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

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Abstract

Background: Hip osteoarthritis (OA) is a growing global health burden with an increasing demand for total hip arthroplasty, especially in older populations. Robotic-assisted total hip arthroplasty (RATHA) has emerged as a technological advancement that promises greater precision, improved implant alignment, and potentially better outcomes than conventional total hip arthroplasty (COTHA). This systematic review aimed to compare the clinical and radiological outcomes of RATHA and COTHA.

Methods: A systematic search was conducted in PubMed, Scopus, and Cochrane Library from their inception until August 31, 2024, adhering to the PRISMA guidelines. The inclusion criteria were randomized controlled trials (RCTs), 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 and cadaveric studies, studies on revision THA or high-grade hip dysplasia, and studies not published in English. Data were extracted and assessed using the Covidence systematic review software and Cochrane Risk of Bias Tool. Primary outcomes were clinical outcomes measured using patient-reported outcome measures (PROMs). The secondary outcomes were operative outcomes, complications and radiological assessment.

Results: Nine trials met the inclusion criteria, representing populations from Asia, the United States, the United Kingdom, and Italy. A total of 933 patients were assessed, 467 of whom underwent RATHA. There were no significant differences observed in PROMs. COTHA had shorter operative times, whereas RATHA showed potential in reducing hospital stay. 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 comparable 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.

Keywords: Robotic-assisted total hip arthroplasty (RATHA); conventional total hip arthroplasty (COTHA); Arthroplasty; Systematic review; Hip

Introduction

Hip osteoarthritis (OA) is a common and debilitating condition that imposes a significant health burden worldwide. The global incidence of hip osteoarthritis 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 in need of these procedures.[2,3] Total hip arthroplasty (THA) is an effective solution for treating hip osteoarthritis, 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 manual 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 place. In contrast, robotic-assisted total hip arthroplasty (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 the accuracy of implant positioning. Several robotic-assist systems have been developed for orthopaedic 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 smaller incision size. This can lead to reduced pain, faster recovery, and reduced scarring. They utilized imaging data to create a three-dimensional model of the anatomy of the patient. This allows surgeons to plan surgery more precisely beforehand, potentially leading to 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 percentage 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 to 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]

There are some drawbacks to RATHA. Robotic systems and their associated technologies can be expensive, potentially increasing the cost of the procedure for patients. Robotic surgery can sometimes take longer than conventional methods, especially for surgeons who are new to the technology. Surgeons require specialized training to effectively use robotic systems, which can involve a significant learning curve. While technology is constantly improving, there is always the potential for technical malfunctions or limitations that could affect the procedure. While 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

In conducting this systematic review, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[12] A comprehensive literature search was performed across three major databases—PubMed, Scopus, and the Cochrane Library—from their inception until August 31, 2024. Our search strategy included specific 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.

We applied specific inclusion and exclusion criteria to identify eligible studies. The inclusion criteria for this review were: (i) randomized controlled trials (RCTs), retrospective studies, prospective studies, and cohort studies comparing RATHA with COTHA; (ii) studies involving patients older than 18 years diagnosed with severe hip diseases such as osteoarthritis, avascular osteonecrosis, rheumatoid arthritis, and Paget's disease; (iii) all included patients had undergone total hip arthroplasty; and (iv) the studies provided data on both short- and long-term outcomes comparing RATHA with COTHA. We excluded studies based on the following criteria: (i) studies not published in English; (ii) case reports, case series, abstracts, review articles, systematic reviews, and meta-analyses; (iii) biomechanical or cadaveric studies; (iv) studies on revision total hip arthroplasty; (v) studies investigating patients with high-grade hip dysplasia; and (vi) studies with insufficient data to extract relevant information. Primary outcomes were clinical outcomes measured using patient-reported outcome measures (PROMs). The secondary outcomes were operative outcomes, complications and radiological assessment.

Including a mix of study designs such as case-control studies, retrospective cohort analyses, and prospective trials in this systematic review, 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, especially in areas where RCTs are limited or infeasible due to ethical, logistical, or financial constraints. For instance, in RATHA, RCTs may not be abundant 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 broader 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 large sample sizes and longer follow-up periods, contributing valuable insights into outcomes like 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, there are imitations of non-RCT studies. Non-RCTs are prone to selection bias, confounding variables, and retrospective reporting inaccuracies. There is also variability in study design, patient populations, and outcomes measured may complicate data synthesis and interpretation. Without randomization, non-RCTs may not establish causality as robustly as RCTs. The steps taken in this review to mitigating the limitations of non-RCT inclusion 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. We also did transparent reporting clearly stating in this review that non-RCTs were included to provide a more comprehensive assessment due to the limited number of RCTs. The potential biases and limitations in the interpretation of findings were mentioned considering the inclusion of non-RCTs. Lastly, 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 (first and second author) independently reviewed the titles, keywords, and abstracts of all studies identified in the search, using Covidence systematic review software to remove duplicates.[13] The full texts of eligible studies were independently reviewed to confirm their suitability. Both reviewers then 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 (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 COTHA, a variety of statistical methods were employed. Standardized mean differences (SMDs) with 95% confidence intervals (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 shortlisted 364 citations from the three databases. Out of this, 236 were removed from the study as they were duplicates. The remaining 128 studies were reviewed based on the selection criteria. Only 9 studies fulfilled all the selection criteria and were included in the qualitative analysis of this review. The screening process is detailed in the PRISMA flowchart (Figure 1). Table 1 provides a detailed characteristics of all the included trials. We included 9 trials published over 9 years from 2015 to 2024. These trials were conducted mainly in Asia (n=5),[15-19] followed by the United States (n=2),[20,21] the United Kingdom (n=1)[22] and Italy (n=1).[23] The sample sizes of these trails ranged from 54 to 176 hips and follow up time ranged between 3 months to 14 years. Two studies were secondary analyses of the same patient population at longer follow up periods.[16,20] The age of samples sizes across the studies ranged from 32 to 85 years old. A total of 933 patients were assessed, 467 of whom underwent RATHA.

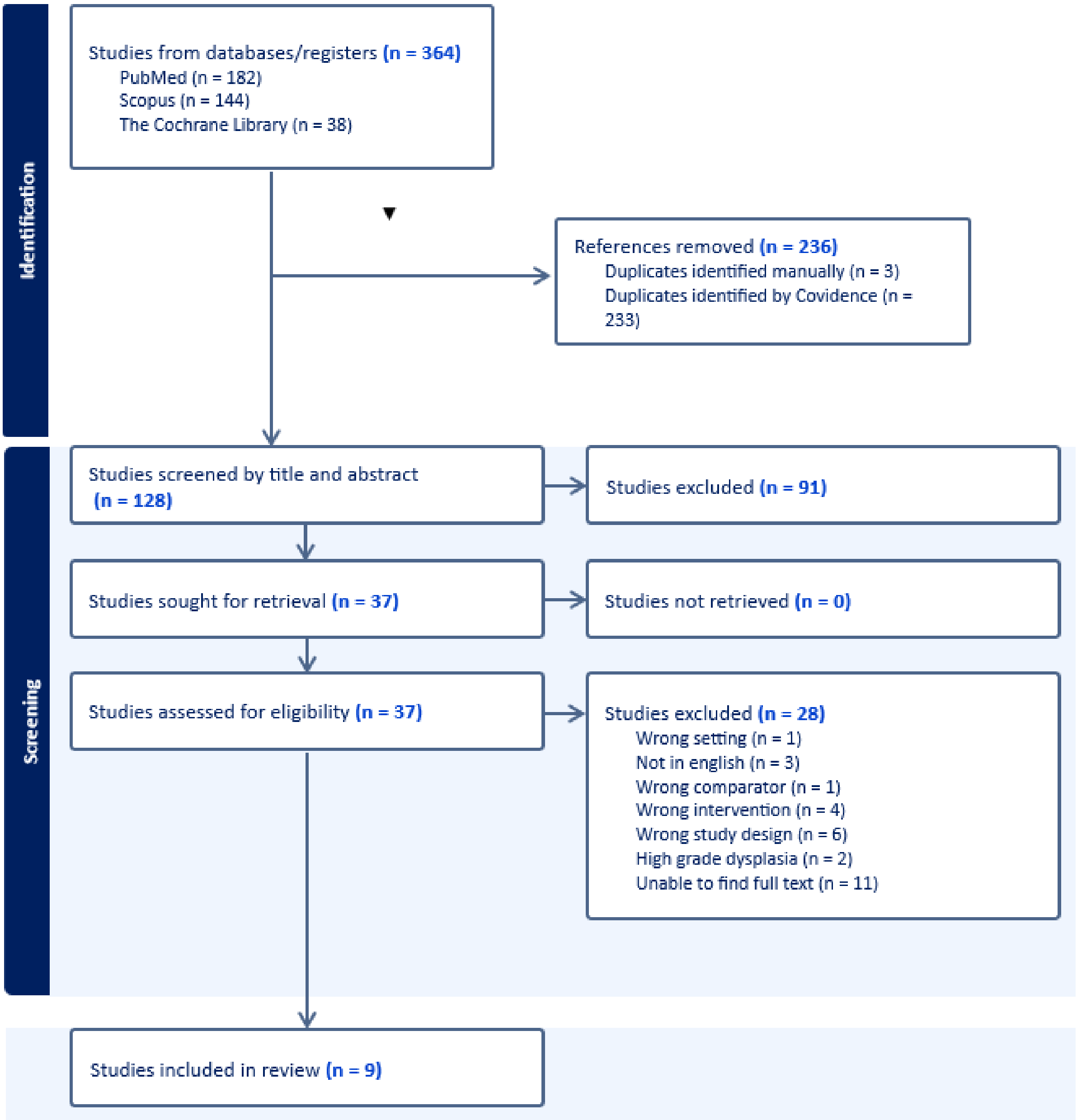


Figure 1: Prisma flow chart.

Table 1: Characteristics of included trials.

Author & 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	United States	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	United Kingdom	Prospective cohort study	N = 100 RATHA = 50	MAKO	36 months	Yes

			COTHA = 50			
Tian 2023	China	Retrospective cohort study	N = 143 RATHA = 63 COTHA = 80	Seven-axis robot-assisted THA system	3 months	Yes
Xu 2023	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
Allesio-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.

The ROBODOC systems (Integrated Surgical Systems or Curexo Technology Corp., CA, USA) was used in 3 studies.[15,16,20] The Mako Robotic-Arm assisted total hip ™, Stryker Corp, USA) was employed in 2 studies.[22,23] One study utilized the ROSA® Total Hip System (Zimmer CAS, Montreal, Canada).[21] The 3 Chinese studies all used different robotic platforms which included the Seven-axis robot-assisted THA system (Jianjia, Hangzhou Jianjia Robot Co., Ltd.),[18] Single semiactive surgical robot (YUANHUA-THA),[17] LANCET robotic system (Hangzhou Lancet Robo Co. Ltd).[19] Table 2 illustrates the outcome level for risk of bias of included trials.

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

Study & Year	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 2023	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

Primary outcomes were clinical outcomes measured using PROMs. Table 3 summarizes the PROMs which includes the Harris Hip Score (HSS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score and the University of California-Los Angeles (UCLA) score which was evaluated in this systematic review. The HSS was evaluated in four studies.[17-19,23] The WOMAC score was evaluated in three studies.[15,17,20] The UCLA was evaluated in three studies.[20-22] In summary, all comparisons in the forest plot for

PROMs which includes the HSS, the WOMAC and UCLA score (Figure 2a,b,c) show confidence intervals crossing zero, meaning there is no statistically significant difference between the RATHA and COTHA groups, either preoperatively or at the end of treatment.

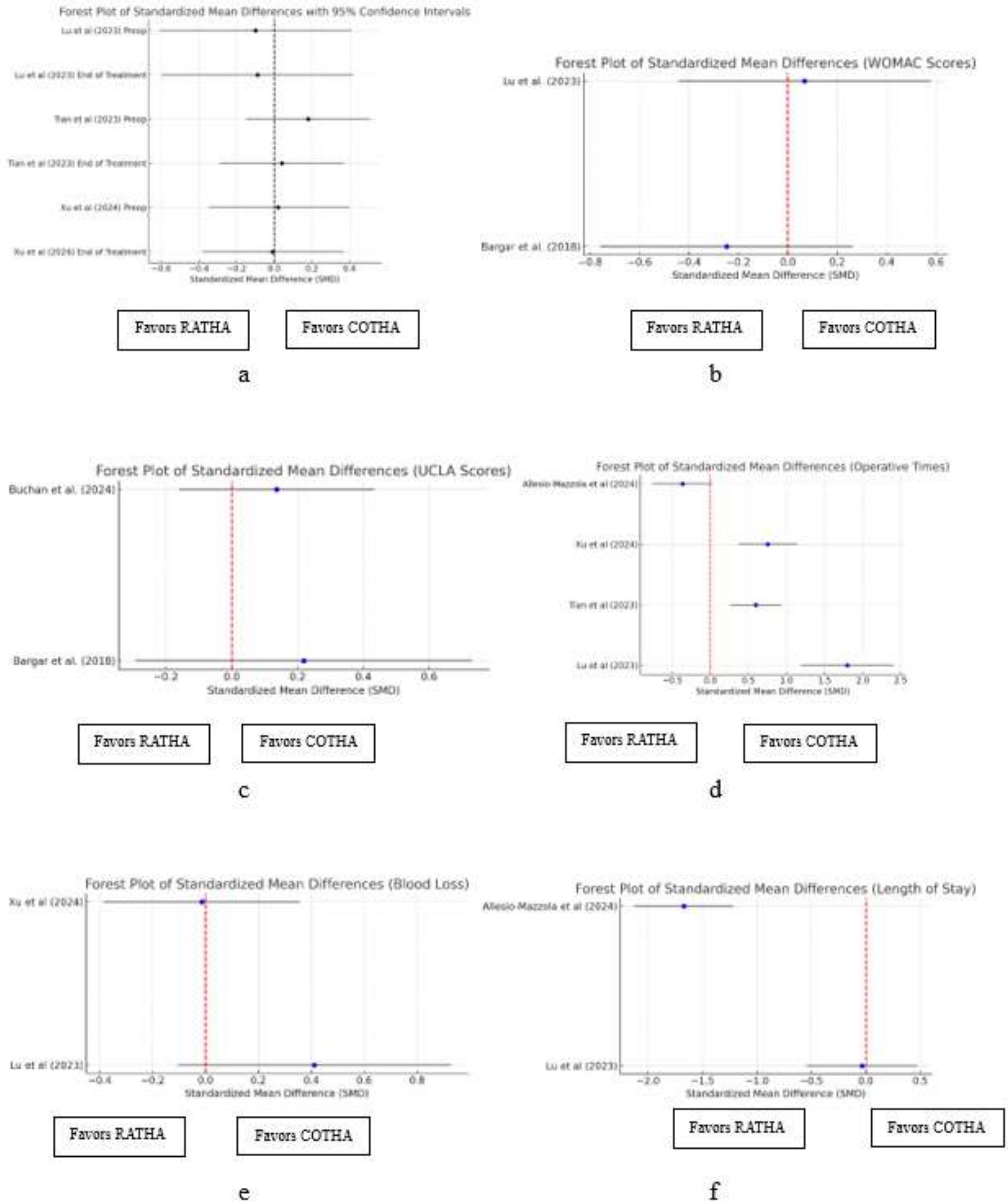
Table 3: Patient-reported outcome measures (PROMs) of included trials.

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

*RATHA: Robotic assisted total hip arthroplasty. COTHA: Conventional total hip arthroplasty. HSS: Harris Hip Score. WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index. UCLA: University of California-Los Angeles. SMD: Standardized mean differences. 95% CI: 95% confidence intervals. SD: Standard deviation.; *level of significance set at p<0.05*

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 across four studies.[17-19,23] Lu et al,[17] shows the largest SMD of 1.80, significantly favouring COTHA with shorter operative times. Tian et al,[18] and Xu et al,[19] also show moderate SMDs (0.60 and 0.75, respectively), both favouring COTHA with statistically significant differences. However, Allesio-Mazzola et al,[23] has a small SMD (-0.37), with a confidence interval 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] shows a small positive SMD (0.41), suggesting that RATHA may have slightly higher blood loss compared to COTHA, but the confidence interval crosses zero, indicating no statistically significant difference. Xu et al,[19] shows a near-zero SMD (-0.01), with the confidence interval also crossing zero, indicating no meaningful difference in blood loss between the two techniques. Overall, both studies suggest 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] shows an SMD of -0.037, with a confidence interval crossing zero, indicating no significant difference in length of stay between the two procedures. In contrast, Allesio-Mazzola et al,[23] shows a large negative SMD of -1.67, with the confidence interval entirely below zero, suggesting that RATHA is associated with a significantly shorter length of stay compared to COTHA. Overall, the results indicate that while Lu et al,[17] found no difference, Allesio-Mazzola et al,[23] found RATHA to reduce hospital stay duration significantly.



RATHA: Robotic assisted total hip arthroplasty. COTHA: Conventional total hip arthroplasty.

Figure 2: Forest plot of showing clinical outcome (a) Harris Hip Score (HSS), (b) Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, (c) University of California-Los Angeles (UCLA) score, (d) operative times, (e) intraoperative blood loss, (f) length of stay between RATHA and COTHA.

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 discrepancy, operative time, blood loss, and length of stay. Overall, the results suggest that there is no significant difference between RATHA and COTHA in terms of most of the complications studied. 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 4: Summary of revision rates, infection, dislocation, limb length discrepancy, blood loss intraoperatively, length of stay and operative time of included trials.

	Lim 2015	**Bargar 2018**	**Nakamura 2018**	**Lu 2023**	**Tian 2023**	**Xu 2024**	**Allesio-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	Mean (range)				Mean ± SD	Mean ± SD	Mean ± SD
Discrepancy (mm)	1.9 (0–6.4)				6.0 ± 5.0	2.27 ± 4.19	0.6 ± 1.4
- RATHA	4.9 (0–16)				8.09 ± 4.33	1.29 ± 4.33	0.4 ± 1.4
- COTHA	0.011*				0.000*	0.2538	0.572
- P Value					-0.448	0.229	0.143
- SMD					-0.772, -0.124	-0.102, 0.56	-0.251, 0.537
- 95% CI							
Blood loss (ml)	Mean (range)			Mean ± SD		Mean ± SD	
- RATHA	1010 (610–			1280.30 ± 404.01		163.8 ± 118.5	
- COTHA	1800)			1094.86 ± 494.39		165.5 ± 113.4	
- P Value	895 (410–			0.137		0.9384	
- SMD	1370)			0.411		-0.015	
- 95% CI	0.271			-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. 95% CI: 95% confidence intervals. SD: Standard deviation.; *level of significance set at p<0.05*

Table 5 presents the results of several studies comparing the radiological outcomes of RATHA and COTHA.[15,18,19,23] The studies examined femur stem alignment outliers, stem appropriate size, cup malalignment, Lewinnek safe zone, and global offset. Overall, the results suggest that there is no significant difference between RATHA and COTHA in terms of most of the radiological outcomes studied. Both procedures have similar rates of femur 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 Allesio-Mazzola et al.[23] The Lewinnek safe zone was also slightly higher for RATHA patients in both studies.

Table 5: Summary of radiological outcomes of included trials.

	Lim 2015	**Tian, 2023**	**Xu 2024**	**Allesio- Mazzola 2024**
Femur stem alignment				
Outlier (>±3º)	0/24			0/50
- RATHA	6/25			1/50
- COTHA	0.022*			0.485
- P Value				
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 (Interquartile range)	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. SD: Standard deviation; *level of significance set at $p<0.05$*

Discussion

This review highlights that RATHA and COTHA yield comparable clinical outcomes in terms of PROMs and no significant differences in complications, a finding consistently reported in previous systematic reviews.[20,22,24-27] COTHA demonstrated shorter operative times, reflecting greater procedural efficiency, as has been well-documented in prior 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 existing 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] Osteoarthritis is the most common cause of arthritis worldwide, being almost a universal problem in people aged 65 years or older.[29] There is a growing need to properly understand the benefits of robotic joint arthroplasty. This systematic review evaluated the comparative performance of RATHA and COTHA across clinical and radiological 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, length of hospital stay), radiological precision (femoral stem alignment, cup malalignment, stem appropriateness, Lewinnek safe zone compliance, and global offset.

The clinical outcomes assessed through the HHS, WOMAC score, and UCLA score 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 demonstrated by the significant reduction in stay duration in Allesio-Mazzola et al,[23] though 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 showed that RATHA was associated with fewer femur 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, although 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, potentially 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, such as Lu et al,[17] and Xu et al,[19] employed adequate randomization methods and ensured blinding of outcome assessors, other studies, particularly Bargar et al,[20] and Lim et al,[15] lacked sufficient details on randomization and blinding procedures, introducing potential for selection and performance bias. Furthermore, the non-randomized nature of studies like Fontalis et al,[22] and Buchan et al,[21] heightened the risk of bias due to the lack of random sequence generation and allocation concealment. 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 allowed for a comprehensive evaluation of the 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 United States, the United Kingdom, and Italy, enhances the generalizability of the findings across various populations and health care 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, which increased 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 published. Lastly, 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. 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

In 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 terms of 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 offer benefits in specific clinical contexts, the decision between these two techniques should be tailored to the patient's needs, surgeon's expertise, and available resources. The cost-effectiveness of RATHA hinges 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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