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Robotic-assisted Versus Conventional Total Hip Arthroplasty: A Systematic Review of Clinical and Radiographic Outcomes

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ABSTRACT

Objectives: Hip osteoarthritis is a growing global health burden with an increasing demand for total hip arthroplasty (THA), particularly among older populations. Robotic-assisted THA (RATHA) has emerged as a technological advancement that may improve precision, implant alignment, and potentially patient outcomes compared with conventional THA (COTHA). This systematic review aimed to compare the clinical and radiological outcomes of RATHA and COTHA. ***Methods***: A systematic search was conducted from PubMed, Scopus, and Cochrane Library inception until 31 August 2024, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The inclusion criteria were randomized controlled trials, retrospective studies, prospective studies, and cohort studies that compared RATHA with COTHA. Exclusion criteria were case reports, case series, abstracts, review articles, systematic reviews, meta-analyses, biomechanical or cadaveric studies, studies on revision THA or high-grade hip dysplasia, and non-English publications. Data were extracted and assessed using the Covidence systematic review software and the Cochrane Risk of Bias Tool. The primary outcomes were clinical outcomes measured by patient-reported outcome measures. The secondary outcomes were operative outcomes, complications, and radiological assessment. ***Results:*** Nine studies met the inclusion criteria, representing populations from Asia, the USA, the UK, and Italy. A total of 933 patients were assessed, 467 of whom underwent RATHA. No significant differences observed in patient-reported outcome measures. COTHA had shorter operative times, whereas RATHA showed potential in reducing hospital stays. RATHA demonstrated improved radiological outcomes, particularly in implant alignment; however, no significant differences were observed in complication rates. ***Conclusions:*** RATHA offers advantages in radiological precision but provides clinical outcomes similar to those of COTHA in terms of patient satisfaction and complications. Further high-quality trials are required to assess the long-term benefits of RATHA.

Hip osteoarthritis (OA) is a common and debilitating condition that imposes a significant health burden worldwide. The global incidence of hip OA has risen from 0.74 million in 1990 to 1.58 million in 2019.[1] By 2060, the demand for hip and knee joint replacements is expected to increase by nearly 40%, with older patients comprising the largest demographic.[2,3] Total hip arthroplasty (THA) is an effective solution for treating hip OA, offering relief from pain and improving mobility. However, to ensure successful outcomes, it is crucial to minimize complications such as infection, dislocation, and loosening while achieving high levels of patient satisfaction. The surgeon's technical skills and judgment are paramount in conventional THA (COTHA). Surgeons use various instruments and techniques to prepare the bone, position the acetabular cup and femoral stem, and secure them. In contrast, robotic-assisted THA (RATHA) integrates computer systems and robotic arms to assist surgeons. The procedure began with detailed preoperative planning using advanced imaging techniques. The robotic system then assists with surgical precision by guiding the instruments according to the surgeon's plan, thereby improving

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the accuracy of implant positioning. Several robotic-assist systems have been developed for orthopedic surgery, including ROBODOC, ROSA, MAKO, CASPAR, NAVIO, and Acrobat.[4,5] The first robot-assisted hip replacement surgery was performed in 1992 using the ROBODOC system.

The potential advantages of robotic assistance in joint replacement surgery include a smaller incision size, which can lead to reduced pain, faster recovery, and reduced scarring. Imaging data are used to create a three-dimensional model of the pateint's anatomy, enabling surgeons to plan surgery more precisely and potentially acheive better outcomes.[6] The robotic arm can provide greater precision and flexibility in implant positioning, which is crucial for optimal function and longevity. A higher proportion of RATHA cases achieved optimal acetabular cup inclination and anteversion angles, improving biomechanical stability.[7] Robotic assistance led to a 30% reduction in leg length discrepancy compared with manual techniques, potentially lowering the risk of complications, such as gait abnormalities.[8] The potential benefits of smaller incisions, faster recovery, and improved outcomes may contribute to higher patient satisfaction. Precise implant placement and reduced surgical trauma may contribute to longer-lasting implants. RATHA showed a slight reduction in early postoperative dislocation rates and comparable infection rates.[9] The use of the MAKO robot in THA improves radiological outcomes by enhancing safe prosthesis placement. However, no significant differences were observed in terms of complications.[10]

Despite its potential benefits, there are some drawbacks to RATHA. Robotic systems and their associated technologies can be expensive, potentially increasing the procedure cost.[11] Robotic surgery can sometimes take longer than conventional methods, particularly for surgeons who are new to the technology. Surgeons require specialized training to effectively use robotic systems, which can involve a significant learning curve. In addition, there is always the potential for technical malfunctions or limitations that could affect the procedure. Although short-term benefits are often observed, long-term data on the true advantages of RATHA are still being collected and analyzed. Based on current evidence, there is no significant difference in the clinical and functional outcomes between RATHA and COTHA.

METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[12] A comprehensive literature search was performed from PubMed, Scopus, and the Cochrane Library databases inception until 31 August 2024. The search strategy included the terms such as 'total hip arthroplasty,' 'THA,' 'total hip replacement,' 'THR,' 'robotic assisted,' 'conventional,' and 'manual'. These terms were applied to all searchable fields (title, keywords, and abstract). The search strategy also incorporated Boolean combinations like 'total hip arthroplasty' OR 'THA' OR 'total hip replacement' OR 'THR' AND 'robotic assisted' AND 'conventional' OR 'manual'. The search process was conducted independently by two reviewers, with a third reviewer consulted to resolve any discrepancies.

Studies were considered eligible if they met the following inclusion criteria: (i) randomized controlled trials (RCTs), retrospective studies, prospective studies, and cohort studies comparing RATHA with COTHA; (ii) studies involving patients > 18 years diagnosed with severe hip diseases such as OA, avascular osteonecrosis, rheumatoid arthritis, and Paget's disease; (iii) patients who had undergone THA; and (iv) studies reported short- and long-term outcomes comparing RATHA with COTHA. Exclusion criteria were as follows: (i) non–English publications; (ii) case reports, case series, abstracts, review articles, systematic reviews, and meta-analyses; (iii) biomechanical or cadaveric studies; (iv) studies on revision THA; (v) studies involving patients with high-grade hip dysplasia; and (vi) studies with insufficient data to extract relevant information. The primary outcomes were clinical outcomes measured using patient-reported outcome measures (PROMs). The secondary outcomes included operative outcomes, complications, and radiological assessment.

This systematic review included a mix of study designs such as case-control studies, retrospective cohort analyses, and prospective trials, rather than limiting the inclusion to RCTs provides a broader evidence base. Non-RCTs, such as retrospective cohort studies and case-control studies, often provide valuable data, particularly in areas where RCTs are limited or infeasible due to ethical, logistical, or financial constraints. For instance, in RATHA, RCTs are relatively scarce because of the novelty of technology and the difficulty in randomizing patients to surgical techniques. Non-RCTs often reflect real-world clinical settings, capturing a wider spectrum of patient populations, surgeon expertise, and institutional variations. This inclusion enhances the external validity (generalizability) of the systematic review findings. Retrospective and prospective studies can provide larger sample sizes and longer follow-up periods, contributing valuable insights into outcomes such as long-term complications, revision rates, and learning curves for surgeons. When RCTs are unavailable or insufficient in number, non-RCTs provide preliminary evidence to guide practice and inform future high-quality research. However, non-RCT studies have some limitations including prone to selection bias, confounding variables, and retrospective reporting inaccuracies. The variability in study design, patient populations, and measured outcomes may complicate data synthesis and interpretation. Without randomization, non-RCTs may not establish causality as robustly as RCTs. To mitigate the limitations of non-RCT inclusion in this review, we conducted include rigorous quality assessment using validated tools such as the Cochrane Risk of Bias Tool, which assessed the quality of included studies and identify potential biases.[13] We also ensured transparent reporting, clearly stating that non-RCTs were included to provide a more comprehensive assessment due to the limited number of RCTs. Potential biases and limitations in the interpretation of findings were mentioned, considering the inclusion of non-RCTs. Finally, we focused on consistency by highlighting consistent trends or findings across study designs, as this reinforces the reliability of conclusions despite differences in study quality.

Two reviewers (the first and second authors) independently screened the titles, keywords, and abstracts of all studies identified in the search, using Covidence systematic review software to remove duplicates.[14] The full texts of eligible studies were independently reviewed to confirm their suitability. Both reviewers independently extracted data from each study, focusing on patient demographics, study design, sample size, robotic system used, operating time, complications, PROMs, conflicts of interest, and funding sources. Any disagreements at this stage were resolved by a senior reviewer (the fourth author). To assess the quality of the included studies, we used the Cochrane Risk of Bias Tool. To assess the treatment effects of RATHA compared with COTHA, a variety of statistical methods were employed. Standardized mean differences (SMDs) with 95% CIs were calculated to quantify the magnitude and precision of the treatment effects. Forest plots were utilized to visually represent the SMDs and their corresponding CIs across multiple studies.

RESULTS

We identified 364 citations from the three databases; of which 236 were removed as duplicates. The remaining 128 studies were reviewed based on the selection criteria. Only nine studies fulfilled all the selection criteria and were included in the qualitative analysis of this review. The screening process is detailed in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis flowchart [Figure 1]. Table 1 summarizes the characteristics of all included trials. We included nine trials that were published from 2015 to 2024 and were conducted in Asia (n = 5),[15–19] followed by the USA (n = 2),[20,21] the UK (n = 1),[22] and Italy (n = 1).[23] The sample sizes of these trials ranged from 54 to 176 hips, and the follow-up time ranged from three months to 14 years. Two studies were secondary analyses of the same patient population at longer follow-up periods.[16,20] The age of participants across the studies ranged from 32 to 85 years old.

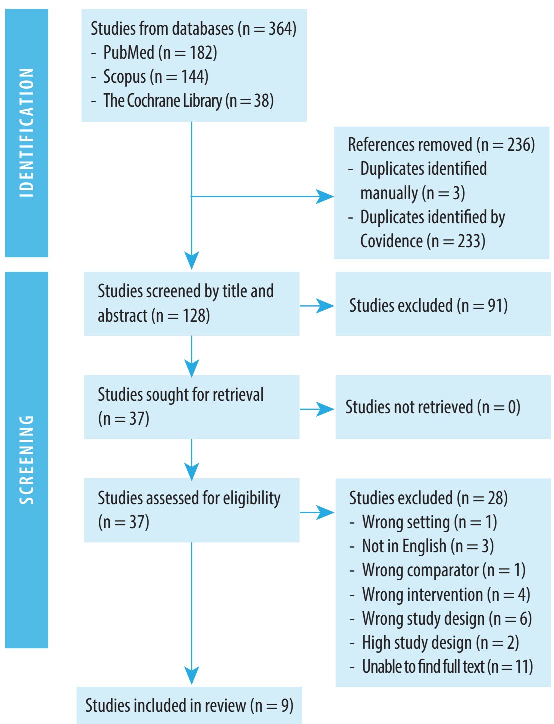

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analysis flow chart.

Table 1: Characteristics of included trials.

Author and year	Country	Study type	Sample size	Robot system	Follow-up	Conflict of interest
Lim 2015	South Korea	Randomized short-term outcome study	N = 49 RATHA = 24 COTHA = 25	ROBODOC	24 months	Yes
Bargar 2018	USA	Randomized clinical trials	N = 67 RATHA = 45 COTHA = 22	ROBODOC	RATHA 13.8 years COTHA 14.2 years	Yes
Nakamura 2018	Japan	Randomized clinical trials	N = 128 RATHA = 64 COTHA = 64	ROBODOC	11.25 years	No
Fontalis 2023	UK	Prospective cohort study	N = 100 RATHA = 50 COTHA = 50	MAKO	36 months	Yes
Tian 2023	China	Retrospective cohort study	N = 143 RATHA = 63 COTHA = 80	Seven-axis robot-assisted THA system	3 months	Yes
Xu 2024	China	Prospective randomized, multicentre, parallel-controlled clinical trial	N = 111 RATHA = 56 COTHA = 55	LANCET robotic system	3 months	Yes
Lu 2023	China	Prospective trial	N = 59 RATHA = 30 COTHA = 29	Single semiactive surgical robot (YUANHUA-THA)	3 months	Yes
Buchan 2024	USA	Retrospective cohort analysis	N = 176 RATHA = 85 COTHA = 91	ROSA	12 months	No
Alessio-Mazzola 2024	Italy	Case control study	N = 100 RATHA = 50 COTHA = 50	MAKO	RATHA 11.6 ± 1.2 months COTHA 14.0 ± 4.7 months	Yes

RATHA: robotic-assisted total hip arthroplasty; COTHA: conventional total hip arthroplasty.

A total of 933 patients were assessed, 467 of whom underwent RATHA.

The ROBODOC systems (Integrated Surgical Systems or Curexo Technology Corp., CA, USA) were used in three studies.[15,16,20] The Mako Robotic-Arm assisted total hip™ (Stryker Corp, USA) was employed in two studies.[22,23] One study utilized the ROSA® Total Hip System (Zimmer CAS, Montreal, Canada).[21] The three Chinese studies used different robotic platforms, which included the Seven-Axis Robot-Assisted THA system (Jianjia, Hangzhou Jianjia Robot Co., Ltd.),[18] the single semiactive surgical robot (YUANHUA-THA),[17] and the LANCET Robotic system (Hangzhou Lancet Robo Co. Ltd).[19] Table 2 illustrates the outcome level for risk of bias for the included trials.

The primary outcomes were clinical outcomes measured using PROMs. Table 3 summarizes the PROMs evaluated in this systematic review, including the Harris Hip Score (HSS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score and the University of California-Los Angeles (UCLA) score. The HSS was evaluated in four studies,[17–19,23] the WOMAC score was evaluated in three studies,[15,17,20] and the UCLA in three studies.[20–22] In summary, all comparisons in the forest plot for PROMs, including the HSS, the WOMAC, and UCLA scores [Figure 2a, b, and c], show CIs crossing zero, indicating no statistically significant difference between the RATHA and COTHA groups, either preoperatively or at the end of treatment.

The secondary outcomes were operative outcomes, complications, and radiological assessment. The forest plot in Figure 2d compares the SMD in operative times between RATHA and COTHA

Table 2: Risk of bias of included trials (outcome level).

Study and rear	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Lim 2015	Unknown	Unknown	Unknown	Low risk	Low risk	Unknown	Unknown
Bargar 2018	Low risk	Unknown	Unknown	Unknown	High risk	Low risk	Unknown
Nakamura 2018	Low risk	Low risk	High risk	Unknown	Low risk	Low risk	Unknown
Fontalis 2023	High risk	Not applicable	Unknown	Unknown	Low risk	Low risk	Unknown
Buchan 2024	Not applicable	Not applicable	Unknown	Unknown	Low risk	Unknown	Unknown
Tian 2023	Low risk	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Lu 2023	Low risk	Low risk	Unclear risk	Unclear risk	Low risk	Low risk	Low risk
Xu 2024	Low risk	Unclear risk	Unclear risk	Low risk	Low risk	Low risk	Low risk
Alessio-Mazzola 2024	Not applicable	Not applicable	Unknown	Low risk	Unknown	Low risk	Unknown

across four studies.[17–19,23] Lu et al,[17] showed the largest SMD of 1.79, significantly favoring COTHA with shorter operative times. Tian et al,[18] and Xu et al,[19] also reported moderate SMDs (0.59 and 0.75, respectively), both favoring COTHA with statistically significant differences. However, Alessio-Mazzola et al,[23] reported a small SMD (-0.36), with a CI crossing zero, indicating no significant difference between the two techniques in this study. Overall, most studies suggest that COTHA has shorter operative times compared to RATHA. The forest plot in Figure 2e compares the SMD in blood loss between RATHA and COTHA across two studies.[17,19] Lu et al,[17] showed a small positive SMD (0.41), suggesting that RATHA may have slightly higher blood loss than COTHA, but the CI crosses zero, indicating no statistically significant difference. Xu et al,[19] reported a near-zero SMD (-0.01), with the CI also crossing zero, indicating no meaningful difference in blood loss between the two techniques. Overall, both studies suggested that there is no significant difference in blood loss between RATHA and COTHA. The forest plot in Figure 2f compares the SMD in length of stay between RATHA and COTHA across two studies.[17,23] Lu et al,[17] showed an SMD of -0.03, with a CI crossing zero, indicating no significant difference in length of stay between the two procedures. In contrast, Alessio-Mazzola et al,[23] showed a large negative SMD of -1.67, with the CI entirely below zero, suggesting that RATHA is associated with a significantly shorter length of stay compared to COTHA. Overall, while Lu et al,[17] found no difference, Alessio-Mazzola et al,[23] found that RATHA reduced hospital stay duration significantly.

Table 4 presents the results of several studies comparing the rates of various complications associated with RATHA and COTHA. The studies examined revision rates, infection rates, dislocation rates, limb length discrepancies, operative times, blood loss, and lengths of stay. Overall, the results suggest no significant difference between RATHA and COTHA for most complications. Both procedures have similar rates of revision, infection, and dislocation. Additionally, there is no significant difference in limb length discrepancy between the two groups.

Table 5 presents the results of several studies comparing the radiological outcomes of RATHA and COTHA.[15,18,19,23] The studies examined femoral stem alignment outliers, stem appropriate size, cup malalignment, Lewinnek safe zone, and global offset. Overall, the results suggest no significant difference between RATHA and COTHA for most radiological outcomes. Both procedures have similar rates of femoral stem alignment outliers, cup malalignment, and global offset. However, there are some minor differences.

The stem appropriate size was slightly higher for RATHA patients in Tian et al,[18] but there was no significant difference in Alessio-Mazzola et al.[23] The Lewinnek safe zone was also slightly higher for RATHA patients in both studies.

Table 3: Patient-reported outcome measures of included trials.

Measures	Lim 2015	Bargar 2018	Fontalis 2023	Lu 2023	Tian 2023	Xu 2024	Allessio-Mazzola 2024	Buchan 2024
HSS								
Preoperative	Mean (range)			Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
RATHA	52 (37–61)			53.55 ± 13.93	53.95 ±14.47	59.31 ± 19.24	81.6 ± 17.4	
COTHA	55 (41–60)			54.71 ± 9.52	51.43 ± 13.55	58.84 ± 20.23	79.1 ± 19	
p-value	0.155			0.718	0.359	0.8993	0.558	
SMD				-0.10	0.18	0.02	0.135	
95% CI				-0.61–0.41	-0.15–0.51	-0.35–0.40	-0.257–0.528	
End of treatment	Mean (range)			Mean ± SD	Mean ± SD	Mean ± SD		
RATHA	93 (85–100)			96.81 ± 5.15	89.03 ±7.72	87.92 ± 10.88		
COTHA	95 (89–100)			97.23 ± 4.26	88.76 ± 5.79	87.99 ± 11.19		
p-value	0.512			0.740	0.818	0.9786		
SMD				-0.09	0.04	-0.01		
95% CI				-0.60–0.42	-0.29–0.37	-0.38–0.37		
WOMAC Score								
Preoperative	Mean (range)	Mean ± SD		Mean ± SD				
RATHA	60 (44–85)	8.44 ±11.48		47.07 ± 13.71				
COTHA	61 (45–89)	11.32 ± 11.92		45.89 ± 10.54				
p-value	0.517	0.034		0.889				
SMD		-0.248						
95% CI		-0.759–0.264						
End of treatment	Mean (range)			Mean ± SD				
RATHA	11 (6–17)			4.30 ± 4.54				
COTHA	12 (5–15)			4.00 ± 4.27				
p-value	0.301			0.875				
SMD				0.068				
95% CI				-0.443–0.579				
UCLA Score								
End of treatment		Mean ± SD	Median (quartile 1, quartile 3)					Mean ± SD
RATHA		6.09 ± 1.86	7.5 (6, 9)					5.5 ± 2.2
COTHA		5.71 ± 1.45	7 (6, 8)					5.2 ± 2.2
p-value		0.417	0.381					0.432
SMD		0.219						0.136
95% CI		-0.293–0.730						-0.160–0.432

HSS: Harris Hip Score; RATHA: robotic-assisted total hip arthroplasty; COTHA: Conventional total hip arthroplasty; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; UCLA: University of California-Los Angeles.
**level of significance set at $p < 0.05$.*

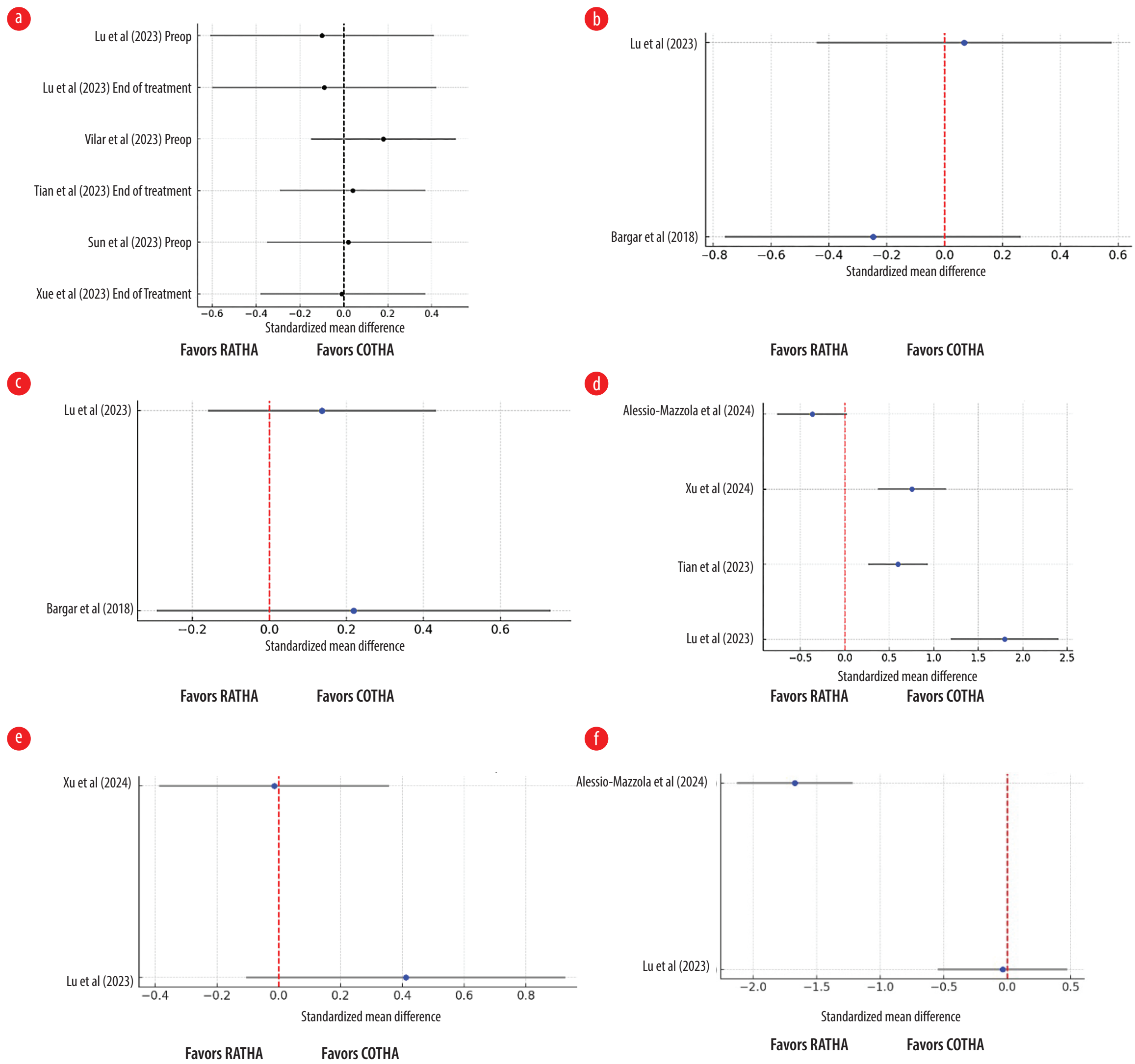

Figure 2: Forest plots showing clinical outcomes between robotic-assisted total hip arthroplasty (RATHA) and conventional total hip arthroplasty (COTHA): **(a)** Harris Hip Score; **(b)** Western Ontario and McMaster Universities Osteoarthritis Index score; **(c)** University of California-Los Angeles score; **(d)** operative times; **(e)** intraoperative blood loss; **(f)** length of stay between RATHA and COTHA.

DISCUSSION

This review highlights that RATHA and COTHA yield comparable clinical outcomes in terms of PROMs, with no significant differences in complications, a finding consistently reported in previous systematic reviews.[24–27] COTHA demonstrated shorter operative times, reflecting greater procedural efficiency, as has been well-documented in previous studies.[16,24–27] In contrast, RATHA offers a distinct advantage in radiological precision, particularly in achieving more accurate implant alignment, which may confer long-term benefits. Systematic reviews by Kumar et al,[25] and Han et al,[26] similarly concluded that RATHA results in superior implant placement accuracy, which is consistent with the findings of this review.

Previous systematic reviews comparing RATHA and COTHA often included older trials, some dating back to 1998.[24–26] The current literature comparing RATHA and COTHA is scarce and low-quality, with findings limited by methodological flaws in study design.[27] The global prevalence of OA has grown from 247.5 million cases in 1990 to 527.8 million in 2019, representing an increase of 113.3% over three decades.[28] OA is the most common cause of arthritis worldwide, being almost a universal problem in individual aged ≥ 65 years.[29] There is a growing need to understand the benefits of robotic joint arthroplasty properly. This systematic review evaluated the comparative performance of RATHA and COTHA across clinical and radiological

Table 4: Summary of revision rates, infection, dislocation, limb length discrepancy, blood loss intraoperatively, length of stay and operative time of included trials.

Variables	Lim 2015	Bargar 2018	Nakamura 2018	Lu 2023	Tian 2023	Xu 2024	Allessio- Mazzola 2024
Revision							
RATHA	0/24	4/45	0/64				
COTHA	2/25	6/22	0/64				
Infection							
RATHA	0/24	0/45	0/30				2/50
COTHA	0/25	0/22	0/29				1/50
p-value	1.000						0.594
Dislocation							
RATHA	0/24	1/45					0/50
COTHA	0/25	0/22					0/50
p-value	1.000						1.000
Limb Length Discrepancy, mm	Mean (range)				Mean ± SD	Mean ± SD	Mean ± SD
RATHA	1.9 (0–6.4)				6.0 ± 5.0	2.27 ± 4.19	0.6 ± 1.4
COTHA	4.9 (0–16)				8.09 ± 4.33	1.29 ± 4.33	0.4 ± 1.4
p-value	0.011*				0.000*	0.2538	0.572
SMD					-0.448	0.229	0.143
95% CI					-0.772–-0.124	-0.102–0.56	-0.251–0.537
Blood loss, mL	Mean (range)			Mean ± SD		Mean ± SD	
RATHA	1010 (610–1800)			1280.30 ± 404.01		163.8 ± 118.5	
COTHA	895 (410–1370)			1094.86 ± 494.39		165.5 ± 113.4	
p-value	0.271			0.137		0.9384	
SMD				0.411		-0.015	
95% CI				-0.104–0.927		-0.387–0.357	
Length of stay, days				Mean ± SD			Mean±SD
RATHA				5.29 ± 0.53			2.5±0.6
COTHA				5.31 ± 0.54			4.3±1.4
p-value				0.863			< 0.001*
SMD				-0.037			-1.671
95% CI				-0.548–0.473			-2.127–-1.216
Operative time, min	Mean (range)			Mean ± SD	Mean ± SD	Mean ± SD	Mean±SD
RATHA	103 (83–141)			104.2 ± 19.63	94.43 ± 18.04	109.5 ± 28.63	62.1±12.4
COTHA	78 (57–147)			69.49 ± 18.97	84.86 ± 14.26	87.11 ± 30.73	67.3±15.7
p-value	0.012*			< 0.001*	0.001*	0.0001*	0.071
SMD				1.798	0.597	0.754	-0.368
95% CI				1.193–2.402	0.260–0.934	0.369–1.139	-0.763–0.028

RATHA: robotic-assisted total hip arthroplasty; COTHA: conventional total hip arthroplasty; SMD: standardized mean differences.
*level of significance set at $p < 0.05$.

Table 5: Summary of radiological outcomes of included trials.

Radiological outcomes	Lim 2015	Tian 2023	Xu 2024	Alessio-Mazzola 2024
Femoral stem alignment Outlier (> ± 3°)				
RATHA	0/24			0/50
COTHA	6/25			1/50
p-value	0.022*			0.485
Cup malalignment				
RATHA				0/50
COTHA				2/50
p-value				0.141
Stem appropriate size				
RATHA		57 (90.5%)		48 (96.0%)
COTHA		69 (86.3%)		49 (98.0%)
p-value		0.438		1.000
Lewinnek safe zone				
RATHA		57 (90.5%)	52 (92.9%)	
COTHA		62 (77.5%)	47 (85.5%)	
p-value		0.039*	0.2092	
Global offset (mm)		Mean (IQR)	Mean ± SD	
RATHA		2.83 (2.30)	2.67 ± 3.26	
COTHA		3.45 (2.40)	2.12 ± 3.00	
p-value		0.067	0.3882	

*RATHA: robotic-assisted total hip arthroplasty; COTHA: conventional total hip arthroplasty. *level of significance set at p < 0.05.*

outcomes using studies published in the last 10 years. Primary outcomes were clinical outcomes measured using PROMs, which included HHS, WOMAC, and UCLA scores. The secondary outcomes were operative outcomes, complications, and radiological assessment. This included operative characteristics (operative time, blood loss, and length of hospital stay) and radiological precision (femoral stem alignment, cup malalignment, stem appropriateness, Lewinnek safe zone compliance, and global offset).

The clinical outcomes assessed through the HHS, WOMAC, and UCLA scores revealed no significant differences between RATHA and COTHA. Across multiple studies, the SMDs were small, and the CI crossed zero, indicating that both techniques are equally effective in improving hip function, reducing pain, and maintaining activity levels. Although RATHA offers more precision in implant placement, as highlighted in the radiological outcomes, these advantages did not translate into significant differences in clinical function or pain relief, as measured by these scores.

RATHA and COTHA showed distinct differences in operative outcomes. COTHA consistently demonstrated shorter operative times across multiple studies, with significant SMDs favoring the conventional technique. This suggests that COTHA remains a faster and potentially more efficient option. On the other hand, RATHA showed a potential benefit in reducing the length of hospital stay, as reported by Alessio-Mazzola et al,[23] although other studies showed no difference. Blood loss, however, showed no consistent difference between the two techniques, indicating that both approaches are comparable in this aspect of surgical management.

RATHA demonstrated notable advantages in several radiological outcomes, suggesting greater precision in implant positioning. Studies have shown that RATHA is associated with fewer femoral stem alignment outliers and better compliance with the Lewinnek safe zone, which are key indicators of proper implant alignment. Specifically, Lim et al,[15] and Tian et al,[18] highlighted the superiority of RATHA in achieving more accurate implant placement. These radiological differences suggest that RATHA may offer long-term benefits in terms of reducing complications such as implant malalignment or dislocation; however, the clinical implications of these findings were not fully realized in the PROMs.

Robotic systems require significant initial capital expenditure and ongoing maintenance, which can strain healthcare budgets, especially in resource-limited settings. RATHA's radiological precision may reduce the likelihood of revision surgeries or long-term complications, particularly benefiting younger, more active patients or those with complex anatomy. However, for older or lower-demand patients, where the emphasis is on immediate functional recovery and cost containment, COTHA remains an efficient and effective choice. While RATHA provides enhanced precision in implant placement, its clinical advantages over COTHA remain limited in the short to medium term, as evidenced by similar functional outcomes and operative efficiency favoring COTHA.

The risk of bias assessment using the Cochrane Risk of Bias Tool revealed variability in the methodological rigor of the studies. While several studies employed adequate randomization methods and ensured blinding of outcome assessors,[17,19] other studies lacked sufficient details on randomization and blinding procedures, introducing potential for selection and performance bias.[15,20] Furthermore, the non-randomized nature of studies heightened the risk of bias due to the lack of random sequence generation and allocation concealment.[21,22] The retrospective design in some studies also limited the strength of evidence, as recognized in Tian et al,[18] where the small sample size and lack of blinding may have influenced the results. Despite these limitations, the overall risk of selective reporting appeared low, as most studies provided comprehensive outcome data.

The studies included in this review had several strengths and limitations that shaped our findings. One notable strength is the diversity of study designs, including RCTs, retrospective cohort studies, and prospective analyses. This diversity has enable a comprehensive evaluation of clinical and radiological outcomes across different healthcare settings and patient populations. Most studies have been published within the last decade, ensuring relevance to current surgical practices and technologies, particularly RATHA. Furthermore, the international representation of studies, with contributions from Asia, the USA, the UK, and Italy, enhances the generalizability of the findings across various populations and healthcare systems. Robust outcome measures were another strength, with studies employing validated metrics, such as the HHS, WOMAC, and UCLA scores for clinical outcomes, along with specific radiological metrics, such as femoral stem alignment and compliance with the Lewinnek safe zone. This multidimensional approach provided a comprehensive evaluation of the performance of RATHA and COTHA. Additionally, a rigorous quality assessment using the Cochrane Risk of Bias Tool helped identify methodological strengths and weaknesses, ensuring transparency and reliability in the interpretation of the results. The review also emphasized RATHA's radiological precision, highlighting its potential long-term benefits, such as reduced complications and improved implant longevity.

Despite these strengths, this study had several limitations. The scarcity of high-quality RCTs is a significant drawback that reduces the ability to draw robust causal inferences. Nonrandomized designs, such as retrospective studies, are inherently more susceptible to bias and confounding factors. Additionally, the studies displayed significant heterogeneity in design, patient population, surgical techniques, robotic systems, and outcome measures, making data synthesis and comparison challenging. Many studies also lacked details on blinding and randomization procedures, increasing the risk of selection and performance bias. Small sample sizes and short follow-up durations are common, limiting the ability to evaluate long-term outcomes, such as implant survival and late complications. The potential for conflicts of interest was another concern, as some studies involved robotic systems developed by commercial entities that were not always disclosed or addressed transparently. Complications such as blood loss, infection rates, and revision rates have been inconsistently reported, potentially underestimating the associated risks. Moreover, the variability in the robotic platforms used, such as the ROBODOC, Mako, and ROSA systems, introduced technological inconsistencies, complicating the generalization of findings to all robotic-assisted surgeries. The review also excluded non-English studies, potentially omitting valuable data and introducing a language bias. Furthermore, reliance on published studies may have led to publication bias, as negative or inconclusive results are less likely to be reported. Finally, the studies focused more on short- and medium-term outcomes, with limited emphasis on long-term results, such as implant durability and patient satisfaction over time.

To mitigate these limitations, this review explicitly acknowledged the inclusion of non-RCTs and addressed their impact through transparent reporting and consistency analysis. A thorough risk of bias assessment highlighted potential methodological flaws, ensuring critical evaluation of the findings. The emphasis on consistent trends across studies reinforced the reliability of conclusions despite the variability in study designs. These mitigation strategies underscore the evolving nature of evidence in the field of RATHA and highlight the need for high-quality, large-scale, and long-term RCTs to validate the findings.

CONCLUSION

The comparison between RATHA and COTHA demonstrated that both techniques yielded similar clinical outcomes in terms of functional recovery and pain relief. However, RATHA shows a clear advantage in radiological precision, particularly in achieving a more accurate implant alignment, which could have long-term benefits. In contrast, COTHA was associated with shorter operative times, indicating greater procedural efficiency. While RATHA's precision may have benefits in specific clinical contexts, the decision between these two techniques should be tailored to the patient's needs, the surgeon's expertise, and available resources. The cost-effectiveness of RATHA depends on the long-term realization of its radiological benefits. The risk of bias assessment highlights the need for more rigorous and well-reported RCTs to better assess the comparative efficacy of these two techniques. Future large-scale, long-term studies are needed to evaluate whether RATHA's precision yields substantial clinical and economic benefits over time, guiding its integration into clinical practice.

Disclosure

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