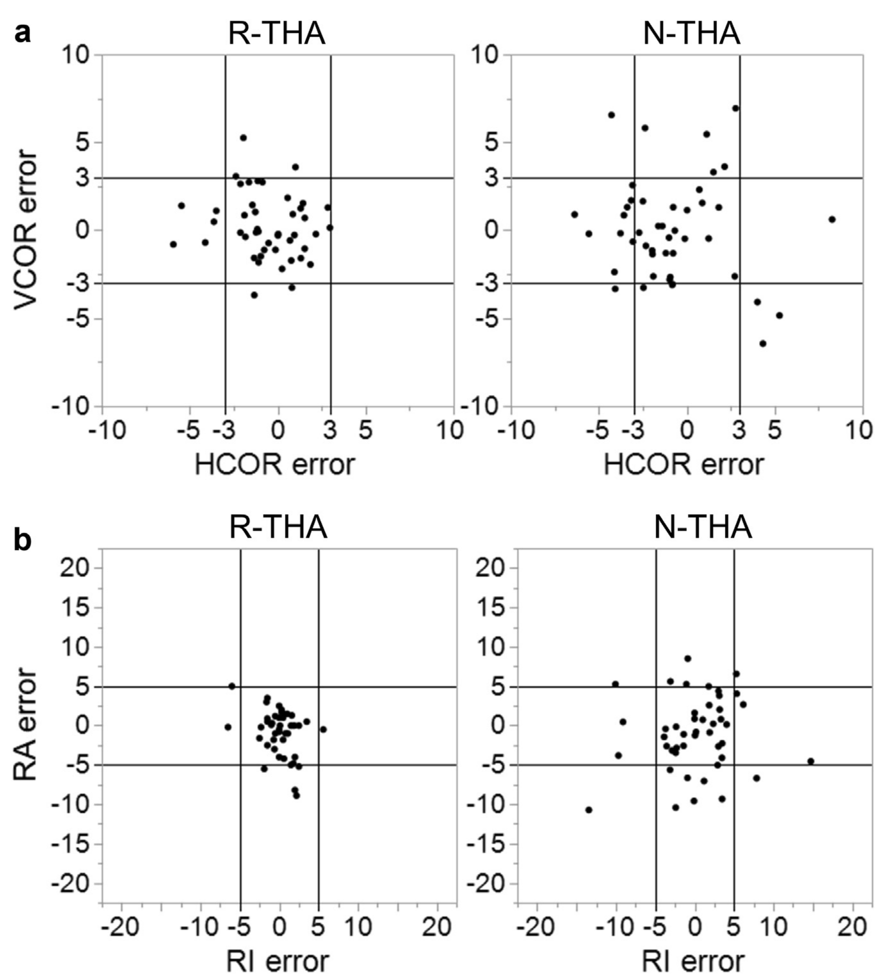


**Figure 4.** (a) Scatter plot of the differences in HCOR and VCOR between postoperative measurement and preoperative planning (R-THA vs N-THA). The square represents the area within 3 mm (78% vs 49%; *P* = .0041). (b) Scatter plot of the differences in RI and RA between postoperative measurements and preoperative planning (R-THA vs N-THA). The square indicates the area within 5° (84% vs 58%; *P* = .0098). HCOR, horizontal center of rotation; N-THA, computed tomography−based navigated total hip arthroplasty; RA, radiographic anteversion; RI, radiographic inclination; R-THA, robotic arm−assisted total hip arthroplasty; VCOR, vertical center of rotation.

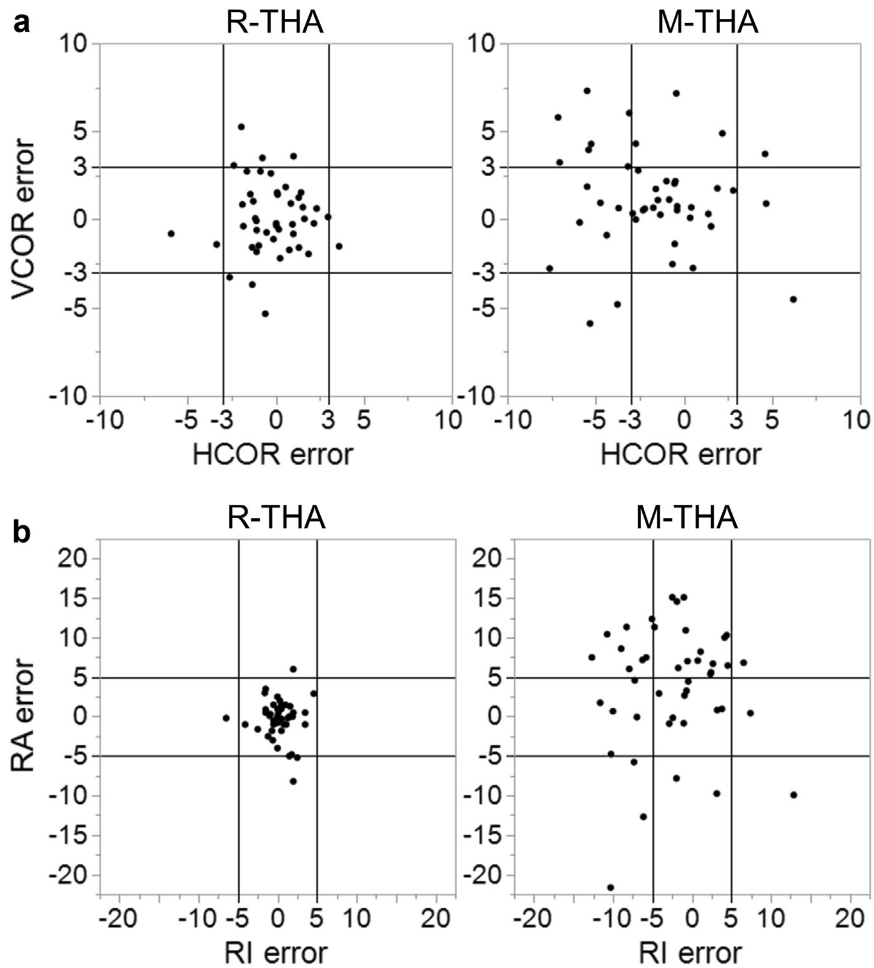


**Figure 5.** (a) Scatter plot of the differences in HCOR and VCOR between postoperative measurement and preoperative planning (R-THA vs M-THA). The square represents the area within 3 mm (78% vs 53%; $P = .0013$). (b) Scatter plot of the differences in RI and RA between postoperative measurement and preoperative planning (R-THA vs M-THA). The square represents the area within 5° (91% vs 20%; $P < .0001$). HCOR, horizontal center of rotation; M-THA, manual total hip arthroplasty; RA, radiographic anteversion; RI, radiographic inclination; R-THA, robotic arm–assisted total hip arthroplasty; VCOR, vertical center of rotation.

difference between CT-based navigation and manual placement in terms of cup position accuracy. The robotic arm–assisted system controls the arm to prevent unintended movement outside the boundaries of the reaming path defined by the preoperative 3D plan [28,29]. This change may have affected the accuracy of the cup placement position. THA for patients with dysplasia tends to result in a high hip center, which decreases the range of motion and increases the dislocation rate [30]. In cementless THA for patients with dysplasia, obtaining adequate host bone-implant contact while maintaining a normal hip center can be challenging. Robotic arm–assisted systems have the advantage of placing cups as planned.

Compared to the manual procedure, the cup orientation was 3 and 1.5 times more accurate in the robotic-arm assisted procedure and CT-based navigation, respectively. Kalteis et al. [31] reported that CT-based navigation improved both RI and RA compared to manual procedures. Meanwhile, Sato et al [9]. reported that the absolute errors of RI and RA were smaller in robotic arm–assisted procedures than in manual procedures. These reports support our findings. In manual procedures, there is a lot of variation in orientation; therefore, CT-based navigation and robotic-arm assisted systems have the advantage of being able to accurately reproduce the orientation. In R-THA, the orientation was twice as accurate as that in N-THA. Comparing CT-based navigation and robotic-arm assisted systems, Tamaki et al. [10] reported that the absolute error of RI and RA was smaller in robotic-arm assisted THA, which supports our study findings. The robotic arm–assisted system can control the cup impactor to the planned angle during installation, which may contribute to the accuracy of cup orientation [32]. In a study evaluating optimal implant alignment based on the range of motion, Harada et al. reported that RI, RA, and the sum of the stem anteversion and cup RA should be within 34°-43°, 18°-26°, and 35°-56°, respectively [33]. The target is quite narrow and challenging to achieve with manual or CT-based navigated procedures. Because patients with dysplasia have a wide range of femoral anteversion, cup RA must be adjusted to maintain the proper combined anteversion [34]. Robotic arm–assisted systems are more effective in cases that require minor adjustments, such as dysplasia, because they can be installed more precisely as planned.

In complex cases of THA, such as revision surgery [35], ankylosing spondylolysis, post-traumatic arthritis [36], and fibrous fused hips [37], robotic arm–assisted systems have been reported to be useful for accurate installation. This study showed that more accurate placement can be achieved in OA secondary to dysplasia using a robotic arm–assisted system compared to manual and CT-based navigated procedures.

This study has some limitations. First, this was a nonrandomized, retrospective study. However, we matched the demographics of the

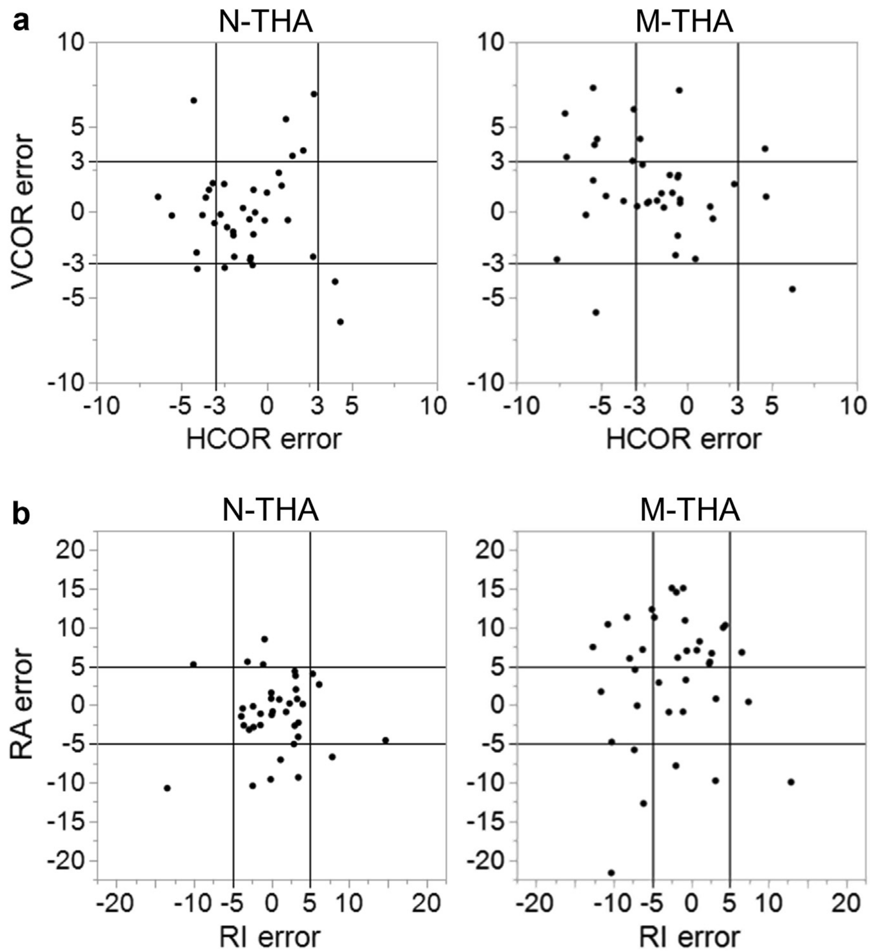


**Figure 6.** (a) Scatter plot of the differences in HCOR and VCOR between postoperative measurement and preoperative planning (N-THA vs M-THA). The square indicates the area within 3 mm (51% vs 51%; $P = 1.0$). (b) Scatter plot of the differences in RI and RA between postoperative measurements and preoperative planning (N-THA vs M-THA). The square indicates the area within 5° (62% vs 14%; $P < .0001$). HCOR, horizontal center of rotation; M-THA, manual total hip arthroplasty; N-THA, computed tomography–based navigated total hip arthroplasty; RA, radiographic anteversion; RI, radiographic inclination; R-THA, robotic arm–assisted total hip arthroplasty; VCOR, vertical center of rotation.

2 groups, including the body mass index and Crowe type, using PSM. Second, there were 4 types of preoperative planning software. Although the comparison in this study was based on the error between placement target and postoperative installation, we believe that the influence of the software is small. Third, although the number of cases was sufficient to evaluate the accuracy of placement, complications, such as dislocation and infection, were too few to be compared and evaluated. Finally, in many cases, the postoperative period was short; hence, we could not compare clinical outcomes. Therefore, a long-term follow-up would be beneficial in future studies to be able to assess clinical outcomes.

## Conclusions

The use of robotic arm–assisted system resulted in a higher accuracy in cup position and orientation than the use of manual procedure or CT-based navigation in THA for OA secondary to dysplasia. CT-based navigation improved the accuracy of cup orientation compared to manual placement but did not improve the accuracy of cup 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.2024.101461.

## CRediT authorship contribution statement

**Toshiki Konishi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Taishi Sato:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Satoshi Hamai:** Resources, Investigation. **Shinya Kawahara:** Resources, Investigation. **Daisuke Hara:** Resources, Investigation. **Yasuharu Nakashima:** Writing – review & editing, Supervision, Resources, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Acknowledgments

We thank Goro Motomura MD, Ph. D, Takeshi Utsunomiya MD, PhD, and Ryosuke Yamaguchi MD, Ph. D (Department of Orthopedic Surgery, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan) for data collection and their invaluable advice for this study. The authors would like to thank Editage (www.editage.com) for the English language editing.

## References


[1] Ferguson RJ, Palmer Jr A, Taylor A, Porter ML, Malchau H, Glyn-Jones S. Hip replacement. Lancet 2018;392:1662–71.
[2] Kelmer G, Stone AH, Turcotte J, King PJ. Reasons for revision: primary total hip arthroplasty mechanisms of failure. J Am Acad Orthop Surg 2021;29:78–87.
[3] Widmer K-H, Zurfluh B. Compliant positioning of total hip components for optimal range of motion. J Orthop Res 2004;22:815–21.
[4] Sugano N. Computer-assisted orthopaedic surgery and robotic surgery in total hip arthroplasty. Clin Orthop Surg 2013;5:1–9.
[5] Iwana D, Nakamura N, Miki H, Kitada M, Hananouchi T, Sugano N. Accuracy of angle and position of the cup using computed tomography-based navigation systems in total hip arthroplasty. Comput Aided Surg 2013;18:187–94. https://doi.org/10.3109/10929088.2013.818713.
[6] Rogers BA, Garbedian S, Kuchinad RA, Backstein D, Safir O, Gross AE. Total hip arthroplasty for adult hip dysplasia. J Bone Joint Surg Am 2012;94:1809–21.
[7] Sugano N, Takao M, Sakai T, Nishii T, Miki H. Does CT-based navigation improve the long-term survival in ceramic-on-ceramic THA? Clin Orthop Relat Res 2012;470:3054–9.
[8] Ando W, Takao M, Hamada H, Uemura K, Sugano N. Comparison of the accuracy of the cup position and orientation in total hip arthroplasty for osteoarthritis secondary to developmental dysplasia of the hip between the Mako robotic arm-assisted system and computed tomography-based navigation. Int Orthop 2021;45:1719–25.
[9] Sato K, Sato A, Okuda N, Masaaki M, Koga H. A propensity score-matched comparison between Mako robotic arm-assisted system and conventional technique in total hip arthroplasty for patients with osteoarthritis secondary to developmental dysplasia of the hip. Arch Orthop Trauma Surg 2023;143:2755–61.
[10] Tamaki Y, Goto T, Wada K, Omichi Y, Hamada D, Sairyo K. Robotic arm-assisted total hip arthroplasty via a minimally invasive anterolateral approach in the supine position improves the precision of cup placement in patients with developmental dysplasia of the hip. J Orthop Sci 2024;29:559–65.
[11] Wyles CC, Heidenreich MJ, Jeng J, Larson DR, Trousdale RT, Sierra RJ. The john charnley award: redefining the natural history of osteoarthritis in patients with hip dysplasia and impingement. Clin Orthop Relat Res 2017;475:336–50.
[12] Muddaluru V, Boughton O, Donnelly T, O'Byrne J, Cashman J, Green C. Developmental dysplasia of the hip is common in patients undergoing total hip arthroplasty under 50 years of age. SICOT J 2023;9:25.
[13] Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg 1979;61:15–23. https://doi.org/10.2106/00004623-197961010-00004.
[14] Fujii M, Nakashima Y, Nakamura T, Ito Y, Hara T. Minimum lateral bone coverage required for securing fixation of cementless acetabular components in hip dysplasia. BioMed Res Int 2017;2017:4937151.
[15] Takao M, Nakamura N, Ohzono K, Sakai T, Nishii T, Sugano N. The results of a press-fit-only technique for acetabular fixation in hip dysplasia. J Arthroplasty 2011;26:562–8.
[16] Murray DW. The definition and measurement of acetabular orientation. J Bone Joint Surg Br 1993;75:228–32.
[17] Jolles BM, Zangger P, Leyvraz P-F. Factors predisposing to dislocation after primary total hip arthroplasty: a multivariate analysis. J Arthroplasty 2002;17:282–8.
[18] Nakashima Y, Hirata M, Akiyama M, Itokawa T, Yamamoto T, Motomura G, et al. Combined anteversion technique reduced the dislocation in cementless total hip arthroplasty. Int Orthop 2014;38:27–32.
[19] Fukushi J-I, Kawano I, Motomura G, Hamai S, Kawaguchi K-I, Nakashima Y. Does hip center location affect the recovery of abductor moment after total hip arthroplasty? Orthop Traumatol Surg Res 2018;104:1149–53.
[20] Wan Z, Boutary M, Dorr LD. The influence of acetabular component position on wear in total hip arthroplasty. J Arthroplasty 2008;23:51–6.
[21] Imai N, Takubo R, Suzuki H, Shimada H, Miyasaka D, Tsuchiya K, et al. Accuracy of acetabular cup placement using CT-based navigation in total hip arthroplasty: comparison between obese and non-obese patients. J Orthop Sci 2019;24:482–7.
[22] Foissey C, Batailler C, Coulomb R, Giebaly DE, Coulin B, Lustig S, et al. Image-based robotic-assisted total hip arthroplasty through direct anterior approach allows a better orientation of the acetabular cup and a better restitution of the centre of rotation than a conventional procedure. Int Orthop 2023;47:691–9.
[23] Dastane M, Dorr LD, Tarwala R, Wan Z. Hip offset in total hip arthroplasty: quantitative measurement with navigation. Clin Orthop Relat Res 2011;469:429–36.
[24] Hayashi S, Hashimoto S, Kuroda Y, Nakano N, Matsumoto T, Ishida K, et al. Robotic-arm assisted THA can achieve precise cup positioning in developmental dysplasia of the hip : a case control study. Bone Joint Res 2021;10:629–38.
[25] Zhang S, Liu Y, Yang M, Ma M, Cao Z, Kong X, et al. Robotic-assisted versus manual total hip arthroplasty in obese patients: a retrospective case-control study. J Orthop Surg Res 2022;17:368.
[26] Armstrong RA. When to use the Bonferroni correction. Ophthalmic Physiol Opt 2014;34:502–8.
[27] Coulomb R, Cascales V, Haignere V, Bauzou F, Kouyoumdjian P. Does acetabular robotic-assisted total hip arthroplasty with femoral navigation improve clinical outcomes at 1-year post-operative? A case-matched propensity score study comparing 98 robotic-assisted versus 98 manual implantation hip arthroplasties. Orthop Traumatol Surg Res 2023;109:103477.
[28] St Mart J-P, Goh EL, Shah Z. Robotics in total hip arthroplasty: a review of the evolution, application and evidence base. EFORT Open Rev 2020;5:866–73.
[29] Banerjee S, Cherian JJ, Elmallah RK, Pierce TP, Jauregui JJ, Mont MA. Robot-assisted total hip arthroplasty. Expert Rev Med Devices 2016;13:47–56.
[30] Komiyama K, Nakashima Y, Hirata M, Hara D, Kohno Y, Iwamoto Y. Does high hip center decrease range of motion in total hip arthroplasty? A computer simulation study. J Arthroplasty 2016;31:2342–7.
[31] Kalteis T, Handel M, Bäthis H, Perlick L, Tingart M, Grifka J. Imageless navigation for insertion of the acetabular component in total hip arthroplasty: is it as accurate as CT-based navigation? J Bone Joint Surg Br 2006;88:163–7.
[32] Bullock EKC, Brown MJ, Clark G, Plant JGA, Blakeney WG. Robotics in total hip arthroplasty: current concepts. J Clin Med Res 2022;11:6674. https://doi.org/10.3390/jcm11226674.
[33] Harada S, Hamai S, Motomura G, Ikemura S, Fujii M, Kawahara S, et al. Evaluation of optimal implant alignment in total hip arthroplasty based on postoperative range of motion simulation. Clin Biomech 2022;92:105555.
[34] Sankar WN, Neubuerger CO, Moseley CF. Femoral anteversion in developmental dysplasia of the hip. J Pediatr Orthop 2009;29:885–8.
[35] Wu X-D, Zhou Y, Shao H, Yang D, Guo S-J, Huang W. Robotic-assisted revision total joint arthroplasty: a state-of-the-art scoping review. EFORT Open Rev 2023;8:18–25.
[36] Chai W, Guo R-W, Puah KL, Jerabek S, Chen J-Y, Tang P-F. Use of robotic-arm assisted technique in complex primary total hip arthroplasty. Orthop Surg 2020;12:686–91.
[37] Zhang S, Liu Y, Ma M, Cao Z, Kong X, Chai W. Is robotic-assisted technology still accurate in total hip arthroplasty for fibrous-fused hips? J Arthroplasty 2023;38:129–34.