Robotic-arm assisted THA can achieve precise cup positioning in developmental dysplasia of the hip : a case control study

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Robotic-arm assisted THA can achieve precise cup positioning in developmental dysplasia of the hip

A CASE CONTROL STUDY

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Aims

This study aimed to evaluate the accuracy of implant placement with robotic-arm assisted total hip arthroplasty (THA) in patients with developmental dysplasia of the hip (DDH).

Methods

The study analyzed a consecutive series of 69 patients who underwent robotic-arm assisted THA between September 2018 and December 2019. Of these, 30 patients had DDH and were classified according to the Crowe type. Acetabular component alignment and 3D positions were measured using pre- and postoperative CT data. The absolute differences of cup alignment and 3D position were compared between DDH and non-DDH patients. Moreover, these differences were analyzed in relation to the severity of DDH. The discrepancy of leg length and combined offset compared with contralateral hip were measured.

Results

The mean values of absolute differences (postoperative CT-preoperative plan) were 1.7° (standard deviation (SD) 2.0) (inclination) and 2.5° (SD 2.1°) (anteversion) in DDH patients, and no significant differences were found between non-DDH and DDH patients. The mean absolute differences for 3D cup position were 1.1 mm (SD 1.0) (coronal plane) and 1.2 mm (SD 2.1) (axial plane) in DDH patients, and no significant differences were found between two groups. No significant difference was found either in cup alignment between postoperative CT and navigation record after cup screws or in the severity of DDH. Excellent restoration of leg length and combined offset were achieved in both groups.

Conclusion

We demonstrated that robotic-assisted THA may achieve precise cup positioning in DDH patients, and may be useful in those with severe DDH.

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Keywords: Robotic-arm assisted THA, 3D alignment, Developmental dysplasia of the hip

Article focus

- How accurate is acetabular component placement with robotic-arm assisted total hip arthroplasty (THA) in developmental dysplasia of the hip (DDH) patients?
- Does the severity of DDH affect cup placement accuracy of robotic-arm assisted THA?

Key messages

- Robotic-arm assisted THA may achieve the accurate reproducibility of cup placement in both non-DDH and DDH patients, even in those with severe DDH.

Strengths and limitations

- This is the first study to analyze the accuracy of cup positioning using robotic-arm assisted THA in DDH patients.

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- This was not a randomized study, but a retrospective cohort study.

Introduction

Acetabular component malposition is recognized as a risk factor for dislocation and increased wear after total hip arthroplasty (THA).[1] Target cup positioning is difficult to achieve even by experienced surgeons.[1] Furthermore, precise cup placement is challenging with THA in patients with developmental dysplasia of the hip (DDH). Previous studies have demonstrated higher rates of loosening of the acetabular component and postoperative dislocation after THA in DDH patients.[2–4] A higher complication rate is caused by acetabular component malposition and poor stability of the cup due to inadequate acetabular roof, double acetabular floor, osteophytes, and difficulty to identify the accurate orientation of acetabulum for DDH patients.[5–7] To address these difficulties, several surgical assistive devices, such as patient-specific guide and navigation system, have been used.[8,9]

Although a systematic review and meta-analysis study demonstrated that no significant differences in pain, quality of life, and satisfaction were found between computer-assisted THA and conventional THA,[10] computerized navigation THA achieved precise cup position and decreased complications within 90 days postoperatively.[9,11] Previous studies have demonstrated the accuracy of cup placement in DDH patients with CT.[12,13] Moreover, a navigation system has been used not only for THA but also for hip resurfacing arthroplasty, periacetabular osteotomy, and stem cell therapy in osteonecrosis of the hip.[14-17]

Recently, a new generation of robotic-arm assisted THA has been introduced, which has achieved precise cup positioning and good clinical results.[18-22] Kanawade et al[20] reported in a CT validation study that robotic-arm assisted THA achieved a precision of cup inclination in 88% of patients and anteversion in 84%, with a 10° discrepancy between intraoperative angles and postoperative CT validation. In another CT validation study, Nodzo et al[19] reported significant correlations for inclination ($R^2 = 0.62$; $p < 0.001$) and anteversion ($R^2 = 0.76$; $p < 0.001$) between intraoperative angles and postoperative CT validation. However, to date, no study has analyzed the accuracy of cup placement with robotic-arm assisted THA in DDH patients. We hypothesized that robotic-arm assisted THA may achieve precise cup placement in DDH, as well as in non-DDH patients. The primary aim of this study was to investigate the accuracy of cup placement with robotic-arm assisted THA in DDH patients, and the secondary aim was to investigate whether the severity of DDH affected cup placement accuracy with robotic-arm assisted THA. In order to clarify the objectives of the study, we compared the cup placement accuracy between non-DDH and DDH patients and the association of accuracy of cup placement with the severity of DDH.

Table I. Patient characteristics, and pre- and postoperative Japanese Orthopaedic Association and University of California, Los Angeles activity scores.

Characteristic	non-DDH (n = 39)	DDH (n = 30)	p-value*
Mean age, yrs (SD)	61.2 (10.5)	60.5 (11.3)	0.708*
Sex (female/male), n	36/3	28/2	0.095†
Treated side (right/left), n	20/19	16/14	0.560‡
Mean BMI, kg/m² (SD)	23.1 (6.2)	22.5 (5.9)	0.736*
Score			
Mean preoperative JOA (SD)	56.5 (10.2)	50.5 (11.2)	0.026
Mean postoperative JOA (SD)	94.7 (4.6)	93.1 (5.4)	0.176
Mean preoperative UCLA activity (SD)	4.1 (1.3)	4.0 (1.3)	0.200
Mean postoperative UCLA activity (SD)	7.6 (1.0)	7.5 (0.9)	0.157

*Mann-Whitney U test.
†Fisher's exact test.
‡Chi-squared test.
DDH, developmental dysplasia of the hip; JOA, Japanese Orthopaedic Association; SD, standard deviation; UCLA, University of California, Los Angeles.

Methods

Ethics. This research was approved by the institutional review board of the authors' institution, and informed consent for participation in the study was obtained from all participants.

Multiple acquisitions of CT images cause disadvantages in terms of cost and radiation exposure to the patients. However, we routinely take CT images preoperatively and one week after surgery to confirm the cup and stem version and 3D positioning.

Patients. In this retrospective cohort study, patients who underwent robotic-arm assisted THA (MAKO Rio Robot; Stryker, USA) by two senior surgeons (S. Hayashi and S. Hashimoto) at our institution between September 2018 and December 2019 and those who were diagnosed with osteoarthritis (OA) (grade 4 according to the Tönnis classification) were selected. A total of 72 patients (75 joints) were enrolled initially. Of the 75 joints, six were excluded because of missing data, including postoperative CT data; finally, 69 patients (69 joints) were analyzed in this study.

All procedures were performed using either an anterolateral or posterior approach by two senior surgeons (S. Hayashi and S. Hashimoto) with patients in the lateral position. One surgeon used an anterolateral approach and the other surgeon used a posterior approach. Of the 69 patients, 30 had DDH and were classified according to the Crowe type (Crowe type I, 14 patients; type II, five patients; type III, ten patients; and type IV, one patient).[2] The patient details are shown in Table I. There were no significant differences in age, sex, treated side, and BMI between the non-DDH and DDH groups.

Clinical evaluation. Hip function was evaluated using the Japanese Orthopaedic Association (JOA) score, which allocates 40 points for pain, 20 points for range of motion, 20 points for walking ability, and 20 points for activities of daily living, with a maximum total score of 100 points.[23] The JOA score was evaluated preoperatively and at the one-year follow-up. The University of California, Los Angeles (UCLA) activity score[24] was also evaluated preoperatively and at the one-year follow-up assessment.

Preoperative plan and surgery. Preoperative CT scans from the iliac wing to the femoral condyle were obtained. The slice pitch was 1 mm. The CT data were transferred to the MAKO planning module. Then, preoperative planning was performed to determine the optimal component size, angle, and position, using the 3D templating software of the MAKO robotic hip system. In order to determine the size and orientation of the cementless stem, CT data were transferred to the OrthoMap 3D Navigation System (Stryker Orthopaedics, USA) and patient-specific virtual 3D bone models were analyzed. Stem anteversion planning of cementless stem angle was determined for adjustment to match the anatomical neck anteversion and shaft axis, and then the size of the femoral stem was determined to fit both the medial canal and lateral flare and fill the canal of the proximal femur as much as possible. Stem anteversion planning of cemented stem was fixed at 30°. We determined the target cup angle at a fixed cup inclination of 40° and the cup anteversion angle according to Widmer's combined anteversion (CA) theory,[25] with respect to the functional pelvic plane.[26] When cup centre edge (CE) angle was less than 0° at the placement of the anatomical hip centre, the 3D cup position was arranged to a higher hip centre to satisfy the cup CE angle over 0°.

Leg length was defined as the distance between the apex of the lesser trochanter and the trans-teardrop line, and combined offset was defined as the distance between the anatomical axis of the femur and the midline of the pelvis, according to previous reports.[19,27] The discrepancy of leg length and offset compared with contralateral hip were measured during preoperative planning and postoperatively for further comparisons.

The patients underwent THA using the Trident hemispherical cup and Accolade II or Exeter v40 stems (Stryker, USA). The robotic-arm assisted THA procedures were performed with the MAKO robotic hip system, which is a robotic-arm assisted computer navigation system that uses the RIO robotic arm (Robotic Arm Interactive Orthopaedic System; Stryker) to ream the acetabulum and place the acetabular component. The patient-specific virtual 3D bone models of the pelvis and femur were created using the MAKO software preoperatively. For the registration process, 32 points on the acetabulum were touched using the probe to the bone surface during surgery. Specific acetabular bone surface pointing matched the anatomy of the bone and virtual 3D bone model on the software regardless of the patient's position intraoperatively. The software accounts for the pelvic tilt using the patient's anterior/posterior pelvic tilt when lying supine on the CT table. After the acetabular component was placed, one or two screws were inserted. Intraoperative cup alignment was confirmed by touching five points at the cup edge using a navigation pointer, and the intraoperative cup alignment was recorded twice: one after cup impaction and before screw insertion, and the second after cup screws. Full weightbearing was allowed for all patients a day after surgery.

Postoperative evaluation. Postoperative CT images were regularly taken one week after surgery to confirm the cup and stem version and 3D positioning. Postoperative CT data were transferred to the OrthoMap 3D Navigation System, and computer-aided design models of the implants were manually adjusted for the postoperative multiplanar reconstruction of CT images (Figure 1). Cup inclination and anteversion angles were measured with respect to the functional pelvic plane. To analyze the accuracy of cup alignment, we compared the absolute difference of cup alignment among postoperative measurement, navigation records, and preoperative plan. To assess the cup position of the axial axis, the normal line through the cup's centre was drawn on the axial view of the preoperative plan on the MAKO workstation (Figure 2) and postoperative reconstruction image of OrthoMap 3D workstation (Figure 3). For assessment of the cup position in the coronal axis, the horizontal line through the cup's centre was drawn on the coronal view of the preoperative plan and postoperative image (Figures 2 and 3). The distance between the outer edge of the cup and the medial edge of the acetabulum was measured, and the absolute differences of the distance between the preoperative plan and postoperative measurement were calculated in the axial and coronal views (Figures 2 and 3). In order to validate the measurement method for positioning of cup placement at preoperative plan and postoperatively, interobserver variabilities were validated in the first ten patients by three authors (TM, NN, YK) who were not operating surgeons, and each person validated it three times to account for intraobserver variabilities.

Statistical analysis. A power calculation determined that a minimum sample size of 24 patients in each group would be sufficient to assess whether there was a significant difference with the power of 0.8 and $p < 0.05$, when the mean differences of 3° and 3 mm were identified as significantly accurate, according to a previous report.[28] The difference in mean age, BMI, JOA score, UCLA activity score, cup angles, cup positions, leg length discrepancy, and the discrepancy of combined offset were analyzed by the Mann-Whitney U test. The chi-squared test or Fisher's exact test was applied to compare the nominal observations. The database was analyzed using SPSS version 16.0 software (SPSS, USA). The data in figures and tables are expressed as means and standard deviations (SDs) unless otherwise indicated. A p-value < 0.05 was considered statistically significant.

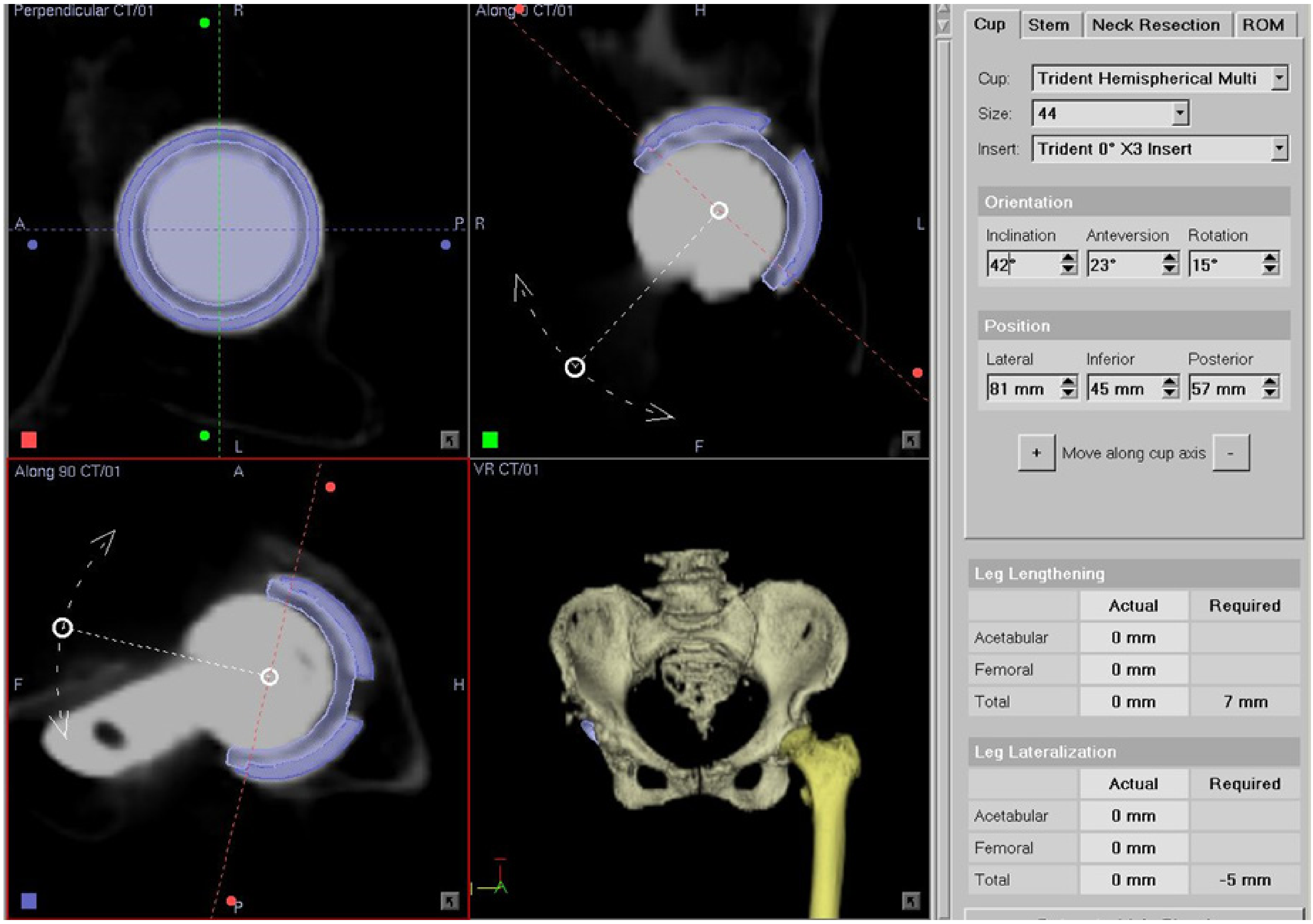

Fig. 1

Acetabular component angles were measured by OrthoMap 3D workstation, superimposing the templates of the acetabular component on the postoperative image of the acetabular component. ROM, range of motion.

Results

Clinical and radiological results. represents the pre- and postoperative JOA and UCLA activity scores in non-DDH and DDH patients. A significant difference was observed in the mean preoperative JOA scores (non-DDH vs DDH: 56.5 (SD 10.2) vs 50.5 (SD 11.2); p = 0.026, Mann-Whitney U test) between the groups. No significant difference was observed for preoperative UCLA scores (non-DDH vs DDH: 4.1 (SD 1.3) vs 4.0 (SD 1.3); p = 0.200, Mann-Whitney U test). The mean postoperative JOA and UCLA activity scores at one year were 94.7 (SD 4.6) and 7.6 (SD 1.0) in non-DDH patients, and 93.1 (SD 5.4) and 7.5 (SD 0.9) in DDH patients, respectively. There were no significant differences in these scores postoperatively between the groups.

In this case series, postoperative complications, such as infection, dislocation, and nerve paralysis, did not occur until one year after THA. There was no case of obvious changing of cup position with radiograph at one year after THA.

Preoperative plan, interoperative, and postoperative cup angles were not changed between the non-DDH and DDH patients. Table II provides the mean angles of cup inclination and anteversion in the non-DDH and DDH patients. At preoperative planning, the mean inclination angle was 40° (SD 0°) in both non-DDH and DDH patients, and the mean anteversion angles were 18.6° (SD 1.3°) and 18.8° (SD 2.7°) in non-DDH and DDH patients, respectively, with no significant difference between the groups. The mean inclination and anteversion angles of interoperative navigation records after cup screws or postoperative measurements were also not significantly different between non-DDH and DDH patients.

Robotic-arm assisted THA accurately reproduced preoperative plan for DDH patients. The mean inclination and anteversion measurement differences between postoperative CT, navigation records after cup screws, and preoperative plan are demonstrated in Table III. There were no significant changes in the mean angle differences between non-DDH and DDH patients. Moreover, we demonstrated the mean absolute differences. In non-DDH patients, the mean absolute differences (postoperative CT-preoperative plan) were 1.9° (SD 1.9°) (inclination) and 2.1° (SD 2.7°) (anteversion), and in DDH patients these were 1.7° (SD 2.0°) (inclination) and 2.5° (SD 2.1°) (anteversion). There were no significant differences in angles

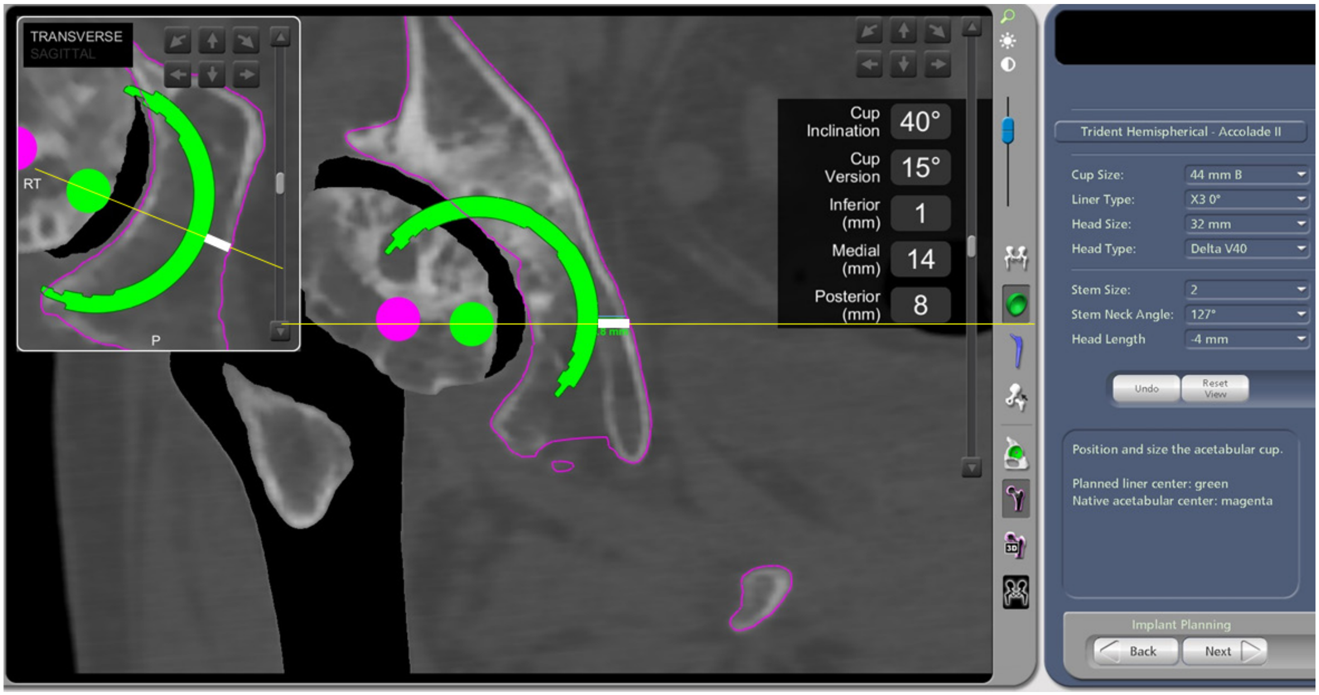

Fig. 2

Preoperative cup positions were measured on the MAKO workstation. White lines indicate the distance between the outer edge of the cup and the medial edge of the acetabulum on axial and coronal view. P, posterior; RT, right.

between non-DDH and DDH patients. Additionally, we demonstrated the accuracy of navigation record for cup inclination and anteversion angles. In non-DDH patients, the mean absolute differences (postoperative CT-navigation record after cup screws) were 2.3° (SD 2.0°) (inclination) and 2.2° (SD 2.7°) (anteversion). In DDH patients, these were 1.7° (SD 1.5°) (inclination) and 2.4° (SD 2.0°) (anteversion). No significant differences were observed in the accuracy of navigation record for cup between non-DDH and DDH patients. Scatter plots demonstrated that the absolute differences (postoperative CT-preoperative plan) for both inclination and anteversion within 5° were observed in 34 of 39 joints (87.2%) of the non-DDH patients (Figure 4a) and 27 of 30 joints (90.0%) of the DDH patients (Figure 4b). There were no significant differences in outliers between the two groups ($p = 0.328$, Fisher's exact test).

Further, we demonstrated the accuracy of the 3D cup positioning. The mean absolute differences of distance (postoperative CT-preoperative plan) were 0.8 mm (SD 0.8) (coronal plane) and 0.7 mm (SD 0.9) (axial plane) in non-DDH patients, and 1.1 mm (SD 1.0) (coronal plane) and 1.2 mm (SD 2.1) (axial plane) in DDH patients. There were no significant differences in the accuracy of 3D cup positioning between non-DDH and DDH patients (Table IV).

Next, we compared the cup placement reproducibility between patients who underwent anterolateral and posterior approaches. The p-values for mean absolute differences (postoperative CT-preoperative plan) between the two approaches were 0.708 (inclination angle), 0.610 (anteversion angle), 0.999 (coronal distance), and 0.203 (axial distance), all calculated using the Mann-Whitney U test. There were no significant differences regarding cup angles and positions between patients with anterolateral and posterior approaches.

Intraclass correlation coefficients for the intraobserver measurements regarding the mean absolute differences of the axial and coronal distances were 0.981 and 0.969 for the preoperative plan, and 0.967 and 0.912 for the postoperative measurement, respectively. Intraclass correlation coefficients for the interobserver measurements of the mean absolute differences of the axial and coronal distances were 0.941 and 0.923 for the preoperative plan and 0.879 and 0.899 for the postoperative measurement, respectively. These data confirmed the reproducibility of this method.

Reproducibility of robotic-arm assisted THA for cup angles did not change with the severity of dysplasia. The mean absolute differences (postoperative CT-preoperative plan) in Crowe I/II patients were 1.0° (SD 0.9°) (inclination) and 2.1° (SD 2.3°) (anteversion), whereas these were 3.0° (SD 2.8°) (inclination) and 3.2° (SD 1.9°) (anteversion) in Crowe III/IV cases (Table V). The significant mean absolute inclination difference was found between Crowe I/II and III/IV patients ($p = 0.037$, Mann-Whitney U test). Additionally, we demonstrated that the mean absolute differences (navigation record after cup screws-before screws) were 0.3° (SD 0.7°) (inclination) and 0.8° (SD 1.6°) (anteversion) in Crowe I/ II patients, and 2.3°

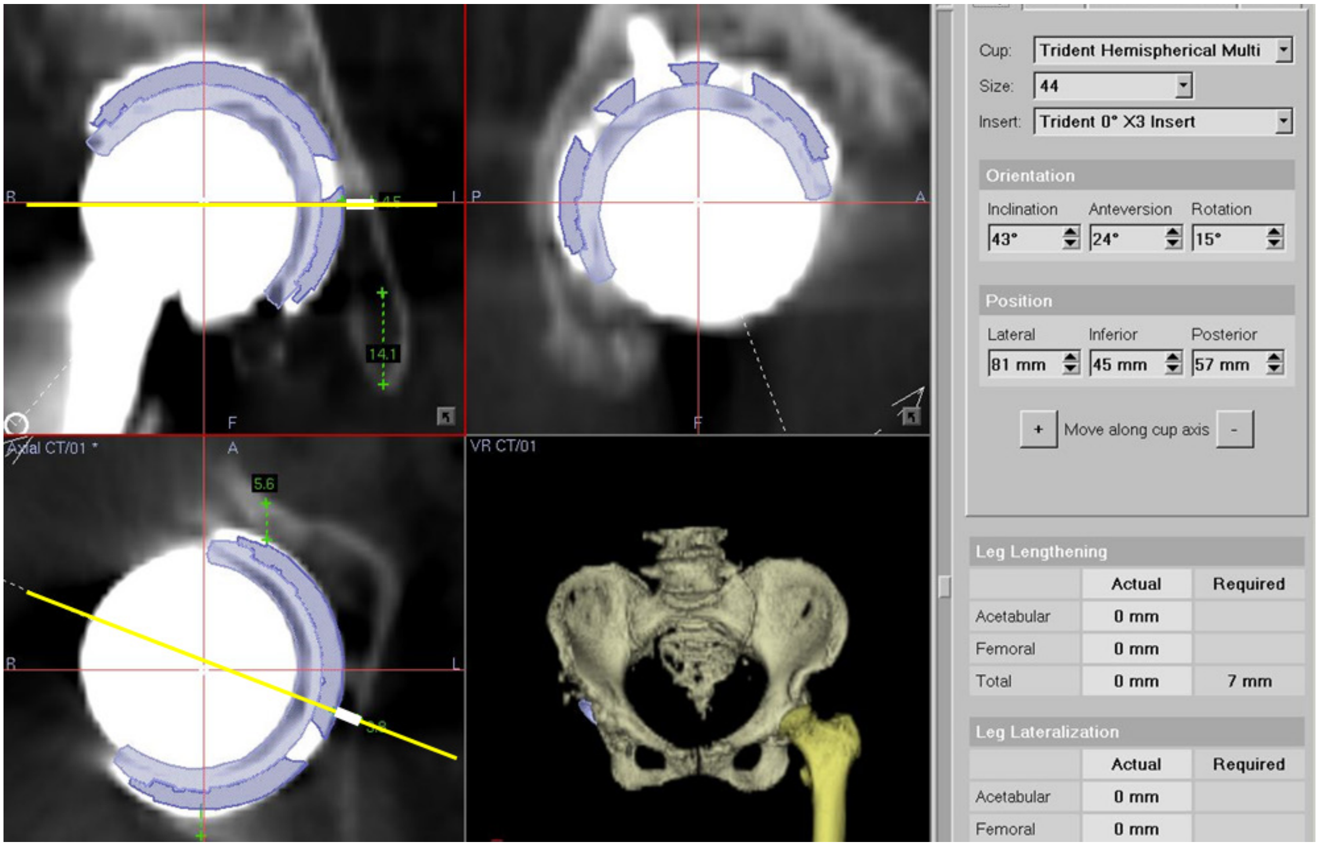

Fig. 3

Postoperative cup positions were measured on the OrthoMap 3D workstation. White lines indicate the distance between the outer edge of the cup and the medial edge of the acetabulum on axial and coronal view.

Table II. Results of mean cup angles.

Variable	Radiological inclination			Radiological anteversion		
	non-DDH	DDH	p-value*	non-DDH	DDH	p-value*
Mean preoperative plan, ° (SD)	40.0 (0.0)	40.0 (0.0)	1.0	18.6 (1.3)	18.8 (2.7)	0.745
Mean navigation record after cup screws, ° (SD)	40.1 (2.1)	40.2 (2.1)	0.549	18.7 (2.2)	18.4 (3.5)	0.831
Mean postoperative measurement, ° (SD)	39.9 (2.6)	40.0 (2.8)	0.799	18.3 (2.9)	19.4 (3.8)	0.281

*Mann-Whitney U test.
DDH, developmental dysplasia of the hip; SD, standard deviation.

Table III. Results of cup angles accuracy.

Variable	Radiological inclination			Radiological anteversion		
	non-DDH	DDH	p-value*	non-DDH	DDH	p-value*
Mean difference (postoperative-navigation records after cup screws), ° (SD)	0.1 (2.9)	0.1 (2.9)	0.890	0.1 (3.3)	-0.4 (3.1)	0.135
Mean difference (postoperative-plan), ° (SD)	0.1 (2.6)	0.0 (2.7)	0.914	-0.3 (2.1)	0.6 (3.2)	0.065
Mean absolute difference (postoperative-navigation records after cup screws), ° (SD)	2.3 (2.0)	1.7 (1.5)	0.205	2.2 (2.7)	2.4 (2.0)	0.423
Mean absolute difference (postoperative-plan), ° (SD)	1.9 (1.9)	1.7 (2.0)	0.708	2.1 (2.7)	2.5 (2.1)	0.322

*Mann-Whitney U test.
DDH, developmental dysplasia of the hip; SD, standard deviation.

(SD 2.0°) (inclination) and 1.7° (SD 2.2°) (anteversion) in Crowe III/IV patients. A significant mean absolute inclination difference was found between Crowe I/II and III/IV patients ($p < 0.001$, Mann-Whitney U test). However,

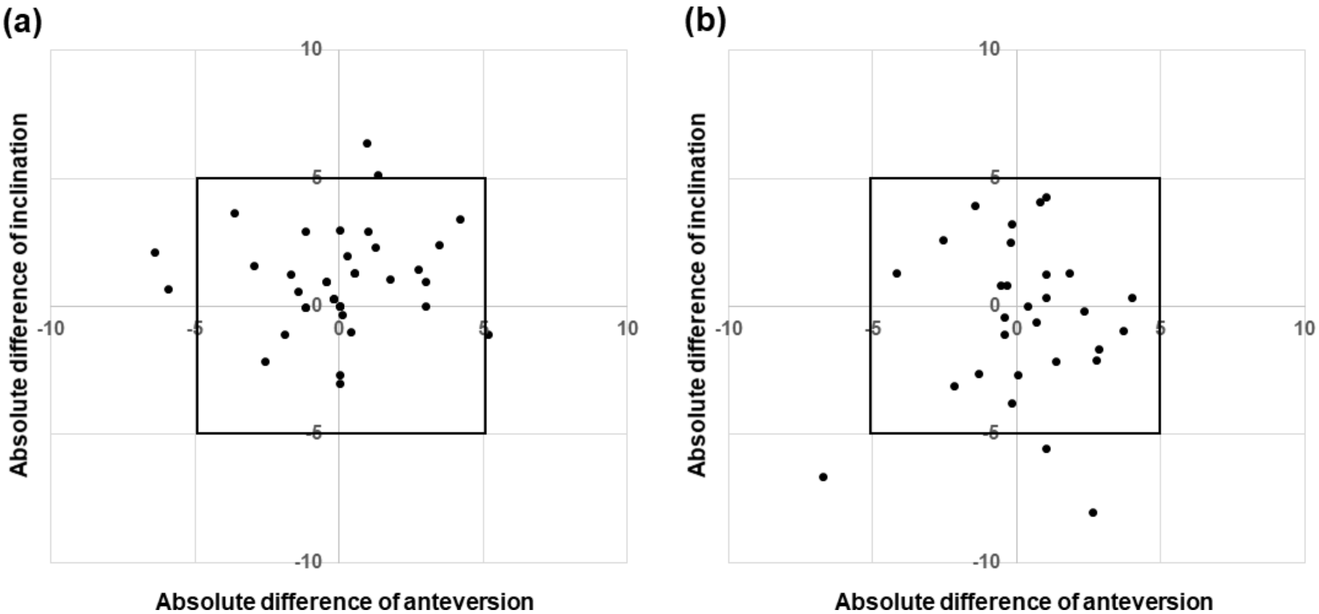

Fig. 4

Scatter plot of the absolute difference of radiological inclination and anteversion between postoperative measurement and preoperative planning. a) Non-developmental dysplasia of the hip (DDH) cases; b) DDH cases.

Table IV. Results of 3D cup position accuracy.

Mean absolute difference of distance, mm (SD)	**non-DDH**	**DDH**	**p-value***
Coronal plane (postoperative-plan)	0.8 (0.8)	1.1 (1.0)	0.464
Axial plane (postoperative-plan)	0.7 (0.9)	1.2 (2.1)	0.976
Results of 3D cup position accuracy with the severity of dysplasia	**Crowe I, II**	**Crowe III, IV**	**p-value***
Coronal plane (postoperative-plan)	0.9 (1.0)	1.3 (1.2)	0.330
Axial plane (postoperative-plan)	1.2 (2.5)	1.3 (1.2)	0.410

*Mann-Whitney U test.
DDH, developmental dysplasia of the hip; SD, standard deviation.

Table V. Results of cup angles accuracy with the severity of dysplasia.

Mean absolute difference, ° (SD)	**Radiological inclination**			**Radiological anteversion**		
	Crowe I, II	**Crowe III, IV**	**p-value***	**Crowe I, II**	**Crowe III, IV**	**p-value***
Postoperative-navigation records before cup screws	1.6 (1.1)	1.8 (2.1)	0.611	2.4 (2.0)	2.4 (2.0)	0.947
Navigation records before cup screws-plan	0.6 (1.0)	1.0 (1.2)	0.989	1.1 (0.9)	1.0 (1.5)	0.258
Navigation records after cup screws-plan	1.0 (1.1)	2.2 (1.7)	0.021	1.3 (1.2)	1.6 (2.2)	0.663
Navigation records after cup screws-before screws	0.3 (0.7)	2.3 (2.0)	< 0.001	0.8 (1.6)	1.7 (2.2)	0.153
Postoperative-plan	1.0 (0.9)	3.0 (2.8)	0.037	2.1 (2.3)	3.2 (1.9)	0.134

*Mann-Whitney U test.
SD, standard deviation.

no significant mean absolute differences were observed for navigation record before cup screws-preoperative plan and postoperative CT-navigation record after cup screws between Crowe I/II and III/IV patients.

Reproducibility of robotic-arm assisted THA for cup position did not change with the severity of dysplasia. The mean absolute differences of distance (postoperative CT-preoperative plan) were 0.9 mm (SD 1.0) (coronal plane) and 1.2 mm (SD 2.5) (axial plane) in Crowe I/II patients, and 1.3 mm (SD 1.2) (coronal plane) and 1.3 mm (SD 1.2) (axial plane) in Crowe III/IV patients. There were no significant differences regarding 3D cup position between the two groups.

Restoration of leg length and femoral/acetabular offset. We demonstrated that the absolute difference of leg length (postoperative measurement-preoperative plan) did not significantly change between non-DDH and DDH patients ($p = 0.566$, Mann-Whitney U test), although postoperative measurements of leg length discrepancy with the contralateral hip were significantly different

Table VI. Results of leg length discrepancy and combined offset.

vs contra-lateral hip	non-DDH	DDH	p-value*
Mean leg length discrepancy (plan), mm (SD)	0.5 (6.0)	-1.8 (6.8)	0.651
Mean leg length discrepancy (postoperative), mm (SD)	1.1 (5.7)	-3.6 (5.8)	0.008
Mean difference of leg length (postoperative–plan), mm (SD)	0.6 (4.8)	-1.7 (5.7)	0.089
Mean absolute difference of leg length (postoperative–plan), mm (SD)	4.2 (2.3)	4.6 (3.7)	0.566
Mean discrepancy of combined offset (plan), mm (SD)	-3.1 (5.9)	-1.3 (5.8)	0.432
Mean discrepancy of combined offset (postoperative), mm (SD)	-2.7 (7.1)	0.2 (6.0)	0.129
Mean difference of combined offset (postoperative–plan), mm (SD)	0.3 (5.9)	1.5 (5.7)	0.570
Mean absolute difference of combined offset (postoperative–plan), mm (SD)	4.4 (4.4)	4.1 (5.9)	0.801

*Mann-Whitney U test.
DDH, developmental dysplasia of the hip; SD, standard deviation.

between the groups (p = 0.008, Mann-Whitney U test) (Table VI). The absolute difference of the femoral and acetabular combined offset (postoperative measurement-preoperative plan) also did not significantly change between non-DDH and DDH patients (p = 0.801, Mann-Whitney U test) (Table VI).

Discussion

We demonstrated the accurate reproducibility of cup placement in both non-DDH and DDH patients, and the high accuracy of the navigation even in those with severe DDH.

Several studies in Caucasians have shown the higher prevalence of hip osteoarthritis (OA) in men than in women.[29,30] However, a previous study on the Japanese population demonstrated that hip OA was more prevalent in women than in men,[31] and more than 70% of hip OA was caused by DDH in Japan.[32] Further, several reports showed that the average age at the THA was similar between DDH and non-DDH patients in the Japanese population.[33–35] In the present study, 30 of 69 patients (43.5%) had DDH; however, most of the patients in the non-DDH group revealed borderline hip dysplasia (centre edge angle, 20° to 25°). Therefore, the patient characteristics of this study cohort, including those of consecutive hip arthroplasties, were similar between DDH and non-DDH patients.

A previous report demonstrated no significant changes in the postoperative clinical outcomes between non-DDH and DDH patients.[36] In line with these results, we also demonstrated that postoperative JOA and UCLA activity scores were not changed between non-DDH and DDH patients, although the preoperative JOA score was different between the two groups.

Several reports have demonstrated the higher complication rates caused by acetabular component malposition and poor stability of the cup in DDH patients.[5-7] However, recent reports showed that complication rates were similar between non-DDH and DDH patients.[37,38] Siddiqi et al[38] demonstrated that no statistically significant differences were found in readmission or reoperation rates between non-DDH and DDH patients. In this study, postoperative complications, such as infection, dislocation, and nerve paralysis, did not occur until one year of follow-up.

An anterior pelvic plane (APP) is defined by both the bilateral anterior superior iliac spine and pubic tubercle.[26] However, the APP is tilted in the sagittal plane due to spinal and pelvic deformities. A plane parallel to the CT table in the supine position with adjustment of the rotation until the bilateral anterior iliac spines touch the same horizontal plane, namely the functional pelvic plane, was not affected by changing of sagittal plane tilt.[26] Many DDH patients represent more femoral anteversion, and the changing of cup anteversion is needed in these patients to avoid cup-stem impingement. Therefore, we preferred to determine cup alignment with Widmer's CA theory[25] with respect to the functional pelvic plane. DDH patients represent insufficient acetabular coverage of the femoral head, shallow acetabular concavity, and decreasing pelvic bone stock.[39] Therefore, it is difficult to place the acetabular component at the anatomical centre in DDH patients. Therefore, a high hip centre of a cementless acetabular component is often required.[40] Several biomechanical studies demonstrated that a cup CE angle of greater than 0° is required for bone coverage. Therefore, we fixed the cup alignment first with CA theory, and the 3D cup position was then arranged to a higher hip centre to have a cup CE angle over 0°.

Several reports have shown the accuracy of cup placement with CT-based navigation in DDH patients.[12,41,42] Yamada et al[12] demonstrated that the mean accuracy of cup inclination was 2.5° (SD 2.2°) and that of anteversion was 2.3° (SD 1.7°) with CT-based navigation in DDH patients. Tsutsui et al[41] reported that the absolute mean differences were 1.5° (SD 1.3°) (inclination) and 2.1° (SD 1.8°) (anteversion) in DDH cases. Our study demonstrated that the absolute mean differences were 1.7° (SD 1.5°) (inclination) and 2.4° (SD 2.0°) (anteversion). These results indicate that robotic-assisted THA may achieve high reproducibility of the preoperative plan as CT-based navigation in DDH patients.

Although several previous studies demonstrated the accuracy of cup alignment after THA, few studies used 3D parameters to analyze the acetabular component position in patients with DDH.[9,41] The reproducibility of the positioning of the acetabular component is crucial for adjusting leg length and offset, especially in patients with DDH with leg length discrepancy and subluxation. Further, accurate cup position can preserve both the anterior and posterior walls of the acetabulum, which is critical for stable cup fixation and outcomes of acetabular reconstruction in revision surgery.[43] Our study demonstrated that robotic-arm assisted THA could achieve accuracy for positioning of cup placement, with < 1.5 mm absolute difference of distance, in comparison with the preoperative plan, even in severe DDH cases. Previous studies on robotic-arm assisted THA demonstrated the acceptable leg length and femoral/acetabular offset restoration.[19,44] We also demonstrated that it could achieve good restoration of leg length and combined offset in both non-DDH and DDH cases. Preoperative leg length discrepancy with contralateral hip was larger in DDH patients, which may cause postoperative shorter leg length due to tightness of the soft-tissue tension. Therefore, postoperative leg length with contralateral hip was significantly shorter in DDH patients compared to that in non-DDH patients.

Several reports compared the accuracy of cup placement with the severity of DDH after CT-based navigation-assisted THA.[9,13] The studies demonstrated that the cup alignment and 3D position did not differ significantly with the severity of DDH in THA with navigation system. Our study demonstrated a significant difference in cup inclination between preoperative plan and postoperative measurement in severe DDH cases, but no significant differences were found in cup inclination between navigation records after cup screws and postoperative measurement or navigation records before cup screws and preoperative plan. Further, we revealed the significant difference in cup inclination between navigation record before cup screws and post-cup screws in severe DDH cases. These results indicate that robotic-arm assisted THA may achieve accurate cup placement, even in severe dysplasia, and that cup screws may affect the accuracy of cup alignment due to cup stability in severe DDH cases. The acetabular wall in severe DDH patients presents inadequate acetabular roof and poor bone quality.[7] We previously reported that the insertion of cup screws induced cup alignment change during surgery.[45] This suggests that the cup alignment was changed by screw insertion after robotic-arm assisted cup placement in severe DDH cases.

Our study had some limitations. First, the number of patients included in the study was too small to analyze full considerations because patients with severe pelvic deformities, such as Crowe III and IV, were rare. Second, this was not a randomized but a retrospective cohort study. Third, we used anterolateral and posterior approaches; however, we could show the differences between the approaches because of the small number of anterolateral approaches in non-DDH cases.

In conclusion, we demonstrated that robotic-arm assisted THA may reproduce precise cup alignment and 3D positions as determined by the preoperative planning, even in DDH patients, and might be useful for severe DDH patients. However, robotic-arm assisted THA relies heavily on preoperative planning and the ability to adjust intraoperatively is lacking. Therefore, we must pay attention to cup positioning during surgery for further improvements.

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