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REVIEW ARTICLE

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Robotics-assisted versus conventional manual approaches for total hip arthroplasty: A systematic review and meta-analysis of comparative studies

Peng-fei Han[1*] | Cheng-long Chen[1*] | Zhi-liang Zhang[1] | Yi-chen Han[2] | Lei Wei[3] | Peng-cui Li[1] | Xiao-chun Wei[1]

[1] Department of Orthopaedics, The Second Hospital of Shanxi Medical University, Shanxi Key Laboratory of Bone and Soft Tissue Injury Repair, Taiyuan, China

[2] Department of Upper School, Subsidiary High School of Taiyuan Normal University, Taiyuan, China

[3] Department of Orthopaedics, The Alpert Medical School of Brown University, Providence, Rhode Island

Correspondence
Peng-cui Li, The Second Hospital of Shanxi Medical University, 382 Wuyi Road, Taiyuan 030001, China.
Email: lpc1977@163.com

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Abstract

Background: Several studies have compared robotics-assisted (RA) and conventional manual (CM) approaches for total hip arthroplasty (THA), but their results are controversial.

Methods: A literature search was conducted for controlled clinical trials (CCTs) comparing the clinical efficacy of the RA and CM approaches for THA and published between August 1998 and August 2018. The obtained data were analyzed using the statistical software Review Manager 5.3.

Results: Fourteen articles were included in the meta-analysis, which revealed that the RA group had less intraoperative complications, better cup angle, and more cases of cup placement in the safe zone than the CM group. However, the operation time required for the CM group was less than that required for the RA group. Moreover, postoperative complications (eg, dislocation and revision surgery) were less frequent in the CM group than in the RA group. However, the two groups had similar functional scores, total number of complications, and rate of occurrence of limb length discrepancy.

Conclusion: Compared with the CM approach, the RA approach yields better radiological outcomes and fewer intraoperative complications in THA, but similar functional scores.

KEYWORDS

conventional, manual, meta-analysis, robotics-assisted, total hip arthroplasty

1 | INTRODUCTION

Total hip arthroplasty (THA) is an effective method for the management of severe hip joint disorders.[1] Precise placement of cups and femoral stems is crucial to the efficacy of THA.[2] Improper or inaccurate placement of the prosthesis results in early postoperative prosthetic impact and dislocation, leading to serious complications, such as loosening of the prosthesis, over the course of time.[3,4] Accurate placement of the cups and femoral stems minimizes the risk of complications and improves functional outcomes. However, this accuracy is difficult to achieve with the conventional manual (CM) approach.

*Peng-fei Han and Cheng-long Chen were considered as co-first authors.

Computer-assisted orthopedic surgery (CAOS) is being performed since the last 30 years. In the 1980s, CAOS was first performed for artificial total hip replacement, which greatly improved the accuracy of THA.[5] The existing CAOS technologies can be broadly categorized into image-guided (based on computed tomography [CT] or X-ray fluoroscopy) or imageless navigation systems, positioning systems (patient-specific models, self-positioning robots, etc), and semi-active or active robotics-assisted (RA) systems.[6,7] The advances in computer and artificial intelligence technology have resulted in parallel developments in RA-THA.[8,9] In 1992, the first clinical trial approved by the Food and Drug Administration found that a RA-THA system (ROBODOC, a custom industrial semi-active robot system) achieved clinical results comparable with those of traditional techniques, without the occurrence of the complications such as femoral fractures.[10]

Both the manual and computer-assisted methods of THA have been compared in many clinical trials; however, most of these studies have small sample sizes. The choice between the CM and RA approach for THA remains controversial. Some studies indicate that the higher accuracy achieved with the RA system translates into a lower rate of implant failure, which in turn means better clinical results. However, others believe that RA-THA requires a larger operating space and longer operation time, which may increase the probability of postoperative infection.[11] Moreover, the need for wider exposure of the proximal femur and placement of the leg in maximal hip adduction and external rotation during RA operation may injure the hip abductors significantly.[12] In this study, we aim to systematically compare the differences between the CM and RA methods of THA through a meta-analysis, in order to gain some theoretical insights that may guide clinical practice.

2 | MATERIALS AND METHODS

2.1 | Search strategy

We searched for controlled clinical trials (CCTs), including randomized controlled studies (RCTs) and retrospective case studies, that compared the RA and CM approaches for THA. We searched the following databases for relevant entries made between August 1998 and August 2018: Embase, PubMed, Cochrane Library, Central, Cinahl, PQDT, CNKI, CQVIP, WanFang Data, and Chinese Biomedical Database. In addition, the reference lists of the relevant studies were manually searched for more articles. No language restriction was applied in the search. The key words used for the database search were as follows: “robotics assisted,” “conventional,” “manual,” “total hip arthroplasty,” and “THA.” The following combinations were used for the search: “total hip arthroplasty” or “THA” and “robotics assisted” and “conventional” or “manual.” The literature searches were performed by two reviewers, and a third reviewer was consulted in case of any difference in opinion.

2.2 | Inclusion criteria

Inclusion criteria for the analysis were as follows: (a) articles published after August 1998; (b) reports on RCTs, prospective studies, retrospective studies, and cohort studies; (c) patients aged greater than 18 years and diagnosed with severe hip disease (eg, osteoarthritis, developmental dysplasia of the hip, avascular osteonecrosis, rheumatoid arthritis, and Paget's disease); (d) THA performed for all patients; and (e) data provided on the short- and long-term outcomes, with comparison of the RA and CM approaches (Table 1).

2.3 | Exclusion criteria

Studies that met the following criteria were excluded from the study: (a) case report or series; (b) meta-analysis, biomechanical or kinematic studies, review articles, or in vitro studies; (c) studies with patient overlap from other qualifying studies or animal studies; (d) studies including patients aged less than 18 years or patients with spinal deformities, tumors, or infections; (e) studies without a nonrobot control group; (f) studies with incomplete data; and (g) study objective or intervention measures that failed to meet the inclusion criteria (Table 1).

2.4 | Data extraction and quality assessment

The selection of the studies was undertaken independently by two reviewers according to the abovementioned eligibility criteria. Disagreement between the two reviewers was resolved by mutual discussion or by consulting a third reviewer, when necessary. The risk-of-bias assessment tool outlined in the Cochrane Handbook was used to measure the methodological quality of the RCTs. Six domains were evaluated: random sequence generation, allocation concealment, blinding of patients and personnel, blinding of outcome assessment,

TABLE 1 Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Articles published after August 1998	Case report or series
RCTs, prospective studies, retrospective studies, and cohort studies	Meta-analysis, biomechanical or kinematic studies, review articles, or in vitro studies
Patients >18 years old	Patients <18 years old
Patients diagnosed with severe hip disease (osteoarthritis, developmental dysplasia of the hip, avascular osteonecrosis, rheumatoid arthritis, Paget's disease, etc)	Study with patient overlap from other qualifying studies or animal studies
All patients underwent for THA	Inclusion of patients with spinal deformities, tumors, or infections
Reporting of short- and long-term outcomes	No non-robot control group or studied with incomplete data
Study compared results of robotic-assisted and conventional manual approach	Study objective or intervention measures failed to meet the inclusion criteria

Abbreviations: RCT, randomized controlled studies; THA, total hip arthroplasty.

incomplete outcome data, and selective reporting risk. The modified Jadad scale was used to assess the quality of cohort studies. Data from the studies were obtained for several parameters: first author's name, published year, sample size of RA and CM approach for THA, duration of follow-up, functional scores, complications, cup angle, cup placement in the safe zone, stem alignment, leg length discrepancy (LLD), and operation time.

2.5 | Statistical analysis

The extracted data were independently entered into Review Manager 5.3 (Cochrane Collaboration, Oxford, UK) by two reviewers. Dichotomous outcomes were expressed in terms of odds ratio (OR), and the weighted mean difference (WMD) was used for continuous outcomes, both with 95% confidence intervals (95% CI). Heterogeneity was tested using both the chi-square test and I^2 test. A fixed-effects model was chosen when there was no statistical evidence of heterogeneity ($I^2 < 50\%$), while the random-effects model was adopted if significant heterogeneity was found. If heterogeneity was detected, we checked the study population, treatment, outcome, and methodology of the study to determine the source of heterogeneity. If it could not be quantitatively synthesized or if the event rate was too low to measure, we used qualitative evaluation. A funnel plot was applied to assess the presence of publication bias.

3 | RESULTS

3.1 | Study characteristics

A total of 249 potentially relevant articles were identified. After screening all the titles and abstracts, 215 studies were excluded from further analysis. After reading the full-text of the remaining 34 studies, 14 studies, comprising 2324 patients, were found to meet all the inclusion criteria (Figure 1). The study quality was assessed by using the modified Jadad scale. As per this scale, the total score was 7 points, with scores of above 4 indicating high quality and those below 3 indicating medium quality. Among the 14 enrolled studies, 12 were of high quality, while two were of medium quality (Tables 2 and 3).

3.2 | Surgical aspects

3.2.1 | Operation time

Eight of the included trials have compared the operation time in the RA and CM procedures. The random effects model was used for the

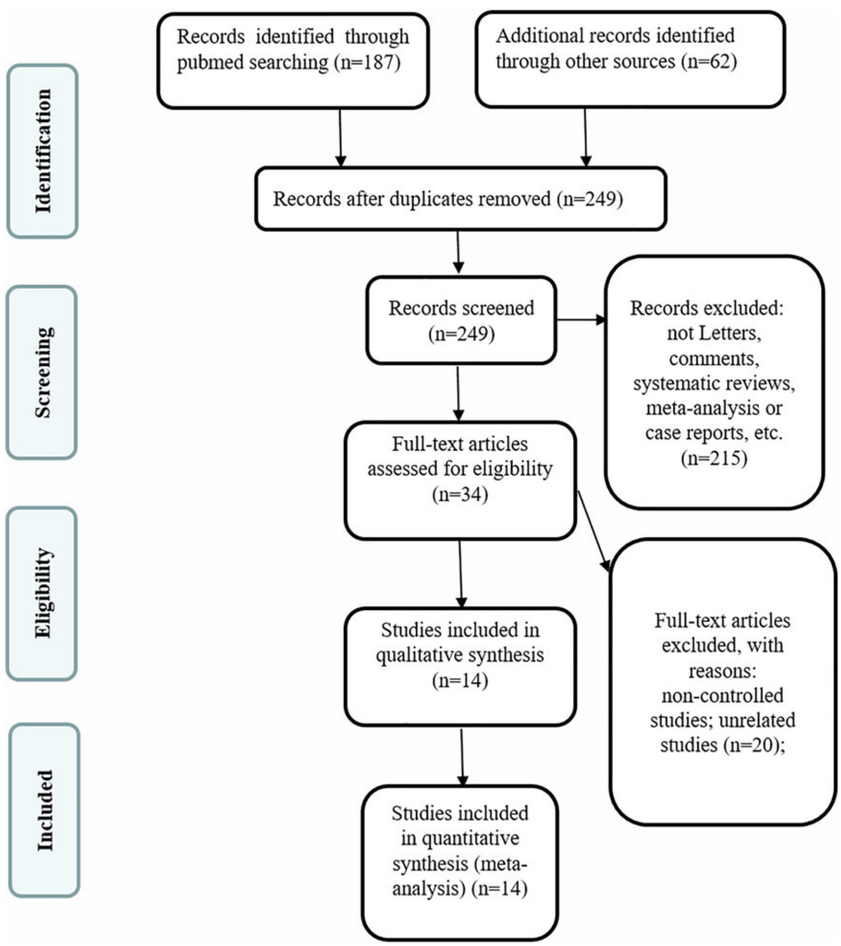

FIGURE 1 Flow diagram of search strategy

TABLE 2 Demographic characteristics of included studies

Author	Study Design	Year	Group	Hips	Age (y)	Gender (M/F)	Outcomes	Modified Jadad Scale
Bargar[13]	Randomized	1998	RA CM	65 62	-	-	(2)	6
Bargar[14]	Randomized	2017	RA CM	45 22	59.1 ± 8.2 59.8 ± 9.4	35/10 12/10	(1)	6
Bitar[15]	Retrospective	2015	RA CM	67 55	60.2 ± 9.6 55.3 ± 9.3	29/38 23/36	(6)	3
Domb[16]	Retrospective	2014	RA CM	50 50	56.8 ± 7.9 56.7 ± 8.1	19/31 19/31	(2), (3), (4), and (7)	5
Domb[17]	Retrospective	2015	RA CM	135 708	58.68 ± 10.82 64.75 ± 11.99	-	(3), (4), and (6)	3
Hananouchi[18]	Retrospective	2007	RA CM	31 27	56.7 ± 9.2 57.4 ± 7.1	-	(1), (2), and (5)	5
Honl[19]	Randomized	2003	RA CM	61 80	71.5 ± 7.1 70.7 ± 8.3	24/37 24/56	(1), (2), (5), and (7)	7
Kamara[20]	Retrospective	2017	RA CM	98 198	-	45/53 93/105	(2), (3), (4), and (7)	5
Lim[21]	Randomized	2015	RA CM	24 25	51.2(19–67) 45.6(21–65)	11/13 13/12	(1), (2), (5), (6), and (7)	7
Nakamura[22]	Retrospective	2009	RA CM	40 78	57(39–84)	-	(2), (5), and (7)	5
Nakamura[23]	Randomized	2010	RA CM	75 71	57 ± 10 58 ± 9	13/56 10/51	(2), (6), and (7)	6
Nishihara[24]	Randomized	2006	RA CM	78 78	58 (27–81) 58 (29–77)	14/64 14/64	(1), (2), (5), and (7)	7
Siebel[25]	Retrospective	2005	RA CM	36 35	58.9 ± 8.9 60.6 ± 7.0	21/15 19/16	(1), (2), and (7)	5
Tsai[26]	Retrospective	2015	RA CM	12 14	61.4 ± 8.9 58.7 ± 7.5	2/10 7/7	(3), (4), and (5)	5

Abbreviations: CM, conventional manual; RA, robotic-assisted. Outcomes: (1) Functional scores; (2) Complication; (3) Cup angle; (4) Safe zone of cup; (5) Stem alignment; (6) Leg length discrepancy; (7) Operation time.

TABLE 3 Robot type and author country

Author	Robot Type	Country
Bargar[10]	Robodoc integrated surgical system	Germany
Bargar[13]	Robodoc integrated surgical system	United States
Bitar[14]	MAKO interactive orthopaedic system	United States
Domb[15]	MAKO interactive orthopaedic system	United States
Domb[16]	MAKO interactive orthopaedic system	United States
Hananouchi[17]	Robodoc integrated surgical system	Japan
Honl[18]	Robodoc integrated surgical system	Germany
Kamara[19]	MAKO interactive orthopaedic system	United States
Lim[20]	Robodoc integrated surgical system	South Korea
Nakamura[7]	Orthodoc integrated surgical system	Japan
Nakamura[21]	Orthodoc integrated surgical system	Japan
Nishihara[22]	Orthodoc integrated surgical system	Japan
Siebel[23]	CASPAR integrated surgical system	Germany
Tsai[24]	MAKO interactive orthopaedic system	United States

meta-analysis because of significant heterogeneity between the studies (I^2 = 88%). The results showed that the operation time required for the CM group was less than that required for the RA group (95% CI [7.50-33.94], *P* = 0.002; see Figure 2).

3.2.2 | Complications

We divided the data on complications into eight subgroups for comparison between the two methods. The subgroups were as follows: intraoperative femoral fracture or cracks, postoperative complications (nerve palsy, thigh pain, knee pain, dislocation, or heterotopic ossification), revision surgery, and the total number of complications. Ten trials were included for this comparison, and intraoperative or postoperative complications between the RA and CM groups were compared. The fixed effects model was used for the meta-analysis because the heterogeneity between the studies and subgroups was not significant (I^2 < 50%). The results of the analysis showed that intraoperative complications (95% CI [0.14-0.72], *P* = 0.006) in RA group

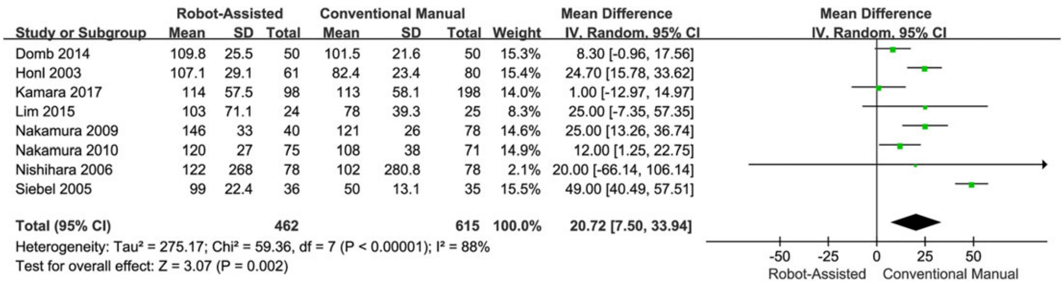

FIGURE 2 Forest plot to assess operation time between two procedures

were less frequent than that in the CM group. However, the CM group has less cases of dislocation (95% CI [1.12-4.67], $P = 0.02$) and revision (95% CI 1.11-7.50], $P = 0.03$) compared with the RA group. Moreover, there were no statistical differences between the two procedures in terms of the total number of complications (95% CI [0.49-1.40], $P = 0.48$; see Figure 3).

3.3 | Functional outcome

A total of six trials were included, and the postoperative clinical outcome of THA in the RA and CM groups were compared. The data were categorized into three groups depending on whether the Harris Hip Score (HHS), Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index, or the Merle D' Aubigne Hip Score was used for comparison. Because the heterogeneity between the studies and subgroups was significant ($I^2 > 50\%$), the random effect model was employed in the meta-analysis. The results indicated that there was no statistical difference between the two procedures with respect to the HHS score (95% CI [−3.70-3.78], $P = 0.98$), WOMAC index (95% CI [−5.42-1.99], $P = 0.36$), or Merle D' Aubigne hip score (95% CI [−0.56-0.68], $P = 0.86$; Figure 4).

3.4 | Radiographic outcomes

3.4.1 | Cup angle

Four of the included trials compared the postoperative cup angle in the RA and CM groups. According to the inclination and anteversion, radiological data were divided into two subgroups. The random effects model was employed in the meta-analysis because of significant heterogeneity between the studies and subgroups ($I^2 > 50\%$). The results showed that the RA group had better cup inclination than the CM group (95% CI [−4.07-0.86], $P = 0.003$), but had similar degrees of cup anteversion (95% CI [−7.68-4.41], $p = 0.60$); however, the intergroup difference in the degree of cup inclination was not statistically significant (see Figure 5).

3.4.2 | Safe zone of cup

According to the criteria used to define the safety zone (Lewinnek et al or Callanan et al), the radiological data were divided into two subgroups. Four trials compared the RA and CM groups in terms of the incidence of cup placement in the safe zone. A fixed effect model was employed in the meta-analysis because the heterogeneity between the studies and subgroups was not significant ($I^2 < 50\%$). The results showed that the RA group had a significantly greater number of cases of cup placement in the safe zone as compared with the CM group (95% CI [6.34-12.35], $P < 0.001$; see Figure 6).

3.4.3 | Stem alignment

Six of included studies compared the RA and CM procedures in terms of stem alignment. Since the heterogeneity between the studies was significant ($I^2 > 50\%$), the random effects model was used for the meta-analysis. The results showed that stem alignment in the RA group was significantly better than that in the CM group (95%CI [−0.72-0.08], $P = 0.02$; see Figure 7).

3.4.4 | Leg length discrepancy

Four studies compared the cases of LLD in the RA and CM procedures. The fixed effect model was employed in meta-analysis since there was no significant heterogeneity ($I^2 = 28\%$). The results showed that the occurrence of LLD was similar in the two groups (95% CI [0.43-1.28], $P = 0.28$), and the difference was not statistically significant (Figure 8).

4 | PUBLICATION BIAS

All the 14 studies included in this meta-analysis were evaluated through a strict quality assessment. Six of them were RCTs, while the remaining eight were CCTs. Therefore, the possibility of a bias was low. However, the funnel figure showed that there was a slight bias; this may be associated with the incomplete collection of relevant literature, insufficient sample size, and differences in the level of expertise of the surgeons. Further, sensitivity analysis showed a good overall result (Figures 9 and 10).

5 | DISCUSSION

CAOS relies on a variety of imaging modes (radiography, MRI, CT, etc), real-time tracking, and various robotics technologies.[6,25] The fundamental concepts and technical elements of CAOS emerged in the mid

Study or Subgroup	Robot-Assisted Events	Robot-Assisted Total	Conventional Manual Events	Conventional Manual Total	Weight	Odds Ratio M-H, Fixed, 95% CI
2.1.1 Intraoperative complication						
Bargar 1998	0	65	3	62	3.4%	0.13 [0.01, 2.56]
Domb 2014	1	50	0	50	0.5%	3.06 [0.12, 76.95]
Hananouchi 2007	0	31	2	27	2.5%	0.16 [0.01, 3.53]
Kamara 2017	0	98	3	198	2.2%	0.28 [0.01, 5.54]
Lim 2015	0	24	2	25	2.3%	0.19 [0.01, 4.21]
Nakamura 2009	2	40	0	78	0.3%	10.19 [0.48, 217.59]
Nakamura 2010	0	75	5	71	5.4%	0.08 [0.00, 1.48]
Nishihara 2006	0	78	5	78	5.2%	0.09 [0.00, 1.57]
Siebel 2005	0	36	2	35	2.4%	0.18 [0.01, 3.96]
Subtotal (95% CI)		**497**		**624**	**24.2%**	**0.32 [0.14, 0.72]**
Total events	3		22			
Heterogeneity: Chi² = 9.24, df = 8 (P = 0.32); I² = 13%						
Test for overall effect: Z = 2.78 (P = 0.006)						
2.1.2 Nerve palsy						
Bargar 1998	2	65	0	62	0.5%	4.92 [0.23, 104.58]
Nakamura 2009	1	40	0	78	0.3%	5.96 [0.24, 149.72]
Siebel 2005	1	36	0	35	0.5%	3.00 [0.12, 76.16]
Subtotal (95% CI)		**141**		**175**	**1.3%**	**4.47 [0.72, 27.90]**
Total events	4		0			
Heterogeneity: Chi² = 0.09, df = 2 (P = 0.95); I² = 0%						
Test for overall effect: Z = 1.60 (P = 0.11)						
2.1.3 Thigh pain						
Nakamura 2009	0	40	1	78	1.0%	0.64 [0.03, 16.01]
Nakamura 2010	1	75	4	71	3.9%	0.23 [0.02, 2.08]
Nishihara 2006	4	78	11	78	10.0%	0.33 [0.10, 1.08]
Subtotal (95% CI)		**193**		**227**	**14.8%**	**0.32 [0.12, 0.87]**
Total events	5		16			
Heterogeneity: Chi² = 0.27, df = 2 (P = 0.87); I² = 0%						
Test for overall effect: Z = 2.23 (P = 0.03)						
2.1.4 Knee pain						
Nakamura 2009	0	40	2	78	1.6%	0.38 [0.02, 8.06]
Nakamura 2010	2	75	0	71	0.5%	4.86 [0.23, 103.09]
Subtotal (95% CI)		**115**		**149**	**2.1%**	**1.40 [0.25, 7.78]**
Total events	2		2			
Heterogeneity: Chi² = 1.34, df = 1 (P = 0.25); I² = 26%						
Test for overall effect: Z = 0.38 (P = 0.70)						
2.1.5 Dislocations						
Bargar 1998	4	65	4	62	3.7%	0.95 [0.23, 3.98]
Honl 2003	11	61	3	80	2.0%	5.65 [1.50, 21.25]
Kamara 2017	1	98	1	198	0.6%	2.03 [0.13, 32.82]
Nakamura 2009	0	40	2	78	1.6%	0.38 [0.02, 8.06]
Nakamura 2010	4	75	1	71	0.9%	3.94 [0.43, 36.17]
Siebel 2005	2	36	1	35	0.9%	2.00 [0.17, 23.11]
Subtotal (95% CI)		**375**		**524**	**9.8%**	**2.28 [1.12, 4.67]**
Total events	22		12			
Heterogeneity: Chi² = 4.81, df = 5 (P = 0.44); I² = 0%						
Test for overall effect: Z = 2.26 (P = 0.02)						
2.1.6 Heterotopic ossification						
Hananouchi 2007	1	31	1	27	1.0%	0.87 [0.05, 14.56]
Honl 2003	6	61	8	80	6.0%	0.98 [0.32, 2.99]
Nakamura 2010	5	75	3	71	2.8%	1.62 [0.37, 7.04]
Siebel 2005	11	36	6	35	4.0%	2.13 [0.69, 6.58]
Subtotal (95% CI)		**203**		**213**	**13.8%**	**1.44 [0.74, 2.80]**
Total events	23		18			
Heterogeneity: Chi² = 1.06, df = 3 (P = 0.79); I² = 0%						
Test for overall effect: Z = 1.06 (P = 0.29)						
2.1.7 Revision						
Honl 2003	9	61	2	80	1.4%	6.75 [1.40, 32.50]
Kamara 2017	2	98	4	198	2.5%	1.01 [0.18, 5.61]
Siebel 2005	2	36	1	35	0.9%	2.00 [0.17, 23.11]
Subtotal (95% CI)		**195**		**313**	**4.8%**	**2.88 [1.11, 7.50]**
Total events	13		7			
Heterogeneity: Chi² = 2.65, df = 2 (P = 0.27); I² = 24%						
Test for overall effect: Z = 2.17 (P = 0.03)						
2.1.8 Total complication						
Bargar 1998	9	65	9	62	7.6%	0.95 [0.35, 2.57]
Domb 2014	1	50	0	50	0.5%	3.06 [0.12, 76.95]
Kamara 2017	2	98	7	198	4.3%	0.57 [0.12, 2.79]
Lim 2015	0	24	2	25	2.3%	0.19 [0.01, 4.21]
Nakamura 2009	3	40	5	78	3.0%	1.18 [0.27, 5.23]
Nakamura 2010	7	75	10	71	8.9%	0.63 [0.23, 1.75]
Siebel 2005	4	36	3	35	2.6%	1.33 [0.28, 6.44]
Subtotal (95% CI)		**388**		**519**	**29.2%**	**0.83 [0.49, 1.40]**
Total events	26		36			
Heterogeneity: Chi² = 2.63, df = 6 (P = 0.85); I² = 0%						
Test for overall effect: Z = 0.71 (P = 0.48)						
Total (95% CI)		**2107**		**2744**	**100.0%**	**1.01 [0.77, 1.33]**
Total events	98		113			
Heterogeneity: Chi² = 43.69, df = 36 (P = 0.18); I² = 18%						
Test for overall effect: Z = 0.09 (P = 0.93)						
Test for subgroup differences: Chi² = 26.75, df = 7 (P = 0.0004), I² = 73.8%						

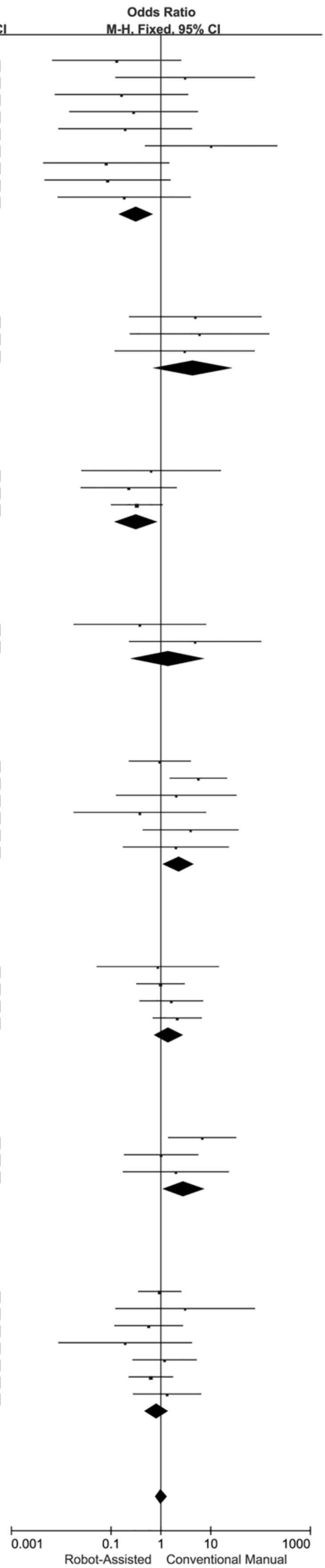

FIGURE 3 Forest plot to assess complication between two procedures

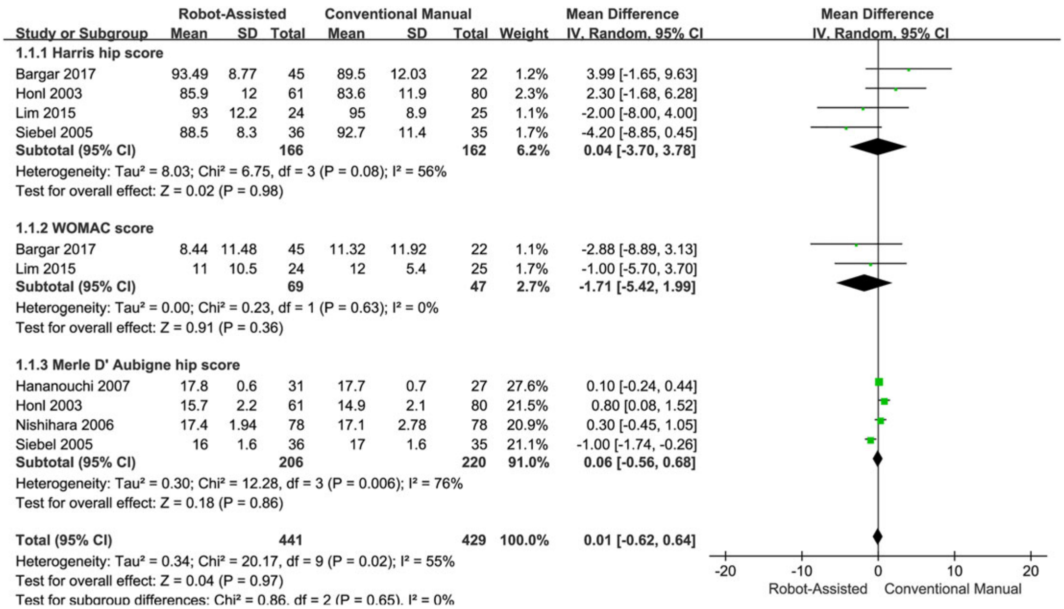

FIGURE 4 Forest plot to assess functional outcome between two procedures

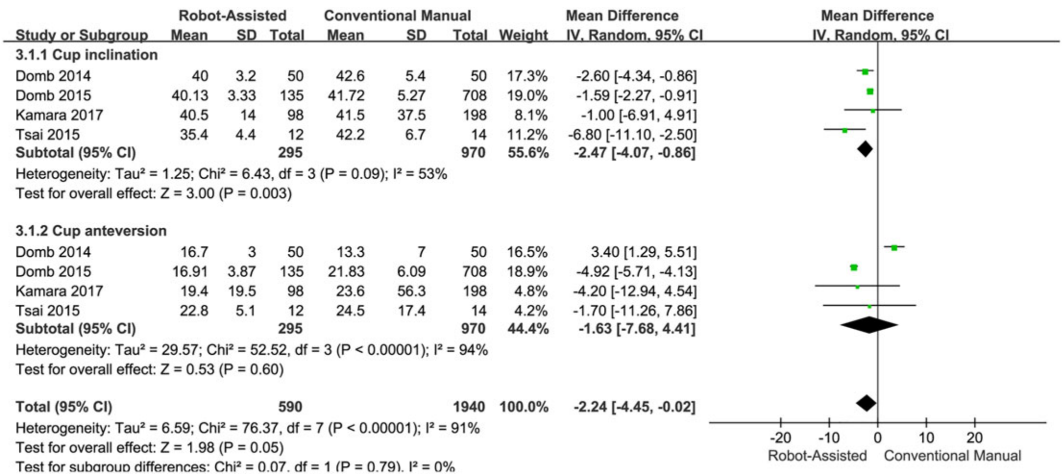

FIGURE 5 Forest plot to assess cup angle between two procedures

to late 1990s.[6,26] With the advances in medical imaging and computer technology, computer-aided surgical systems (CAS) have gained acceptance, but were only employed in high-risk, difficult surgical fields, such as neurosurgery, at the outset.[27,28] Over the last 30 years, the accuracy and richness of the digital images of bone tissue have improved since it is a rigid structure; this has facilitated the reconstruction of bones in three dimensions (3-D), which is particularly suitable for CAS, eventually leading to the development of CAOS.[29,30] Thus far, CAOS is performed with three types of methods[31-33]: (a) According to the stereo-positioning method, it can be divided into optical, electromagnetic, ultrasonic, and mechanical positioning. Optical positioning is the most widely applied method in orthopedics. (b) Depending on the type of image establishment, these methods are classified into CT-based, X-ray fluoroscopy-based, and imageless navigation systems. X-ray fluoroscopy-based navigation used the first technique applied in orthopedics. (c) According to the different interaction modes, these systems are divided into passive, semi-active, and active types. Among them, semi-active and active CAOS can be called as surgical robots because they have mechanical operating arms.[34,35]

The first robotics system used in orthopedics for THA was ROBODOC, a customized industrial active robot[36]; it is an intelligent system that automatically completes the surgical procedure according to the preoperative plan and does not require manual operation or assistance.[37,38] ROBODOC allows the surgeon to operate the robotic arm manually. The semi-active robot allows the surgeon to operate the mechanical arm manually[39] (eg, MAKO Systems, Los Angeles, California). RA technology has been reported to improve the accuracy of the placement of the prosthesis by computer and robotic arm operations, resulting in small deviations and few outliers.[39,40]

Despite numerous advantages, RA hip replacement also has some inherent deficiencies.[41,42] For example, robotic manipulators require more space and longer operating time, which may increase the risk of bleeding and infection. We compared the operation time in the RA and CM procedures. The results indicated that the operation time

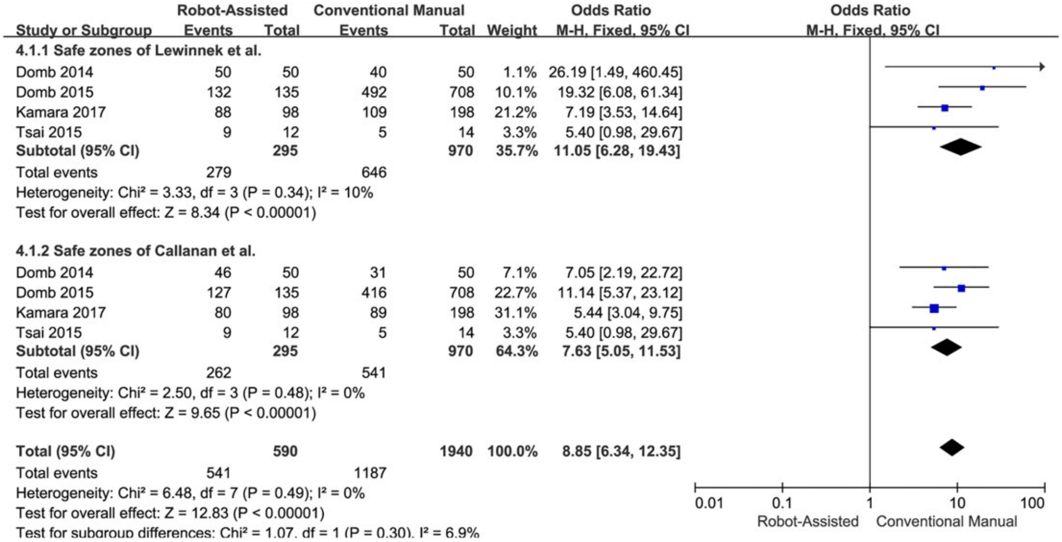

FIGURE 6 Forest plot to assess safe zone of cup between two procedures

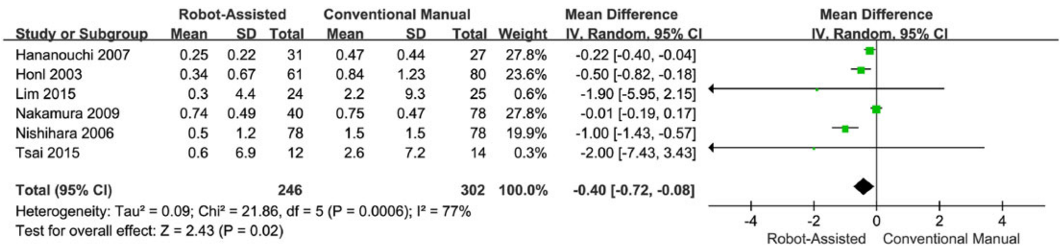

FIGURE 7 Forest plot to assess stem alignment between two procedures

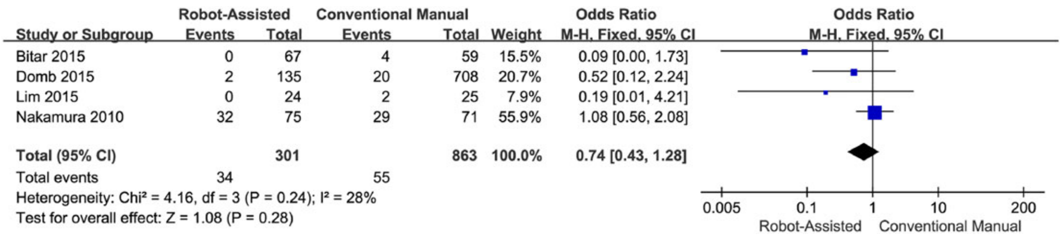

FIGURE 8 Forest plot to assess leg length discrepancy (LLD) between two procedures

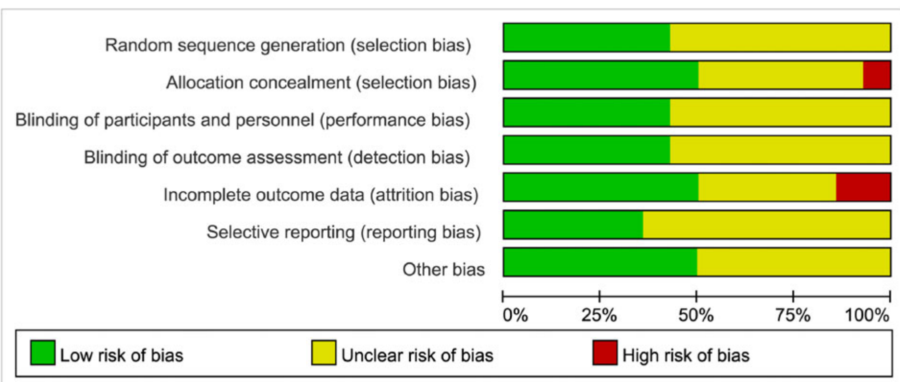

FIGURE 9 Risk of bias graph. Each risk of bias item is presented as a percentage across all included studies and indicates the proportional level for each risk of bias item

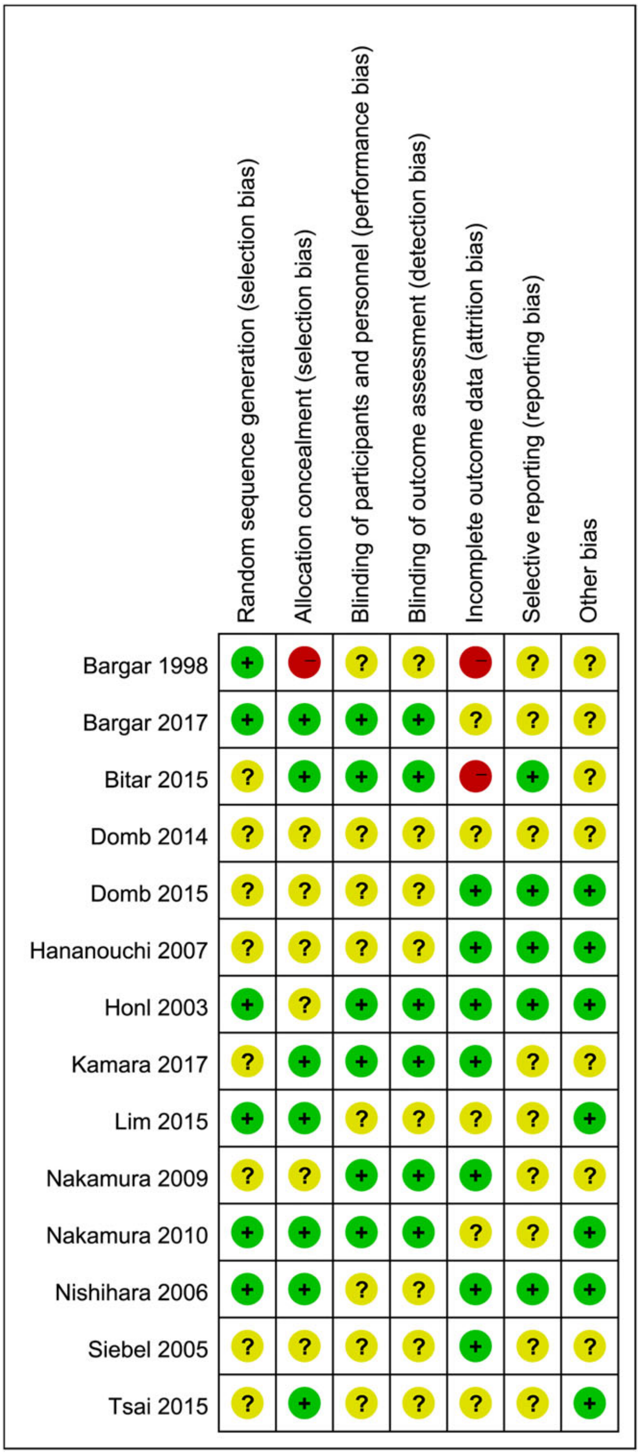

FIGURE 10 Risk of bias summary. Methodological quality of the included studies. This risk of bias tool incorporates assessment of randomization (sequence generation and allocation concealment), blinding (participants, personnel and outcome assessors), completeness of outcome data, selection of outcomes reported, and other sources of bias. The items were scored with "yes," "no," or "unclear"

required in the CM group was less than that required in the RA group (95%CI [7.50-33.94], P = 0.002). The longer operation time required for the RA group may be attributed to the time required for the registration or placement of the positioning pins.

Intraoperative and postoperative complications are a major factor influencing the safety of robotic technology. In their study, Perets et al found that they 3.8% (n = 6) of their patients who underwent RA-THA sustained greater trochanteric or calcar fractures. These rates are less that those expected for the CM approach.[43] In our study, nine trials were included in the comparison of the intraoperative complications (intraoperative femoral fissure or fracture). The results showed that intraoperative complications (95% CI [0.14-0.72], P = 0.006) in the CM group were significantly more frequent than those in the RA group. The lower rate of intraoperative fissure or fracture in the RA group than in the CM group may be associated with more precise grinding of the acetabulum and more accurate placement of the femoral stem, which eliminates the need for wedging. This provided protection against intraoperative fracture for patients undergoing RA-THA.

Dislocation is one of the early postoperative complications in THA. We observed a much lower dislocation rate (95% CI [1.12-4.67], P = 0.02) and revision rate (95% CI [1.11-7.50], P = 0.03) in the CM group than in the RA group. Lewinnek et al found that anterior dislocations after THA were associated with increased acetabular cup anteversion.[44] In contrast, posterior dislocation was due to the insufficiency of the abductor muscles (eg, gluteus medius and piriformis). However, the injury to abductor muscle or tendon may be associated with the differences in the surgical approaches. Adopting the posterior approach may reduce the need for muscle excision and interference. Weeden et al reviewed 945 cases in which the posterior approach THA was performed, and they reported an early dislocation rate of 0.85%.[45] Another study that reviewed 60 patients who underwent THA via the direct anterior approach revealed an early dislocation rate of 1.7%.[46] Therefore, significant differences in dislocation rates may be less relevant to robotic techniques. Moreover, our results of meta-analysis demonstrated that the rates of the complications nerve palsy, knee pain, and heterotopic ossification in the two groups were similar.

Heterotopic ossification is caused by the abnormal growth of new bone in the soft tissue around the hip joint after THA, which often causes joint rigidity and movement disorder.[47] However, Chen et al have shown that the rate of heterotopic ossification was significantly higher with RA-THA than with conventional THA.[48] This is very different from our results. Chen et al reported the following risk factors associated with heterotopic ossification: etiology, cement implant, and muscle trauma. It is clear that the first two factors played a very limited role in this study, and muscle trauma was the main relevant factor. In RA total knee arthroplasty, it is possible to delineate the optimal cutting path, thereby avoiding injury to the abductor tendon and greater trochanter.[21,48] In other words, the damage caused by RA-THA will be minimal, and the risk of heterotopic ossification should be lower, which contradicts the findings of Chen et al. Therefore, we have reason to believe that our conclusions are more credible.

Three clinical outcome measures (HHS, WOMAC, and Merle D' Aubigne hip score) were used in this study. Comparison of the outcome measures obtained with the CM and RA methods showed no significant difference between the two groups in terms of the functional scores (95% CI [0.62-0.64], P = 0.97). In other words, RA technology yielded clinical outcomes comparable with those obtained with traditional manual techniques. In theory, because of the precise nature of the preoperative planning and intraoperative procedures in the RA method, the fitting of the prosthesis is more accurate, which in turn results in better postoperative clinical function. Bukowski et al recently compared the functional scores in the traditional and RA total knee arthroplasty and found that robotic surgery achieved better functional scores than the CM method.[49] Bargar et al have shown that the robotics group had significantly higher pain scores in the Health Status Questionnaire and Harris Pain scores and lower WOMAC scores,[13] as compared with the manual approaches; thus, they noticed that the robot group exhibited small, but crucial, improvement in the clinical outcomes. Interestingly, this is significantly different from the results obtained by some of the earlier published studies. Honl et al randomly assigned 154 patients to undergo either CM or RA THA. They found that the clinical results at the end of a 24-month follow-up period were similar in the two groups.[18] We believe that although the RA-THA simplifies the operative procedure for the surgeon, the technique still has a certain learning curve, and the success of the operation can only be ensured by expertise in the relevant operation techniques. Obviously, with the advancement of artificial intelligence technology and increase in the surgeons' level of expertise, RA-THA can yield better clinical results.

The parameters of cup angle and safe zone have been associated with complications, including dislocation, instability, and revision surgery.[16] Poor cup position, ie, positioning external to the safe zone,[50] as described by Lewinnek et al (30°-50° inclination and 5°-25° anteversion) and Callanan et al (30°-45° inclination and 5°-25° anteversion), increases the risk of complications. Our meta-analysis showed that the CM group had poorer cup inclination than the RA group (95% CI [−4.07 to 0.86], P = 0.003), although cup anteversion (95% CI [−7.68 to 4.41], P = 0.60) was similar in the two groups. Further, the RA group had significantly more cases with cup placement in the safe zone as compared with the CM group. Stem alignment was defined as the angle between the femoral stem and medullary axis.[20] We observed that the RA group has better stem alignment (95% CI [−0.72 to 0.08], P = 0.02). Comparison of the radiological outcomes in the two groups showed that RA technology offered significantly greater accuracy in the placement of the cup and stem. Our results are consistent with those reported previously[15,17,19,24] and confirmed the clinical expectations. LLD is the most common cause and a major source of patient dissatisfaction, and LLD of more than 3 mm and 5 mm represents outliers.[43] A total of four trials compared the occurrence of LLD in this paper. The results showed that the incidence was similar in two groups (95% CI [0.43-1.28], P = 0.28). None of the patients in any of the studies had LLD of more than 10 mm.

Regrettably, few reports focused on the learning curve of RA-THA. Redmond et al performed a review of 105 RA-THAs.[11] They observed a significant learning curve, which means a decrease in surgical time and lower acetabular cup outliers with increase in the level of experience. The mean operative time in Groups A (Cases 1-35), B (Cases 36-70), and C (Cases 71-105) was 79.8 minutes, 63.2 minutes, and 69.4 minutes, respectively. In another study, by Kamara et al, 300 THAs were compared in a retrospective cohort.[19] They found that orthopedic surgeons can immediately and significantly improve the placement accuracy of the acetabular cup during the learning curve of robotic techniques. Because the exposure to robotics technology is basically consistent with that of traditional surgery, the learning curve will not be too long. Orthopedics were able to grasp this technology within 10 RA-THA procedures.

6 | LIMITATIONS

This systematic review has several limitations. First, the level of evidence obtained from the 14 included studies was moderate. Eight of the studies were case-control studies, while the remaining six were RCTs. This lack of quality could add to the risk of potential bias in this study. Second, two studies published in different years by the same authors were included in this meta-analysis. These studies have different research designs and sample sizes. For example, Domb et al compared 160 RA-THAs with manual alignment techniques, using a matched-pair controlled study design in 2014.[15] In a subsequent study, published in 2015, the same group assessed and compared the accuracy of 1980 THAs through a multi-surgeon study.[16] It is difficult to determine whether the same data overlaps in different literatures. This undoubtedly increases the risk bias in the results of the meta-analysis. Third, some of the studies contained insufficient information for pooled analyses. In the case of the study by Bargar et al, some continuous variables in that study do not have standard deviations, which could not be included in the analysis. Fourth, the meta-analysis encompassed three different RA systems (ROBODOC, MAKO, and CASPAR), which may also potentially increase bias. Finally, we reviewed literatures that were published over a period of 20 years. During this period, the RA systems have undergone significant changes. For instance, the registration time of different versions of the same system was reduced from 30 to 2 minutes. Different versions of the same robotics systems were included in this meta-analysis, which could introduce some degree of bias in the study.

Nevertheless, we screened and identified the relevant articles carefully using multiple strategies. Strict exclusion and inclusion criteria were used by two independent researchers who individually evaluated the methodologic quality of each study. Besides evaluating the safety and accuracy of RA-THA, we also determined the rates of specific complications, component (acetabular cup and femur stem), radiological outcomes, etc. Hence, our study provided the most detailed and latest information in this area.

7 | CONCLUSION

In conclusion, RA-THA achieves the same clinical results as traditional manual techniques, with fewer intraoperative complications and better radiological assessment results. On the other hand, the advantages of the traditional techniques are shorter operation time, lower revision rate, and less postoperative complications such as dislocation, which may also be related to the surgical approach. Despite some shortcomings and controversies, with the advancement of artificial intelligence technology, we believe that RA hip replacement technology has good potential for clinical application. The above conclusions need to be further verified in more randomized controlled trials of higher quality and larger sample sizes.

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ORCID

Cheng-long Chen https://orcid.org/0000-0001-7085-6793
Xiao-chun Wei https://orcid.org/0000-0002-6175-4346

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