



Systematic Review Minimally Invasive versus Conventional Approaches in Total Hip Arthroplasty: A Systematic Review and Meta-Analysis of 47 Randomized Controlled Trials

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Abstract: Background: Recent meta-analyses have shown indifferent results between minimally invasive (MI) and conventional approach (CA) total hip arthroplasty (THA), not including the superior MI approach SuperPATH. The aim was to compare the surgical, functional and radiological outcomes and postoperative complications of MI THA, including SuperPATH, with CA THA in patients with hip disease or femoral neck fracture. Methods: PubMed, CNKI, The Cochrane Library, clinical trials, CINAHL and Embase were searched for randomized controlled trials (RCTs) comparing MI THA and CA THA up to 31 July 2023. Mean differences (MDs) with 95% confidence intervals (CIs) were calculated for continuous outcomes and odds ratios (ORs) with 95% CIs were calculated for dichotomous outcomes using a common effect/random effects model. The random effects model was used to present the results. Heterogeneity was assessed using the Cochrane Q test and the Higgins I² test. Results: A total of 47 RCTs with 4086 THAs in 4063 patients were included in our meta-analysis. MI THA showed better results than CA THA in 8 of 18 outcome parameters studied. MI THA showed a higher Harris Hip Score (HHS) than CA THA at 0–1.5, 3, 6 and \geq 12 months postoperatively (p < 0.01; p = 0.02; p = 0.01; p = 0.01). MI THA showed an indifferent overall postoperative complication risk compared to CA THA (p = 0.61). Acetabular positioning angles were within the safe zone in all approaches. Conclusions: The results of the meta-analysis suggest that MI THA has several advantages over CA THA in terms of short-term surgical and functional outcomes, with equal postoperative complication rates. We cannot recommend a change in surgical approach based on our results, as the differences between the investigated approaches did not reach minimal clinically important differences. Level of evidence I: a systematic review of all relevant randomized controlled trials.

Keywords: MI approach; THA; conventional approach; minimally invasive approach; total hip arthroplasty; total hip replacement

1. Introduction

Total hip arthroplasty (THA) is one of the most successful orthopedic procedures for restoring hip function and relieving pain. There has been an increasing trend in THA volumes in recent years and this is expected to continue in the future [1]. At the same time, there was a constant striving for even better surgical results. This improvement was to be achieved by introducing various minimally invasive (MI) approaches and surgical techniques. With the establishment and publicity of the procedure, the expectations of surgeons and informed patients of MI THA increased.



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Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). There are six conventional approaches (CAs) in hip arthroplasty: anterior, anterolateral, lateral, posterolateral, posterior and superior. MI surgical approaches to THA have been developed as modifications of known CAs to improve patient outcomes. The CAs were modified by trying to reduce the incision length and not incise the tendons and muscles in depth. Opponents have claimed that as a result of the limited view of the surgical field, MI THA could lead to misplacement of components or impaired fixation [2]. This is why MI THAs are considered potentially more prone to complications [2,3]. For this reason, some surgeons remain skeptical of improvement, resist switching and hold on to the good results of their CA THA. Proponents of MI THA claim that it results in less soft tissue trauma, which in turn leads to less blood loss and better functional outcomes. Other postoperative benefits include less pain, faster recovery and better cosmetic appearance [4,5].

The scientific discussion on the topic is still open and a final recommendation on the preference of MI THA cannot yet be given. It was assumed that MI approaches would result in a better THA outcome for the patient because they cause less tissue trauma compared to CAs. However, this assumption has not been scientifically proven [6–10]. The metaanalyses that have addressed this issue have a serious limitation in that they did not include the SuperPATH technique using a MI superior approach. Since SuperPATH has shown better initial short-term results compared to both CAs [11] and other MI approaches [12], it is reasonable to assume that including SuperPATH in the group of MI approaches would lead to different overall results compared to CAs. The aim of this study was to perform the first meta-analysis including SuperPATH in the MI THA group and comparing it with CA THA, using only randomized controlled trials (RCTs) as the primary data source.

The aim was to compare the surgical, functional and radiological outcomes and postoperative complications of MI THA, including SuperPATH, with CA THA in patients with hip disease or femoral neck fracture.

2. Materials and Methods

We formulated the following PICO (Population, Intervention, Control and Outcomes) question: In human participants with hip disorders such as osteoarthritis, femoral neck fracture, dysplasia, or femoral head avascular necrosis, is MI THA including SuperPATH superior to CA THA in terms of surgical, functional and radiological outcomes and postoperative complications?

We strictly followed the updated version of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [13]. The PRISMA checklist is available in the Supplement (Table S1). The study protocol was registered in PROSPERO on 10 August 2022 (CRD42022350279). It should be noted that this meta-analysis was based on the same study protocol as a previously published meta-analysis by the same group of authors [14]. This is because the data extraction process found far too much interesting data on different outcome parameters to be summarized in a single article. The authors of this meta-analysis have some experience with meta-analyses in hip arthroplasty research. Similarities with previous publications are only due to the use of comparable high quality methods.

2.1. Data Sources and Search Strategies

PubMed, CNKI, The Cochrane Library, Clinical trials, CINAHL and Embase were searched up to 31 July 2023. Citations of related meta-analyses were screened for relevant articles. A BOOLEAN search strategy was constructed and adapted to the syntax of the databases used. No restrictions on publication language were applied. As MI approaches and techniques are constantly evolving, we arbitrarily excluded old studies published more than 15 years ago.

2.2. Study Screening and Selection

A stepwise screening process was carried out according to the PRISMA guidelines [13]. First, the titles and abstracts of the identified records were screened. The full texts of the

screened articles were then assessed for eligibility. The decision to include each study was made by consensus between two reviewers (NR and PMK). The agreement between the reviewers was measured using the kappa coefficient (κ).

2.3. Inclusion Criteria

Types of studies:

• Only RCTs.

2.3.1. Types of Participants

 Human participants with hip disorders such as osteoarthritis, femoral neck fracture, dysplasia or avascular necrosis of the femoral head.

2.3.2. Types of Interventions

• MI THA or CA THA

Definition of MI THA: There is no uniform definition for MI approaches to THA. In general, the scientific community agrees on two conditions that must be met: an incision length ≤ 10 cm and, most importantly, preservation of muscles and tendons. In our meta-analysis, an approach with the related technique was defined as MI if it was known as MI per se in the literature or if it was explicitly referred to as MI in the individual RCTs. Mini-incision approaches that did not spare muscles or tendons were considered conventional rather than MI.

2.3.3. Types of Outcome Measures

I. Surgical outcome parameters: operation time, incision length, intraoperative blood loss, pain Visual Analogue Scale (VAS) [15];

- II. Functional outcome: Harris Hip Score (HHS) [16];
- III. Radiological outcome: acetabular cup abduction and anteversion angle;

IV. Postoperative complications: dislocation, infection, periprosthetic fracture, deep vein thrombosis, hematoma, and reoperation.

2.4. Exclusion Criteria

- Robotic assistance and computer navigation;
- Revision operation;
- Dual-mobility THA;
- Hemiarthroplasty;
- Comparison of MI and CA THA simultaneously in the same patients.

2.5. Data Extraction

Two reviewers (NR and PMK) independently extracted all relevant data on RCT characteristics, methods, quality assessment, participant characteristics, details of interventions, relevant outcomes and relevant additional information. The extracted data are available in the Supplement (Table S2). Disagreements were resolved by consensus between two reviewers (NR and PMK). The raw data extraction set available in the Supplement (Table S2).

2.6. Quality Assessment of RCTs

Two reviewers independently assessed the quality of the included RCTs. Risk of bias (RoB) was assessed using the Cochrane RoB 2 tool [17]. Level of evidence was assessed according to the recommendations of the GRADE system [18]. Disagreements were resolved by consensus between two reviewers (NR and PMK). In addition, publication bias was calculated using Begg's and Egger's tests.

2.7. Missing Data

The corresponding authors of the included RCTs were contacted to obtain missing primary data. If standard deviation information was missing, it was calculated by imputation [19]. If the RCTs provided different information for the intention to treat (ITT) and per protocol (PP) analyses, we used the numbers from the ITT analysis.

2.8. Measures of Treatment Effect

For continuous outcomes, mean differences (MDs) with 95% confidence intervals (CIs) were calculated using the Hartung-Knapp-Sidik-Jonkman method and a common effect/random effects model. For dichotomous outcomes, odds ratios (ORs) with 95% CIs were calculated using the Mantel-Haenszel method and a common effect/random effects model. The heterogeneity of the RCTs was measured by I² and τ^2 values. As these values indicated a high degree of heterogeneity for some parameters, we retained the random effects model in our presentation of the results. In cases where the included RCTs included primary data from patients with bilateral THA, the number of hips operated on was used in our calculations rather than the number of patients. Studies were weighted using inverse variance. The t-test was calculated to determine the differences between the means of the two groups. Statistical heterogeneity was assessed using the Cochrane Q test (p value < 10 indicates heterogeneity) and the Higgins test I² (low heterogeneity < 25%, moderate heterogeneity: 25–75% and high heterogeneity: >75%) [20]. A professional statistician (RH) performed all statistical calculations using the R packages meta and metafor. Meta results were analyzed using the Cochrane Handbook for Systematic Reviews of Interventions, Cochrane's Review Manager Version 5.3.

3. Results

The study selection process is presented in a flowchart (Figure 1). The initial literature search of the databases yielded 6908 records. A total of 50 RCTs [21–70] were screened for eligibility by full text analysis. Three RCTs [68–70] were excluded for the following reasons: one RCT evaluated hemiarthroplasty [68], another RCT compared two MI approaches [69] and another RCT evaluated MI and CA THA simultaneously in the same patients [70]. A total of 47 RCTs with 4086 THAs in 4063 patients [21–67] were included in this meta-analysis. The main characteristics of the patients and the included RCTs are listed in Table 1. It is important to note that two of the RCTs used identical patient cohorts, providing different outcome parameters with different follow-up periods [43,44]. In addition, two RCTs [42,62] included patients with bilateral THA (see Table 1). The risk of bias and the level of evidence are shown in Tables 2 and 3. The assessment of publication bias using Begg's and Egger's tests is shown in Table 4. The clinical characteristics for sex, age and BMI (Table 1) showed no relevant differences between the MI THA and CA THA groups. Table 5 shows the weighted means of the continuous outcome parameters and the weighted event percentages of the dichotomous outcome parameters.



Figure 1. PRISMA flow diagram of the search results and selection process. MI: minimally invasive; CA: conventional approach; THA: total hip arthroplasty [21–70].

RCT	Year of Publication, Origin	Patients, N	Hips, N	Sex, Male, N	Approach	THA with Bone Cement, N	Table/ Patient Position	Mean Age, Years, SD	Mean BMI, kg/m², SD	Mean HHS Preoperatively, Points, SD	Osteoarthritis, N	Femoral Neck Fracture, N	Dysplasia, N	ANFH, N
Barrett WP	2012 110 4	43	43	29	MI DAA	0	TT	61.4 ± 9.2	30.7 ± 5.4	57.6 ± 10.2	43	0	0	0
et al. [21]	2013, USA	44	44	19	CA PL	0	Lat	63.2 ± 7.7	29.1 ± 5	55.1 ± 9.1	44	0	0	0
Bon G et al.	2010 Error	50	50	21	MI DAA	7	TT	67.3 ± 10	26.5 ± 3.6	54 ± 15	50	0	0	0
[22]	2019, France	50	50	23	CA P	7	NR	69 ± 7.9	26.7 ± 3.1	52.3 ± 13.1	50	0	0	0
Brismar BH	2018,	50	50	18	MI DAA	0	Supine	66 ± 4	27 ± 1.3	NR	50	0	0	0
et al. [23]	Sweden	50	50	17	CA L	0	Lat	67 ± 4	27 ± 1.5	NR	50	0	0	0
Cheng TE	2016,	35	35	15	MI DAA	NR	TT	59 ± 3.8	27.7 ± 1.1	NR	35	0	0	0
et al. [24]	Australia	37	37	18	CA P	NR	Lat	62.5 ± 3.5	28.3 ± 1.6	NR	37	0	0	0
D'Arrigo C	2000 Italy	20	20	12	MI DAA	0	NR	64 ± 8	22.7 ± 1.5	37.7 ± 19	20	0	0	0
et al. [25] 2009, Italy	2009, Italy	149	149	81	CA L	0	NR	65 ± 9.8	28 ± 1.8	39 ± 10.2	149	0	0	0
De Anta-Diaz B et al. [26] 20	2016 Spain	49	49	26	MI DAA	8	NR	64.8 ± 10.1	26.6 ± 3.9	44.4 ± 13.6	49	0	0	0
	2016, Spain	50	50	26	CA L	6	NR	63.5 ± 12.5	26.9 ± 3.1	42.9 ± 15.2	50	0	0	0
		42	42	14	MI MH	2	Lat	61 ± 13	26.1 ± 3	48 ± 15	42	0	0	0
Dienstknecht	2013, Germany	36	36	12	CA L	1	NR	62 ± 13	24.3 ± 3.6	46 ± 16	36	0	0	0
T et al. [27] *		41	41	24	MI MH	3	Lat	61 ± 11	34.3 ± 4.4	44 ± 15	41	0	0	0
		15	15	10	CA L	0	NR	61 ± 10	34.6 ± 4.1	46 ± 16	15	0	0	0
Fink B et al.	2010,	50	50	25	MI P	50	NR	71.9 ± 6.1	27 ± 4.8	NR	44	0	1	5
[28]	Germany	50	50	23	CA PL	50	NR	71.5 ± 5.6	28 ± 3.8	NR	44	0	1	5
Gao P et Shi X	2020 China	35	35	23	MI S	NR	Lat	69.3 ± 3.3	23.1 ± 2.6	15.4 ± 2.9	0	35	0	0
[29]	2020, China	35	35	20	CA P	NR	Lat	68.8 ± 3.5	23.2 ± 2.4	15.7 ± 2.7	0	35	0	0
Hou JZ et al.	2017 China	20	20	13	MI S	NR	Lat	54.3 ± 13.7	24.5 ± 3.6	33.8 ± 5.4	6	0	0	14
[30]	2017, China	20	20	12	CA	NR	Lat	53.8 ± 12.9	23.9 ± 4.1	31.9 ± 6.1	5	0	0	15
		37	37	31	MI S	NR	Lat	56.2 ± 11.5	NR	47.3 ± 6.1	0	0	0	37
Huang K et al.	2021 China	58	58	50	CA L	NR	Lat	53 ± 10.4	NR	45.7 ± 8.1	0	0	0	58
[31] **	2021, Ciuita	16	16	2	MI S	NR	Lat	78.1 ± 7.8	NR	40.6 ± 11.5	0	16	0	0
		18	18	8	CA L	NR	Lat	77.7 ± 10.1	NR	40.9 ± 11.6	0	18	0	0

Table 1. Main characteristics of RCTs.

Table 1. Cont.

Femoral Year of Sex, THA with Table/ Mean Mean HHS Mean Age, Patients, Hips, ANFH, Osteoarthritis, Neck Dysplasia, RCT Publication, Male, Approach Bone Patient BMI, Preoperatively, Ν Ν Years, SD Ν Ν Ν Fracture, Origin Cement, N Position kg/m², SD Points, SD Ν Ν 29 29 14 MI DAA 0 62.7 ± 4.9 28.7 ± 3.4 49.2 ± 9.0 29 0 0 0 Supine Iorio R et al. 2021, Italy [32] 31 31 14 CA L 0 Lat 67.2 ± 8.8 29.9 ± 3.1 46.4 ± 12.6 31 0 0 0 44 44 24 MI P 44 Lat 72.3 ± 1 28.5 ± 0.7 NR 42 0 0 2 Khan RJK 2012, et al. [33] Australia 45 NR 0 2 45 19 CA P 45 Lat 72.8 ± 1.1 28.9 ± 0.6 43 0 20 20 10 MI S 0 NR 56.8 ± 12.9 28.2 ± 4.5 45.6 ± 11.3 NR NR NR NR Korytkin A 2023, Russia et al. [34] 24 24 CA P 0 NR 57.0 ± 13.2 29.0 ± 4.9 46.0 ± 11.0 NR NR NR NR 11 36 NR 36 12 MI AL 36 Lat 70.3 ± 4.1 27 ± 2.8 36 0 0 0 Landgraeber 2013, S et al. [35] Germany 40 40 14 CA L 40 Supine 71 ± 5.4 26.7 ± 3.8 NR 40 0 0 0 30 30 16 MI S NR Lat 70.4 ± 4.3 NR 25.4 ± 2.4 NR NR NR NR Li L [36] 2020, China 30 30 18 CA PL NR Lat 70.1 ± 4.8 NR 26.4 ± 2.5 NR NR NR NR 49 75.5 ± 7.3 23 ± 2.9 NR 0 15 49 27 MI S NR Lat 0 34 Li X et al. 2021, China [37] 47 47 24 CA PL NR 77.2 ± 7.8 22.7 ± 3 NR 0 0 Lat 16 31 50 50 MI S NR NR 46.1 ± 3.3 50 0 31 89.1 ± 3.6 NR 0 0 Ling Z et al. 2020, China [38] 50 50 29 CA PL NR NR 89 ± 3.7 NR 45.9 ± 3.7 0 50 0 0 47 47 26 MI S NR Lat 68.3 ± 3.7 NR 67.7 ± 7.3 0 47 0 0 Liu Y et al. 2021, China [39] 47 47 CA PL NR Lat 68.6 ± 3.4 NR 68.7 ± 6.2 0 47 0 0 24 30 17 MI S NR NR 58.7 ± 4.3 3 13 0 14 30 Lat 58.6 ± 4.3 Liu W et al. 2022, China [40] 30 30 18 CA NR Lat 58.3 ± 4.6 NR 58.8 ± 4.3 6 9 0 15 42 42 12 MI AL 42 Lat 66.7 ± 10.1 30.6 ± 6.1 37.4 ± 15.5 37 0 0 5 Martin R 2011, Belgium et al. [41] 41 41 NR 37 0 0 41 14 CAL 63.1 ± 10.2 29.4 ± 5.5 40.2 ± 12.9 4 2 2 MI S NR 51 ± 4.5 21.5 ± 1.7 37.9 ± 13.3 0 0 0 4 4 Lat Meng W 2020, China et al. [42] 2 4 2 CA PL NR Lat 51 ± 4.5 21.5 ± 1.7 37.7 ± 7 0 0 0 4 83 83 25 MI DAA 83 Supine 67.2 ± 8.6 27.7 ± 3.6 53.6 ± 13.7 83 0 0 0 Mjaaland KE 2015, et al. [43] *** Norway 80 80 30 CAL 80 Lat 65.6 ± 8.6 27.6 ± 3.9 56 ± 11.2 80 0 0 0 0 83 83 25 MI DAA 83 67.2 ± 8.6 27.7 ± 3.6 53.6 ± 13.7 83 0 0 Supine 2018, Mjaaland KE et al. [44] *** Norway 80 80 30 CA L 80 Lat 65.6 ± 8.6 27.6 ± 3.9 56 ± 11.2 80 0 0 0

Table 1. Cont.

Femoral Year of Sex, THA with Table/ Mean Mean HHS Mean Age, Patients, Hips, Neck ANFH, Osteoarthritis, Dysplasia, RCT Publication, Male, Approach Bone Patient BMI, Preoperatively, Ν Ν Years, SD Ν Ν Ν Fracture, kg/m², SD Origin Cement, N Position Points, SD Ν Ν 28 28 MI DAA 0 TT 70.4 ± 9.1 27.6 ± 4.4 52.1 ± 19.7 NR 0 0 NR 11 Moerenhout 2019, Canada K et al. [45] 27 27 18 CA P 0 Lat 69 ± 8.8 26.5 ± 4.3 48.2 ± 10.1 NR 0 0 NR 21 21 12 MI AL 0 NR 66 ± 6.8 28 ± 4.3 55.9 ± 8 21 0 0 0 2010, Müller M et al. [46] Germany 16 16 8 CA L 0 NR 64 ± 13.8 26 ± 2.5 55.6 ± 12 16 0 0 0 35 35 26 MI DAA 0 Supine 67 ± 4.8 27.5 ± 3.8 NR 35 0 0 0 Nistor DV 2017, et al. [47] Romania 35 35 CA L 0 64 ± 3.3 28.6 ± 3.1 NR 0 0 0 16 Supine 35 12 45.7 ± 5.9 5 0 0 7 12 8 MI S NR 54 ± 6.5 23.1 ± 2.3 Lat Ouyang C 2018, China et al. [48] 12 12 9 CA PL NR Lat 55 ± 5 23.9 ± 3.4 46.9 ± 8.9 6 0 0 6 58 58 34 MI S NR Lat 65.2 ± 6.8 22.2 ± 4.2 83.9 ± 2.7 12 26 NR 15 Pan F et al. 2020, China [49] 58 25 58 33 CA PL NR Lat 65.6 ± 7 22.6 ± 4.2 84 ± 3.2 11 NR 18 NR NR 0 44 44 18 MI DAA 0 Supine NR 44 0 0 Parvizi I et al. 2016, USA [50] 40 CAL 0 NR NR NR 40 0 0 0 40 14 Supine 77 77 MI DAA Supine 28.1 ± 3.7 54 ± 14.2 77 0 0 45 4 63.2 ± 8.2 0 Reichert et al. 2018, [51] Germany 5 71 71 39 CAL Supine 61.9 ± 7.8 28.3 ± 3.4 53 ± 15.7 71 0 0 0 21 21 12 MI S NR NR 58 ± 6.9 NR 35.4 ± 4.9 0 0 0 21 Ren D et al. 2016, China [52] 21 21 13 CA NR NR 58.5 ± 6.3 NR 36.3 ± 3.5 0 0 0 21 MI DAA 50 50 17 25.2 ± 11.1 51.9 ± 7.9 0 0 0 0 Supine 62 ± 12.4 50 Restreppo C 2010, USA et al. [53] 50 50 22 CAL 0 59.9 ± 9 25.2 ± 2.5 55 ± 5.5 50 0 0 0 Supine 23 23 8 MI DAA 23 Supine 62.8 ± 6.1 29 ± 5.6 52 ± 6.7 23 0 0 0 Rykov K 2017. et al. [54] Netherlands 23 CA PL 23 23 0 0 23 11 Lat 60.2 ± 8.1 29.3 ± 4.8 51 ± 9 0 22 22 MI AL 0 59 ± 9 26.7 ± 4.2 53 ± 12 22 0 0 0 13 Supine 2017, Schwarze M et al. [55] Germany 21 21 13 CAL 0 59 ± 9 26.7 ± 4.2 59 ± 15 21 0 0 0 Supine 27 NR 12 MI DAA NR Supine 62.1 27.7 55 ± 4.3 27 0 0 0 Taunton M 2014, USA et al. [56] 27 NR 13 CA P NR Lat 66.4 29.2 51 ± 6 27 0 0 0 52 52 27 MI DAA 0 NR 29 ± 22 57 ± 13 52 0 0 0 65 ± 10 Taunton M 2018, USA et al. [57] 49 49 25 CA P 0 NR 64 ± 11 30 ± 4 56 ± 12 49 0 0 0

RCT	Year of Publication, Origin	Patients, N	Hips, N	Sex, Male, N	Approach	THA with Bone Cement, N	Table/ Patient Position	Mean Age, Years, SD	Mean BMI, kg/m ² , SD	Mean HHS Preoperatively, Points, SD	Osteoarthritis, N	Femoral Neck Fracture, N	Dysplasia, N	ANFH, N
Varela-	2012 6	25	25	12	MI L	0	NR	64.8 ± 10.5	28.3 ± 3.7	52.7 ± 12.9	21	0	0	4
et al. [58]	2013, Spain	25	25	12	CA L	0	NR	63.8 ± 9.7	27.8 ± 3.2	51.3 ± 14.9	22	0	0	3
Wang Z et Ge	2021 CL:	43	43	26	MI S	NR	Supine	71.5 ± 3.8	22.5 ± 1.1	62.2 ± 5.2	0	43	0	0
W [59]	2021, China	42	42	24	CA PL	NR	Lat	71.6 ± 3.8	22.5 ± 1.2	62.7 ± 6.6	0	42	0	0
Xiao C et al.	2021 China	49	49	16	MI P	0	Lat	71.1 ± 10.9	26.7 ± 4.2	NR	0	49	0	0
[60]	2021, China	57	57	26	CA PL	0	Lat	73.9 ± 10	26.4 ± 4.6	NR	0	57	0	0
V:- I -+ -1 [(1]	2017 China	46	46	12	MI S	0	Lat	66.6 ± 11.9	23.6 ± 1.6	28.9 ± 11.3	46	0	0	0
Xie J et al. [61] 2017, Chi	2017, China	46	46	19	CA P	0	Lat	64.5 ± 12.1	24.1 ± 2.7	29.3 ± 17.4	46	0	0	0
Yan T et al.	2017 China	64	70	29	MI S	NR	NR	66 ± 4	24.5 ± 3.5	33.5 ± 5.3	14	11	0	39
[62]	2017, China	90	103	42	CA L	NR	NR	65 ± 6.5	23.6 ± 3.6	30.7 ± 7.6	12	23	0	55
Yang C et al.	2010 China	55	55	26	MI AL	0	Lat	59.5 ± 13.2	23.1 ± 3.2	25.9 ± 11.3	12	11	0	32
[63]	2010, China	55	55	30	CA PL	0	Lat	55.8 ± 13.9	22.4 ± 4	28.2 ± 13.7	19	13	0	23
Yuan H et al.	2018 China	40	40	24	MI S	0	Lat	74.3 ± 3	22.7 ± 1.7	33 ± 1.9	5	21	4	10
[64]	2018, China	44	44	21	CA PL	0	Lat	75.7 ± 3.3	22.4 ± 2.7	32.7 ± 1.3	6	24	2	12
Zhang ZL	2010 China	27	27	10	MI S	NR	NR	62.4 ± 6.4	24.5 ± 5.3	35.6 ± 8.8	7	0	5	15
et al. [65]	2019, China	27	27	12	CA PL	NR	NR	61.3 ± 6.7	23.9 ± 4.9	36.2 ± 9.2	9	0	4	14
Zhao HY et al.	2017 China	60	60	24	MI DAA	NR	Supine	64.9 ± 12.1	24.4 ± 3.1	40.2 ± 9.2	41	0	6	13
[66]	2017, China	60	60	22	CA PL	NR	Lat	62.2 ± 14.7	25.6 ± 2.8	43.1 ± 15.6	40	0	7	13
Zhao 6 [67]	2021 China	48	48	28	MI S	NR	Lat	70.4 ± 1.5	22.6 ± 1.5	NR	0	48	0	0
Zhao S [67] 2021	2021, China	48	48	29	CAL	NR	Lat	70.5 ± 1.5	22.5 ± 1.5	NR	0	48	0	0

Table 1. Cont.

MI: minimally invasive; AL: anterolateral; DAA: direct anterior approach; L lateral; MH: MicroHip; P: posterior; PL: posterolateral; S: SuperPATH; CA: conventional approach; TT: traction table; Lat: lateral decubitus position; THA: total hip arthroplasty; BMI: Body Mass Index; SD: standard deviation; HHS: Harris Hip Score; ANFH: avascular necrosis of the femoral head; NR: not reported. * This RCT divided the patient cohort according to their BMI; ** this RCT divided the patient cohort according to their diagnosis; *** both RCTs used identical patient cohorts, giving different outcome parameters.

Study	Bias Arising from the Randomization Process	Bias Due to Deviation from Intended Interventions	Bias Due to Missing Outcome Data	Bias in Measurement of the Outcome	Bias in Selection of the Reported Result	Overall Risk of Bias
Barrett WP et al. [21]	+	_	?	?	+	_
Bon G et al. [22]	+	+	+	+	+	+
Brismar BH et al. [23]	+	+	_	+	+	_
Cheng TE et al. [24]	+	+	_	+	+	_
D'Arrigo C et al. [25]	+	+	+	+	+	+
De Anta-Diaz B et al. [26]	—	+	+	+	+	-
Dienstknecht T et al. [27]	_	+	+	+	+	_
Fink B et al. [28]	+	+	+	+	+	+
Gao P and Shi X [29]	+	?	_	+	+	_
Hou JZ et al. [30]	+	?	+	+	+	?
Huang K et al. [31]	_	?	+	+	+	_
Iorio R et al. [32]	+	?	?	?	+	?
Khan RJK et al. [33]	+	+	+	+	+	+
Korytkin A et al. [34]	+	?	+	+	+	?
Landgraeber S et al. [35]	+	?	+	+	?	?
Li L [36]	+	?	-	-	+	—
Li X et al. [37]	+	+	-	+	+	—
Ling Z et al. [38]	?	+	-	+	+	—
Liu Y et al. [39]	+	+	—	+	+	_
Liu W et al. [40]	+	+	+	+	+	+
Martin R et al. [41]	?	?	+	+	?	?
Meng W et al. [42]	+	+	+	+	+	+
Mjaaland KE et al. [43]	+	+	+	+	+	+
Mjaaland KE et al. [44]	+	+	+	+	+	+
Moerenhout K et al. [45]	+	+	+	+	+	+
Müller M et al. [46]	+	+	?	?	+	?
Nistor DV et al. [47]	_	+	+	+	+	-
Ouyang C et al. [48]	+	+	+	+	+	+
Pan F et al. 2020 [49]	+	?	_	+	+	—
Parvizi J et al. [50]	+	+	-	+	+	_
Reichert JC et al. [51]	-	+	+	+	+	-
Ren D et al. [52]	+	?	_	?	?	-
Restreppo C et al. [53]	+	+	+	+	+	+
Rykov K et al. [54]	+	+	_	+	+	_
Schwarze M et al. [55]	?	?	_	_	+	-
Taunton M et al. [56]	+	+	?	+	+	?
Taunton M et al. [57]	+	+	?	+	+	?
Varela-Egocheaga JR et al. [58]	_	_	+	+	+	-
Wang Z and Ge W [59]	+	?	_	+	+	-
Xiao C et al. [60]	?	+	+	+	+	?
Xie J et al. [61]	+	+	+	+	+	+
Yan T et al. [62]	+	?	?	+	+	?

Table 2. Risk of bias assessment.	
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Table 2. Cont.

Study	Bias Arising from the Randomization Process	Bias Due to Deviation from Intended Interventions	Bias Due to Missing Outcome Data	Bias in Measurement of the Outcome	Bias in Selection of the Reported Result	Overall Risk of Bias
Yang C et al. [63]	+	+	+	+	+	+
Yuan H et al. [64]	+	?	_	+	+	_
Zhang ZL et al. [65]	+	+	?	+	+	?
Zhao HY et al. [66]	+	+	+	+	+	+
Zhao S [67]	_	?	+	+	+	_

(+): low risk of bias; (?): some concerns; (–): high risk of bias.

Table 3. Level of evidence assessment according to GRADE recommendations.

No. of Studies	Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Quality of Evidence					
				I. Surgical outco	ome							
				1. Operation ti	me							
39	RCT	Serious	Serious	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					
				2. Incision leng	;th							
28	RCT	Serious	No serious inconsistency	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					
			3	. Intraoperative blo	ood loss							
26	RCT	Serious	Serious	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					
	4. VAS 1 day postoperatively											
9	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low					
	5. VAS 3 days postoperatively											
8	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low					
				II. Functional out	come							
			1. HH	S 0–1.5 months pos	stoperatively							
26	RCT	Serious	No serious inconsistency	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					
			2. H	HS 3 months poste	operatively							
22	RCT	Serious	Serious	No serious indirectness	No serious imprecision	-	Very low					
			3. H	HS 6 months poste	peratively							
13	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low					
			4. HI	HS 12 months post	operatively							
16	RCT	Serious	No serious inconsistency	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					
			I	II. Radiological or	utcome							
			1. Ace	etabular cup antev	ersion angle							
17	RCT	Serious	Serious	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					
			2. Ac	etabular cup inclin	ation angle							
22	RCT	Serious	Serious	No serious indirectness	Serious	In some cases SD was calculated via imputation	Very low					

No. of Studies	Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Quality of Evidence		
			IV. I	Postoperative com	plications				
			1. Over	all postoperative c	complications				
34	RCT	Serious	Serious	No serious indirectness	No serious imprecision	-	Very low		
2. Dislocation									
31	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low		
3. Infection									
31	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low		
				4. Periprosthetic fr	acture				
31	RCT	Serious	No serious inconsistency	No serious indirectness	Serious	-	Very low		
				5. Deep vein thron	nbosis				
31	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low		
				6. Hematoma	a				
27	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low		
				7. Reoperatio	n				
25	RCT	Serious	No serious inconsistency	No serious indirectness	No serious imprecision	-	Low		

Table 3. Cont.

RCT: randomized controlled trial; HHS: Harris Hip Score; VAS: Visual Analogue Scale.

 Table 4. Publication bias evaluation.

	Number of RCTs	Egger.p.Value	Begg.p.Value								
	I. Surgical outcome										
1.Operation time	39	0.0038 **	0.5779								
2.Incision length	28	0.5494	0.7670								
3.Intraoperative blood loss	26	0.1562	0.4806								
4.Pain VAS 1 day postoperatively	9	0.7491	0.7545								
5. Pain VAS 3 days postoperatively	8	0.9212	0.7105								
	II. Functional outcome										
1. HHS 0–1.5 months postoperatively	26	0.4812	0.0778 *								
2. HHS 3 months postoperatively	22	0.1843	0.6118								
3. HHS 6 months postoperatively	13	0.4700	0.7603								
4. HHS \geq 12 months postoperatively	16	0.2160	0.2604								
	III. Radiological outco	me									
1. Cup anteversion	17	0.3168	0.5923								
2. Cup inclination	22	0.0057 **	0.6519								

	Number of RCTs	Egger.p.Value	Begg.p.Value
	IV. Postoperative complic	ations	
1. Overall postoperative complications	34	0.8312	0.7098
2. Dislocation	31	0.5516	0.6404
3. Infection	31	0.1585	0.3359
4. Periprosthetic fracture	31	0.2566	0.7603
5. Deep vein thrombosis	31	0.8549	0.2758
6. Hematoma	27	0.2438	1.0000
7. Reoperation	25	0.0244 *	0.0375 *

Table 4. Cont.

* Significant result; ** highly significant result; VAS: visual analog scale; HHS: Harris Hip Score.

Table 5. The weighted mean values of the continuous outcome parameters and the weighted event percentages of the dichotomous outcome parameter.

Outcome Parameter	MI THA	CA THA
I. Surgical outcome		
1. Operation time (min.)	82.3	72.8
2. Incision length (cm)	9.0	13.1
3. Intraoperative blood loss (mL)	262.3	435.3
4. VAS 1 day postoperatively (points)	3.5	4.9
5. VAS 3 days postoperatively (points)	2.6	3.7
II. Functional outcome		
1. HHS 0–1.5 months postoperatively (points)	83.2	79.1
2. HHS 3 months postoperatively (points)	88.6	86.3
3. HHS 6 months postoperatively (points)	91.5	89.9
4. HHS 12 months postoperatively (points)	93.5	92.4
III. Radiological outcome		
1. Acetabular cup anteversion angle (degrees)	20.4	20.5
2. Acetabular cup inclination angle (degrees)	42.3	42.6
IV. Postoperative complications		
1. Overall postoperative complications (%)	5.72	4.21
2. Dislocation (%)	0.68	0.76
3. Infection (%)	0.53	0.90
4. Periprosthetic fracture (%)	1.06	0.62
5. Deep vein thrombosis (%)	0.38	1.18
6. Hematoma (%)	0.09	0.61
7. Reoperation (%)	1.47	1.04

MI: minimally invasive; CA: conventional approach; THA: total hip arthroplasty.

3.1. Surgical Outcome

3.1.1. Operation Time: MI THA vs. CA THA

Data on 3370 THAs from 39 RCTs were pooled ($I^2 = 98\%$, p < 0.01, Figure 2). The operation time for MI THA was 10.6 min. longer than that for CA THA (MD = 10.64, 95% CI 5.29 to 15.99).

		Expe	rimental			Control				Weight	Weight
Study	Total	Mean	SD	Total	Mean	SD	Mean Difference	MD	95%-CI	(common)	(random)
Barrett WP et al. 2013	43	84.30	12.4000	44	60.50	12.4000	; i +-	23.80	18.59; 29.01]	1.3%	2.6%
Bon G et al. 2019	50	70.10	11.0000	50	56.70	11.7900	i +-	13.40	[8.93; 17.87]	1.7%	2.7%
Brismar BH et al. 2018	50	101.00	15.6985	50	80.00	13.5762		21.00 [15.25; 26.75]	1.0%	2.6%
Cheng TE et al. 2016	35	125.00	15.6985	37	100.00	13.5762		25.00 [18.20; 31.80]	0.7%	2.6%
D'Arrigo C et al. 2009	20	121.00	23.6000	149	77.00	15.1000		44.00 [33.38; 54.62]	0.3%	2.4%
De Anta-Diaz B et al. 2016	49	78.20	16.2000	50	82.20	15.2000	-++: 1	-4.00	[-10.19; 2.19]	0.9%	2.6%
Dienstknecht T et al. 2013	83	68.00	27.4000	51	58.60	13.5000	+ +	9.40	[2.44; 16.36]	0.7%	2.6%
Fink B et al. 2010	50	51.90	11.4000	50	50.90	10.2000	- 1 :	1.00	[-3.24; 5.24]	1.9%	2.7%
Gao P et Shi X 2020	35	68.59	5.3700	35	61.56	6.0200	(m)	7.03	[4.36; 9.70]	4.8%	2.7%
Hou JZ 2017	20	115.00	10.0900	20	105.00	15.4000	1 1 4	10.00	[1.93; 18.07]	0.5%	2.5%
Huang K et al. 2021	53	83.10	18.8000	76	73.90	22.3000	1 	9.20	[2.08; 16.32]	0.7%	2.6%
Iorio R et al. 2021	29	92.00	11.0000	31	69.00	9.0000	1 · · · ·	23.00 [17.89; 28.11]	1.3%	2.6%
Khan RJK et al. 2012	44	87.00	2.9700	45	90.00	2.1200		-3.00	[-4.07; -1.93]	29.7%	2.7%
Korytkin A et al. 2023	20	63.20	9.9000	24	61.70	14.1000	-++	1.50	[-5.62; 8.62]	0.7%	2.6%
Landgraeber S et al. 2013	36	93.64	19.4600	40	85.11	21.8500	 •! -	8.53	[-0.76; 17.82]	0.4%	2.5%
Li X et al. 2021	49	83.16	7.4200	47	63.77	9.1300	+	19.39	16.05; 22.73]	3.1%	2.7%
Ling Z 2020	50	118.25	16.9500	50	68.81	10.3700	ii →	49.44	43.93; 54.95]	1.1%	2.6%
Liu W et al. 2022	30	88.83	7.3600	30	90.29	7.2700		-1.46	[-5.16; 2.24]	2.5%	2.7%
Martin R et al. 2011	42	114.12	21.4700	41	95.78	18.5300		18.34	[9.72; 26.96]	0.5%	2.5%
Meng W et al. 2020	4	103.25	12.4100	4	66.50	13.7900		36.75	18.57; 54.93]	0.1%	2.0%
Mjaaland KE et al. 2015	83	77.00	21.0000	80	62.00	10.7500	 • •	15.00	[9.90; 20.10]	1.3%	2.6%
Moerenhout K et al. 2019	28	59.90	12.7000	27	45.70	17.9000	1 	14.20	[5.97; 22.43]	0.5%	2.5%
Müller M et al. 2010	21	51.00	6.8000	16	50.00	7.4000		1.00	[-3.65; 5.65]	1.6%	2.6%
Nistor DV et al. 2017	35	70.00	1.2500	35	70.00	3.7500	<u> </u>	0.00	[-1.31; 1.31]	20.0%	2.7%
Ouyang C et al. 2018	12	109.60	28.3000	12	67.50	16.2000		42.10	23.65; 60.55]	0.1%	2.0%
Pan F et al. 2020	58	92.58	12.3500	58	125.32	12.6300	+	-32.74	37.29; -28.19]	1.7%	2.6%
Parvizi J et al. 2016	44	84.51	33,5000	40	87.53	47.0000		-3.02	-20.63: 14.591	0.1%	2.1%
Restreppo C et al. 2010	50	56.42	13.7500	50	54.88	16.0000	-+	1.54	[-4.31; 7.39]	1.0%	2.6%
Rykov K et al. 2017	23	71.00	7.0000	23	62.00	7.0000	1 4	9.00	[4.95; 13.05]	2.1%	2.7%
Schwarze M et al. 2017	22	70.00	20.0000	21	67.00	18.0000	- { ÷	3.00	[-8.36; 14.36]	0.3%	2.4%
Varela-Egocheaga JR et al. 2013	25	62.04	15.6985	25	60.60	13.5762		1.44	[-6.70; 9.58]	0.5%	2.5%
Wang Z et Ge W 2021	43	105.79	18,7500	42	73.16	9.8200	lii →-	32.63	26.29: 38.971	0.9%	2.6%
Xiao C et al. 2021	49	84.47	19.3700	57	105.44	10.5000	i i	-20.97	27.04: -14.901	0.9%	2.6%
Xie J et al. 2017	46	103.60	11.8000	46	106.50	16.5000	-+1:	-2.90	[-8.76; 2.96]	1.0%	2.6%
Yan T et al. 2017	70	52.00	5.0000	103	36.00	15.0000	; +	16.00	12.88: 19.121	3.5%	2.7%
Yang C et al. 2010	55	77.55	13.3900	55	73.67	14.5100		3.88	[-1.34: 9.10]	1.3%	2.6%
Yuan H et al. 2018	40	57.50	5.6600	44	63.64	6,5000	* i	-6.14	[-8.74: -3.54]	5.1%	2.7%
Zhao HY et al. 2017	60	83.26	6.6900	60	65.48	13.3200	÷ +	17.78	14.01: 21.551	2.4%	2.7%
Zhao S et al. 2021	48	95.80	12,1000	48	71.60	8.2000	¦ +	24.20	20.06; 28.341	2.0%	2.7%
Common effect model	1604			1766			4	3.53	[2.94; 4.12]	100.0%	
Random effects model							\$	10.64	[5.29; 15.99]		100.0%
Heterogeneity: $I^2 = 98\%$, $\tau^2 = 253.825\%$	9. p < 0	.01									
Heterogeneity: / = 98%, \(\tau\) = 253.8259, \(\no\) < 0.01 -60 -40 -20 0 20 40 60											

Figure 2. Comparison of the operation time (min.). SD: standard deviation; MD: mean difference; CI: confidence interval [21–35,37,38,40–43,45–50,53–55,58–64,66,67].

3.1.2. Incision Length: MI THA vs. CA THA

Data on 2513 THAs from 28 RCTs were pooled ($I^2 = 99\%$, p = 0, Figure 3). The incision length for MI THA was 4.1 cm. shorter than that for CA THA (MD = -4.12, 95% CI -5.26 to -2.98).

		Exper	imental			Control					Weight	Weight
Study	Total	Mean	SD	Total	Mean	SD	Mean Di	fference	MD	95%-CI	(common)	(random)
Barrett WP et al. 2013	43	13.70	0.9000	44	12.70	1.3000	ii.	+	1.00	[0.53; 1.47]	2.5%	3.6%
Cheng TE et al. 2016	35	10.70	1.2410	37	13.50	1.3955	-		-2.80	[-3.41; -2.19]	1.5%	3.6%
De Anta-Diaz B et al. 2016	49	10.40	0.9000	50	11.50	0.7000	*		-1.10	[-1.42; -0.78]	5.4%	3.6%
Dienstknecht T et al. 2013	83	13.50	2.6000	51	9.00	1.0000		-	4.50	[3.88; 5.12]	1.4%	3.6%
Gao P et Shi X 2020	35	7.41	0.8500	35	14.55	1.8600	+		-7.14	[-7.82; -6.46]	1.2%	3.6%
Hou JZ 2017	20	7.20	0.5000	20	15.00	1.6000	+		-7.80	[-8.53; -7.07]	1.0%	3.6%
Huang K et al. 2021	53	7.60	1.1000	76	10.60	1.1000	i +		-3.00	[-3.39; -2.61]	3.7%	3.6%
Khan RJK et al. 2012	44	12.60	0.7200	45	19.30	0.3700			-6.70	[-6.94; -6.46]	9.6%	3.6%
Landgraeber S et al. 2013	36	10.29	0.8600	40	11.72	1.6900	1 +		-1.43	[-2.02; -0.84]	1.5%	3.6%
Li X et al. 2021	49	6.88	0.5400	47	11.91	1.2200	*		-5.03	[-5.41; -4.65]	3.8%	3.6%
Ling Z 2020	50	7.06	0.9900	50	9.13	1.1800	1 +		-2.07	[-2.50; -1.64]	3.0%	3.6%
Liu Y et al. 2021	47	7.32	1.3000	47	13.30	2.4600	- ii		-5.98	[-6.78; -5.18]	0.9%	3.6%
Liu W et al. 2022	30	7.83	0.3600	30	12.29	1.2700	+		-4.46	[-4.93; -3.99]	2.4%	3.6%
Martin R et al. 2011	42	9.50	1.4000	41	14.80	3.3000			-5.30	[-6.40; -4.20]	0.5%	3.5%
Meng W et al. 2020	4	7.62	0.9700	4	11.12	1.2100			-3.50	[-5.02; -1.98]	0.2%	3.4%
Mjaaland KE et al. 2015	83	9.50	1.2500	80	13.50	1.2500	t.		-4.00	[-4.38; -3.62]	3.7%	3.6%
Müller M et al. 2010	21	8.00	1.6000	16	10.40	2.0000	ii→-		-2.40	[-3.60; -1.20]	0.4%	3.5%
Nistor DV et al. 2017	35	12.18	1.9100	35	14.79	2.2500	ii		-2.61	[-3.59; -1.63]	0.6%	3.5%
Ouyang C et al. 2018	12	10.40	3.0000	12	12.50	1.4000	¦ ⊢ +−		-2.10	[-3.97; -0.23]	0.2%	3.3%
Pan F et al. 2020	58	7.51	0.8200	58	15.23	2.1400	+		-7.72	[-8.31; -7.13]	1.6%	3.6%
Wang Z et Ge W 2021	43	8.26	1.0200	42	11.19	0.9300	. *		-2.93	[-3.34; -2.52]	3.2%	3.6%
Xiao C et al. 2021	49	9.10	0.9400	57	15.56	1.2000	+		-6.46	[-6.87; -6.05]	3.3%	3.6%
Xie J et al. 2017	46	7.40	1.0600	46	14.50	2.3800	- 1		-7.10	[-7.85; -6.35]	1.0%	3.6%
Yan T et al. 2017	70	5.80	0.6000	103	14.30	1.2000	E		-8.50	[-8.77; -8.23]	7.4%	3.6%
Yang C et al. 2010	55	7.49	0.8600	55	15.19	1.8200	+		-7.70	[-8.23; -7.17]	1.9%	3.6%
Yuan H et al. 2018	40	7.50	1.1300	44	10.73	1.3000	1 <u>+</u>		-3.23	[-3.75; -2.71]	2.0%	3.6%
Zhao HY et al. 2017	60	9.09	0.4500	60	13.14	0.3100	•		-4.05	[-4.19; -3.91]	28.6%	3.6%
Zhao S et al. 2021	48	7.10	0.5000	48	12.50	0.8000			-5.40	[-5.67; -5.13]	7.7%	3.6%
Common effect model	1240			1273			ò		-4.48	[-4.56; -4.41]	100.0%	
Random effects model									-4.12	[-5.26; -2.98]		100.0%
Heterogeneity: $I^2 = 99\%$, $\tau^2 = 8$	8.5295,	p < 0.0	1				-5 (

Figure 3. Comparison of the incision length (cm). SD: standard deviation; MD: mean difference; CI: confidence interval [21,24,26,27,29–31,33,35,37–43,46–49,59–64,66,67].

3.1.3. Intraoperative Blood Loss: MI THA vs. CA THA

Data on 2321 THAs from 26 RCTs were pooled ($I^2 = 99\%$, p = 0, Figure 4). The intraoperative blood loss for MI THA was indifferent compared to that for CA THA (MD = -43.58, 95% CI -94.76 to 7.61).

		Exp	erimental			Control				Weight	Weight
Study	Total	Mean	SD	Total	Mean	SD	Mean Diffe	erence MD	95%-CI	(common)	(random)
Barrett WP et al. 2013	43	391.00	206.0000	44	191.00	107.0000	11	200.00	[130.79; 269.21]	0.1%	3.9%
Brismar BH et al. 2018	50	325.00	250.6092	50	300.00	170.9897	 	- 25.00	[-59.09; 109.09]	0.1%	3.7%
D'Arrigo C et al. 2009	20	1344.00	710.0000	149	1644.00	757.7000		-300.00	[-634.10; 34.10]	0.0%	1.4%
Dienstknecht T et al. 2013	83	411.80	610.0000	51	333.10	161.2000	i ii -	- 78.70	[-59.79; 217.19]	0.0%	3.1%
Fink B et al. 2010	50	262.70	149.7000	50	382.00	179.9000	-+	-119.30	[-184.17; -54.43]	0.1%	3.9%
Gao P et Shi X 2020	35	88.68	6.0400	35	208.52	4.6100		-119.84	[-122.36; -117.32]	61.2%	4.2%
Hou JZ 2017	20	315.00	116.0000	20	470.00	127.1000	-++ i	-155.00	[-230.41; -79.59]	0.1%	3.8%
Huang K et al. 2021	53	72.10	17.4000	76	171.90	50.0000	+ 1	-99.80	[-111.98; -87.62]	2.6%	4.2%
Korytkin A et al. 2023	20	177.50	54.9000	24	204.20	83.3000	17	-26.70	[-67.80; 14.40]	0.2%	4.1%
Landgraeber S et al. 2013	36	268.73	178.5600	40	183.40	82.6000	ii -	+ 85.33	[21.63; 149.03]	0.1%	3.9%
Li X et al. 2021	49	204.99	60.2900	47	343.61	88.6100		-138.62	[-169.06; -108.18]	0.4%	4.1%
Ling Z 2020	50	185.47	20.2300	50	388.95	47.7100	+	-203.48	[-217.84; -189.12]	1.9%	4.2%
Liu Y et al. 2021	47	92.43	7.1400	47	195.83	18.9900	φ.	-103.40	[-109.20; -97.60]	11.5%	4.2%
Liu W et al. 2022	30	203.03	23.1400	30	387.49	24.2500	• []	-184.46	[-196.45; -172.47]	2.7%	4.2%
Meng W et al. 2020	4	1108.50	163.6300	4	843.50	111.6000		265.00	[70.90; 459.10]	0.0%	2.5%
Ouyang C et al. 2018	12	138.33	42.8200	12	141.67	35.8900	11	-3.34	[-34.95; 28.27]	0.4%	4.1%
Parvizi J et al. 2016	44	209.00	175.0000	40	257.40	125.0000	+ + +	-48.40	[-113.01; 16.21]	0.1%	3.9%
Restreppo C et al. 2010	50	172.50	137.5000	50	170.00	112.5000	11	2.50	[-46.74; 51.74]	0.2%	4.0%
Rykov K et al. 2017	23	325.70	99.7400	23	273.70	181.0000	: :++	- 52.00	[-32.46; 136.46]	0.1%	3.7%
Wang Z et Ge W 2021	43	89.47	9.3200	42	253.86	42.5800	•	-164.39	[-177.57; -151.21]	2.2%	4.2%
Xie J et al. 2017	46	303.60	106.3000	46	326.40	127.2000	1	-22.80	[-70.70; 25.10]	0.2%	4.0%
Yan T et al. 2017	70	349.00	28.0000	103	165.00	70.0000		+ 184.00	[168.97; 199.03]	1.7%	4.2%
Yang C et al. 2010	55	376.18	168.3000	55	605.00	225.1200		-228.82	[-303.10; -154.54]	0.1%	3.8%
Yuan H et al. 2018	40	175.00	11.3200	44	209.09	16.9600	0	-34.09	[-40.21; -27.97]	10.4%	4.2%
Zhao HY et al. 2017	60	165.89	42.6000	60	123.84	56.8300	i +	42.05	[24.08; 60.02]	1.2%	4.2%
Zhao S et al. 2021	48	184.30	26.4000	48	295.70	33.9000	1	-111.40	[-123.56; -99.24]	2.6%	4.2%
Common effect model	1081			1240			() ()	-103.85	[-105.82; -101.89]	100.0%	
Random effects model							\	-43.58	[-94.76; 7.61]		100.0%
Heterogeneity: $I^2 = 99\%$, $\tau^2 = 1$	13766.2	440, p < 0.	.01					1 1 1			
						-(600-400-200 0	200 400 600			

Figure 4. Comparison of the intraoperative blood loss (mL). SD: standard deviation; MD: mean difference; CI: confidence interval [21,23,25,27–31,34,35,37–40,42,48,50,53,54,59,61–64,66,67].

3.1.4. Pain VAS 1 Day Postoperatively: MI THA vs. CA THA

Data on 800 THAs from 9 RCTs were pooled ($I^2 = 96\%$, p < 0.01, Figure 5). The pain VAS 1 day postoperatively for MI THA was 1.1 points lower than that for CA THA (MD = -1.06, 95% CI -1.74 to -0.37).

Study	Total	Experi Mean	imental SD	Total	Mean	Control SD	Mean Di	fference	MD	95%-CI	Weight (common)	Weight (random)
D						4 0000	<i>i</i>	1	0.50		0.50	
Barrett WP et al. 2013	43	4.00	1.0000	44	4.50	1.2000			-0.50	[-0.96; -0.04]	2.5%	11.6%
Hou JZ 2017	20	3.10	1.3000	20	4.90	1.7000			-1.80	[-2.74; -0.86]	0.6%	9.1%
Huang K et al. 2021	53	2.80	0.7000	76	4.00	1.3000			-1.20	[-1.55; -0.85]	4.5%	12.1%
Meng W et al. 2020	4	8.25	0.9500	4	7.00	0.8100	1	— • —	1.25	[0.03; 2.47]	0.4%	7.6%
Mjaaland KE et al. 2015	83	2.60	2.0000	80	4.00	2.3000			-1.40	[-2.06; -0.74]	1.2%	10.7%
Nistor DV et al. 2017	35	1.00	0.2500	35	3.00	0.5000	* {		-2.00	[-2.19; -1.81]	15.8%	12.6%
Ouyang C et al. 2018	12	3.50	0.8000	12	4.17	0.7200	÷.		-0.67	[-1.28; -0.06]	1.5%	10.9%
Xiao C et al. 2021	49	5.00	0.2500	57	5.75	0.2500	+		-0.75	[-0.85; -0.65]	59.4%	12.7%
Yan T et al. 2017	70	4.80	0.6000	103	6.50	0.7000	*		-1.70	[-1.90; -1.50]	14.2%	12.6%
Common effect model	369			431			6		-1.10	[-1.18; -1.03]	100.0%	
Random effects model							\sim		-1.06	[-1.74; -0.37]		100.0%
Heterogeneity: $I^2 = 96\%$, τ^2	= 0.57	70, p < (0.01					1 1 1				
							-2 -1) 1 2				

Figure 5. Comparison of the pain VAS 1 day postoperatively (points). SD: standard deviation; MD: mean difference; CI: confidence interval [21,30,31,42,43,47,48,60,62].

3.1.5. Pain VAS 3 Days Postoperatively: MI THA vs. CA THA

Data on 644 THAs from 8 RCTs were pooled ($I^2 = 96\%$, p < 0.01, Figure 6). The pain VAS 3 days postoperatively for MI THA was 0.8 point lower than that for CA THA (MD = -0.82, 95% CI -1.38 to -0.25).

Study	Total	Exper Mean	imental SD	Total	Mean	Control SD	Mean Difference	MD	95%-CI	Weight (common)	Weight (random)
Hou JZ 2017 lorio R et al. 2021 Meng W et al. 2020 Mjaaland KE et al. 2015 Nistor DV et al. 2017 Ouyang C et al. 2018 Xiao C et al. 2021 Yan T et al. 2017	20 29 4 83 35 12 49 70	1.50 2.70 7.00 1.60 2.00 2.17 4.00 3.10	1.4000 1.0989 1.4100 1.7000 0.7500 0.7200 0.3300 0.2000	20 31 4 80 35 12 57 103	2.90 3.60 6.50 2.80 2.00 2.92 4.50 4.80	1.3000 1.0476 0.5700 2.1000 0.5000 0.9000 0.3300 0.8000		-1.40 -0.90 0.50 -1.20 0.00 -0.75 -0.50 -1.70	[-2.24; -0.56] [-1.44; -0.36] [-0.99; 1.99] [-1.79; -0.61] [-0.30; 0.30] [-1.40; -0.10] [-0.63; -0.37] [-1.86; -1.54]	1.2% 2.7% 0.4% 2.4% 9.1% 1.9% 51.2% 31.2%	10.4% 13.0% 6.0% 12.6% 14.8% 12.0% 15.5%
Common effect model Random effects model Heterogeneity: $l^2 = 96\%$, τ^2	302 = 0.35	22, p < 1	0.01	342			-2 -1 0 1 2	-0.87 -0.82	[-0.96; -0.78] [-1.38; -0.25]	100.0%	100.0%

Figure 6. Comparison of the pain VAS 3 days postoperatively (points). SD: standard deviation; MD: mean difference; CI: confidence interval [30,32,42,43,47,48,60,62].

3.2. Functional Outcome

3.2.1. HHS 0-1.5 Months Postoperatively: MI THA vs. CA THA

Data on 2190 THAs from 26 RCTs were pooled ($I^2 = 95\%$, p < 0.01, Figure 7). The HHS 0–1.5 months postoperatively for MI THA was 5.2 points higher than that for CA THA (MD = 5.22, 95% CI 3.18 to 7.26).

		Expe	rimental			Control							Weight	Weight
Study	Total	Mean	SD	Total	Mean	SD		Mean	Difference		MD	95%-CI	(common)	(random)
Barrett WP et al. 2013	43	89.50	8.1000	44	81.40	9.8000			+		8.10	[4.33; 11.87]	0.7%	3.8%
Bon G et al. 2019	50	83.52	13,4400	50	80.37	13.3800			<u></u>		3.15	[-2.11: 8.41]	0.3%	3.3%
D'Arrigo C et al. 2009	20	93.10	7.8000	149	86.70	8.9000			_}		6.40	[2.69; 10.11]	0.7%	3.9%
Dienstknecht T et al. 2013	83	74.50	13.5000	51	78.40	12.1000		_	+ }		-3.90	[-8.31; 0.51]	0.5%	3.6%
Gao P et Shi X 2020	35	80.21	2.6200	35	67.74	5.0800			{ +		12.47	[10.58; 14.36]	2.6%	4.4%
Hou JZ 2017	20	76.10	4.8000	20	65.20	5.9000			}		10.90	[7.57; 14.23]	0.9%	4.0%
Huang K et al. 2021	53	71.30	2.3000	76	60.60	3.5000			1 ×		10.70	[9.70; 11.70]	9.5%	4.5%
Korytkin A et al. 2023	20	78.60	9.2000	24	68.80	15.1000			+	-	9.80	[2.54; 17.06]	0.2%	2.6%
Li L 2020	30	70.52	3.3200	30	61.15	2.0100			<u>+</u>		9.37	[7.98; 10.76]	4.9%	4.5%
Liu Y et al. 2021	47	88.24	4.4700	47	80.01	3.8200			} +		8.23	[6.55; 9.91]	3.4%	4.4%
Liu W et al. 2022	30	83.22	5.3500	30	72.41	4.3400			{		10.81	[8.34; 13.28]	1.6%	4.2%
Meng W et al. 2020	4	62.50	8.3400	4	77.50	3.4100	\rightarrow				-15.00	[-23.83; -6.17]	0.1%	2.2%
Moerenhout K et al. 2019	28	76.70	16.4000	27	68.70	16.8000			+++	-	8.00	[-0.78; 16.78]	0.1%	2.2%
Ouyang C et al. 2018	12	78.67	5.3500	12	75.50	4.5000			++		3.17	[-0.79; 7.13]	0.6%	3.8%
Pan F et al. 2020	58	89.81	2.4300	58	84.42	2.3400			-		5.39	[4.52; 6.26]	12.6%	4.6%
Reichert et al. 2018	77	81.60	12.1000	71	82.40	12.0000		0	-+- {		-0.80	[-4.69; 3.09]	0.6%	3.8%
Ren D et al. 2016	21	87.43	9.0500	21	86.34	10.2400		2	- - } -		1.09	[-4.75; 6.93]	0.3%	3.1%
Restreppo C et al. 2010	50	93.64	5.7300	50	88.80	8.6800					4.84	[1.96; 7.72]	1.1%	4.1%
Rykov K et al. 2017	23	93.00	10.8700	23	90.00	9.1400			++		3.00	[-2.80; 8.80]	0.3%	3.1%
Taunton M et al. 2014	27	97.00	9.7562	27	93.00	7.1649			<u>++</u>		4.00	[-0.57; 8.57]	0.5%	3.6%
Taunton et al. 2018	52	95.00	6.0000	49	92.00	8.0000			⊢+ {		3.00	[0.23; 5.77]	1.2%	4.2%
Xiao C et al. 2021	49	86.00	2.0000	57	79.00	2.5000					7.00	[6.14; 7.86]	12.9%	4.6%
Xie J et al. 2017	46	81.40	3.1800	46	76.80	2.9300			+		4.60	[3.35; 5.85]	6.1%	4.5%
Yan T et al. 2017	70	81.50	7.3000	103	79.80	6.1000			+- i		1.70	[-0.38; 3.78]	2.2%	4.3%
Yuan H et al. 2018	40	82.50	1.1300	44	80.73	1.3000			- 1		1.77	[1.25; 2.29]	35.2%	4.6%
Zhang ZL et al. 2019	27	70.50	5.6000	27	63.80	6.1000			1 -		6.70	[3.58; 9.82]	1.0%	4.1%
Common effect model	1015			1175					i i		5 17	[4 86: 5 48]	100.0%	
Random effects model	1010										5.22	[3.18: 7.26]		100.0%
Heterogeneity: $l^2 = 05\%$ $r^2 = 1$	18 424	7 0 < 0	01					1				[01.0, 1120]		
neterogeneity. 7 = 55%, t =	10.424	, p = 0.					-20	-10	0 10	20				

Figure 7. Comparison of the HHS 0–1.5 months postoperatively (points). SD: standard deviation; MD: mean difference; CI: confidence interval [21,22,25,27,29–31,34,36,39,40,42,45,48,49,51–54,56,57,60–62,64,65].

3.2.2. HHS 3 Months Postoperatively: MI THA vs. CA THA

Data on 1827 THAs from 22 RCTs were pooled ($I^2 = 91\%$, p < 0.01, Figure 8). The HHS 3 months postoperatively for MI THA was 2.2 points higher than that for CA THA (MD = 2.15, 95% CI 0.31 to 3.99).

Study	Total	Expe Mean	rimental SD	Total	Mean	Control SD	N	Nean	Differenc	e	м) 95%-C	Weight (common)	Weight (random)
Barrett WP et al. 2013	43	91.20	9.7000	44	91.40	9.7000		-			-0.20	0 [-4.28; 3.88	0.3%	4.4%
Bon G et al. 2019	50	89.95	12.7300	50	91.30	9.4800		-	• 		-1.3	5 [-5.75; 3.05	0.3%	4.2%
De Anta-Diaz B et al. 2016	49	94.60	10.2000	50	92.80	11.3000					1.8	0 [-2.44; 6.04	0.3%	4.3%
Dienstknecht T et al. 2013	83	86.00	15.4000	51	88.00	14.6000			-		-2.00	0 [-7.20; 3.20	0.2%	3.8%
Li L 2020	30	87.32	3.7400	30	81.21	2.0400			ii →		6.1	1 [4.59; 7.63	2.3%	5.6%
Meng W et al. 2020	4	72.25	3.8600	4	83.25	2.3600 -					-11.00	0 [-15.43; -6.57	0.3%	4.2%
Moerenhout K et al. 2019	28	88.40	11.8000	27	83.30	15.1000					5.10	0 [-2.08; 12.28	0.1%	2.9%
Müller M et al. 2010	21	80.50	14.0000	16	76.20	19.0000		-			- 4.30	0 [-6.77; 15.37	0.0%	1.7%
Ouyang C et al. 2018	12	82.08	4.7600	12	79.25	5.9900			-++	-	2.8	3 [-1.50; 7.16	0.3%	4.3%
Pan F et al. 2020	58	92.25	2.5300	58	90.32	1.6100			ti		1.93	3 [1.16; 2.70	9.0%	5.8%
Reichert et al. 2018	77	89.80	9.3000	71	88.40	9.9000			-+		1.40	0 [-1.70; 4.50	0.6%	4.9%
Ren D et al. 2016	21	86.51	5.1300	21	87.84	5.4300		_	•++;		-1.3	3 [-4.52; 1.86	0.5%	4.9%
Schwarze M et al. 2017	22	90.00	12.0000	21	85.00	14.0000		-			5.00	0 [-2.81; 12.81	0.1%	2.7%
Varela-Egocheaga JR et al. 2013	25	94.00	10.8695	25	93.80	7.4363		-	- <u><u>+</u>;</u>		0.20	0 [-4.96; 5.36	0.2%	3.8%
Wang Z et Ge W 2021	43	93.25	3.9600	42	89.54	3.7200			1 i		3.7	1 [2.08; 5.34	2.0%	5.5%
Xiao C et al. 2021	49	91.00	1.0000	57	90.00	0.7500			+		1.00	0 [0.66; 1.34	46.0%	5.8%
Xie J et al. 2017	46	87.60	1.7600	46	80.10	4.4900			- 18 -	+	7.50	0 [6.11; 8.89	2.8%	5.6%
Yan T et al. 2017	70	89.60	2.1000	103	88.20	6.1000			H÷		1.40	0 [0.12; 2.68	3.3%	5.6%
Yang C et al. 2010	55	83.80	5.6400	55	74.96	7.4700			- 18 -	<u> </u>	8.84	4 [6.37; 11.31	0.9%	5.2%
Yuan H et al. 2018	40	86.53	1.1500	44	86.14	0.7700					0.3	9 [-0.03; 0.81	29.9%	5.8%
Zhang ZL et al. 2019	27	83.10	5.5000	27	78.00	5.6000			_ ii-+-	_	5.10	2.14; 8.06	0.6%	5.0%
Zhao HY et al. 2017	60	85.90	17.3600	60	79.60	11.8700			¦i →		6.3	0 [0.98; 11.62	0.2%	3.8%
Common effect model	913			914					0		1.3	2 [1.09; 1.56]	100.0%	
Random effects model									\diamond		2.1	5 [0.31; 3.99]		100.0%
Heterogeneity: $I^2 = 91\%$, $\tau^2 = 13.5072$,	p < 0.0	01				I	1	1	1 1	1	1			
						-1	5 -10	-5	0 5	10	15			

Figure 8. Comparison of the HHS 3 months postoperatively (points). SD: standard deviation; MD: mean difference; CI: confidence interval [21,22,26,27,36,42,45,46,48,49,51,52,55,58–66].

3.2.3. HHS 6 Months Postoperatively: MI THA vs. CA THA

Data on 1072 THAs from 13 RCTs were pooled ($I^2 = 76\%$, p < 0.01, Figure 9). The HHS 6 months postoperatively for MI THA was 1.9 points higher than that for CA THA (MD = 1.88, 95% CI 0.48 to 3.29).

		Expe	rimental			Control				Weight	Weight
Study	Total	Mean	SD	Total	Mean	SD	Mean Difference	MD	95%-CI	(common)	(random)
Barrett WP et al. 2013	43	95.80	7.8000	44	95.90	6.8000		-0.10	[-3.18; 2.98]	2.7%	7.6%
Li L 2020	30	95.75	3.9200	30	90.11	3.0700		5.64	[3.86; 7.42]	7.9%	10.3%
Ling Z 2020	50	85.26	5.4100	50	79.67	4.8000		5.59	[3.59; 7.59]	6.2%	9.9%
Meng W et al. 2020	4	84.25	6.1800	4	86.75	3.8600		-2.50	[-9.64; 4.64]	0.5%	2.8%
Moerenhout K et al. 2019	28	90.10	11.3000	27	90.30	12.3000		-0.20	[-6.45; 6.05]	0.6%	3.4%
Ouyang C et al. 2018	12	84.92	5.8700	12	84.17	7.0400		0.75	[-4.44; 5.94]	0.9%	4.4%
Pan F et al. 2020	58	93.67	2.2200	58	92.91	3.0500	E i	0.76	[-0.21; 1.73]	26.6%	11.9%
Reichert et al. 2018	77	90.30	9.8000	71	89.10	10.0000		1.20	[-1.99; 4.39]	2.5%	7.4%
Schwarze M et al. 2017	22	96.00	5.0000	21	91.00	10.0000		5.00	[0.24; 9.76]	1.1%	4.9%
Yan T et al. 2017	70	93.10	3.7000	103	92.80	4.7000	- ** *	0.30	[-0.96; 1.56]	15.9%	11.4%
Yuan H et al. 2018	40	90.00	2.0300	44	89.34	2.2900	善	0.66	[-0.26; 1.58]	29.4%	11.9%
Zhang ZL et al. 2019	27	88.00	3.6000	27	86.40	5.3000		1.60	[-0.82; 4.02]	4.3%	9.0%
Zhao HY et al. 2017	60	92.20	13.2500	60	89.90	11.7400		2.30	[-2.18; 6.78]	1.3%	5.3%
Common effect model	521			551			4	1.41	[0.91; 1.91]	100.0%	
Random effects model								1.88	[0.48; 3.29]		100.0%
Heterogeneity: $I^2 = 76\%$, $\tau^2 =$	3.7198	p < 0.	01								
							-5 0 5				

Figure 9. Comparison of the HHS 6 months postoperatively (points). SD: standard deviation; MD: mean difference; CI: confidence interval [21,36,38,42,45,48,49,51,55,62,64–66].

3.2.4. HHS \geq 12 Months Postoperatively: MI THA vs. CA THA

Data on 1161 THAs from 16 RCTs were pooled (I² = 12%, p = 0.32, Figure 10). The HHS \geq 12 months postoperatively for MI THA was 0.9 point higher than that for CA THA (MD = 0.85, 95% CI 0.27 to 1.43).

Study	Total	Expe Mean	rimental SD	Total	Mean	Control SD	м	ean Di	fferen	се		MD	9	5%-CI	Weight (common)	Weight (random)
Barrett WP et al. 2013	43	97.50	5.7000	44	97.30	5.5000		_	₩-			0.20	[-2.15;	2.55]	4.5%	4.5%
De Anta-Diaz B et al. 2016	49	96.20	10.1000	50	94.50	9.7000		_	H•			1.70	[-2.20;	5.60]	1.6%	1.6%
Martin R et al. 2011	42	86.70	14.8000	41	87.40	12.6000			H—			0.70	[-6.61;	5.21]	0.7%	0.7%
Meng W et al. 2020	4	92.50	1.7300	4	92.50	1.7300		-	H-			0.00	[-2.40;	2.40]	4.4%	4.4%
Moerenhout K et al. 2019	28	94.40	8.0000	27	91.40	13.0000			H+			3.00	[-2.73;	8.73]	0.8%	0.8%
Müller M et al. 2010	21	87.30	7.0000	16	80.40	17.0000		_		•	_	6.90	[-1.95; 1	5.75]	0.3%	0.3%
Ouyang C et al. 2018	12	85.58	6.5400	12	86.75	3.1400			H-			1.17	[-5.27;	2.93]	1.5%	1.5%
Pan F et al. 2020	58	94.72	2.9200	58	94.04	2.8100			÷			0.68	[-0.36;	1.72]	23.0%	23.0%
Reichert et al. 2018	77	92.40	8.6000	71	91.40	9.1000		-	-			1.00	[-1.86;	3.86]	3.1%	3.1%
Schwarze M et al. 2017	22	97.00	3.0000	21	92.00	6.0000			→			5.00	[2.14;	7.86]	3.1%	3.1%
Taunton M et al. 2014	27	98.00	7.6213	27	97.50	7.0286						0.50	[-3.41;	4.41]	1.6%	1.6%
Taunton et al. 2018	52	97.00	4.0000	49	95.00	7.0000			H+			2.00	[-0.24;	4.24]	5.0%	5.0%
Varela-Egocheaga JR et al. 2013	25	96.80	7.6213	25	93.60	7.0286		-	H+	_		3.20	[-0.86;	7.26]	1.5%	1.5%
Xie J et al. 2017	46	92.30	1.6200	46	91.60	2.4100			-			0.70	[-0.14;	1.54]	35.6%	35.6%
Yang C et al. 2010	55	91.20	5.3800	55	91.64	4.8100			H			0.44	[-2.35;	1.47]	6.9%	6.9%
Zhang ZL et al. 2019	27	91.30	3.8000	27	90.10	3.6000		-	<u>k</u>			1.20	[-0.77;	3.17]	6.4%	6.4%
									li							
Common effect model	588			573					¢.			0.85	[0.35;	1.35]	100.0%	
Random effects model									\$			0.85	[0.27;	1.43]		100.0%
Heterogeneity: $I^2 = 12\%$, $\tau^2 < 0.0001$, p	= 0.32	2						1		1	1					
							15 -10	-5 () 5	10	15					

Figure 10. Comparison of the HHS \geq 12 months postoperatively (points). SD: standard deviation; MD: mean difference; CI: confidence interval [21,26,41,42,45,46,48,49,51,55–58,61,63,65].

3.3. Radiological Outcome

3.3.1. Acetabular Cup Anteversion Angle: MI THA vs. CA THA

Data on 1341 THAs from 17 RCTs were pooled ($I^2 = 97\%$, p < 0.01, Figure 11). The acetabular cup anteversion angle for MI THA was indifferent compared to that for CA THA (MD = -0.46, 95% CI -2.05 to 1.13).

		Exper	imental			Control								Weight	Weight
Study	Total	Mean	SD	Total	Mean	SD		Mea	n Differ	ence		MD	95%-CI	(common)	(random)
Barrett WP et al. 2013	43	20.10	5.9000	44	25.80	8.1000	_					-5.70	[-8.67; -2.73]	0.6%	5.3%
Cheng TE et al. 2016	35	24.60	3.8447	37	20.30	3.8042						4.30	[2.53; 6.07]	1.8%	6.1%
Fink B et al. 2010	50	25.10	5.2000	50	24.60	4.9000						0.50	[-1.48; 2.48]	1.4%	6.0%
Hou JZ 2017	20	17.70	1.2000	20	18.00	0.9000			1美			-0.30	[-0.96; 0.36]	12.7%	6.6%
Khan RJK et al. 2012	44	15.50	1.0100	45	20.10	1.2500						-4.60	[-5.07; -4.13]	24.6%	6.7%
Korytkin A et al. 2023	20	18.00	2.9407	24	19.00	3.8042		-				-1.00	[-2.99; 0.99]	1.4%	6.0%
Landgraeber S et al. 2013	36	19.71	6.1500	40	19.19	4.9600			+++-	-		0.52	[-2.01; 3.05]	0.9%	5.6%
Li X et al. 2021	49	15.27	2.6500	47	15.85	2.1400			博			-0.58	[-1.54; 0.38]	5.9%	6.5%
Meng W et al. 2020	4	15.00	1.8200	4	14.25	2.0600			++++	_		0.75	[-1.94; 3.44]	0.8%	5.5%
Moerenhout K et al. 2019	28	26.90	8.6000	27	21.90	13.4000			1			5.00	[-0.97; 10.97]	0.2%	3.2%
Ouyang C et al. 2018	12	21.92	5.7800	12	21.75	4.4800		_				0.17	[-3.97; 4.31]	0.3%	4.4%
Taunton M et al. 2014	27	26.00	3.8447	27	29.00	3.8042			-+il			-3.00	[-5.04; -0.96]	1.3%	5.9%
Taunton et al. 2018	52	23.00	4.0000	49	25.00	6.0000		-	+++			-2.00	[-4.00; 0.00]	1.4%	6.0%
Xie J et al. 2017	46	17.40	1.6000	46	18.50	1.8000			- 18			-1.10	[-1.80; -0.40]	11.3%	6.6%
Yan T et al. 2017	70	21.70	4.1000	103	16.10	2.8000						5.60	[4.50; 6.70]	4.5%	6.5%
Yang C et al. 2010	55	20.20	1.1000	55	19.90	1.5000						0.30	[-0.19; 0.79]	22.7%	6.7%
Zhao HY et al. 2017	60	17.10	2.1000	60	21.30	2.4000		-				-4.20	[-5.01; -3.39]	8.4%	6.6%
Common effect model	651			690					*			-1.38	[-1.61; -1.14]	100.0%	
Random effects model							_		\Leftrightarrow			-0.46	[-2.05; 1.13]		100.0%
Heterogeneity: $I^2 = 97\%$, $\tau^2 = 8$	3.3977,	$p < 0.0^{\circ}$	1				1	1	1	1	1				
-							-10	-5	0	5	10				

Figure 11. Comparison of the acetabular cup anteversion angle (degrees). SD: standard deviation; MD: mean difference; CI: confidence interval [21,24,28,30,33–35,37,42,45,48,56,57,61–63,66].

3.3.2. Acetabular Cup Inclination Angle: MI THA vs. CA THA

Data on 1843 THAs from 22 RCTs were pooled ($I^2 = 86\%$, p < 0.01, Figure 12). The acetabular cup inclination angle for MI THA was indifferent compared to that for CA THA (MD = -0.79, 95% CI -1.73 to 0.15).

Study	Total	Exper Mean	imental SD	Total	Mean	Control SD		Mean Difference	e	MD	95%-CI	Weight (common)	Weight (random)
Barrett WP et al. 2013	43	47.10	6.1000	44	42.40	7.6000			-	4.70	[1.81; 7.59]	0.9%	3.8%
Bon G et al. 2019	50	37.74	4.2000	50	39.60	6.8700		- ; ; 		-1.86	[-4.09; 0.37]	1.4%	4.6%
Cheng TE et al. 2016	35	46.20	4.8259	37	45.90	4.5813		<u> </u> ++}−		0.30	[-1.88; 2.48]	1.5%	4.7%
Dienstknecht T et al. 2013	83	49.60	6.1000	51	48.20	6.0000		¦ }+ ⊷		1.40	[-0.71; 3.51]	1.6%	4.8%
Fink B et al. 2010	50	43.70	5.9000	50	42.80	6.6000		i de		0.90	[-1.55; 3.35]	1.2%	4.4%
Hou JZ 2017	20	43.90	2.9000	20	44.70	3.1000		÷++		-0.80	[-2.66; 1.06]	2.1%	5.1%
Khan RJK et al. 2012	44	41.80	1.0200	45	45.30	0.9800		•		-3.50	[-3.92; -3.08]	41.8%	6.6%
Korytkin A et al. 2023	20	43.00	4.0202	24	44.00	4.5813		-++		-1.00	[-3.54; 1.54]	1.1%	4.2%
Landgraeber S et al. 2013	36	42.18	5.0400	40	38.96	5.3100		i →→		3.22	[0.89; 5.55]	1.3%	4.5%
Li X et al. 2021	49	43.88	2.9400	47	46.47	1.8700		+		-2.59	[-3.57; -1.61]	7.5%	6.2%
Meng W et al. 2020	4	38.75	8.2100	4	44.50	3.6400				-5.75	[-14.55; 3.05]	0.1%	0.8%
Moerenhout K et al. 2019	28	43.30	8.4000	27	39.80	5.4000				3.50	[-0.22; 7.22]	0.5%	3.0%
Nistor DV et al. 2017	35	36.97	1.8500	35	39.63	2.8800		국민		-2.66	[-3.79; -1.53]	5.6%	6.0%
Ouyang C et al. 2018	12	37.08	6.5300	12	39.67	6.9500	-			-2.59	[-7.99; 2.81]	0.2%	1.9%
Reichert et al. 2018	77	38.60	5.7000	71	40.28	6.2000				-1.68	[-3.60; 0.24]	2.0%	5.0%
Taunton M et al. 2014	27	38.00	4.8259	27	40.00	4.5813				-2.00	[-4.51; 0.51]	1.1%	4.3%
Taunton et al. 2018	52	37.00	5.0000	49	39.00	6.0000		-+		-2.00	[-4.16; 0.16]	1.5%	4.7%
Varela-Egocheaga JR et al. 2013	25	43.70	4.8259	25	45.30	4.5813		-+++		-1.60	[-4.21; 1.01]	1.1%	4.2%
Xie J et al. 2017	46	43.60	6.8000	46	44.50	6.5000		-++-		-0.90	[-3.62; 1.82]	1.0%	4.0%
Yan T et al. 2017	70	38.90	2.6000	103	39.50	0.4000		100		-0.60	[-1.21; 0.01]	19.1%	6.5%
Yang C et al. 2010	55	48.30	5.3000	55	48.90	6.6000		++-		-0.60	[-2.84; 1.64]	1.4%	4.6%
Zhao HY et al. 2017	60	40.30	2.8000	60	41.80	3.4000		1 total		-1.50	[-2.61; -0.39]	5.8%	6.0%
Common effect model	921			922				•		-2.05	[-2.32; -1.79]	100.0%	
Random effects model							_		_	-0.79	[-1.73; 0.15]		100.0%
Heterogeneity: $I^2 = 86\%$, $\tau^2 = 2.9258$, p	< 0.0	1					1	1 1 1	I				
							-10	-5 0 5	10				

Figure 12. Comparison of the acetabular cup inclination angle (degrees). SD: standard deviation; MD: mean difference; CI: confidence interval [21,22,24,27,28,30,33–35,37,42,45,47,48,51,56–58,61–63,66].

3.4. Postoperative Complications

3.4.1. Overall Postoperative Complications: MI THA vs. CA THA

Data on 2959 THAs from 34 RCTs were pooled ($I^2 = 64\%$, p < 0.01, Figure 13). The overall postoperative complication risk for MI THA was indifferent compared to that for CA THA (OR = 1.20, 95% CI 0.58 to 2.49).

	Experin	nental	C	ontrol				Weight	Weight
Study	Events	Total	Events	Total	Odds Ratio	OR	95%-CI	(common)	(random)
Barrett WP et al. 2013	0	43	2	44	<u> </u>	0.20	[0.01; 4.19]	3.4%	3.0%
Bon G et al. 2019	10	50	1	50	· 12	2.25	[1.50; 99.80]	1.4%	4.3%
Brismar BH et al. 2018	3	50	0	50	- 7	.44	[0.37; 147.92]	0.0%	3.1%
Cheng TE et al. 2016	32	35	2	37	ii	6.67	[29.28; 1189.90]	0.3%	4.7%
D'Arrigo C et al. 2009	2	20	3	149	8	5.41	[0.85; 34.56]	1.1%	4.7%
Dienstknecht T et al. 2013	3	83	3	51	<u> </u>	0.60	[0.12; 3.09]	6.1%	5.1%
Fink B et al. 2010	1	50	1	50		00.1	[0.06; 16.44]	1.7%	3.4%
Gao P et Shi X 2020	2	35	8	35	- <u></u> (; 0	0.20	[0.04; 1.04]	12.8%	5.1%
Hou JZ 2017	2	20	1	20	2	2.11	[0.18; 25.35]	1.5%	3.8%
Iorio R et al. 2021	2	29	2	31	<u></u> 1	1.07	[0.14; 8.17]	3.1%	4.4%
Khan RJK et al. 2012	2	44	3	45	<u> </u>	0.67	[0.11; 4.20]	4.8%	4.7%
Korytkin A et al. 2023	0	20	0	24	ŧ.			0.0%	0.0%
Landgraeber S et al. 2013	0	36	0	40	<u> </u>			0.0%	0.0%
Ling Z 2020	2	50	12	50	(i (i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i(i _(i).13	[0.03; 0.63]	19.6%	5.2%
Liu Y et al. 2021	1	47	5	47		0.18	[0.02; 1.63]	8.3%	4.2%
Liu W et al. 2022	0	30	0	30	8			0.0%	0.0%
Martin R et al. 2011	0	42	0	41	ŧ.			0.0%	0.0%
Meng W et al. 2020	0	4	0	4	li i i i i i i i i i i i i i i i i i i			0.0%	0.0%
Mjaaland KE et al. 2018	7	83	2	80		8.59	[0.72; 17.84]	3.2%	5.1%
Moerenhout K et al. 2019	1	28	2	27		0.46	[0.04; 5.43]	3.3%	3.8%
Nistor DV et al. 2017	4	35	2	35		2.13	[0.36; 12.46]	3.0%	4.9%
Ouyang C et al. 2018	1	12	0	12		3.26	[0.12; 88.35]	0.0%	2.8%
Pan F et al. 2020	3	58	4	58).74	[0.16; 3.45]	6.4%	5.2%
Reichert et al. 2018	3	77	1	71	_ + 2	2.84	[0.29; 27.93]	1.7%	4.0%
Restreppo C et al. 2010	0	50	0	50				0.0%	0.0%
Schwarze M et al. 2017	0	22	0	21	8			0.0%	0.0%
Taunton M et al. 2014	2	27	2	27		00.1	[0.13; 7.67]	3.1%	4.4%
Taunton et al. 2018	1	52	4	49	<u> </u>).22	[0.02; 2.05]	6.9%	4.1%
Varela-Egocheaga JR et al. 2013	0	25	0	25	8			0.0%	0.0%
Xie J et al. 2017	1	46	3	46		0.32	[0.03; 3.18]	5.0%	4.0%
Yan T et al. 2017	0	70	0	103	8			0.0%	0.0%
Yang C et al. 2010	0	55	0	55	ŧ.			0.0%	0.0%
Zhang ZL et al. 2019	0	27	2	27).19	[0.01; 4.05]	3.4%	3.0%
Zhao HY et al. 2017	1	60	0	60		8.05	[0.12; 76.39]	0.0%	2.9%
Common effect model		1415		1544	Å 1	.41	[1.01; 1.96]	100.0%	
Random effects model					1	.20	[0.58; 2.49]		100.0%
Heterogeneity: $I^2 = 64\%$, $\tau^2 = 1.9349$, μ	o < 0.01								
				0.0	01 01 1 10 1000				

Figure 13. Comparison of the overall postoperative complication rate. OR: odds ratio; CI: confidence interval [21–25,27–30,32–35,38–42,44,45,47–49,51,53,55–58,61–63,65,66].

3.4.2. Dislocation: MI THA vs. CA THA

Data on 2755 THAs from 31 RCTs were pooled ($I^2 = 0\%$, p = 0.91, Figure 14). The dislocation risk for MI THA was indifferent compared to that for CA THA (OR = 0.85, 95% CI 0.43 to 1.66).

	Experim	nental	Co	ontrol			Weight	Weight
Study	Events	Total	Events	Total	Odds Ratio OR	95%-CI	(common)	(random)
Parrott M/P at al. 2012	0	42	1	44	1 0.22	10.01: 0.411	0 10/	7 204
Ballell WP et al. 2013 Bon C et al. 2019	1	43		44 50	- 0.33	[0.01, 8.41]	9.1%	7.3%
Brismar PH at al. 2019	2	50	0	50	5.00	[0.12, 70.95]	0.0%	0.104
Chopg TE at al. 2016	2	20	1	27	5.21	[0.24, 111.24]	0.0%	0.1%
Cherrigo C et al. 2010		30		140	1.00	[0.00, 17.01]	0.7%	9.0%
Diapatkoacht Tatal 2009	0	20		149	8		0.0%	0.0%
Fink P at al. 2010	1	60	1	51	<u> </u>	10.06: 46.441	0.0%	0.0%
Cas Dat Chi V 0000		50		50	1.00	[0.00, 10.44]	9.0%	9.7%
Gao P et Shi X 2020	0	35	0	35			0.0%	0.0%
Khop D IK at al. 2012	0	20	1	20		10.04: 0.441	0.0%	0.0%
Kilali KJK et al. 2012	0	44		45		[0.01, 8.41]	9.1%	7.3%
Landgraeber S et al. 2013	0	30	0	40		10.04: 4.401	0.0%	0.0%
Liu Y et al. 2021	0	47	2	4/	0.19	[0.01, 4.10]	18.4%	8.1%
Liu w et al. 2022	0	30	0	30			0.0%	0.0%
Mana Watal 2000	0	42	0	41			0.0%	0.0%
Minglood KE at al. 2020	0	4	0	4			0.0%	0.0%
Maaraahaut Katal 2018	0	83	0	80			0.0%	0.0%
Moerenhout K et al. 2019	0	28	0	21			0.0%	0.0%
Nistor DV et al. 2017	0	35	0	30			0.0%	0.0%
Duyang C et al. 2018	0	12	0	12		10 40: 02 001	0.0%	0.0%
Pan Fetal. 2020	2	58		38	2.04	[0.18, 23.09]	8.9%	12.9%
Reichert et al. 2018	0		1	71	0.30	[0.01; 7.57]	9.6%	7.3%
Restreppo C et al. 2010	0	50	0	50			0.0%	0.0%
Schwarze M et al. 2017	0	22	0	21			0.0%	0.0%
Taunton M et al. 2014	1	52	1	21	<u> </u>	10.06: 15.471	0.0%	0.0%
Versia Escabagea ID et al. 2012		02		49	0.94	[0.00, 15.47]	9.3%	9.7%
Vareia-Egocheaga JR et al. 2013	1	20	0	20		10.04: E E01	10.0%	10.0%
Neg T et al. 2017		40	2	40	0.49	[0.04, 5.59]	10.0%	12.0%
Vana Catal 2017	0	70		103			0.0%	0.0%
Tang C et al. 2010 Zhang ZL et al. 2010	0	22	0	22			0.0%	0.0%
Zhang ZL et al. 2019 Zhao LIV et al. 2017	0	21	0	21	2		0.0%	0.0%
Zhao HY et al. 2017	0	60	0	60	l l		0.0%	0.0%
Common effect model		1316		1439	0.81	[0.34; 1.98]	100.0%	
Random effects model					0.85	[0.43; 1.66]		100.0%
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.9^{\circ}$	1				1 1 1 1			
				0.	01 0.1 1 10 100			

Figure 14. Comparison of the dislocation rate. OR: odds ratio; CI: confidence interval [21–25,27–30,33,35,39–42,44,45,47–49,51,53,55–58,61–63,65,66].

3.4.3. Infection: MI THA vs. CA THA

Data on 2755 THAs from 31 RCTs were pooled ($I^2 = 0\%$, p = 0.95, Figure 15). The infection risk for MI THA was indifferent compared to that for CA THA (OR = 0.71, 95% CI 0.39 to 1.29).

3.4.4. Periprosthetic Fracture: MI THA vs. CA THA

Data on 2755 THAs from 31 RCTs were pooled ($I^2 = 0\%$, p = 0.56, Figure 16). The periprosthetic fracture risk for MI THA was indifferent compared to that for CA THA (OR = 1.76, 95% CI 0.75 to 4.13).

3.4.5. Deep Vein Thrombosis: MI THA vs. CA THA

Data on 2755 THAs from 31 RCTs were pooled ($I^2 = 0\%$, p = 0.98, Figure 17). The deep vein thrombosis risk for MI THA was 0.39 times smaller than that for CA THA (OR = 0.39, 95% CI 0.23 to 0.66).

3.4.6. Hematoma: MI THA vs. CA THA

Data on 2287 THAs from 27 RCTs were pooled ($I^2 = 0\%$, p = 0.79, Figure 18). The hematoma risk for MI THA was indifferent compared to that for CA THA (OR = 0.26, 95% CI 0.05 to 1.47).

Study	Experime Events T	ntal otal	Co Events	ontrol Total	Odds Ratio	OR	95%-CI	Weight (common)	Weight (random)
Barrett WP et al. 2013	0	43	0	44	11			0.0%	0.0%
Bon G et al. 2019	0	50	1	50	<u> </u>	0.33	[0.01; 8.21]	8.3%	6.8%
Brismar BH et al. 2018	1	50	0	50		3.06	[0.12; 76.95]	0.0%	6.8%
Cheng TE et al. 2016	0	35	0	37	iil iil			0.0%	0.0%
D'Arrigo C et al. 2009	0	20	1	149		2.41	[0.10; 61.27]	2.0%	6.8%
Dienstknecht T et al. 2013	0	83	0	51	11			0.0%	0.0%
Fink B et al. 2010	0	50	0	50	11			0.0%	0.0%
Gao P et Shi X 2020	1	35	2	35		0.49	[0.04; 5.61]	16.1%	11.8%
Hou JZ 2017	0	20	1	20 -	<u>≖ ii</u>	0.32	[0.01; 8.26]	8.3%	6.7%
Khan RJK et al. 2012	1	44	2	45		0.50	[0.04; 5.72]	16.0%	11.9%
Landgraeber S et al. 2013	0	36	0	40	_!!			0.0%	0.0%
Liu Y et al. 2021	1	47	3	47		0.32	[0.03; 3.18]	24.4%	13.4%
Liu W et al. 2022	0	30	0	30				0.0%	0.0%
Martin R et al. 2011	0	42	0	41				0.0%	0.0%
Meng W et al. 2020	0	4	0	4				0.0%	0.0%
Mjaaland KE et al. 2018	0	83	1	80 ·		0.32	[0.01; 7.91]	8.5%	6.9%
Moerenhout K et al. 2019	1	28	0	27		3.00	[0.12; 76.91]	0.0%	6.7%
Nistor DV et al. 2017	0	35	0	35				0.0%	0.0%
Ouyang C et al. 2018	0	12	0	12				0.0%	0.0%
Pan F et al. 2020	0	58	0	58				0.0%	0.0%
Reichert et al. 2018	0	77	0	71				0.0%	0.0%
Restreppo C et al. 2010	0	50	0	50	<u>ii</u>			0.0%	0.0%
Schwarze M et al. 2017	1	22	1	21		0.95	[0.06; 16.28]	8.1%	8.8%
Taunton M et al. 2014	0	27	1	27		0.32	[0.01; 8.24]	8.3%	6.7%
Taunton et al. 2018	0	52	0	49				0.0%	0.0%
Varela-Egocheaga JR et al. 2013	1	25	0	25		3.12	[0.12; 80.39]	0.0%	6.7%
Xie J et al. 2017	0	46	0	46				0.0%	0.0%
Yan T et al. 2017	0	70	0	103				0.0%	0.0%
Yang C et al. 2010	0	55	0	55				0.0%	0.0%
Zhang ZL et al. 2019	0	27	0	27				0.0%	0.0%
Zhao HY et al. 2017	0	60	0	60				0.0%	0.0%
Common effect model	1	316		1439	÷	0.56	[0.22; 1.44]	100.0%	
Random effects model						0.71	[0.39; 1.29]		100.0%
Heterogeneity: $l^2 = 0\%$, $\tau^2 = 0$, $p = 0.9$	5								
					0.1 0.51 2 10				

Figure 15. Comparison of the infection rate. OR: odds ratio; CI: confidence interval [21–25,27–30,33,35,39–42,44,45,47–49,51,53,55–58,61–63,65,66].

	Experim	ental	C	ontrol				Weight	Weight
Study	Events	Total	Events	Total	Odds Ratio	OR	95%-CI	(common)	(random)
Barrett WP et al. 2013	0	43	1	44		0.33	[0.01: 8.41]	11 7%	6.4%
Bon G et al. 2019	ŏ	50	, o	50	-	0.00	[0.01, 0.41]	0.0%	0.0%
Brismar BH et al. 2018	0	50	0	50				0.0%	0.0%
Cheng TE et al. 2016	2	35	0	37		- 5.60	[0.26: 120.80]	0.0%	7.0%
D'Arrigo C et al. 2009	2	20	1	149	 •	- 16.44	[1.42: 190.53]	2.5%	11.1%
Dienstknecht T et al. 2013	3	83	1	51		1.88	10.19: 18.531	14.2%	12.6%
Fink B et al. 2010	0	50	0	50				0.0%	0.0%
Gao P et Shi X 2020	0	35	0	35				0.0%	0.0%
Hou JZ 2017	0	20	0	20				0.0%	0.0%
Khan RJK et al. 2012	1	44	0	45		3.14	[0.12; 79.13]	0.0%	6.4%
Landgraeber S et al. 2013	0	36	0	40				0.0%	0.0%
Liu Y et al. 2021	0	47	0	47				0.0%	0.0%
Liu W et al. 2022	0	30	0	30	11			0.0%	0.0%
Martin R et al. 2011	0	42	0	41				0.0%	0.0%
Meng W et al. 2020	0	4	0	4				0.0%	0.0%
Mjaaland KE et al. 2018	1	83	0	80		2.93	[0.12; 72.92]	0.0%	6.4%
Moerenhout K et al. 2019	0	28	2	27		0.18	[0.01; 3.91]	24.2%	7.0%
Nistor DV et al. 2017	1	35	0	35		3.09	[0.12; 78.41]	0.0%	6.3%
Ouyang C et al. 2018	1	12	0	12		3.26	[0.12; 88.35]	0.0%	6.1%
Pan F et al. 2020	0	58	0	58				0.0%	0.0%
Reichert et al. 2018	0	77	0	71				0.0%	0.0%
Restreppo C et al. 2010	0	50	0	50				0.0%	0.0%
Schwarze M et al. 2017	0	22	0	21				0.0%	0.0%
Taunton M et al. 2014	2	27	1	27		2.08	[0.18; 24.41]	11.0%	10.9%
Taunton et al. 2018	0	52	2	49		0.18	[0.01; 3.87]	24.5%	7.1%
Varela-Egocheaga JR et al. 201	3 0	25	1	25		0.32	[0.01; 8.25]	11.9%	6.3%
Xie J et al. 2017	0	46	0	46				0.0%	0.0%
Yan T et al. 2017	0	70	0	103				0.0%	0.0%
Yang C et al. 2010	0	55	0	55				0.0%	0.0%
Zhang ZL et al. 2019	0	27	0	27	11			0.0%	0.0%
Zhao HY et al. 2017	1	60	0	60		3.05	[0.12; 76.39]	0.0%	6.4%
Common effect model		1316		1439	4	1.75	[0.76; 4.05]	100.0%	
Random effects model						1.76	[0.75; 4.13]		100.0%
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0$.	56								
					0.01 0.1 1 10 10	00			

Figure 16. Comparison of the periprosthetic fracture rate. OR: odds ratio; CI: confidence interval [21–25,27–30,33,35,39–42,44,45,47–49,51,53,55–58,61–63,65,66].

Study	Experime Events T	ntal otal	Co Events	ontrol Total	Odds Ratio	OR	95%-CI	Weight (common)	Weight (random)
Barrett WP et al. 2013	0	43	0	44	8.1			0.0%	0.0%
Bon G et al. 2019	1	50	0	50		3.06	[0.12; 76.95]	0.0%	7.1%
Brismar BH et al. 2018	0	50	0	50				0.0%	0.0%
Cheng TE et al. 2016	0	35	1	37		0.34	[0.01; 8.70]	5.6%	7.0%
D'Arrigo C et al. 2009	0	20	0	149				0.0%	0.0%
Dienstknecht T et al. 2013	0	83	2	51		0.12	[0.01; 2.52]	14.3%	7.8%
Fink B et al. 2010	0	50	0	50				0.0%	0.0%
Gao P et Shi X 2020	1	35	3	35	- <u>-</u>	0.31	[0.03; 3.17]	16.9%	13.7%
Hou JZ 2017	0	20	0	20				0.0%	0.0%
Khan RJK et al. 2012	0	44	1	45		0.33	[0.01; 8.41]	5.7%	7.0%
Landgraeber S et al. 2013	0	36	0	40				0.0%	0.0%
Liu Y et al. 2021	0	47	0	47				0.0%	0.0%
Liu W et al. 2022	1	30	2	30		0.48	[0.04; 5.63]	11.2%	12.2%
Martin R et al. 2011	0	42	0	41				0.0%	0.0%
Meng W et al. 2020	0	4	0	4	11 L			0.0%	0.0%
Mjaaland KE et al. 2018	1	83	1	80		0.96	[0.06; 15.67]	5.8%	9.4%
Moerenhout K et al. 2019	0	28	0	27				0.0%	0.0%
Nistor DV et al. 2017	0	35	0	35				0.0%	0.0%
Ouyang C et al. 2018	0	12	0	12	11			0.0%	0.0%
Pan F et al. 2020	1	58	3	58	1	0.32	[0.03; 3.19]	17.1%	13.9%
Reichert et al. 2018	0	11	0	/1				0.0%	0.0%
Restreppo C et al. 2010	0	50	0	50				0.0%	0.0%
Schwarze M et al. 2017	0	22	0	21				0.0%	0.0%
Taunton M et al. 2014	0	27	0	27	11 I I I I I I I I I I I I I I I I I I	0.04	10.04. 7.74	0.0%	0.0%
Taunton et al. 2018		52	1	49		0.31	[0.01; 7.74]	6.0%	7.1%
Vareia-Egocheaga JR et al. 2013		25	0	25	<u>9</u>	0.00	10.04: 0.001	0.0%	0.0%
Xie J et al. 2017	0	40		40		0.33	[0.01, 8.22]	0.0%	7.0%
Yang C at al. 2017	0	70	0	103				0.0%	0.0%
Theng 7L at al. 2010	0	27	0	27		0.10	10.04: 4.051	11.6%	7 704
Zhao HV et al. 2019	0	21	2	21		0.19	[0.01, 4.05]	0.0%	0.0%
Zilav mi etal. 2017	U	00	0	00				0.0%	0.0%
Common effect model	1	316		1439	÷	0.28	[0.10; 0.75]	100.0%	
Random effects model	-					0.39	[0.23; 0.66]		100.0%
Heterogeneity: $l^{*} = 0\%$, $\tau^{*} = 0$, $p = 0.9$	8								
				(0.01 0.1 1 10 10	0			

Figure 17. Comparison of the deep vein thrombosis rate. OR: odds ratio; CI: confidence interval [21–25,27–30,33,35,39–42,44,45,47–49,51,53,55–58,61–63,65,66].

Study	Experin Events	nental Total	C Events	ontrol Total	Odds Ratio	OR	95%-CI	Weight (common)	Weight (random)
Dienstknecht T et al. 2013	0	83	0	51				0.0%	0.0%
Fink B et al. 2010	0	50	0	50				0.0%	0.0%
Gao P et Shi X 2020	0	35	3	35		0.13	[0.01; 2.63]	43.6%	29.0%
Hou JZ 2017	0	20	0	20				0.0%	0.0%
lorio R et al. 2021	0	29	2	31	<u> </u>	0.20	[0.01; 4.35]	28.1%	27.5%
Khan RJK et al. 2012	0	44	0	45				0.0%	0.0%
Landgraeber S et al. 2013	0	36	0	40				0.0%	0.0%
Liu Y et al. 2021	0	47	0	47				0.0%	0.0%
Liu W et al. 2022	0	30	0	30				0.0%	0.0%
Martin R et al. 2011	0	42	0	41				0.0%	0.0%
Meng W et al. 2020	0	4	0	4				0.0%	0.0%
Mjaaland KE et al. 2018	0	83	0	80				0.0%	0.0%
Moerenhout K et al. 2019	0	28	0	27				0.0%	0.0%
Nistor DV et al. 2017	1	35	2	35		0.49	[0.04; 5.61]	28.3%	43.5%
Ouyang C et al. 2018	0	12	0	12				0.0%	0.0%
Pan F et al. 2020	0	58	0	58				0.0%	0.0%
Reichert et al. 2018	0	77	0	71				0.0%	0.0%
Restreppo C et al. 2010	0	50	0	50				0.0%	0.0%
Schwarze M et al. 2017	0	22	0	21				0.0%	0.0%
Taunton M et al. 2014	0	27	0	27	1 1			0.0%	0.0%
Taunton et al. 2018	0	52	0	49				0.0%	0.0%
Varela-Egocheaga JR et al. 2013	30	25	0	25				0.0%	0.0%
Xie J et al. 2017	0	46	0	46				0.0%	0.0%
Yan T et al. 2017	0	70	0	103				0.0%	0.0%
Yang C et al. 2010	0	55	0	55				0.0%	0.0%
Zhang ZL et al. 2019	0	27	0	27				0.0%	0.0%
Zhao HY et al. 2017	0	60	0	60				0.0%	0.0%
Common effect model		1147		1140		0.14	[0.02; 1.14]	100.0%	-
Random effects model						0.26	[0.05; 1.47]		100.0%
Heterogeneity: $I^{2} = 0\%$, $\tau^{2} = 0$, $p = 0.7$	79				01 01 1 10	100			

Figure 18. Comparison of the hematoma rate. OR: odds ratio; CI: confidence interval [27–30,32,33,35, 39–42,44,45,47–49,51,53,55–58,61–63,65,66].

3.5. Reoperation: MI THA vs. CA THA

Data on 2314 THAs from 25 RCTs were pooled ($I^2 = 0\%$, p = 0.81, Figure 19). The reoperation risk for MI THA was indifferent compared to that for CA THA (OR = 1.35, 95% CI 0.69 to 2.61).

	MI		CAs					
Study	Events	Total	Events	Total	Odds Ratio	OR	95%-CI	Weight
Barrett WP et al. 2013	0	43	2	44		0.20	[0.01; 4.19]	5.9%
Bon G et al. 2019	0	50	0	50				0.0%
Brismar BH et al. 2018	1	50	0	50		3.06	[0.12; 76.95]	5.3%
Cheng TE et al. 2016	1	35	0	37		3.26	[0.13; 82.75]	5.3%
Dienstknecht T et al. 2013	1	83	0	51		1.87	[0.07; 46.85]	5.3%
Fink B et al. 2010	0	50	0	50				0.0%
Khan RJK et al. 2012	1	44	0	45		3.14	[0.12; 79.13]	5.3%
Landgraeber S et al. 2013	0	36	0	40				0.0%
Martin R et al. 2011	2	42	0	41	- <u>+-</u> ×	5.12	[0.24; 110.05]	5.9%
Mjaaland KE et al. 2018	1	83	5	80		0.18	[0.02; 1.60]	11.7%
Moerenhout K et al. 2019	1	28	0	27		3.00	[0.12; 76.91]	5.2%
Nistor DV et al. 2017	0	35	0	35				0.0%
Ouyang C et al. 2018	1	12	0	12		3.26	[0.12; 88.35]	5.1%
Pan F et al. 2020	0	58	0	58				0.0%
Reichert et al. 2018	1	77	0	71		2.80	[0.11; 69.95]	5.3%
Restreppo C et al. 2010	0	50	0	50				0.0%
Schwarze M et al. 2017	1	22	1	21	<u></u>	0.95	[0.06; 16.28]	6.8%
Taunton M et al. 2014	2	27	2	27		1.00	[0.13; 7.67]	13.3%
Taunton et al. 2018	2	52	2	49		0.94	[0.13; 6.95]	13.8%
Varela-Egocheaga JR et al. 2013	0	25	0	25				0.0%
Xie J et al. 2017	0	46	0	46				0.0%
Yan T et al. 2017	2	70	0	103	- <u>+</u>	7.55	[0.36; 159.79]	5.9%
Yang C et al. 2010	0	55	0	55				0.0%
Zhang ZL et al. 2019	0	27	0	27				0.0%
Zhao HY et al. 2017	0	60	0	60				0.0%
Random effects model		1160		1154	&	1.35	[0.69; 2.61]	100.0%
Heterogeneity: $I^{2} = 0\%$, $\tau^{2} = 0$, $p = 0.81$								
Test for subgroup differences: $\chi_1^2 = 8.19$, df = 1 ($\rho < 0.01$)				0.0	01 0.1 1 10	1000		

Figure 19. Comparison of the reoperation rate. OR: odds ratio; CI: confidence interval [21–24,27,28, 33,35,41,44,45,47–49,51,53,55–58,61–63,65,66].

4. Discussion

The main finding of this study is that MI THA gives statistically better results overall than CA THA. This finding is based on a meta-analysis of 47 RCTs with 4086 THAs in 4063 patients, which allowed us to look at a large number of outcome parameters. For 8 of the 18 outcome parameters examined, MI THA showed better results than CA THA. For 9 of the 18 outcome parameters examined, MI THA showed indifferent results compared with CA THA, and in 1 case worse results than CA THA. However, the differences in outcome parameters between the two approaches do not reach the minimum clinically important difference (MCID). Therefore, we recommend that the choice of surgical approach should continue to be left to the experience and preference of the surgeon, in the knowledge that even better results might be achieved with MI THA.

A 2019 meta-analysis by Migliorini et al. [4], which included 4761 patients from 48 RCTs and non-RCTs, found no significant advantages of MI THA compared with CA THA. In particular, MI THA had a lower estimated total blood loss, shorter operation time and shorter hospital stay. In contrast, CA THA had a higher HHS score. Radiological results showed no significant differences between the two approaches. There was no difference in the risk of femoral fracture, dislocation or reoperation. Migliorini et al. [4] found an increased risk of iatrogenic nerve palsy with the MI approach. A 2022 meta-analysis by Clesham et al. [2] of 2633 THAs from 20 RCTs and non-RCTs found that MI THA was equivalent to CA THA in terms of all-cause revision, aseptic revision, infection, dislocation, fracture rates and functional outcomes. A 2010 meta-analysis by Smith et al. [5] of 2849 THAs from 28 RCTs and non-RCTs reached similar conclusions. There was little difference in clinical and radiological outcomes between MI and CA THA, while MI

approaches were associated with an increased risk of lateral femoral cutaneous nerve palsy. These meta-analyses [2,4,5] did not include primary data from studies of the SuperPATH superior MI approach.

4.1. Surgical Outcomes

In our meta-analysis, MI THA showed a 10.6 min. longer operation time than CA THA (Figure 2). This was the only outcome parameter where MI THA showed statistically worse results. A recent analysis of 35 articles by Cantrell et al., reporting on 630,675 THAs, found a mean operation time of approximately 95 min., which remained relatively stable over two decades between 1996 and 2016 [71]. In a 2019 analysis of 89,802 THAs, Surace et al. [72] suggested an operation time of approximately 80 min. with a lower risk of perioperative complications. Longer operation times are known to be associated with perioperative complications [72,73]. The mean operation time for MI THA was 82.3 min and the mean operative time for CA THA was 72.8 min. This means that the operation time for MI THA was well within the recommendation of Surace et al. [73].

MI THA had a 4.1 cm shorter incision length than CA THA (Figure 3). The mean incision length for MI THA was 9.0 cm, ranging from 5.8 cm to 13.7 cm, and the mean incision length for CA THA was 13.1 cm, ranging from 9.0 cm to 15.6 cm. Incision length must always be considered in relation to other outcome parameters. A very short incision must not be forced at the expense of functional outcome and complication rate. Apart from the obvious cosmetic benefit of a short incision, the importance of mini-incision approaches for THA outcomes is questionable [10,74].

There was no difference in intraoperative blood loss between MI THA and CA THA (Figure 4). However, the mean intraoperative blood loss for MI THA was 262.3 mL, ranging from 72.1 mL to 1344.0 mL, and the mean intraoperative blood loss for CA THA was 435.3 mL, ranging from 123.84 mL to 1644.0 mL. The correlation between blood loss and intraoperative trauma is well established. However, there is no information in the literature on the level of blood loss at which an MCID is present in THA. Logically, any blood loss requiring transfusion should be considered clinically relevant. In some cases, this insignificant difference in blood loss between MI THA and CA THA might be the amount of blood required to avoid the need for blood transfusion. Then there is the hidden blood loss, which can only be measured using laboratory parameters. The first meta-analysis investigating postoperative serum biomarkers of MI THA versus CA THA was recently published by the authors of this study [14]. Based on 13 included RCTs with 1186 THA patients, this 2023 meta-analysis found no statistically significant differences in postoperative hemoglobin levels of MI THA compared to CA THA [14]. In addition to the choice of surgical approach, there are other measures to reduce blood loss in THA. Systemic and local application of tranexamic acid [75] and intraoperative warming of the patient have a positive effect on blood loss [76]. The cell saver device offers the possibility of autotransfusion. The use of iron supplements and erythropoietin is considered a postoperative option to avoid transfusions [77].

MI THA had a 1.1 points lower pain VAS 1 day postoperatively and a 0.8 point lower pain VAS 3 days postoperatively than CA THA (Figures 5 and 6). However, these differences do not appear to be of clinical significance. A recent comparative study by Danoff et al. [78] found that a pain improvement of 18.6 mm for THA patients, measured on a VAS-P scale of 100, is one MCID. Applied to our 10-point pain VAS, this would be a difference of 1.9 points. This is a difference that could not be achieved by the MI THA compared to the CA THA. Low pain in the postoperative period is important for patient comfort. A very simple and effective way to reduce short-term postoperative pain and hospital stay in THA patients is intraoperative infiltration with local anesthetics [79].

4.2. Functional Outcome

Probably the most important outcome parameter is the HHS, as it provides information on the function of the operated hip. At 0–1.5 months postoperatively, MI THA had a HHS

5.2 points higher than CA THA (Figure 7). At 3 months postoperatively, MI THA had a HHS 2.2 points higher than CA THA (Figure 8). At 6 months postoperatively, MI THA had a 1.9 point higher HHS than CA THA (Figure 9). At \geq 12 months postoperatively, MI THA had a 0.9 point higher HHS than CA THA (Figure 10). The lowest MCID reported in the literature is not less than 7.9 points on the 0–100 HHS scale [80]. Therefore, we can state that the short-term functional outcome of MI THA is statistically superior to that of CA THA without reaching the MCID. Most impressively, the difference in functional outcome between MI HTA and CA THA gradually almost disappears over 12 months. This reinforces the finding that MI THA has a particular advantage in early short-term functional outcome.

4.3. Radiological Outcome

There were no significant differences in cup positioning between MI THA and CA THA or in the subgroup analysis. The ideal anteversion angle for cup positioning is $15^{\circ} \pm 10^{\circ}$ and the ideal inclination angle for cup positioning is $40^{\circ} \pm 10^{\circ}$ [81]. The ideal anteversion angle is particularly important as it correlates with the risk of dislocation. The mean anteversion angle of the MI THA was 20.4° (range: $15.0-26.9^{\circ}$) (Figure 11). The mean inclination angle of the MI THA was 20.5° (range: $37.0-49.6^{\circ}$) (Figure 12). The mean anteversion angle of the CA THA was 20.5° (range: $14.3-29^{\circ}$) (Figure 11). The mean inclination angle of the CA THA was 42.6° (range: $39.0-48.9^{\circ}$) (Figure 12). However, the acetabular positioning angles were within the safe zone for MI THA and CA THA.

4.4. Overall Postoperative Complications

In addition to HHS, postoperative complications are probably the most important parameters that allow us to draw conclusions about the outcome of THA patients. We evaluated the following complications: dislocation, infection, periprosthetic fracture, deep vein thrombosis, hematoma and reoperation. MI THA showed indifferent postoperative complication rates compared with CA THA (Figure 13). In 12 RCTs, MI THA resulted in 86 complications out of 1415 THAs compared to 65 complications out of 1544 THAs with CA THA. The well-known alleged disadvantage of MI approaches, that they lead to significantly higher complication rates because the operative field is impaired for the surgeon, seems to be only an assumption without scientific evidence.

The risk of deep vein thrombosis was 0.39 times lower with MI THA than with CA THA (Figure 17). In 31 RCTs, there were 5 cases of deep vein thrombosis with MI THA out of 1316 THAs compared to 17 cases of deep vein thrombosis with CA THA out of 1439 THAs. MI THA had similar rates of dislocation, infection, periprosthetic fracture, hematoma and reoperation compared with CA THA (Figures 14–16, 18 and 19).

When assessing the quality of trials, it is striking that a large proportion of RCTs are of low quality (Table 2). Nevertheless, the RCT has been shown to be the most reliable scientific form in the hierarchy of evidence in medical research. The RCT is considered the best study design for making a clear statement with a clear question and for proving causality. Meta-analyses of RCTs are increasingly used for evidence-based practice and guideline development. It is important to note that only RCTs were included in our meta-analysis.

Finally, the fact that the differences between the approaches did not reach minimal clinical significance must be put into perspective. The outcome parameters for which MI THA showed better results but did not reach an MCID were very numerous and, taken together, may still be of clinical importance.

Our study contributes to daily clinical practice. The mean values of relevant outcome parameters such as operating time, incision length, intraoperative blood loss, pain VAS, HHS, acetabular cup positioning angles and postoperative complication rates can be used for self-critical comparison with the results of the reader's orthopedic department. In addition, our findings may encourage some orthopedic surgeons to try MI THA in an attempt to achieve even better patient outcomes, although perhaps without reaching an MCID.

5. Limitations

We identified the following strengths and limitations of our meta-analysis: (1) We only included RCTs in our systematic review and meta-analysis. This is the top of the pyramid of evidence and ensures that our conclusions are reliable and meaningful. (2) We used high-quality statistical methods to conduct the meta-analysis. (3) The RCTs and patients included were of substantial size. (4) Significant heterogeneity was found among the included studies for several outcome parameters. (5) The included studies combined different surgical indications in one meta-analysis: osteoarthritis, femoral neck fracture, dysplasia and avascular necrosis of the femoral head. (6) For some outcomes, the sample size and number of included RCTs were small. (7) Long-term THA outcomes were not included. (8) Surgeon skill, learning curve, perioperative management or type of implant probably influenced the results and must be considered as confounding factors.

6. Conclusions

Our meta-analysis suggests that MI THA has several advantages over CA THA in terms of short-term surgical and functional outcomes, with equal postoperative complication rates. However, a general recommendation for orthopedic surgeons to change their surgical approach to hip THA based on our results cannot be made, as the differences between the investigated approaches did not reach the MCID.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/prosthesis5030067/s1, Table S1: PRISMA Checklist; Table S2: Raw data extraction set.

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Abbreviations

CA	conventional approach
CI	confidence interval
CNKI	China National Knowledge Infrastructure
HHS	Harris Hip Score
ITT	intention to treat
MCID	minimal clinically important difference
MD	mean difference
OR	odds ratio
MI	minimally invasive
PP	per protocol
RCT	randomized controlled trials
THA	total hip arthroplasty

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