Randomised controlled trial

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A new designed full process coverage robot-assisted total hip arthroplasty: a multicentre randomized clinical trial

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Objective: To compare the effect of a new complete robot-assisted total hip arthroplasty (RA-THA) with that of the manual total hip arthroplasty (MTHA) and to verify the accuracy and safety of the former.

Methods: Overall, 148 patients were enroled from 3 March 2021 to 28 December 2021 in this study and classified into RA-THA ($n = 74$ patients) and MTHA ($n = 74$ patients) groups. The sex, age, operative side, BMI, diagnosis, other basic information, operative time, acetabular prosthesis anteversion and inclination, femoral prosthesis anteversion and angulation, femoral prosthesis filling rate, leg length discrepancy (LLD), Harris hip score, and visual analogue scale (VAS) score of the two groups were compared.

Results: No significant differences were observed in the two groups regarding sex, age, operative side, BMI, diagnosis, Harris hip score, VAS score, acetabular inclination, acetabular prosthesis anteversion, femoral prosthesis anteversion, combined anteversion, and femoral prosthesis filling rate ($P > 0.05$). The operative time was significantly longer in the RA-THA group than in the MTHA group (106.71 ± 25.22 min vs. 79.42 ± 16.16 min; $t = 7.30$, $P < 0.05$). The femoral angulation (1.78° ± 0.64°) and LLD (2.87 ± 1.55 mm) in the RA-THA group were significantly lesser than those in the MTHA group (2.22° ± 1.11° and 5.81 ± 6.27 mm, respectively; $t = -2.95$ and $t = -3.88$, $P < 0.05$).

Conclusion: The complete RA-THA has some advantages over the traditional procedure in restoring the lower limb length and controlling the femoral prosthesis angulation. Thus, this study verifies the accuracy and safety of the robot-assisted system.

Key words: Multicenter clinical study, randomized controlled trial, robot-assisted total hip arthroplasty

Introduction

Total hip arthroplasty (THA) has been one of the most successful orthopaedic procedures for treating end-stage hip diseases such like avascular necrosis (AVN) and developmental dysplasia of the hip (DDH) in the past decades, with up to 80% patients experiencing pain relief and being able to rebuild function[1–3]. Despite the high patient satisfaction and long-term component durability of THA, complications such as dislocation and leg length discrepancy (LLD) persist as challenges, affecting the clinical satisfaction of patients and sometimes leading to devastating outcomes[4]. Several factors have been associated with THA failure, with implant orientation being the most crucial[5]. Lewinnek proposed a cup orientation of 40° ± 10° of inclination and 15° ± 10° of anteversion as a "safe zone," which has been used as a practical reference to date[6]. Nevertheless, with increasing research regarding functional anatomy and imaging technology development, several studies have determined that the Lewinnek safe zone is inefficient in predicting hip stability[7,8].

HIGHLIGHTS

- The new robot can assist total hip arthroplasty of both acetabular and femoral stem.
- The robot-assisted total hip arthroplasty has less femoral angulation and leg length discrepancy.
- All imaging data confirm that the robot is accurate.

Owing to our improved understanding regarding the effect of proximal femoral morphology and neck orientation on hip stability over the years, component positioning is now being re-evaluated. For example, excessive femoral stem version has been reportedly associated with a higher risk of dislocation[9]. Stem version is crucial in determining combined anteversion[10]; however, methods for accurate stem placement remain unclear. Reportedly, more accurate cup positioning and equal leg length can be achieved via RA-THA than manual THA (MTHA)[11–13].

Dorr *et al.*[14] suggested that the ideal stem version is 15° ± 5° to reduce the risk of dislocation. Former methods to achieve proper stem version have been based on anatomical landmarks, patient-specific instrumentation, or navigation. Appropriate stem placement may not be achievable as it is prone to judgment bias and affected by arthritic and dysplastic knee conditions[15]. Although

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navigation allows intraoperative assessment and correction during stem placement, but the placement of the femoral prosthesis still depends on the experience of the surgeon.

Herein, we designed a new type of haptic robotic-assisted system (TRex-RS, Longwell corp.) based on computed tomography (CT) to implant femoral prosthesis (Fig. 1). This system requires the preoperative CT data of the lower extremity of patients for preoperative planning, sizing, determining component orientation, acetabular reaming, cup implantation, and stem broaching and implantation. We performed a randomized multicenter single-blind parallel group controlled trial compared with the manual method to verify the accuracy and safety of the new system for placement of prosthesis.

Methods and materials

Study design

This study was a randomized multicenter clinical single-blind parallel group controlled trial involving three medical centres in China. This work has been reported in line with Consolidated Standards of Reporting Trials (CONSORT) Guidelines[16]. The study was registered at ClinicalTrial.gov and was approved by the ethics committee of three class A tertiary hospital. Informed consent was obtained from all the study participants.

Patient recruitment

The sample size is calculated according to the non-inferiority sample size formula $n_T = n_C = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2[P_C(1-P_C) + P_T(1-P_T)]}{(|D| - \Delta)^2}$. According to the research of Domb[17] and clinical experience, the accuracy of robot placement of prosthesis (P_T) is about 96%, and the accuracy of manual group (P_C) is about 96.1%, $|D| = | P_C - P_T |$, when α (unilateral) = 0.025, $Z_{1-\alpha} = 1.960$, when $\beta = 0.20$, $Z_{1-\beta} = 0.842$, the non-inferiority margin(Δ) is 10%, and the $n_T \approx 59$. Consider the drop rate of 20%, and finally $n_T \approx 74$. The number of MTHA group is the same as that of RA-THA group, so the $n_C = 74$.

Figure 1. The new designed robot-assisted system.

In total, 148 patients were recruited from 3 March 2021 to 28 December 2021 and randomly divided into two groups: RA-THA ($n = 74$) and MTHA ($n = 74$). Patients with end-stage hip diseases who underwent primary THA via the cementless stem Accolade II system (Stryker) were included. The inclusion criteria were patients aged 18–75 years who required primary and unilateral THA. The exclusion criteria were as follows: patients with an active infection or severe systematic diseases (diabetes or heart or liver or renal failure) so that surgery cannot be performed, those with a neuromuscular dysfunction of the lower extremities, and those who had participated in other clinical trials. All the surgeries were performed by experienced surgical teams in the three medical centres. Additionally, all the patients underwent radiological and clinical assessments.

Surgical procedures

A preoperative bilateral hip and knee CT scan was obtained for all the patients and the CT data were imported into the robotic preoperative planning system (Longwell corp.). The initial cup orientation was 40° inclination and 15° anteversion and the femoral stem version was 15°.

For patients in the RA-THA group, a pelvic marker was fixed and assembled near the anterior superior iliac spine before operation. After exposure and hip dislocation, a screw was inserted into the proximal femur. Thereafter, a femoral marker was fixed near the great trochanter, and three landmarks of the greater trochanter were captured: the anterior, inferior, and lateral aspects. To finish the femoral registration, 20 randomly distributed points were registered. The femoral head was cut using a saw attached to the robotic arm at the preoperatively planned level. Subsequently, three landmarks were identified in the acetabulum: the posterior, anterior, and superior rim, and 20 randomly distributed registration points were selected around the rim and inside the socket in a disperse pattern. The reamer connected to the haptic robotic arm was used to remove the preplanned bone volume. The cup was implanted with the assist of robot arm. Every step of the procedure was accompanied by visual real-time feedback from the system. After reducing the hip, the final implant position and leg length were displayed on the screen (Fig. 2). The MTHA and RA-THA both choose the way of direct anterior approach as the mode of operation[18]. The procedures in the RA-THA and MTHA group were performed by the same surgical team in the three medical centres.

Clinical outcome evaluation

The demographic data and patient-reported outcomes were prospectively collected by two independent and well-trained surgeons. The collected baseline data included age at the time of surgery (years), sex (men/women), BMI (kg/m^2), side of intervention (left/right), diagnosis (DDH/AVN), and operation time (min). The primary evaluation index was the postoperative cup inclination and anteversion, stem version, femoral prosthesis filling rate, and LLD. The safety objective of this study included intraoperative and postoperative complications. The operative time was recorded and the Harris hip score was calculated

Figure 2. Dealing with acetabulum with the assistance of robot (A); System interface of robot assisted with osteotomy (B); Dealing with femur with the assistance of robot (C); Close-up for dealing with femur with the assistance of robot (D).

preoperatively and at 3 and 6 months postoperatively. All preoperative and postoperative clinical data were collected by an independent investigator.

Radiographic measurement and evaluation

A standard postoperative CT scan (1 mm layer thickness) was performed to scan the area from L4 to 18 mm below the tip of the lesser trochanter and the distal femur in all the patients. To assess the intraobserver and interobserver variations, the measurements were performed randomly and independently by two investigators who were blinded to the group assignments and the measurements were averaged for all the patients.

Inclination and anteversion of the acetabular

Acetabular inclination was defined as the angle between the projection of the long axis of the cup and a horizontal line drawn through the distal edge of both the ischial tuberosities in the coronal plane (Fig. 3A). Anteversion was calculated with respect to the line connecting the lateral, anterior, and posterior margins of the cup and a perpendicular line connecting two identical points on either side of the pelvis[19] (Fig. 3B).

Femoral stem anteversion

Femoral stem anteversion was calculated as the angle between a line connecting the tip of the posterior surface of the medial and lateral condyles and a line from the centre of the head to the centre of the femoral neck component[20] (Fig. 3C).

Combined anteversion

Combined anteversion was used as a reference to predict dislocation risk and was defined as the sum of the anteversion of the cup and femoral stem[21].

Leg length discrepancy

LLD was defined as the difference in the distance between a line connecting the two anterior superior iliac spines and a line connecting the tips of the lesser trochanters (Fig. 3D)[22]. LLD within 10 mm was considered acceptable[23].

Statistical analysis

Statistical analyses were performed using SPSS (version 26; SPSS Inc). A *P* value of less than 0.05 was considered statistically

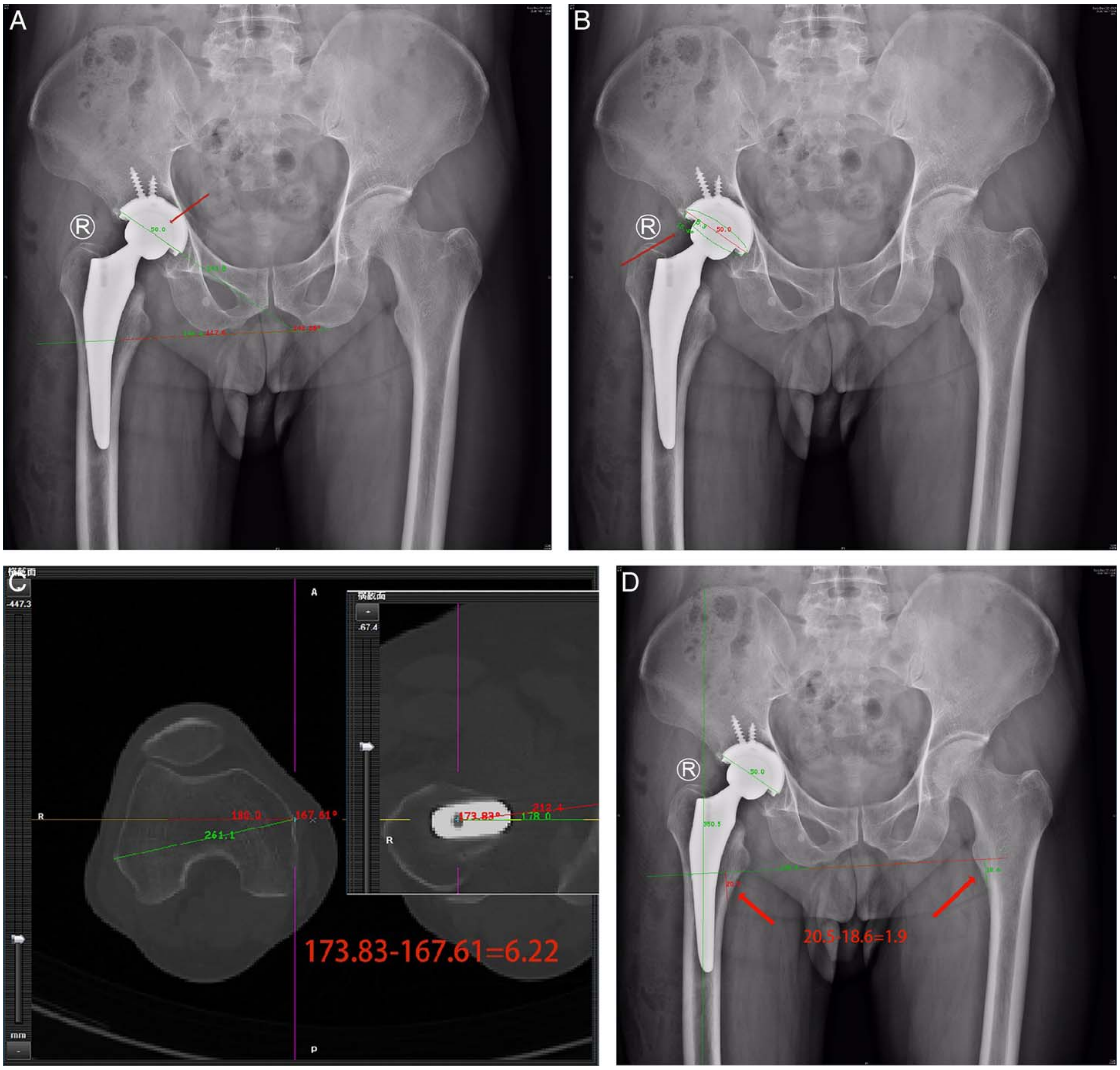

Figure 3. Acetabular inclination was defined as the angle between the projection of the long axis of the cup and a horizontal line drawn through the distal edge of both the ischial tuberosities in the coronal plane (A). Acetabular anteversion was calculated with respect to the line connecting the lateral, anterior, and posterior margins of the cup and a perpendicular line connecting two identical points on either side of the pelvis (B). Femoral stem anteversion was calculated as the angle between a line connecting the tip of the posterior surface of the medial and lateral condyles and a line from the centre of the head to the centre of the femoral neck component (C) and leg length discrepancy was defined as the difference in the distance between a line connecting the two anterior superior iliac spines and a line connecting the tips of the lesser trochanters (D).

significant with a 95% CI. Independent *t*-test is used for continuous variables in accordance with normal distribution, such as age, BMI, operation time, Harris score, VAS score, acetabular inclination, acetabular anteversion, femoral anteversion, femoral angulation, combine anteversion, leg length discrepancy and filling rate of femoral prosthesis. The measurements were expressed as Mean ± SD. χ^2 test is used for classification variables such as sex, operative side and diagnosis.

Randomized method

The method of hierarchical block randomization is used for randomization, and the random seeds are first established. Determine the length of the block, stratify according to the centre, and use statistical analysis software to generate a random grouping table of 148 patients who received treatment (RA-THA group or MTHA group).

Results

In RA-THA group, two cases lost contact after operation, so the finally $n = 72$; in MTHA group, there was one case of femoral fracture during operation, so the finally $n = 73$.

No statistical differences were observed in the baseline characteristics of the two groups ($P > 0.05$; Table 1). Furthermore, no statistically significant differences were observed in the Harris and VAS scores between the two groups ($P > 0.05$; Table 2).

Table 1

Basic information (Mean ± SD).

	Sex		Age (year)	Side		BMI (kg/m²)	Diagnosis		Operation time (min)
	Male	Female		Right	Left		DDH	AVN	
RA-THA group	35	37	58.14 ± 9.04	39	33	25.18 ± 3.57	20	52	106.71 ± 25.22
MTHA group	44	29	55.26 ± 10.69	29	44	25.28 ± 3.42	11	62	79.42 ± 16.16
Statistical value	1.99[a]		1.75[b]	3.04[a]		– 1.70[b]	3.483[a]		7.30[b]
P value	0.159		0.082	0.081		0.865	0.062		< 0.001

AVN, avascular necrosis; DDH, developmental dysplasia of hip; MTHA, manual total hip arthroplasty; RA-THA, robot-assisted total hip arthroplasty.
[a]χ2 value.
[b]t value.

Inclination and anteversion of the acetabular cup

The acetabular inclination in the RA-THA and MTHA groups was 41.62° ± 5.80° and 40.3° ± 7.39° after operation respectively (Fig. 4A). The acetabular anteversion in the RA-THA and MTHA groups was 18.43° ± 3.37° and 19.57° ± 3.78° after operation respectively (Fig. 4B). No significant differences were observed in the acetabular inclination and anteversion between the two groups ($P > 0.05$; Table 3).

Femoral stem anteversion

The femoral anteversion in the RA-THA and MTHA groups was 14.71° ± 8.87° and 12.89° ± 8.36° after operation respectively (Fig. 4C), and the difference was not significant ($P > 0.05$, Table 4). The femoral angulation of the RA-THA group was significantly lesser than that of the MTHA group both after operation (Fig. 4D) and 3month after operation ($t = -2.95$, $P < 0.05$; $t = -3.16$, $P < 0.05$, Table 4).

Combined anteversion

The combined anteversion of the RA-THA and MTHA groups was 33.12° ± 9.65° and 32.39° ± 9.08° after operation respectively (Fig. 4E); and the difference was not statistically significant ($P > 0.05$; Table 5).

Leg length discrepancy and femoral prosthesis filling

The LLD in the RA-THA group was significantly lesser than that in the MTHA group after operation (Fig. 4F) ($t = -3.88$, $P < 0.001$; Table 5), but there were no statistically significant in 3month and 6month after operation ($P > 0.05$; Table 5). No patient in the RA-THA group had an LLD of greater than 10 mm; however, 11 patients (15.07%) in the MTHA group had an LLD of greater than 10 mm. There was no significant difference in the femoral prosthesis filling rate between the two groups ($P > 0.05$; Table 6).

Complications

No complications, such as postoperative dislocation, wound infection, or deep venous thrombosis, occurred in either group. In the MTHA group, intraoperative iatrogenic proximal femoral fracture occurred in one patient while broaching, which was fixed using a cable.

Discussion

Instability, wear and tear due to postoperative component impingement, and subsequent component loosening can lead to early THA failure[24]. Studies have shown that many dislocations after THA are related to the location of acetabular[25]. In a CT-based study, Nodzo *et al.*[26] reported that values obtained via RA-THA can accurately determine component positioning. There was no statistical difference ($P > 0.05$) in acetabular inclination and acetabular anteversion between RA-THA group and MTHA group in this study, which indicates that this RA-THA system is reliable for acetabular prosthesis placement.

Most studies have focused on acetabular orientation, which has led to the underestimation of the importance of femoral inclination in ensuring postoperative hip stability. Dorr *et al.*[14] reported that the combined anteversion should be 25°–50° and that the target stem version should be 15° ± 5°. The femoral inclination of femur in RA-THA group was 14.71° ± 8.87°, which was closer to the recommended range of Dorr than that in MTHA group (12.89° ± 8.36°), although there was no statistical difference between the two groups($P > 0.05$).

Although there is no consensus regarding the ideal combined anteversion, several studies have used combined anteversion to predict hip stability and obtained good clinical results[27,28]. There was no statistical difference in combined anteversion between RA-THA group and MTHA group, and there is no significant difference between them in the range of 25°–50°.

Table 2

Harris score and VAS score (Mean ± SD).

	Harris score (0–100)			VAS score (0–10)	
	Pre-operation	3 mnthso	6 months	Pre-operation	Post-operation
RA-THA group	48.08 ± 15.92	85.18 ± 10.61	92.52 ± 8.82	8.13 ± 1.13	5.18 ± 1.12
MTHA group	49.24 ± 13.97	85.37 ± 10.60	93.29 ± 6.78	8.33 ± 1.17	5.41 ± 0.96
t value	– 0.46	– 0.10	– 0.54	– 1.07	– 1.34
P value	0.645	0.922	0.591	0.286	0.184

MTHA, manual total hip arthroplasty; RA-THA, robot-assisted total hip arthroplasty; VAS, visual analogue scale.

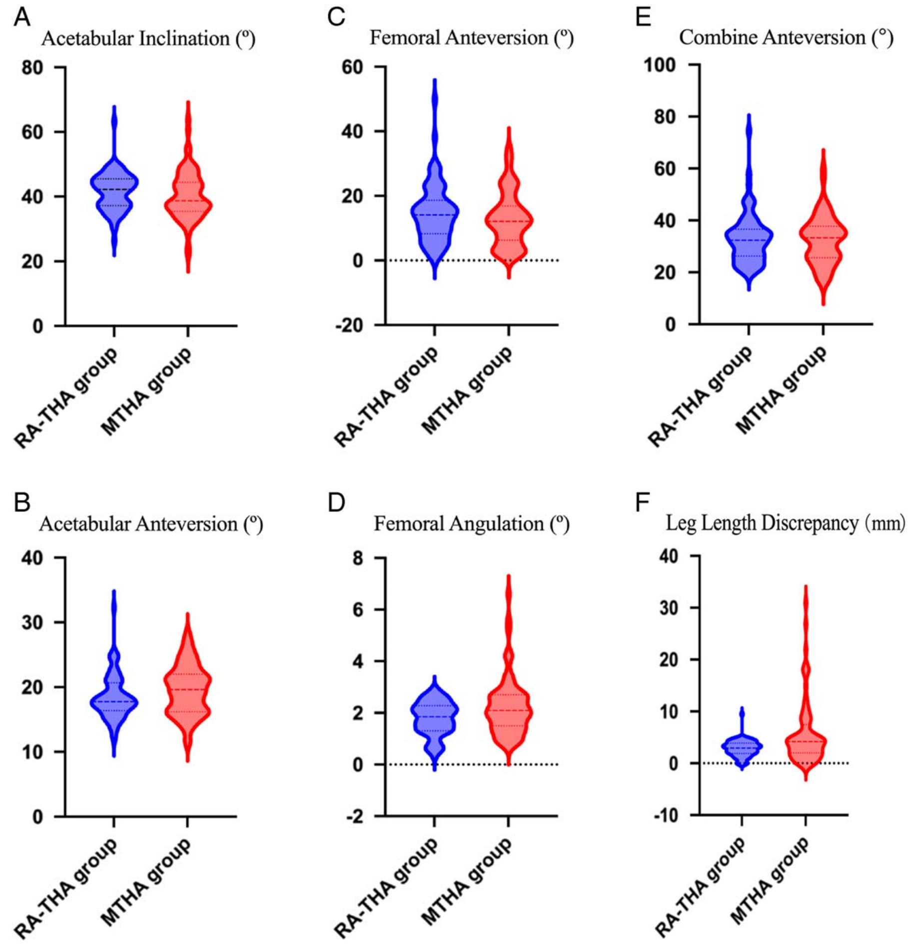

Figure 4. Comparison of acetabular inclination between robot-assisted total hip arthroplasty RA-THA group and manual total hip arthroplasty (MTHA) group after operation (A); Comparison of acetabular anteversion between RA-THA group and MTHA group after operation (B); Comparison of femoral anteversion between RA-THA group and MTHA group after operation (C); Comparison of femoral angulation between RA-THA group and MTHA group after operation (D); Comparison of combined anteversion between RA-THA group and MTHA group after operation (E); Comparison of leg length discrepancy between RA-THA group and MTHA group after operation (F).

The study of Leiss have shown that if the angulation of the femoral prosthesis is more than 3°, the risk of prosthesis sinking increases[29]. The angulation of femur in RA-THA group was significantly smaller than that in MTHA group, and there was statistical significance ($t = -2.95$, $P < 0.05$). It can be proved that the RA-THA system is more helpful to ensure the neutral position of the femoral prosthesis.

Shi *et al.* found that LLD has great influence to DDH patients[30]. Several studies have shown that RA-THA has an obvious effect on reducing LLD[31,32]. In this study, the LLD of RA-THA group (2.87 ± 1.55 mm) was significantly lower than that of MTHA group (5.81 ± 6.27 mm), and the difference was statistically significant ($t = -3.88$, $P < 0.001$). Besides, 11 patients in the MTHA group had a LLD more than 10 mm while no patient in the RA-THA group had a LLD more than 10 mm.

Poor filling of the femoral prosthesis is one of the important causes of loosening of the femoral stem and may lead to thigh pain[33]. And there was no significant difference in the femoral prosthesis filling rate between the two groups ($P > 0.05$). It can be considered that RA-THA is not inferior to MTHA in the filling rate of femoral prosthesis.

Stem implantation is technically challenging, and intraoperative fractures, undersizing or oversizing the stem, and unexpected anteversion or higher vertically seated cup can occur early in the postoperative period. Fukunishi *et al.*[34] evaluated 79 THA cases and reported a greater variability in stem version compared with cup version. Because femoral prosthesis required manual manipulation, which can potentially lead to a discrepancy in the surgical results. In patients with a narrow canal and small femoral size, correcting the version becomes difficult if the canal is misbroached. Our study results reveal that the robotic system employed herein can determine the position of the initial canal entry, thus enabling broaching to be performed by the robotic arm with stability and reproducibility.

Other studies have reported favourable short-term clinical outcomes using RA-THA, with lower complication rates and good scores than MTHA[35]. Bargar *et al.*[36] found no significant difference in the clinical scores between RA-THA and MTHA. Meanwhile, the Harris and VAS scores were not significantly different between the two groups in this study.

Table 3

Acetabular data (Mean ± SD).

	Acetabular inclination after operation (°)	Acetabular inclination 3 months after operation (°)	Acetabular inclination 6 months after operation (°)	Acetabular anteversion after operation (°)	Acetabular anteversion 3 months after operation (°)	Acetabular anteversion 6 months after operation (°)
RA-THA group	41.62 ± 5.80	42.14 ± 6.16	41.98 ± 6.69	18.43 ± 3.37	19.12 ± 4.73	20.21 ± 3.96
MTHA group	40.34 ± 7.39	40.29 ± 7.27	39.73 ± 3.96	19.57 ± 3.78	20.84 ± 4.78	21.68 ± 3.92
t value	1.16	1.50	1.87	− 1.92	− 1.32	− 2.00
P value	0.250	0.136	0.065	0.057	0.189	0.047

MTHA, manual total hip arthroplasty; RA-THA, robot-assisted total hip arthroplasty.

Table 4

Femoral data (Mean ± SD)

	Femoral anteversion after operation (°)	Femoral anteversion 3 months after operation (°)	Femoral anteversion 6 months after operation (°)	Femoral angulation after operation (°)	Femoral angulation 3 months after operation (°)	Femoral angulation 6 months after operation (°)
RA-THA group	14.71 ± 8.87	13.71 ± 9.81	13.89 ± 11.01	1.78 ± 0.64	1.81 ± 0.76	2.08 ± 1.13
MTHA group	12.89 ± 8.36	12.95 ± 8.76	12.21 ± 8.32	2.22 ± 1.11	2.48 ± 1.44	2.40 ± 1.51
t value	1.27	0.44	0.88	− 2.95	− 3.16	− 1.28
P value	0.208	0.661	0.380	0.004	0.002	0.202

MTHA, manual total hip arthroplasty; RA-THA, robot-assisted total hip arthroplasty.

Table 5

Combine anteversion and LLD (Mean ± SD).

	Combine anteversion after operation (°)	Combine anteversion 3 months after operation (°)	Combine anteversion 6 months after operation (°)	LLD after operation (mm)	LLD 3 months after operation(mm)	LLD 6 months after operation(mm)
RA-THA group	33.12 ± 9.65	33.54 ± 10.65	34.35 ± 11.33	2.87 ± 1.55	4.80 ± 4.13	5.28 ± 4.33
MTHA group	32.39 ± 9.08	33.86 ± 10.13	34.26 ± 9.18	5.81 ± 6.27	6.29 ± 5.20	5.65 ± 5.41
t value	0.46	– 0.16	0.05	– 3.88	– 1.72	– 0.406
P value	0.644	0.874	0.963	< 0.001	0.087	0.686

LLD, leg length discrepancy; MTHA, manual total hip arthroplasty; RA-THA, robot-assisted total hip arthroplasty.

Table 6

Filling rate of femoral prosthesis (Mean ± SD, %).

	Osteotomy line		2.5 cm of osteotomy line		7.5 cm of osteotomy line		Isthmus of femur	
Position	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal
RA-THA group	61.59 ± 8.31	94.77 ± 3.53	78.50 ± 9.20	94.42 ± 3.72	80.10 ± 7.32	58.79 ± 12.59	75.30 ± 8.72	54.64 ± 11.85
MTHA group	62.82 ± 8.49	95.31 ± 3.76	78.21 ± 8.99	94.26 ± 3.95	78.68 ± 7.83	59.38 ± 10.06	73.87 ± 8.78	54.43 ± 10.75
t value	– 0.62	– 0.89	0.20	0.25	1.10	– 0.30	0.94	0.10
P value	0.534	0.377	0.845	0.805	0.273	0.764	0.348	0.917

MTHA, manual total hip arthroplasty; RA-THA, robot-assisted total hip arthroplasty.

To the best of our knowledge, the robotic system used in our study is the first system to prepare the femoral stem and implant it using a robotic arm.

Limitations

This study mainly considered the accuracy of the placement of the prosthesis, not the survival time, so the design follow-up time is 6 months. But all patients were kept in touch, and the survival time of the prosthesis will be further studied in the future.

Conclusion

Our study assessed the accuracy of component implantation in THA using a novel robotic-assisted system via a prospective multicenter randomized clinical trial. Furthermore, the early clinical outcomes of patients who underwent RA-THA were compared with those of patients who underwent MTHA, serving as the control group. The values of the acetabular cup and femoral stem version obtained via the robotic system were similar to those of postoperative CT scans. Additionally, the limb length achieved was reasonable. Our study results indicate that accurate implantation can be achieved using the novel robotic system. Furthermore, femoral stem preparation and insertion can be accomplished with the assistance of the seven-axes robotic arm.

Ethical approval

The Affiliated Hospital of Qingdao University (QYFYEC 2020-017-01), Weifang People's Hospital (2020-061-10), and First Affiliated Hospital of Institute Science and Technology (2021 Ethics No. 87).

Consent

Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

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Author contribution

X.L., Z.Z.: writing—original draft, data curation. H.X.: project administration, validation. W.W.: formal analysis. H.Z.: writing—review and editing, supervision.

Conflicts of interest disclosure

None.

Research registration unique identifying number (UIN)

The study was registered at ClinicalTrial.gov (ref. no. ChiCTR 2100044124).

Guarantor

Haining Zhang.

Data availability statement

All datasets generated during and/or analyzed during the current study are not applicable sharing in this article.

Provenance and peer review

Not commissioned, externally peer-reviewed.

References

[1] Caton J, Prudhon JL. Over 25 years survival after Charnley's total hip arthroplasty. Int Orthop 2011;35:185–8.
[2] Lavernia CJ, Alcerro JC. Quality of life and cost-effectiveness 1 year after total hip arthroplasty. J Arthroplasty 2011;26:705–9.
[3] Callaghan JJ, Templeton JE, Liu SS, *et al*. Results of Charnley total hip arthroplasty at a minimum of thirty years. A concise follow-up of a previous report. J Bone Joint Surg Am Vol 2004;86:690–5.
[4] Ryan JA, Jamali AA, Bargar WL. Accuracy of computer navigation for acetabular component placement in THA. Clin Orthop Relat Res 2010;468:169–77.
[5] Perets I, Walsh JP, Close MR, *et al*. Robot-assisted total hip arthroplasty: clinical outcomes and complication rate. Int J Med Robot + Computer Assisted Surg MRCAS 2018;14:e1912.
[6] Lewinnek GE, Lewis JL, Tarr R, *et al*. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60:217–20.
[7] Sadhu A, Nam D, Coobs BR, *et al*. Acetabular component position and the risk of dislocation following primary and revision total hip arthroplasty: a matched cohort analysis. J Arthroplasty 2017;32:987–91.
[8] Dorr LD, Callaghan JJ. Death of the Lewinnek "Safe Zone". J Arthroplasty 2019;34:1–2.
[9] Suh KT, Kang JH, Roh HL, *et al*. True femoral anteversion during primary total hip arthroplasty: use of postoperative computed tomography-based sections. J Arthroplasty 2006;21:599–605.
[10] Marcovigi A, Ciampalini L, Perazzini P, *et al*. Evaluation of native femoral neck version and final stem version variability in patients with osteoarthritis undergoing robotically implanted total hip arthroplasty. J Arthroplasty 2019;34:108–15.
[11] Domb BG, Chen JW, Lall AC, *et al*. Minimum 5-year outcomes of robotic-assisted primary total hip arthroplasty with a nested comparison against manual primary total hip arthroplasty: a propensity score-matched study. J Am Acad Orthop Surg 2020;28:847–56.
[12] Hayashi S, Hashimoto S, Kuroda Y, *et al*. Robotic-arm assisted THA can achieve precise cup positioning in developmental dysplasia of the hip : a case control study. Bone & Joint Research 2021;10:629–38.
[13] Hepinstall M, Mota F, Naylor B, *et al*. Robotic-assisted total hip arthroplasty in patients who have developmental hip dysplasia. Surg Technol Int 2021;39:338–47.
[14] Dorr LD, Jones RE, Padgett DE, *et al*. Robotic guidance in total hip arthroplasty: the shape of things to come. Orthopedics 2011;34:e652–5.
[15] Domb BG, Chandrasekaran S, Gui C, *et al*. Can stem version consistently correct native femoral version using robotic guidance in total hip arthroplasty? Surg Technol Int 2017;31:389–95.
[16] Schulz KF, Altman DG, Moher D. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. J Pharmacol Pharmacother 2010;1:100–7.
[17] Domb BG, El Bitar YF, Sadik AY, *et al*. Comparison of robotic-assisted and conventional acetabular cup placement in THA: a matched-pair controlled study. Clin Orthop Relat Res 2014;472:329–36.
[18] Post ZD, Orozco F, Diaz-Ledezma C, *et al*. Direct anterior approach for total hip arthroplasty: indications, technique, and results. J Am Acad Orthop Surg 2014;22:595–603.
[19] Lee GC, Lee SH, Kang SW, *et al*. Accuracy of planar anteversion measurements using anteroposterior radiographs. BMC Musculoskelet Disord 2019;20:586.

[20] Fujishiro T, Hayashi S, Kanzaki N, *et al*. Computed tomographic measurement of acetabular and femoral component version in total hip arthroplasty. Int Orthop 2014;38:941–6.

[21] Dorr LD, Malik A, Dastane M, *et al*. Combined anteversion technique for total hip arthroplasty. Clin Orthop Relat Res 2009;467:119–27.

[22] Gheewala RA, Young JR, Villacres Mori B, *et al*. Perioperative management of leg-length discrepancy in total hip arthroplasty: a review. Arch Orthop Trauma Surg 2023;143:5417–23.

[23] Ranawat CS, Rao RR, Rodriguez JA, *et al*. Correction of limb-length inequality during total hip arthroplasty. J Arthroplasty 2001;16:715–20.

[24] Rowan FE, Benjamin B, Pietrak JR, *et al*. Prevention of dislocation after total hip arthroplasty. J Arthroplasty 2018;33:1316–24.

[25] Seagrave KG, Troelsen A, Malchau H, *et al*. Acetabular cup position and risk of dislocation in primary total hip arthroplasty. Acta Orthop 2017; 88:10–7.

[26] Nodzo SR, Chang CC, Carroll KM, *et al*. Intraoperative placement of total hip arthroplasty components with robotic-arm assisted technology correlates with postoperative implant position: a CT-based study. Bone Joint J 2018;100-B:1303–9.

[27] Fujishiro T, Hiranaka T, Hashimoto S, *et al*. The effect of acetabular and femoral component version on dislocation in primary total hip arthroplasty. Int Orthop 2016;40:697–702.

[28] Murphy WS, Yun HH, Hayden B, *et al*. The safe zone range for cup anteversion is narrower than for inclination in THA. Clin Orthop Relat Res 2018;476:325–35.

[29] Leiss F, Götz JS, Meyer M, *et al*. Differences in femoral component subsidence rate after THA using an uncemented collarless femoral stem: full weight-bearing with an enhanced recovery rehabilitation versus partial weight-bearing. Arch Orthop Trauma Surg 2022;142:673–80.

[30] Shi X-T, Li C-F, Han Y, *et al*. Total hip arthroplasty for Crowe type IV hip dysplasia: surgical techniques and postoperative complications. Orthop Surg 2019;11:966–73.

[31] Guo D-H, Li X-M, Ma S-Q, *et al*. Total hip arthroplasty with robotic arm assistance for precise cup positioning: a case-control study. Orthop Surg 2022;14:1498–505.

[32] Zhang S, Liu Y, Yang M, *et al*. Robotic-assisted versus manual total hip arthroplasty in obese patients: a retrospective case-control study. J Orthop Surg Res 2022;17:368.

[33] Cruz-Pardos A, Garcia-Cimbrelo E, Cordero-Ampuero J. Porous-coated anatomic uncemented total hip arthroplasty. A 10-17-year follow-up. Hip Int 2005;15:78–84.

[34] Fukunishi S, Fukui T, Nishio S, *et al*. Combined anteversion of the total hip arthroplasty implanted with image-free cup navigation and without stem navigation. Orthop Rev (Pavia) 2012;4:e33.

[35] Hepinstall M, Zucker H, Matzko C, *et al*. Adoption of robotic arm-assisted total hip arthroplasty results in reliable clinical and radiographic outcomes at minimum two-year follow up. Surg Technol Int 2021;38: 440–5.

[36] Bargar WL, Bauer A, Börner M. Primary and revision total hip replacement using the Robodoc system. Clin Orthop Relat Res 1998;354:82–91.