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ORIGINAL ARTICLE

Clinical efficacy of robot-assisted total hip arthroplasty for developmental dysplasia of the hip: A meta-analysis

Hao-tian Yin[1]*, Yi-xiang Zhang[1,2]*, Tao Yang[1,2], MD*, Xin Fu[1], MD, Lei Wang[1], MD, Jun Liu[1], MD

[1]Department of Joints, Tianjin University Tianjin Hospital (Tianjin Hospital), Tianjin, China
[2]Tianjin Medical University, Clinical College of Orthopedics, Tianjin, China

ABSTRACT

Objectives: The aim of this meta-analysis was to compare the clinical efficacy of robot-assisted total hip arthroplasty (R-THA) versus conventional total hip arthroplasty (C-THA) for the treatment of developmental dysplasia of the hip (DDH).

Materials and methods: Eligible articles published until May 2025 were searched from the Cochrane Library, Web of Science, PubMed, Embase, ScienceDirect, and Springer. Search terms included "robot-assisted", "developmental dysplasia of the hip", "total hip arthroplasty", using mean differences (MDs) and risk differences (RDs) as combined variables, and selecting 95% as the confidence interval (CI).

Results: Seven clinical studies with a total of 876 patients were finally included in this study. There were no significant differences between the two groups in terms of cup inclination (MD=0.07; 95% CI: –0.95 ~ 1.10; p=0.89), cup anteversion (MD=–4.02; 95% CI:–9.59 ~ 1.55; p=0.16), intraoperative bleeding (MD=11.25; 95% CI:–56.02 ~ 78.52; p=0.74), operative time (MD=3.03; 95% CI:–15.66 ~ 21.72; p=0.75), postoperative complications (dislocation [RD=–0.01; 95% CI:–0.03 ~ 0.01; p=0.26], deep infection [RD=0.01; 95% CI:–0.01 ~ 0.02; p=0.37] and nerve injury [RD=0.01; 95% CI:–0.01 ~ 0.03; p=0.56], revision/reoperation [RD=–0.00; 95% CI:–0.03 ~ 0.03; p=1.00], and absolute vertical distance of center of rotation [COR] [MD=–0.50; 95% CI:–1.07 ~ 0.06; p=0.08]). However, compared to the C-THA group, the R-THA group showed significantly higher Harris Hip Score (HHS) (MD=2.17, 95% CI: 0.11 ~ 4.22, p=0.04) and more accurate placement of the horizontal COR (MD=–0.77; 95% CI:–1.21 ~ –0.32; p=0.0008).

Conclusion: In the R-THA group, the accuracy of horizontal placement of the COR was moderately improved, and the postoperative HHS was higher than that in the C-THA group, although such differences might not be obviously perceived by patients. Additionally, no significant differences were found between the two groups in other surgery-related parameters and safety.

Keywords: Developmental dysplasia of the hip, meta-analysis, robot-assisted, total hip arthroplasty.

Developmental dysplasia of the hip (DDH) represents a complex skeletal disorder characterized by multiple pathological presentations, including acetabular dysplasia, hip subluxation, true hip dislocation, and joint instability, with severe cases potentially progressing to secondary osteoarthritis.[1] Both genetic predisposition and environmental factors contribute significantly to its pathogenesis. The condition demonstrates higher prevalence in Asian, Caucasian, Mediterranean, and American populations, with a marked female predominance. Notably, first-degree relatives of DDH patients exhibit substantially elevated disease susceptibility compared to the general population.[2,3]

Contemporary surgical management for adult DDH encompasses diverse approaches, where surgeons can select the most appropriate technique based on the patient's specific condition and anatomical characteristics, ranging from

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Correspondence: Jun Liu, MD. Department of Joints, Tianjin University Tianjin Hospital (Tianjin Hospital), Tianjin, China.

E-mail: liujun1968tju@163.com

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* These authors contributed equally to this work.

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hip arthroscopy and modified periacetabular osteotomy to total hip arthroplasty (THA).[4] For severe DDH cases, THA still remains the primary therapeutic strategy, effectively restoring normal joint anatomy and function while alleviating pain, enhancing stability and mobility, and ultimately improving quality of life. Precise prosthesis implantation proves critical for restoring hip biomechanical properties and achieving favorable long-term outcomes. Suboptimal component positioning may accelerate prosthetic wear and increase risks of complications including loosening and dislocation, ultimately compromising both functional recovery and surgical longevity.[5,6]

Although preoperative digital planning utilizing computed tomography (CT) scans and specialized software has demonstrated improved prosthesis positioning accuracy, human error persists as a significant variable in acetabular cup placement.[7] To ensure faithful execution of preoperative plans, particularly in cases with anatomical deformities, robot-assisted THA (R-THA) has gained increasing adoption. This advanced technology demonstrates superior performance compared to conventional THA (C-THA) in enhancing intraoperative precision, reducing complication rates, and optimizing overall surgical outcomes.[8,9]

Nevertheless, in patients with DDH, the acetabulum is underdeveloped, with insufficient coverage and indistinct bony markers, which makes it difficult to establish the surgical approach. In addition, bone defects make the positioning and fixation of the prosthesis complex, and increase the risk of fractures and neurovascular injuries.[10] The efficacy of R-THA in achieving precise implantation under such anatomically compromised conditions remains undetermined. In this meta-analysis, we comparatively evaluate clinical outcomes between R-THA and C-THA approaches, providing evidence-based guidance for DDH management.

MATERIALS AND METHODS

Search strategy

This meta-analysis adhered to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We systematically searched Cochrane Library, Web of Science, PubMed, Embase, ScienceDirect, and Springer until May 2025 using title/abstract terms: “robot-assisted,” “developmental dysplasia of the hip,” and “total hip arthroplasty” without date/study type restrictions. After deduplication, two investigators independently screened titles/abstracts, followed by full-text evaluation of eligible studies, supplemented by bibliography reviews for potential omissions. The study is registered at PROSPERO (CRD420251078180). As all data were derived from previously published studies, ethical approval was not required for this meta-analysis. The study adhered to the ethical principles outlined in the Declaration of Helsinki.

Inclusion criteria

This study employed the Population, Intervention, Comparison, Outcomes, and Study design (PICOS) framework to establish eligibility criteria. Following established criteria, studies were selected through rigorous quality assessment and data extraction protocols: *(i)* patients with DDH requiring THA; *(ii)* comparative investigations between R-THA and C-THA surgical groups; and *(iii)* documented evaluation of postoperative parameters including cup inclination, anteversion, intraoperative blood loss, operative duration, Harris Hip Score (HHS), complication rates, revision/reoperation, and absolute distances of center of rotation (COR). Two independent investigators determined study eligibility through standardized screening. Any discrepancies in article selection were resolved through blinded adjudication by a third researcher, ensuring impartial resolution of conflicting assessments.

Exclusion criteria

Studies were excluded according to the following criteria: *(i)* duplicate publications, non-original research (e.g., reviews, case reports, conference abstracts, meta-analyses), or basic studies; *(ii)* implementation of interventions deviating from predefined protocols; *(iii)* compromised data integrity due to inaccuracies, incompleteness, or inaccessible primary data; and *(iv)* absence of clinically pertinent outcome measures aligned with predefined research objectives.

Data extraction

Two independent investigators conducted parallel data extraction from the included studies. The extracted dataset comprised the following parameters: primary author, publication year, sample size, study design, and intervention protocols. Outcome measures encompassed postoperative cup inclination, anteversion, intraoperative blood loss, operative duration, HSS, documented postoperative complication, revision/reoperation, and absolute distances of COR.

Quality assessment

Methodological quality assessment of all included studies was independently conducted by two investigators. For randomized-controlled trials (RCTs), the Cochrane Collaboration's risk of bias tool was systematically applied to evaluate methodological rigor. Non-randomized-controlled trials (nRCTs) underwent critical appraisal using the validated Methodological Index for Non-Randomized Studies (MINORS) instrument, with strict adherence to its standardized scoring criteria.

Statistical analysis

Statistical analysis was performed using the RevMan version 5.4 software (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were expressed in mean differences (MDs) with 95% confidence intervals (CIs), whereas dichotomous outcomes were analyzed using risk differences (RDs) and associated 95% CIs. Heterogeneity was evaluated via the I^2 values and *p* values, with predefined thresholds: low heterogeneity ($I^2<50\%$ and $p>0.1$) supported the application of a fixed-effects model, while substantial heterogeneity ($I^2\geq50\%$ or $p\leq0.1$) necessitated a random-effects model. Potential publication bias was assessed through Egger's regression test to evaluate small-study effects.

RESULTS

The systematic search identified 303 potentially relevant records, with no additional studies retrieved from supplementary sources. Automated deduplication using EndNote software identified and removed 116 duplicate records. Title/abstract screening led to the exclusion of 176 studies failing to meet eligibility thresholds. Full-text review of the remaining 21 articles culminated in the inclusion of seven studies meeting predefined eligibility criteria,[11-17] with the complete selection process detailed in Figure 1.

For nRCTs, scores ranged from 18 to 22 according to the MINORS criteria, reflecting the relative quality of the study design. The evaluation of the methodological quality of nRCTs is presented in Table I.

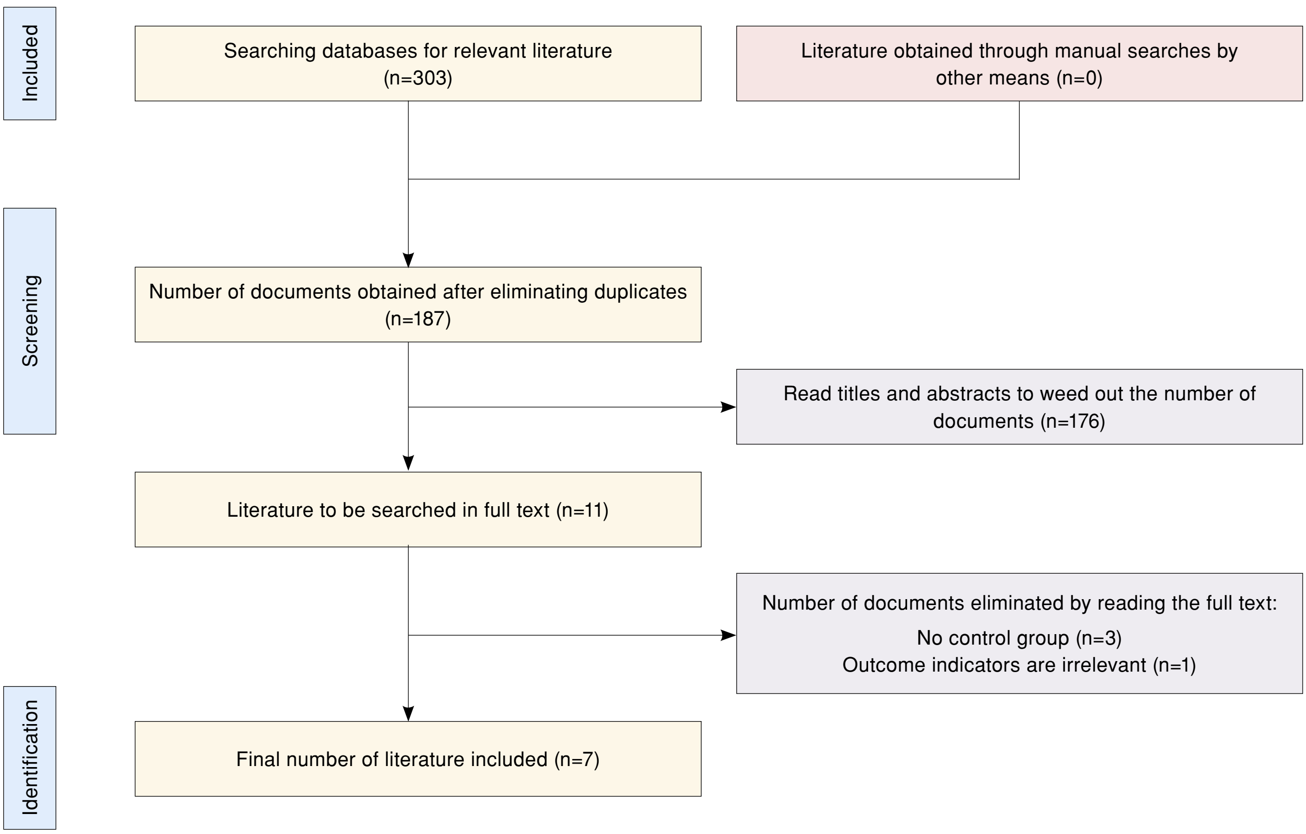

FIGURE 1. Study flowchart.

TABLE I
Quality assessment for non-randomized trials

Quality assessment for non-randomized trials	Chai et al.[11] 2022	Konishi et al.[12] 2024	Sato et al.[13] 2022	Shi et al.[14] 2025	Zhang et al.[15] 2024	Zhou et al.[16] 2021	Zora et al.[17] 2025
A clearly stated aim	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	1	2	2	1
Prospective data collection	0	1	0	0	0	0	2
Endpoints appropriate to the aim of the study	2	2	2	2	2	2	2
Unbiased assessment of the study endpoint	2	1	1	1	2	2	1
A follow-up period appropriate to the aims of study	2	2	2	2	2	2	2
Less than 5% loss to follow-up	2	0	2	2	2	2	0
Prospective calculation of the sample size	2	2	2	1	2	1	2
An adequate control group	2	2	2	2	2	2	2
Contemporary groups	1	2	2	2	2	2	1
Baseline equivalence of groups	2	2	2	2	2	2	2
Adequate statistical analyses	2	2	1	1	2	1	1
Total score	21	20	20	18	22	20	18

Demographic profiles and pertinent study characteristics of the included cohorts are systematically summarized in Table II.

Outcomes of the meta-analysis

Cup inclination

Three studies[11,16,17] evaluated acetabular cup inclination, demonstrating no significant statistical heterogeneity across trials (p=0.66, I^2=0%), thereby supporting the use of a fixed-effects model. Pooled analysis revealed no statistically significant difference in acetabular cup inclination between R-THA and C-THA (MD=0.07; 95% CI:–0.95 ~ 1.10; p=0.89) (Figure 2, Table III).

Cup anteversion

Three studies[11,16,17] quantitatively evaluated acetabular cup anteversion, demonstrating marked heterogeneity across trials (p<0.00001, I^2=94%), thus necessitating the application of a random-effects model. Pooled data analysis revealed no statistically significant intergroup difference in acetabular anteversion between the two groups (MD=–4.02; 95% CI:–9.59 ~ 1.55; p=0.16) (Figure 3, Table III).

Postoperative HHS

Postoperative HSS were extractable from four studies,[11,14-17] which demonstrated significant statistical heterogeneity (p=0.001, I^2=72%), thereby mandating the use of a random-effects model. Meta-analytic synthesis revealed superior postoperative HSS outcomes in R-THA cohorts compared to C-THA counterparts (MD=2.17; 95% CI: 0.11 ~ 4.22; p=0.04) (Figure 4, Table III).

Operative time

Three studies[13,15,16] incorporated surgical duration as an outcome measure, revealing substantial heterogeneity among trials (p<0.00001, I^2=93%), which necessitated the application of a random-effects model. Pooled analysis demonstrated no statistically significant difference in operative time between R-THA and C-THA cohorts (MD=3.03; 95% CI:–15.66 ~ 21.72; p=0.75) (Figure 5, Table III).

Estimated blood loss

Three studies[13,15,16] reported intraoperative blood loss, with significant statistical heterogeneity observed across the included studies (p=0.03, I^2=72%). A random-effects model was, therefore, employed for the pooled analysis. The meta-analysis demonstrated no statistically significant difference in intraoperative blood loss

TABLE II
Characteristics of included studies

Study	Date	Design	Group	Cases	Age year	Female	Follow-up
Chai et al.[11]	2022	RCS	R-THA	27	43.04±8.92	27	24
			C-THA	27	44.56±9.53	27	24
Konishi et al.[12]	2024	RCS	R-THA	88	64±9	78	NR
			C-THA	46	67±9	37	NR
Sato et al.[13]	2022	RCS	R-THA	84	66±8	83	NR
			C-THA	84	66±8	83	NR
Shi et al.[14]	2025	RCS	R-THA	56	45.5	42	12.78±0.76
			C-THA	56	43	40	12.78±0.76
Zhang et al.[15]	2024	RCS	R-THA	147	47.1±11.9	128	NR
			C-THA	147	47.3±12.1	128	NR
Zhou et al.[16]	2021	RCS	R-THA	59	49.9±11.2	44	NR
			C-THA	59	49.7±11.5	44	NR
Zora et al.[17]	2025	PCT	R-THA	20	63.75±6.13	18	29.3±8.51
			C-THA	20	61.50±11.9	18	52.95±18.96

RCS: Retrospective controlled trial; R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; NR: No report; PCT: Prospective controlled trial; Follow-up time in months; Means±SD were used for age and follow-up time.

between the two groups (MD=11.25; 95% CI:–56.02 ~ 78.52; p=0.74) (Figure 6, Table III).

Postoperative complications

Six studies[11-16] documented postoperative complications, with no significant heterogeneity detected among the included studies (dislocation: p=0.63, I^2=0%; deep infection: p=0.85, I^2=0%; nerve injury: p=0.84, I^2=0%). A fixed-effects model was consequently applied for meta-analysis. The pooled data showed no statistically significant differences between groups regarding the incidence of postoperative dislocation (RD=–0.01; 95% CI:–0.03 ~ 0.01; p=0.26), deep infection (RD=0.01; 95% CI:–0.01 ~ 0.02; p=0.37) or nerve injury (RD=0.01; 95% CI:–0.01 ~ 0.03; p=0.56) (Figure 7, Table III).

Revision/reoperation

Two studies[12,15] evaluated postoperative reoperation/ revision, and there was no statistical heterogeneity between the studies (p=0.42, I^2=0%). Therefore, a fixed-effect model was used for the analysis. The pooling results showed that there was no statistically significant difference in postoperative reoperation/revision between R-THA and C-THA (RD=–0.00; 95% CI:–0.03 ~ 0.03; p=1.00) (Figure 8, Table III).

Absolute distances of COR

Three studies[12,13,15] evaluated the absolute values of the placement errors between the COR and the preoperative plan. There was statistical heterogeneity among the studies (p=0.04, I^2=69%); therefore a random-effects model was used for

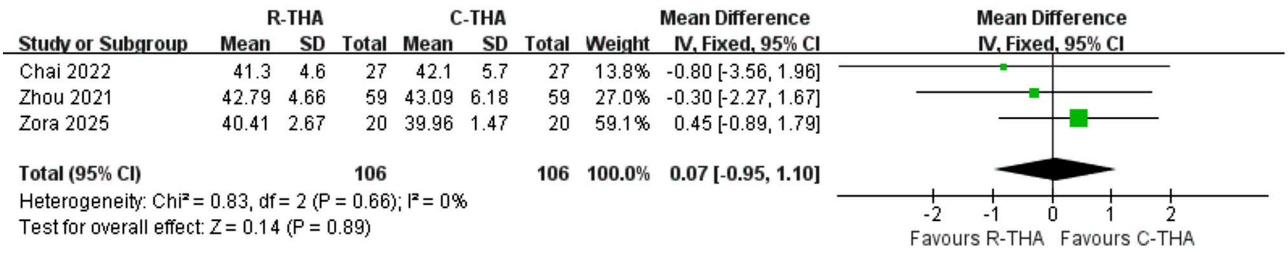

FIGURE 2. Cup inclination (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

TABLE III
GRADE evidence summary

Quality assessment							No. of patients		Effect	
No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	R-THA	C-THA	MD (95% CI)	Quality
Cup inclination (3 articles)	2 RCS 1 PCT	No serious risk of bias	No serious	No serious indirectness	No serious imprecision	None	106	106	0.07 (–0.95~1.10)	⊗⊗⊗⊗High
Cup anteversion (3 articles)	2 RCS 1 PCT	No serious risk of bias	Very serious	No serious indirectness	No serious imprecision	None	106	106	–4.02 (–9.59~1.55)	⊗⊗Low
Postoperative HHS (4 articles)	3 RCS 1 PCT	No serious risk of bias	Serious	No serious indirectness	No serious imprecision	None	250	250	2.17 (0.11~4.22)	⊗⊗⊗Moderate
Operative time (3 articles)	3 RCS	No serious risk of bias	Very serious	No serious indirectness	No serious imprecision	None	290	290	3.03 (–15.66~21.72)	⊗⊗Low
Estimated blood loss (3 articles)	3 RCS	No serious risk of bias	Serious	No serious indirectness	No serious imprecision	None	290	290	11.25 (–56.02~78.52)	⊗⊗⊗Moderate
Postoperative complications (6 articles)	6 RCS	No serious risk of bias	No serious	No serious indirectness	No serious imprecision	None	418	418	–0.00 (–0.01~0.01)	⊗⊗⊗⊗High
Revision/reoperation (2 articles)	2 RCS	No serious risk of bias	No serious	No serious indirectness	No serious imprecision	None	192	192	–0.00 (–0.03~0.03)	⊗⊗⊗⊗High
Absolute distances of COR (3 articles)	3 RCS	No serious risk of bias	Serious	No serious indirectness	No serious imprecision	None	276	276	–0.64 (–0.97~0.31)	⊗⊗⊗Moderate

R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; RCS: Retrospective controlled trial; PCT: Prospective controlled trial; MD: Mean difference; CI: Confidence interval.

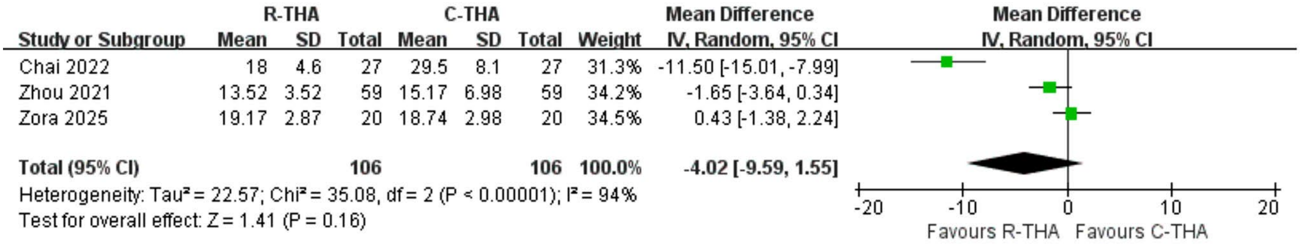

FIGURE 3. Cup anteversion (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

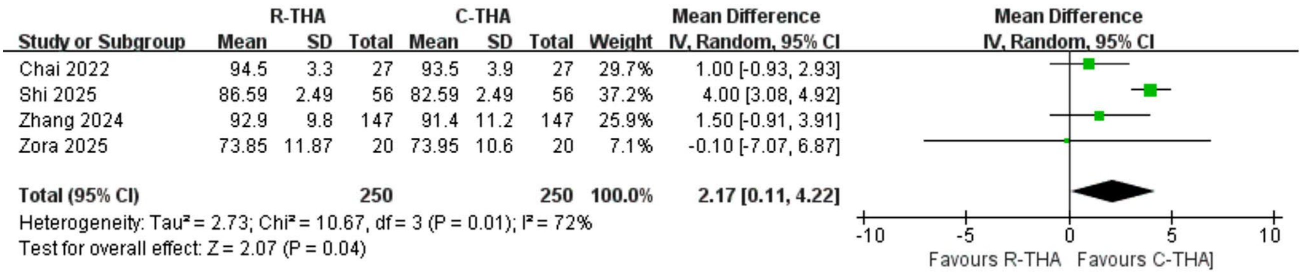

FIGURE 4. Harris hip score (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

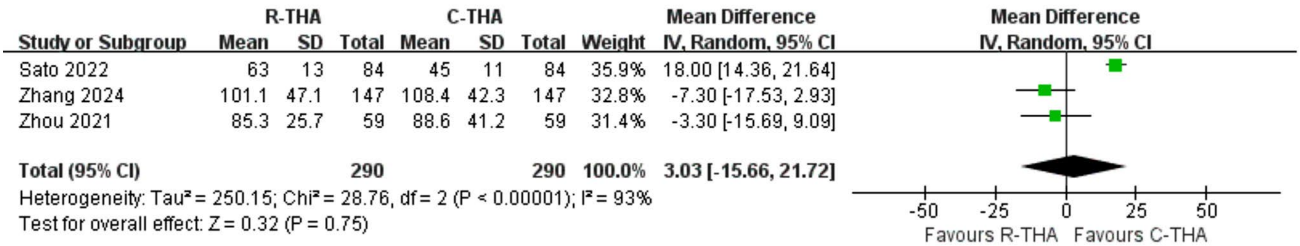

FIGURE 5. Operative time (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

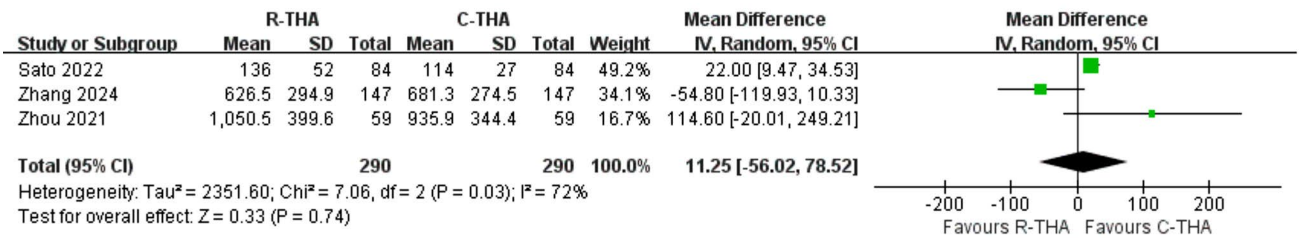

FIGURE 6. Estimated blood loss (Forest plot)
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

the analysis. The pooling results showed that, for R-THA compared with C-THA, there was a statistically significant difference in the horizontal distance of the COR (MD=–0.77; 95% CI:–1.21 ~ –0.32; p=0.0008). However, there was no statistically significant difference in the vertical distance of the COR (MD: –0.50; 95% CI:–1.07 ~ 0.06; p=0.08) (Figure 9, Table III).

Sensitivity and heterogeneity analysis

Given the significant heterogeneity in cup anteversion and operative time (I^2>90%), we

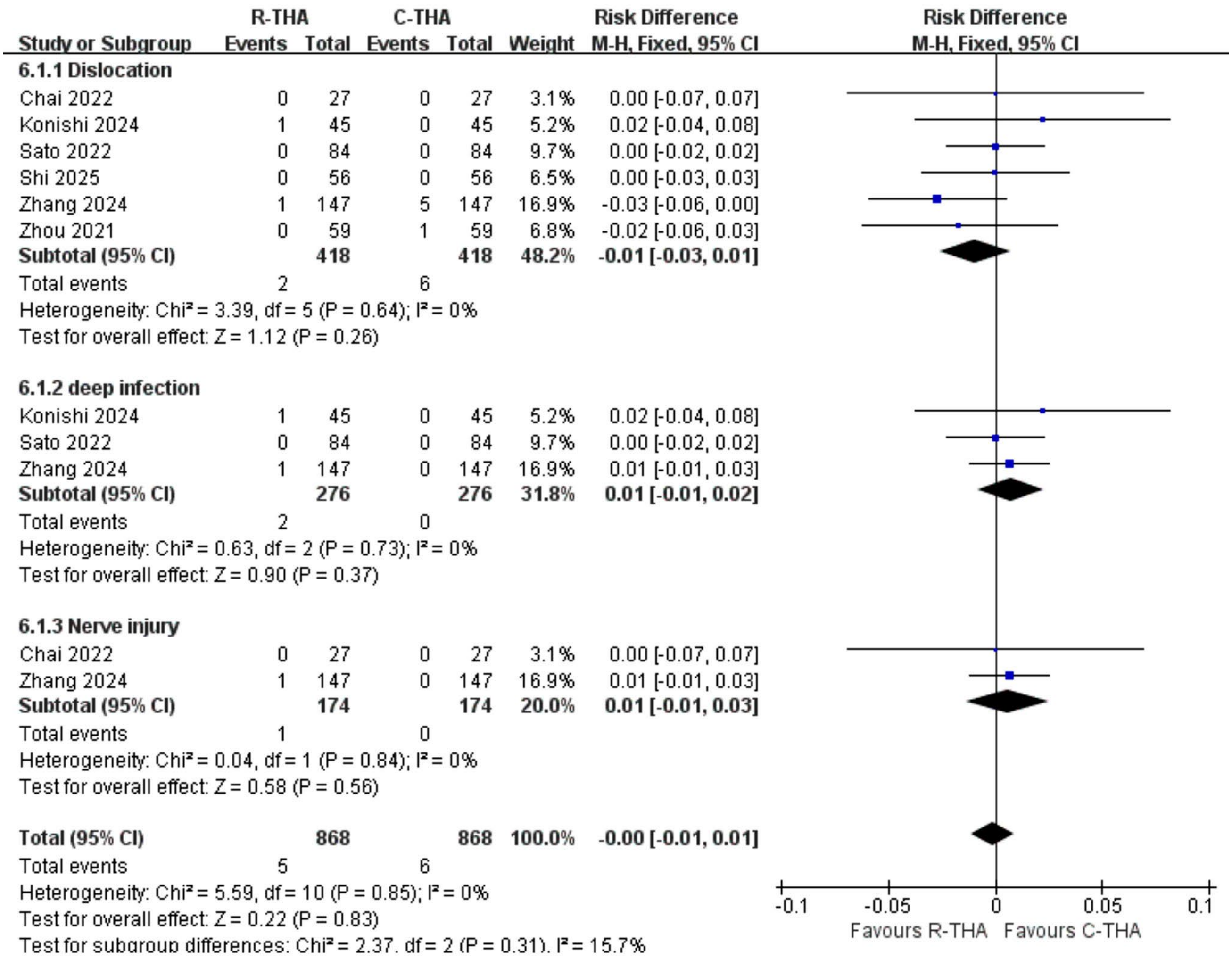

FIGURE 7. Postoperative Complications (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

FIGURE 8. Revision reoperation (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval.

conducted sensitivity analyses and heterogeneity investigations for these two indicators, observing changes in heterogeneity by sequentially excluding the relevant data of each study.

After excluding the study by Chai et al.,[11] the heterogeneity of cup anteversion was reduced to a certain extent (I^2=56%), indicating that it had a certain impact on the stability of the results. After

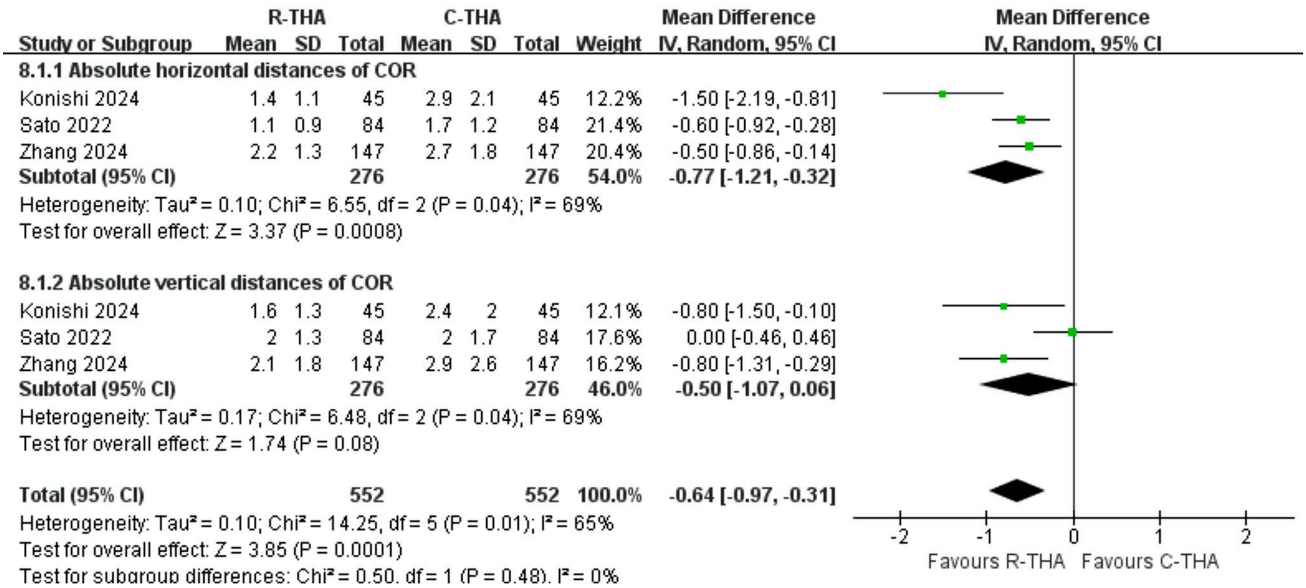

FIGURE 9. Absolute distances of COR (Forest plot).
R-THA: Robot-assisted total hip arthroplasty; C-THA: Conventional total hip arthroplasty; SD: Standard deviation; CI: Confidence interval; COR: Center of rotation.

reviewing the original literature, it was found that this study only included patients with Crowe type 3/4, and the proportion of Crowe type 4 was high. The other two studies included a larger proportion of mild-to-moderate cases (such as Crowe type 1), which might lead to differences in the difficulty of acetabular cup positioning and results among different studies. In addition, the study by Chai et al.[11] used propensity score matching (PSM) and stratified analysis, with more stringent bias control. However, Zora et al.[17] did not mention matching or stratified analysis, and there might be selection bias. Meanwhile, the small sample sizes may have led to insufficient statistical power and affect the stability of the results.

After excluding the study by Sato et al.,[13] the heterogeneity of operative time was significantly reduced (I^2=0%). After re-reading the original literature, it was found that the PSM method in this study reduced the selection bias, but its short-term follow-up (three months) could not reflect the long-term effect. At the same time, this study did not clearly report the specific proportion of Crowe classification, which might lead to inconsistencies in the degree of acetabular bone defect and surgical difficulty among different studies. In addition, the participation of multiple surgeons (nine surgeons) in the study by Sato et al.[13] might introduce technical proficiency bias and affect the stability of the results.

Finally, all the included studies in this meta-analysis were retrospective studies. The lack of randomization is one of the sources of inherent heterogeneity, which may lead to the stable existence of heterogeneity.

Publication bias

We conducted Egger's regression tests using Stata 18.0 software to assess publication bias across various outcome measures in the included studies. The results demonstrated that the p values for Egger's tests all exceeded the threshold of 0.05: cup inclination (p=0.107), cup anteversion (p=0.066), HHS (p=0.195), intraoperative blood loss (p=0.885), operative time (p=0.157), dislocation (p=0.894), deep infection (p=0.789), and absolute horizontal/vertical distance of the COR (p=0.205/0.535). These findings collectively indicate the absence of significant publication bias among the studies included in this meta-analysis.

DISCUSSION

In recent years, R-THA has significant attention for its potential to enhance surgical precision and reduce complication risks, whereas C-THA remains more dependent on surgeons' expertise and technical proficiency. For patients with DDH, the inherent complexity of anatomical structures and frequent coexistence of bone defects dramatically increase surgical challenges, as suboptimal prosthesis positioning may adversely impact joint stability and functional outcomes. The robot-assisted approach enables precise control over acetabular preparation and prosthesis positioning through real-time intraoperative feedback, effectively minimizing human errors. However, this technique presents a steeper learning curve that may prolong operative durations and demands advanced surgical skills and experience.[18,19] Previous meta-analytical evidence demonstrates that R-THA achieves superior accuracy in acetabular cup placement, better restoration of native hip anatomy, and reduced postoperative complication rates compared to conventional methods.[20] Nevertheless, while performing THA surgery on patients with DDH, there is still some controversy as to whether robot-assisted technology can achieve the same ideal effect as C-THA.

This meta-analysis incorporated seven studies evaluating the clinical outcomes of R-THA versus C-THA in treating DDH. The pooled results demonstrated significantly superior postoperative HHS and more accurate placement of the horizontal COR in the R-THA cohort compared to the C-THA group. However, no statistically significant differences were observed between the two surgical approaches regarding postoperative acetabular cup inclination and anteversion angles, operative duration, intraoperative blood loss, complication rates, revision/reoperation, or absolute vertical distance of COR.

Precise control of acetabular abduction and anteversion angles during THA constitutes a critical biomechanical determinant for achieving optimal postoperative outcomes. Insufficient abduction angle predisposes to anterior undercoverage of the acetabulum, whereas excessive abduction compromises posterior column support, both scenarios elevating dislocation risks. Abnormal anteversion angles exert dual effects on joint stability: excessive anteversion increases vulnerability to anterior impingement-induced dislocation during hip flexion-internal rotation, while insufficient anteversion or retroversion amplifies shear stress during extension-external rotation maneuvers, thereby potentiating posterior dislocation risks. The proposed "safe zone" for acetabular component positioning encompasses 40°±10° radiographic inclination and 15°±10° anteversion.[21-23] Sugano et al.[24] further refined these parameters, recommending target ranges of 36° to 45° radiographic inclination and 10° to 24° anteversion to mitigate dislocation and other THA-related complications. In the current investigation, comparative analysis revealed no statistically significant differences in postoperative acetabular inclination or anteversion angles between study cohorts. Nevertheless, Konishi et al.[12] and Sato et al.[13] both reported smaller absolute deviations between the achieved and preoperatively planned angles in R-THA groups compared to C-THA groups. Our study also demonstrated that R-THA achieved superior accuracy in the horizontal placement of COR, suggesting that robotic assistance enhances acetabular positioning precision. Notably, significant anatomical variations secondary to femoral or acetabular dysplasia may complicate manual component placement, potentially increasing risks of acetabular malpositioning and compromised stability.[25]

The expanding adoption of robotic technology in orthopedic surgery raises concerns regarding potential prolongation of operative duration and increased intraoperative blood loss, both of which may elevate risks of postoperative heterotopic ossification, dislocation, and revision surgery.[26] Bensa et al.[20] documented extended operative times in R-THA without significant blood loss differences; however, our study demonstrated comparable operative duration and intraoperative hemorrhage between the two groups while addressing DDH. This phenomenon may be attributed to the capacity of the robotic system to facilitate direct acetabular preparation at target positions, particularly in complex DDH cases, eliminating the need for sequential reaming, thereby optimizing surgical efficiency. Furthermore, the gradually increasing proficiency of the surgical team with the robotic system as well as the well-established surgical workflow likely contributed to the reduction in operative times. As a result, there was no statistically significant difference between robot-assisted surgery and C-THA in terms of operative time and bleeding.[27]

The theoretical superiority of R-THA lies in its capacity to achieve enhanced prosthetic congruence through meticulous preoperative planning and intraoperative execution, thereby optimizing postoperative functional outcomes. Chai et al.[11] and Zhou et al.[16] demonstrated that robotic assistance significantly improves implant positioning accuracy, particularly in Crowe type 3/4 DDH cases, with superior alignment within Lewinnek and Callanan safe zones compared to conventional techniques. This precision enhances hip biomechanics, correlating with improved functional scores, a finding corroborated by our study showing significantly higher HHS in the R-THA cohort. However, no intergroup disparity emerged in postoperative complication rates or revision/reoperation rates. This suggests that although robotic assistance demonstrates marked advantages in precision and functional outcomes, these benefits may not directly translate to reduced complications. This discrepancy may be attributable to multifactorial determinants including surgical expertise, postoperative protocols, and inherent patient variability in DDH populations.[28] Critical evaluation of therapeutic efficacy necessitates incorporation of the minimal clinically important difference (MCID), defined as the smallest measurable improvement perceived as clinically meaningful by patients. Singh et al.[29] established an MCID threshold of 15.9 to 18 points for HHS improvement post-THA. Our R-THA cohort demonstrated a mean HHS improvement of merely 2.17 points from baseline. While statistically significant, this increment failed to surpass the MCID threshold, indicating comparable clinical relevance of functional improvements between the groups. Moreover, leg length discrepancy (LLD) following THA is more common in DDH patients and is a significant contributor to patient dissatisfaction. A discrepancy of <4 mm has proven suitable for many patients.[30,31] Shi et al.[14] observed smaller LLD in patients undergoing R-THA. Zhang et al.[15] also reported that robot-assisted surgery facilitates better leg-length balancing in DDH patients, particularly those with Crowe type 2/3 dysplasia, though no significant differences emerged in Crowe type 1/4 cases. A smaller LLD may be associated with better subjective patient sensation.

A comprehensive analysis of the cost-effectiveness of R-THA reveals that its short-term in-hospital costs are relatively higher, potentially attributed to the initial investment in robotic systems, maintenance costs, and expenses related to consumables. However, the R-THA group exhibits a significantly shorter length of hospital stay (and reduced personnel costs, which, to some extent, offsets the additional expenditures. Additionally, robot-assisted technology demonstrates potential advantages in enhancing surgical precision, reducing postoperative complications, and accelerating postoperative recovery. In the long term, these merits are likely to contribute to lower revision rates and decreased long-term medical expenses, thereby improving overall cost-effectiveness.[32,33]

Nonetheless, this study has certain limitations. First, all seven included studies were nRCTs, which to some extent weakened the strength of evidence in the meta-analysis. Second, the follow-up periods of the various studies differed, and some studies only evaluated intraoperative indicators and postoperative radiological indicators without clearly reporting the follow-up period, which may lead to bias in the results. Additionally, some studies included a relatively small number of cases, which may affect the accuracy of the assessment of postoperative complication rates.

In conclusion, robot-assisted technology has certain advantages in improving the precise placement of COR and postoperative HHS. However, such improvement may not necessarily translate into tangible benefits perceived by patients. Moreover, no significant differences were found in key surgical parameters including cup inclination, anteversion, intraoperative blood loss, operation time, and postoperative complication rate, compared to conventional techniques. Due to inherent methodological limitations, future research should focus on multi-center, large-scale, clinical controlled trials to validate the clinical efficacy and long-term outcomes of robot-assisted interventions.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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