Radial head arthroplasty vs. open reduction and internal fixation for the treatment of terrible triad injury of the elbow: A systematic review and meta-analysis update

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Abstract. Terrible triad injury of the elbow (TTIE) is a severe high-energy injury to the elbow, mainly including elbow dislocation, coronoid fracture and radial head fracture. It is difficult to maintain the stability of the elbow joint using traditional conservative treatment, and there is a high risk of redislocation and various complications. Therefore, surgical treatment is currently advocated, mainly for repairing damaged ligaments and reconstructing bony structures, but there is still controversy about the treatment plan for the radial head. The current meta-analysis was conducted to compare the differences in efficacy of radial head arthroplasty (RHA) and open reduction internal fixation (ORIF) in the treatment of TTIE. Published literature related to the treatment (either ORIF or RHA) of TTIE was searched for in Embase, PubMed, Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health Literature, ProQuest Dissertations and Theses, Cochrane Library and Chinese Biomedical Literature Database. According to the search strategy, a total of 1,928 related publications were retrieved. The patient must have been diagnosed with TTIE and required surgery on the radial head. The interventions were RHA and ORIF. Non-case-control studies, case reports, review articles, letters, duplicate reports and literature without sufficient relevant data were excluded. The quality of the literature was evaluated according to the Cochrane systematic review methodology and the Jadad scale. After data extraction, meta-analysis was performed using ReviewManager 5.4 software (Cochrane). A total of 15 studies involving 455 patients (189 who underwent RHA and 266 who underwent ORIF) were included. Range of motion (ROM) of the forearm (pronation-supination arc) after surgery in the RHA group [95% CI (0.28, 9.59); P=0.04] was found to be significantly superior to the ORIF group, with a lower incidence of complications [95% CI (0.22, 0.84); P=0.01]. However, there was no statistically significant difference for the Mayo Elbow Performance Score, Disabilities of the Arm, Shoulder and Hand Score nor for ROM of the elbow (flexion-extension arc). Overall, compared with the ORIF group, the RHA group had better forearm rotational ROM and fewer complications after surgery. Therefore, RHA was found to be superior to ORIF in the treatment of TTIE.

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Abbreviations: RHA, radial head arthroplasty; ORIF, open reduction internal fixation; TTIE, terrible triad injury of the elbow; ROM, range of motion; MEPS, Mayo Elbow Performance Score; DASH, Disabilities of the Arm, Shoulder and Hand; CI, confidence interval

Key words: terrible triad injury of the elbow, radial head arthroplasty, open reduction internal fixation, meta-analysis

Introduction

Terrible triad injury of the elbow (TTIE) refers to dislocation of the elbow joint, accompanied by fractures of the radial head and coronoid process. TTIE is one of the more serious and complex injuries in the elbow joint (1). TTIE was first proposed by Hotchkiss in 1996 (2). The injury is often accompanied by valgus, rotation, axial and other stresses, as well as damage to the medial and lateral ligament complexes, which make the elbow joint markedly unstable even after reduction (3). Conservative treatment cannot restore the stability of the key structures of the elbow, resulting in traumatic instability of the elbow joint (4). Patients often experience repeated dislocation or subluxation, and the immobilization time is too long during treatment, resulting in stiffness of the elbow joint and loss of mobility (5). The overall outcome of treatment is therefore not ideal for patients. With in-depth understanding of the mechanism and anatomical structure related to TTIE, the latest research shows that the key to a successful recovery from TTIE is to restore the stability of the elbow joint as soon as possible (6). At present, more active surgical treatment is advocated.

The stability of the elbow joint is generally maintained by the distal humerus, radial head and other bony structures, as well as the ligaments and soft tissues around the elbow joint. In addition to repairing the damaged ligaments, the method of restoration of the physiological function of the radial head has become the top priority in the treatment of TTIE (7). Among them, the surgical methods for radial head fractures are mainly open reduction internal fixation (ORIF) and radial head arthroplasty (RHA). It is believed that ORIF can achieve good clinical efficacy in restoring the anatomical structure of the radial head, but complications also arise, such as internal fixation loosening and nonunion. Other studies have shown that RHA can also effectively treat complex elbow injuries, although RHA has complications too, such as internal fixation loosening and excessive filler (1,8). Consequently, Carroll and Morrissey (9) suggested that even with surgical treatment, instability and arthritis may be predisposed. Furthermore, in numerous cases, the choice of surgical approach is one of the key factors that contribute to instability, limited range of motion (ROM) and elbow stiffness (10). Therefore, selecting the most suitable surgical method for patients has become the focus of clinical attention.

Certain researchers have previously conducted studies to compare the efficacy of two surgical approaches for radial head fractures. For example, Chen *et al* (11) indicated that RHA for the treatment of TTIE had better postoperative outcomes than ORIF, along with fewer complications. However, Kyriacou *et al* (12) found no difference in functional outcomes between the two procedures. In recent years, there have been new reports (13-16) of clinical case-control studies on the subject of TTIE surgical treatment that meet the inclusion criteria of the present study. In order to compare the differences between the two treatments more objectively, the current study included an updated meta-analysis compared with the aforementioned studies to provide a theoretical basis for clinical practice.

Materials and methods

Inclusion and exclusion criteria. Study subjects included those in published, controlled clinical studies. Based on the patient's medical history, physical examination and imaging examination, the patient must have been diagnosed with TTIE and required surgery on the radial head. Non-case-control studies, case reports, review articles, letters and duplicate reports were excluded. Literature without sufficient relevant data were also excluded. The interventions were RHA and ORIF. The outcome indicators were the Mayo Elbow Performance Score (MEPS), the Disabilities of the Arm, Shoulder and Hand (DASH) score, the range of the flexion-extension arc and of the pronation-supination arc and complications.

Search strategy. The databases used to retrieve the studies included Embase, PubMed, Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health Literature, ProQuest Dissertations and Theses, Cochrane Library and Chinese Biomedical Literature Database. The date limits for the search were January 2002 to April 2022. Journal catalogues and bibliographical references were also searched in an effort to find grey literature, such as unpublished academic papers or chapters in monographs. All relevant documents were searched for in any language and translated if necessary. The searched keywords were terrible triad of the elbow, radial head fracture, replacement, open reduction internal fixation, and the retrieval strategy was ('repair' OR 'fixation' OR 'open reduction internal fixation' OR 'restore' OR 'renovate') AND ('replacement' OR 'arthroplasty') AND ('terrible triad of the elbow' OR 'terrible triad' OR 'elbow' OR 'radial head fracture').

Quality assessment. The included literature was independently analyzed by two physicians, and any disagreements were resolved through discussion or handed over to a third senior physician to jointly determine the quality of the literature. The Cochrane bias risk assessment criteria was strictly followed (17), including: i) Whether the experimental design adopted the principle of randomization; ii) whether the subjects, performers and measurers used the double-blind principle; iii) whether the experimental data was complete and credible; iv) whether the allocation concealment method was used; v) whether the experiment used a selective data reporting method; and vi) other factors of bias. The quality of the literature was also evaluated according to the modified Jadad scale (18), with a total possible score of 7 points (2 points for adequate randomization, 2 points for randomization concealment, 2 points for adopting the double-blind principle and 1 point for lost follow-up). The literature was divided into low-quality (1-3 points), medium-quality (4 points) and high-quality (5-7 points) according to score.

Statistical analysis. Meta-analysis of the extracted data was performed using ReviewManager 5.4 software (Cochrane). Data from dichotomous variables are presented as an odds ratio with a 95% confidence interval (CI), while data from continuous variables are presented as the mean ± standard deviation and a 95% CI. The I^2, tau^2, χ^2, degrees of freedom and Z values were calculated to assess the heterogeneity between different studies (minimum of 6 papers, maximum of 13 papers). If the calculated I^2-value was <50%, indicating that the heterogeneity between the studies was small, a fixed effects model was used. If an I^2-value was ≥50%, indicating that the heterogeneity between the studies was large, the reasons for the heterogeneity were analyzed and a random effects model was used. Sensitivity analyses were performed when heterogeneity was high, and funnel plots were constructed to assess publication bias (the abscissa is generally the effect size of a single study, and the ordinate is the scatter plot of the sample size). $P<0.05$ was considered to indicate a statistically significant difference.

Results

Essential features of the included literature. According to the above search strategy, a total of 1,928 related publications were retrieved. By reading the titles and abstracts, 1,891 uncontrolled studies, duplicate publications and publications irrelevant to the research aim were excluded, and 37 relevant publications were preliminarily included. The full text was then screened according to the inclusion and exclusion criteria, to finally include 15 articles. After analysis, it was found that

Table I. Fundamental characteristics of the included studies.

First author, year	Study design	Country	Group	Number of patients	Age, years (mean ± standard deviation)	Sex, male/ female	Outcome measures	Modified Jadad score	(Refs.)
Afifi *et al*, 2020	Prospective	Egypt	RHA	16	40.40±14.90	17/13	a, b, c, d	6	(13)
			ORIF	14					
Giannicola *et al*, 2015	Prospective	Italy	RHA	16	53.13±12.49	7/9	a, b, c, d, e	6	(19)
			ORIF	9	48.89±20.25	5/4			
Hou *et al*, 2021	Retrospective	China	RHA	3	37.33±5.86	1/2	a, b, c, d, e	4	(14)
			ORIF	21	33.81±7.30	15/6			
Jeong *et al*, 2010	Retrospective	Korea	RHA	3	43.80±38.00	7/6	a, c, d, e	4	(20)
			ORIF	10					
Klug *et al*, 2020	Retrospective	Germany	RHA	26	53.90±43.57	8/18	a, b, c, d	4	(15)
			ORIF	51	NA	NA			
Leigh and Ball, 2012	Retrospective	New Zealand	RHA	11	45.50±22.50	6/5	b, c, d	5	(21)
			ORIF	13	42.20±16.29	6/7			
Li *et al*, 2018	Retrospective	China	RHA	24	37.50±75.63	34/20	a, e	4	(22)
			ORIF	30					
Liu *et al*, 2018	Retrospective	China	RHA	4	48.23±10.95	29/12	a, c, d, e	4	(23)
			ORIF	37					
Matar *et al*, 2017	Retrospective	England	RHA	9	55.67±8.56	4/5	a, c, d, e	5	(24)
			ORIF	4	61.50±12.26	0/4			
Pierrart *et al*, 2015	Retrospective	France	RHA	7	NA	NA	a, c	3	(25)
			ORIF	10					
Toros *et al*, 2012	Retrospective	Turkey	RHA	5	40.60±6.39	3/2	a, b, c, d	4	(26)
			ORIF	11	33.00±8.68	8/3			
Watters *et al*, 2014	Retrospective	USA	RHA	30	48.00±64.49	21/18	c	2	(27)
			ORIF	9					
Yan *et al*, 2015	Retrospective	China	RHA	20	36.54±6.58	11/9	a, c, d, e	6	(28)
			ORIF	19	35.51±6.28	7/12			
Zhang *et al*, 2014	Retrospective	China	RHA	2	NA	NA	a, c, d, e	5	(29)
			ORIF	18					
Zheng *et al*, 2020	Retrospective	China	RHA	13	47.08±6.20	9/4	a	3	(16)
			ORIF	10	48.20±7.22	6/4			

Outcome measures: a, Mayo Elbow Performance Score; b, Disabilities of the Arm, Shoulder and Hand Score; c, flexion-extension arc; d, pronation-supination arc; e, complications. RHA, radial head arthroplasty; ORIF, open reduction internal fixation; NA, not applicable.

a total of 189 cases underwent RHA and 266 cases underwent ORIF in the included literature. The baseline conditions, such as patient age and disease course, of all the included studies were compared and found to be similar (P>0.05). The literature screening process and results are illustrated in Fig. 1, and the fundamental characteristics of the included studies are presented in Table I (13-16,19-29).

Quality assessment of included literature. The present study included two prospective studies, 13 retrospective studies and no randomized controlled trials. After following the Cochrane bias risk assessment criteria, the quality was then evaluated using the modified Jadad score. Of the fifteen studies, there were six high-quality papers (three of which scored 6 points and three of which scored 5 points), eight medium-quality papers (six of which scored 4 points and two of which scored 3 points) and one low-quality paper (which scored 2 points). Although the number of included papers is limited and there is a certain bias, the overall quality is moderate.

Outcome measures

MEPS. A total of 13 studies including 392 patients compared the MEPS between RHA and ORIF. The heterogeneity test showed that there was significant heterogeneity among studies (I^2=84.0%; P<0.00001). Therefore, the random effects model was used. A total of seven studies had a greater mean MEPS

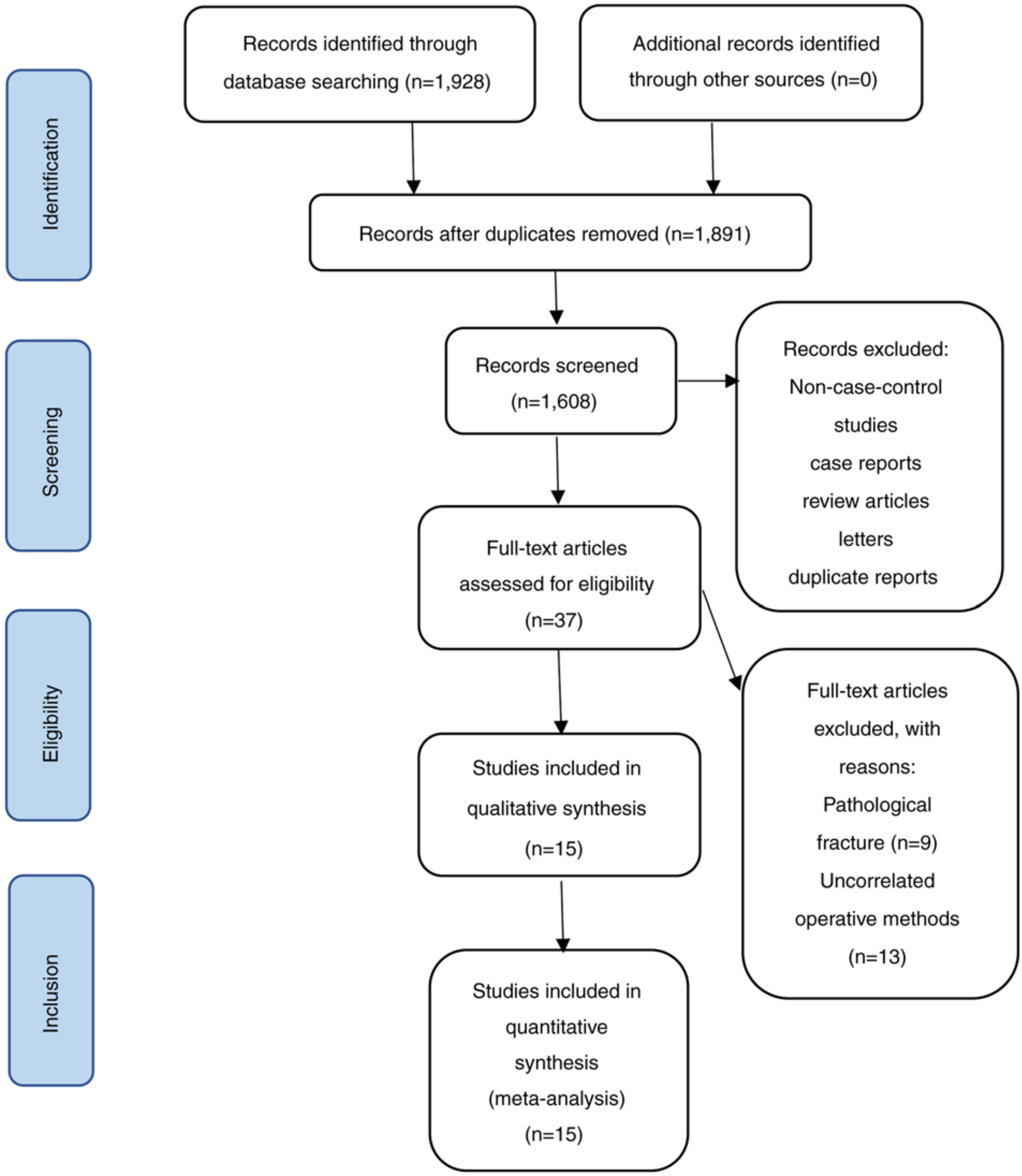

Figure 1. Flow diagram of study identification and selection.

in the RHA group compared with the ORIF group, while five studies favored ORIF. The remaining one showed no difference between the two groups. However, MEPS was found to be similar in the two groups, and the difference was not statistically significant [95% CI (-2.81, 8.11); P=0.34] (Fig. 2).

DASH score. A total of six articles provided detailed information on the DASH score. The fixed effect model was employed for meta-analysis since there was no significant heterogeneity among the results (I^2=15%). From the meta-analysis, no significance was observed [95% CI (-0.66, 5.23); P=0.13] for the DASH score between the RHA and ORIF groups (Fig. 3).

Range of the flexion-extension arc. Data were divided into three groups: Range of the flexion-extension arc, flexion and extension. The heterogeneity test performed on the studies and subgroups showed that there was no significant heterogeneity among them (I^2=42.0%; P=0.008), so the fixed effect model was employed in the meta-analysis. A total of 13 studies assessed the range of the flexion-extension arc, with nine studies showing that the mean range of the flexion-extension arc for the RHA group was higher than that in the ORIF group. However, the result was not significant [95% CI (-0.32, 5.51); P=0.08]. Furthermore, 10 studies showed that the range of flexion [95% CI (-0.72, 3.75); P=0.18] did not differ significantly

Study or Subgroup	RHA Mean	RHA SD	RHA Total	ORIF Mean	ORIF SD	ORIF Total	Weight	Mean Difference IV, Random, 95% CI
Afifi et al, 2020	90.94	9.35	16	93.57	8.42	14	8.7%	-2.63 [-8.99, 3.73]
Giannicola et al, 2015	96.25	5.92	16	93.89	10.54	9	8.3%	2.36 [-5.11, 9.83]
Hou et al, 2021	88.33	2.89	3	86.67	13.07	21	8.6%	1.66 [-4.82, 8.14]
Jeong et al, 2010	95	8.66	3	95	6.67	10	7.2%	0.00 [-10.64, 10.64]
Klug et al, 2020	81.7	17.5	26	89.1	17.6	51	8.0%	-7.40 [-15.68, 0.88]
Li et al, 2018	96.13	10.16	24	72.35	11.05	30	8.9%	23.78 [18.11, 29.45]
Liu et al, 2018	92.5	8.66	4	88.51	10.86	37	7.7%	3.99 [-5.19, 13.17]
Matar et al, 2017	78.33	25.37	9	95	10	4	4.4%	-16.67 [-35.93, 2.59]
Pierrart et al, 2015	77.14	24.13	7	79	14.3	10	4.3%	-1.86 [-21.81, 18.09]
Toros et al, 2012	90	7.07	5	94.09	8.31	11	8.2%	-4.09 [-12.00, 3.82]
Yan et al, 2015	85.8	7.5	20	77.9	13.8	19	8.5%	7.90 [0.88, 14.92]
Zhang et al, 2014	97.5	3.54	2	95	5.69	18	8.9%	2.50 [-3.07, 8.07]
Zheng et al, 2020	91.15	6.81	13	79.5	10.39	10	8.3%	11.65 [4.22, 19.08]
Total (95% CI)			**148**			**244**	**100.0%**	**2.65 [-2.81, 8.11]**

Heterogeneity: Tau² = 78.89; Chi² = 73.43, df = 12 (P < 0.00001); I² = 84%
Test for overall effect: Z = 0.95 (P = 0.34)

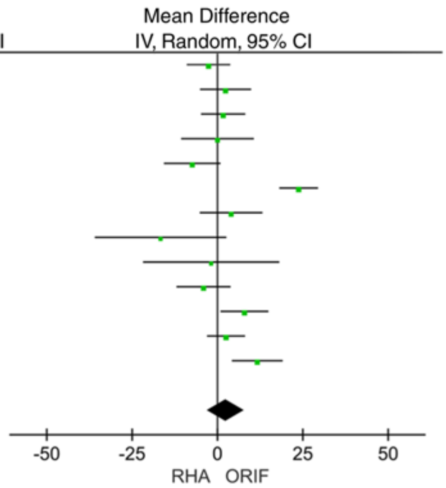

Figure 2. Forest plot for the Mayo Elbow Performance Score. RHA, radial head arthroplasty; ORIF, open reduction internal fixation; SD, standard deviation; IV, inverse variation; CI, confidence interval; df, degrees of freedom.

Study or Subgroup	RHA Mean	RHA SD	RHA Total	ORIF Mean	ORIF SD	ORIF Total	Weight	Mean Difference IV, Fixed, 95% CI
Afifi et al, 2020	7.11	7.13	16	4.95	2.33	14	63.3%	2.16 [-1.54, 5.86]
Giannicola et al, 2015	4.98	5.61	16	11.08	18.31	9	5.8%	-6.10 [-18.37, 6.17]
Hou et al, 2021	20	5	3	22.38	20.35	21	8.0%	-2.38 [-12.76, 8.00]
Klug et al, 2020	26.9	22.8	26	15.3	19.8	51	8.2%	11.60 [1.29, 21.91]
Leigh and Ball, 2012	10.83	28.3	11	9.16	10.8	13	2.8%	1.67 [-16.05, 19.39]
Toros et al, 2012	11.8	7.01	5	7.91	9.95	11	12.0%	3.89 [-4.61, 12.39]
Total (95% CI)			**77**			**119**	**100.0%**	**2.28 [-0.66, 5.23]**

Heterogeneity: Chi² = 5.85, df = 5 (P = 0.32); I² = 15%
Test for overall effect: Z = 1.52 (P = 0.13)

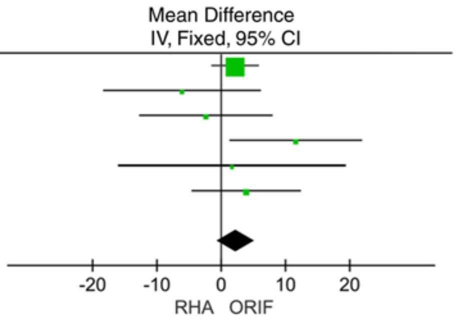

Figure 3. Forest plot for the Disabilities of the Arm, Shoulder and Hand Score. RHA, radial head arthroplasty; ORIF, open reduction internal fixation; SD, standard deviation; IV, inverse variation; CI, confidence interval; df, degrees of freedom.

between the treatment groups, whereas the range of extension in the RHA group was significantly lower than that in the ORIF group [95% CI (-5.12, -1.62); P=0.0002] (Fig. 4).

Range of the pronation-supination arc. A total of 10 articles reported on forearm rotational ROM, and these were divided into three subgroups according to the range of forearm pronation, supination and the pronation-supination arc. Since the heterogeneity of each subgroup and that of the overall study was not significantly different (I^2=28.9%), a fixed-effects model was used for meta-analysis. Subgroup analysis showed that when RHA was used to treat TTIE, the maximum pronation degree of the forearm [95% CI (0.59, 6.33); P=0.02] and the pronation-supination arc [95% CI (0.28, 9.59); P=0.04] was significantly superior to patients treated with ORIF. The curative effect on forearm supination ROM was similar between the two groups [95% CI (-2.45, 3.77); P=0.68], and the difference was not statistically significant (Fig. 5).

Complications. A total of eight articles investigated the difference in postoperative complications between RHA and ORIF, with a total of 66 cases. The present analysis found that the postoperative complication rate (number of cases with complications to the total number of cases) of the RHA group was 22%, which was significantly lower than that of the ORIF group at 31% [95% CI (0.22, 0.84); P=0.01]. The heterogeneity test resulted in I^2=0%, indicating that there was no significant heterogeneity among the studies. Therefore, a fixed effect model was decided upon for classification. The results showed that the incidence of postoperative complications in the RHA group was significantly lower than that in the ORIF group for the treatment of TTIE [95% CI (0.22, 0.84); P=0.01] (Fig. 6).

Publication bias and sensitivity analysis. The ReviewManager 5.4 software (Cochrane) was used to evaluate the postoperative MEPS, DASH score, flexion-extension arc, pronation-supination arc and complications of TTIE. Publication bias analysis was carried out on all outcome indicators, and the results showed that the funnel plots were essentially symmetrical, indicating that there was no evident publication bias (Figs. 7-9). After sensitivity analysis, the data were considered to be stable and reliable.

Discussion

Previous studies have shown that the radial head is a key structure involved in maintaining the stability of the lateral side of the elbow joint and bears 20-30% of the valgus stability (30). When subjected to valgus stress, the radial head can reduce the tension stress on the inside of the elbow

Study or Subgroup	RHA Mean	RHA SD	RHA Total	ORIF Mean	ORIF SD	ORIF Total	Weight	Mean Difference IV, Fixed, 95% CI
Arc°								
Afifi et al, 2020	122.81	13.29	16	120.36	13.22	14	1.7%	2.45 [-7.06, 11.96]
Giannicola et al, 2015	126.56	17.49	16	124.44	25.18	9	0.5%	2.12 [-16.43, 20.67]
Hou et al, 2021	123.33	2.89	3	115.71	22.43	21	1.5%	7.62 [-2.52, 17.76]
Jeong et al, 2010	130	5	3	130.5	11.41	10	1.9%	-0.50 [-9.56, 8.56]
Klug et al, 2020	109	24.4	26	123	21.5	51	1.3%	-14.00 [-25.08, -2.92]
Leigh and Ball, 2012	128	7.33	11	115	29.5	13	0.6%	13.00 [-3.61, 29.61]
Liu et al, 2018	115	19.15	4	108.11	21.29	37	0.4%	6.89 [-13.09, 26.87]
Matar et al, 2017	101.11	23.15	9	122	12.49	4	0.4%	-20.89 [-40.35, -1.43]
Pierrart et al, 2015	112.14	20.59	7	115	24.49	10	0.3%	-2.86 [-24.38, 18.66]
Toros et al, 2012	120	13.86	5	118	15.17	11	0.7%	2.00 [-13.10, 17.10]
Watters et al, 2014	118	43.72	30	106	21.46	9	0.4%	12.00 [-9.01, 33.01]
Yan et al, 2015	101.4	11.35	20	92.42	9.06	19	3.8%	8.98 [2.55, 15.41]
Zhang et al, 2014	127.5	3.54	2	125.56	5.91	18	4.9%	1.94 [-3.67, 7.55]
Subtotal (95% CI)			**152**			**226**	**18.3%**	**2.60 [-0.32, 5.51]**
Heterogeneity: Chi² = 22.16, df = 12 (P = 0.04); I² = 46%								
Test for overall effect: Z = 1.74 (P = 0.08)								
Flex								
Giannicola et al, 2015	137.19	10.48	16	134.44	14.46	9	1.3%	2.75 [-8.00, 13.50]
Hou et al, 2021	130	0	3	124.29	22.21	21		Not estimable
Jeong et al, 2010	138.33	2.89	3	137	4.22	10	8.9%	1.33 [-2.86, 5.52]
Leigh and Ball, 2012	135	5.23	11	135	11.8	13	3.1%	0.00 [-7.12, 7.12]
Liu et al, 2018	135	12.25	4	128.11	13.66	37	1.0%	6.89 [-5.90, 19.68]
Pierrart et al, 2015	138.57	6.9	7	134	9.66	10	2.5%	4.57 [-3.30, 12.44]
Toros et al, 2012	135	10	5	132.09	8.49	11	1.5%	2.91 [-7.19, 13.01]
Watters et al, 2014	137	25.83	30	130	8.94	9	1.3%	7.00 [-3.93, 17.93]
Yan et al, 2015	117.4	9.12	20	114.63	6.94	19	6.0%	2.77 [-2.30, 7.84]
Zhang et al, 2014	132.5	3.54	2	135.56	4.5	18	5.5%	-3.06 [-8.39, 2.27]
Subtotal (95% CI)			**101**			**157**	**31.1%**	**1.51 [-0.72, 3.75]**
Heterogeneity: Chi² = 5.60, df = 8 (P = 0.69); I² = 0%								
Test for overall effect: Z = 1.33 (P = 0.18)								
Ext								
Giannicola et al, 2015	10.63	10.78	16	10	13.28	9	1.5%	0.63 [-9.53, 10.79]
Hou et al, 2021	6.67	2.89	3	8.57	2.8	21	12.8%	-1.90 [-5.38, 1.58]
Jeong et al, 2010	4.67	2.89	3	8	3.5	10	10.1%	-3.33 [-7.25, 0.59]
Leigh and Ball, 2012	5	15.7	11	15	29.5	13	0.5%	-10.00 [-28.53, 8.53]
Liu et al, 2018	20	10.8	4	19.73	10.54	37	1.3%	0.27 [-10.85, 11.39]
Pierrart et al, 2015	26.43	17.73	7	19	18.97	10	0.5%	7.43 [-10.20, 25.06]
Toros et al, 2012	15	7.38	5	14.09	10.95	11	1.9%	0.91 [-8.24, 10.06]
Watters et al, 2014	20	49.68	30	24	14.31	9	0.4%	-4.00 [-24.09, 16.09]
Yan et al, 2015	17	4.35	20	22.21	4.16	19	21.8%	-5.21 [-7.88, -2.54]
Zhang et al, 2014	5	0	2	10	2.97	18		Not estimable
Subtotal (95% CI)			**101**			**157**	**50.7%**	**-3.37 [-5.12, -1.62]**
Heterogeneity: Chi² = 6.29, df = 8 (P = 0.61); I² = 0%								
Test for overall effect: Z = 3.77 (P = 0.0002)								
Total (95% CI)			**354**			**540**	**100.0%**	**-0.76 [-2.01, 0.48]**
Heterogeneity: Chi² = 51.65, df = 30 (P = 0.008); I² = 42%								
Test for overall effect: Z = 1.20 (P = 0.23)								
Test for subgroup differences: Chi² = 17.60, df = 2 (P = 0.0002), I² = 88.6%								

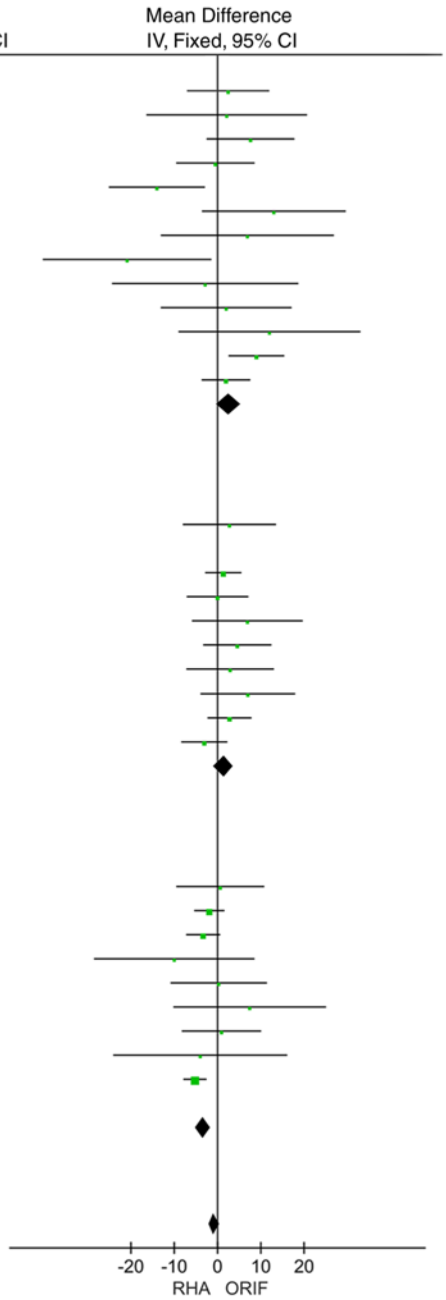

Figure 4. Forest plots for the range of the flexion-extension arc, flexion and extension. RHA, radial head arthroplasty; ORIF, open reduction internal fixation; SD, standard deviation; IV, inverse variation; CI, confidence interval; df, degrees of freedom; Flex, flexion; Ext, extension.

joint by acting on the fulcrum of the force arm (12,31). TTIE is often accompanied by damage to the lateral collateral ligament complex. At this time, if the radial head is removed, the valgus deformity and instability of the elbow joint will be aggravated, resulting in various complications, such as muscle weakness, wrist pain and elbow pain (32). It is widely believed that ORIF is effective in the treatment of simple radial head fractures (33), and the elbow joints are also stabilized after surgery, which coincides with the view of Leigh and Ball (21). To that end, ORIF should be prioritized in the treatment of radial head fractures. However, it has been demonstrated that in the case of complex fractures of the radial head, especially when there are >3 articular fracture fragments of the radial head, the reduction of the radial head cause difficulties because the fracture fragments are mostly comminuted and displaced (34). When this occurs, the blood supply of the radial head is notably damaged and forced reduction can easily lead to complications, such as nonunion of fractures, loosening of internal fixation and fractures even after internal fixation. In addition, it is believed that although the internal fixation materials are increasingly miniaturized, they may still cause slight scratches to the surrounding tissue, thereby reducing the enthusiasm of patients for postoperative functional exercise (35). Therefore, Watters *et al* (27) concluded that RHA has better stability and forearm rotational ROM than ORIF in the treatment of high-energy injury and comminuted complex radial head fractures. However, radial head replacement requires

Study or Subgroup	RHA Mean	RHA SD	RHA Total	ORIF Mean	ORIF SD	ORIF Total	Weight	Mean Difference IV, Fixed, 95% CI
Arc°								
Giannicola et al, 2015	162.19	11.83	16	142.78	50.5	9	0.3%	19.41 [-14.09, 52.91]
Hou et al, 2021	146.67	2.89	3	147.14	26.01	21	2.7%	-0.47 [-12.07, 11.13]
Jeong et al, 2010	141.67	2.89	3	132.5	23.72	10	1.6%	9.17 [-5.89, 24.23]
Klug et al, 2020	161	21.2	26	161	18.3	51	4.0%	0.00 [-9.57, 9.57]
Leigh and Ball, 2012	150	26.16	11	120	64.92	13	0.2%	30.00 [-8.53, 68.53]
Liu et al, 2018	142.5	15.55	4	142.84	15.12	37	1.4%	-0.34 [-16.34, 15.66]
Matar et al, 2017	110.56	53.59	9	148.75	12.5	4	0.3%	-38.19 [-75.28, -1.10]
Toros et al, 2012	156	16.73	5	141.36	35.85	11	0.6%	14.64 [-11.13, 40.41]
Yan et al, 2015	114.1	13.56	20	103.12	19.47	19	3.3%	10.98 [0.40, 21.56]
Zhang et al, 2014	142.5	3.54	2	133.33	23.95	18	2.5%	9.17 [-2.93, 21.27]
Subtotal (95% CI)			**99**			**193**	**17.1%**	**4.93 [0.28, 9.59]**
Heterogeneity: Chi² = 12.38, df = 9 (P = 0.19); I² = 27%								
Test for overall effect: Z = 2.08 (P = 0.04)								
Pro								
Afifi et al, 2020	76.25	15	16	80	0	14		Not estimable
Giannicola et al, 2015	81.25	8.06	16	73.89	20.88	9	1.8%	7.36 [-6.84, 21.56]
Hou et al, 2021	75	5	3	75.48	15.48	21	4.9%	-0.48 [-9.19, 8.23]
Jeong et al, 2010	71.67	2.89	3	67.5	7.91	10	10.6%	4.17 [-1.72, 10.06]
Leigh and Ball, 2012	80	10.46	11	70	23.6	13	1.8%	10.00 [-4.24, 24.24]
Liu et al, 2018	72.5	9.57	4	72.57	8.3	37	3.9%	-0.07 [-9.82, 9.68]
Matar et al, 2017	53.33	28.28	9	70	0	4		Not estimable
Toros et al, 2012	78	8.37	5	69.1	22	11	1.7%	8.90 [-6.03, 23.83]
Yan et al, 2015	63	9.98	20	56.74	13.74	19	6.4%	6.26 [-1.31, 13.83]
Zhang et al, 2014	72.5	3.54	2	70.56	3.79	18	13.6%	1.94 [-3.27, 7.15]
Subtotal (95% CI)			**89**			**156**	**44.7%**	**3.46 [0.59, 6.33]**
Heterogeneity: Chi² = 3.81, df = 7 (P = 0.80); I² = 0%								
Test for overall effect: Z = 2.36 (P = 0.02)								
Sup								
Afifi et al, 2020	75	18.71	16	76.43	17.15	14	2.2%	-1.43 [-14.27, 11.41]
Giannicola et al, 2015	80.94	6.12	16	68.89	31.5	9	0.9%	12.05 [-8.75, 32.85]
Hou et al, 2021	71.67	2.89	3	71.67	11.11	21	11.1%	0.00 [-5.77, 5.77]
Jeong et al, 2010	70	0	3	65	15.81	10		Not estimable
Leigh and Ball, 2012	75	10.46	11	75	11.8	13	4.7%	0.00 [-8.91, 8.91]
Liu et al, 2018	70	14.72	4	70.27	9.5	37	1.7%	-0.27 [-15.02, 14.48]
Matar et al, 2017	57.22	29.17	9	78.75	12.5	4	0.7%	-21.53 [-44.18, 1.12]
Toros et al, 2012	78	8.37	5	72.27	21.02	11	1.8%	5.73 [-8.70, 20.16]
Yan et al, 2015	51.1	5.48	20	49.53	9.58	19	15.2%	1.57 [-3.36, 6.50]
Zhang et al, 2014	70	0	2	68.3	2.97	18		Not estimable
Subtotal (95% CI)			**89**			**156**	**38.2%**	**0.66 [-2.45, 3.77]**
Heterogeneity: Chi² = 5.63, df = 7 (P = 0.58); I² = 0%								
Test for overall effect: Z = 0.41 (P = 0.68)								
Total (95% CI)			**277**			**505**	**100.0%**	**2.64 [0.72, 4.56]**
Heterogeneity: Chi² = 24.63, df = 25 (P = 0.48); I² = 0%								
Test for overall effect: Z = 2.69 (P = 0.007)								
Test for subgroup differences: Chi² = 2.81, df = 2 (P = 0.25), I² = 28.9%								

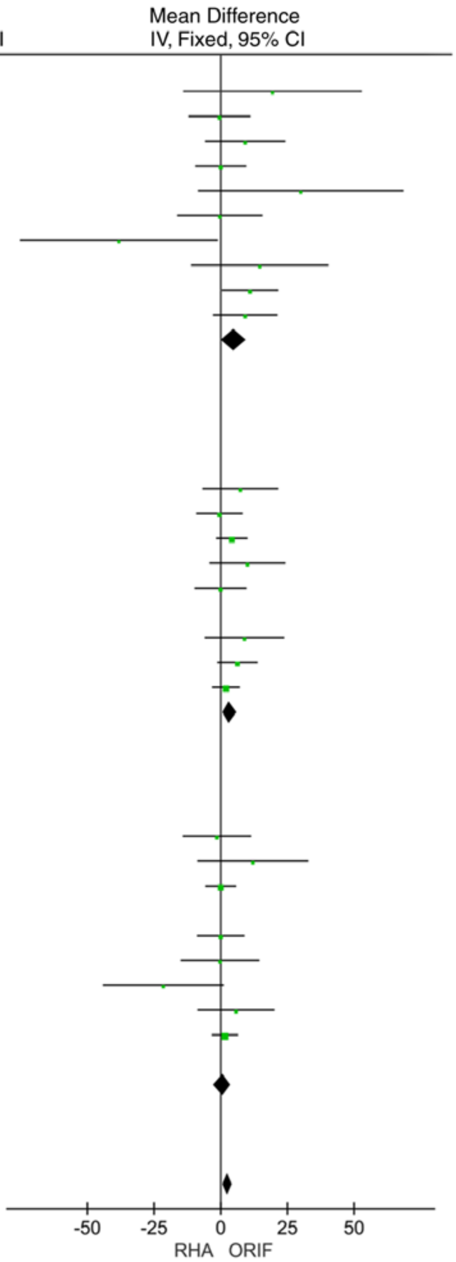

Figure 5. Forest plot for the range of the pronation-supination arc, pronation and supination. RHA, radial head arthroplasty; ORIF, open reduction internal fixation; SD, standard deviation; IV, inverse variation; CI, confidence interval; df, degrees of freedom; Pro, pronation; Sup, supination.

Study or Subgroup	RHA Events	RHA Total	ORIF Events	ORIF Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Hou et al, 2021	0	3	1	21	1.5%	1.95 [0.07, 58.23]
Jeong et al, 2010	1	3	2	10	2.2%	2.00 [0.11, 34.82]
Matar et al, 2017	3	9	1	4	3.3%	1.50 [0.11, 21.31]
Zhang et al, 2014	0	2	5	18	4.5%	0.49 [0.02, 11.97]
Liu et al, 2018	0	4	10	37	7.9%	0.29 [0.01, 5.89]
Giannicola et al, 2015	8	16	4	9	9.2%	1.25 [0.24, 6.44]
Yan et al, 2015	4	29	9	19	33.9%	0.18 [0.04, 0.71]
Li et al, 2018	4	24	14	30	37.4%	0.23 [0.06, 0.83]
Total (95% CI)		**90**		**148**	**100.0%**	**0.43 [0.22, 0.84]**
Total events	20		46			
Heterogeneity: Chi² = 6.90, df = 7 (P = 0.44); I² = 0%						
Test for overall effect: Z = 2.48 (P = 0.01)						

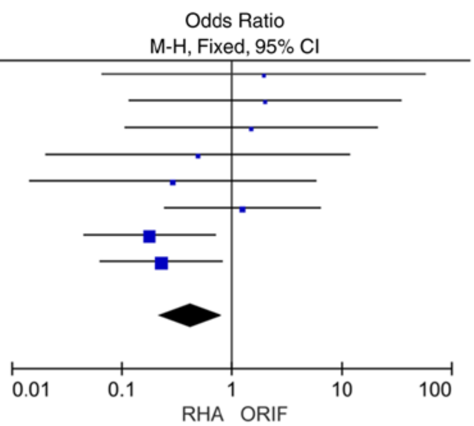

Figure 6. Forest plot for postoperative complications. RHA, radial head arthroplasty; ORIF, open reduction internal fixation; M-H, Mantel-Haenszel; CI, confidence interval; df, degrees of freedom.

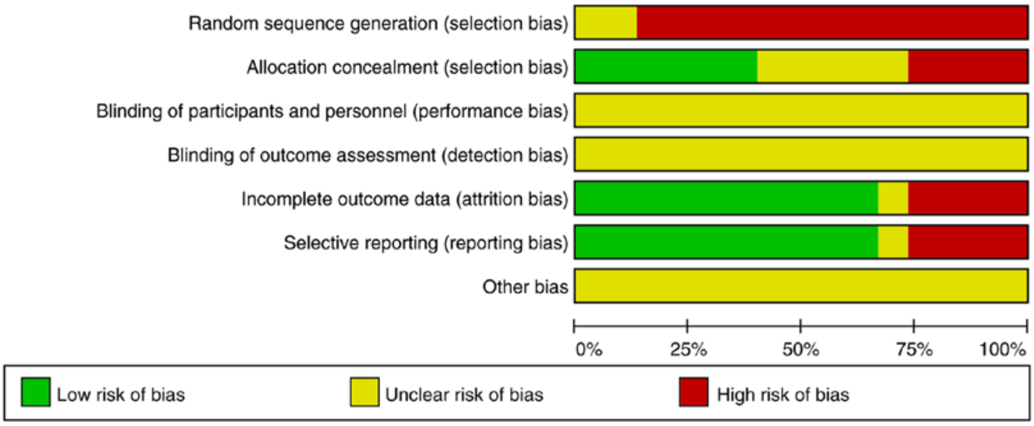

Figure 7. Overall risk of bias assessment of the studies included in the present meta-analysis.

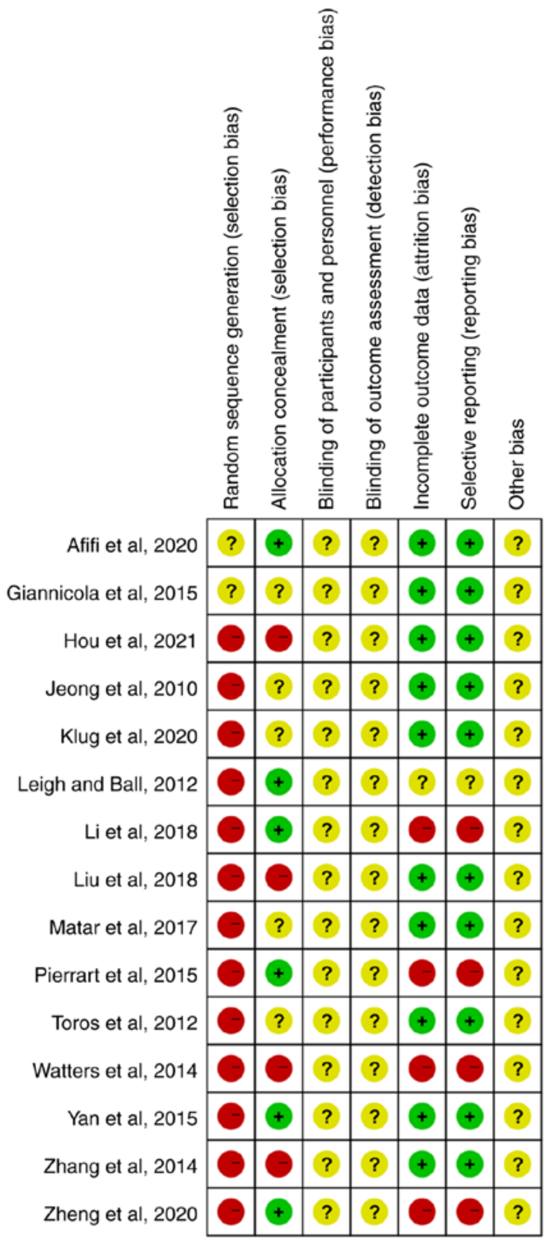

Figure 8. Risk of bias assessment of the specific studies included in the present meta-analysis. A green circle with a + symbol indicates a low risk of bias. A red circle with a-symbol indicates a high risk of bias. A yellow circle with a ? symbol indicates an unclear risk of bias.

accurate restoration of the biomechanical relationship of the joint (36), which puts forward certain requirements for the operator, such as selecting the appropriate prosthesis and the degree of mastery of the operation. Therefore, there is still certain controversy about which surgical method to choose.

At present, the way to obtain a good therapeutic effect from TTIE is still one of the major problems perplexing surgeons. Chen *et al* (11) concluded that patients with TTIE who received RHA had better clinical outcomes and fewer postoperative complications compared with patients who received ORIF. However, the present meta-analysis found that the postoperative MEPS [95% CI (-2.81, 8.11); P=0.34] and DASH score [95% CI (-0.66, 5.23); P=0.13] are fundamentally similar, with no statistical significance between the two groups. After analysis, it was found that a total of 189 cases underwent RHA and 266 cases underwent ORIF in the included literature. Most of the patients in the RHA group had Mason type III fractures caused by high-energy injury (37), and their soft tissue conditions were poor, which may be one of the reasons why the RHA group did not have a significant advantage in postoperative functional scores compared with ORIF. It has also been shown that early elbow surgery is one of the influencing factors for restoration of elbow function (38), and the soft tissue edema caused by the severe injury in the RHA group was likely to delay the optimum time for surgery, so it could be difficult to achieve the desired functional efficacy. However, in terms of postoperative complications, the results of the present study are consistent with the results from Chen *et al* (11). The present analysis found that the postoperative complication rate of the RHA group was 22%, which was significantly lower than that of the ORIF group at 31% [95% CI (0.22, 0.84); P=0.01]. Although both surgical methods have various complications, such as postoperative elbow instability, heterotopic ossification and elbow stiffness, the results of the present study suggested that the RHA group may have better postoperative elbow stability than the ORIF group, perhaps due to early functional exercise reducing the risk of complications, such as elbow stiffness. In addition, Kyriacou *et al* (12) concluded that there was no statistical difference in forearm ROM after RHA and ORIF. The current study found that the RHA group had certain significant advantages, for example in elbow extension [95% CI (-5.12, -1.62); P=0.0002], forearm

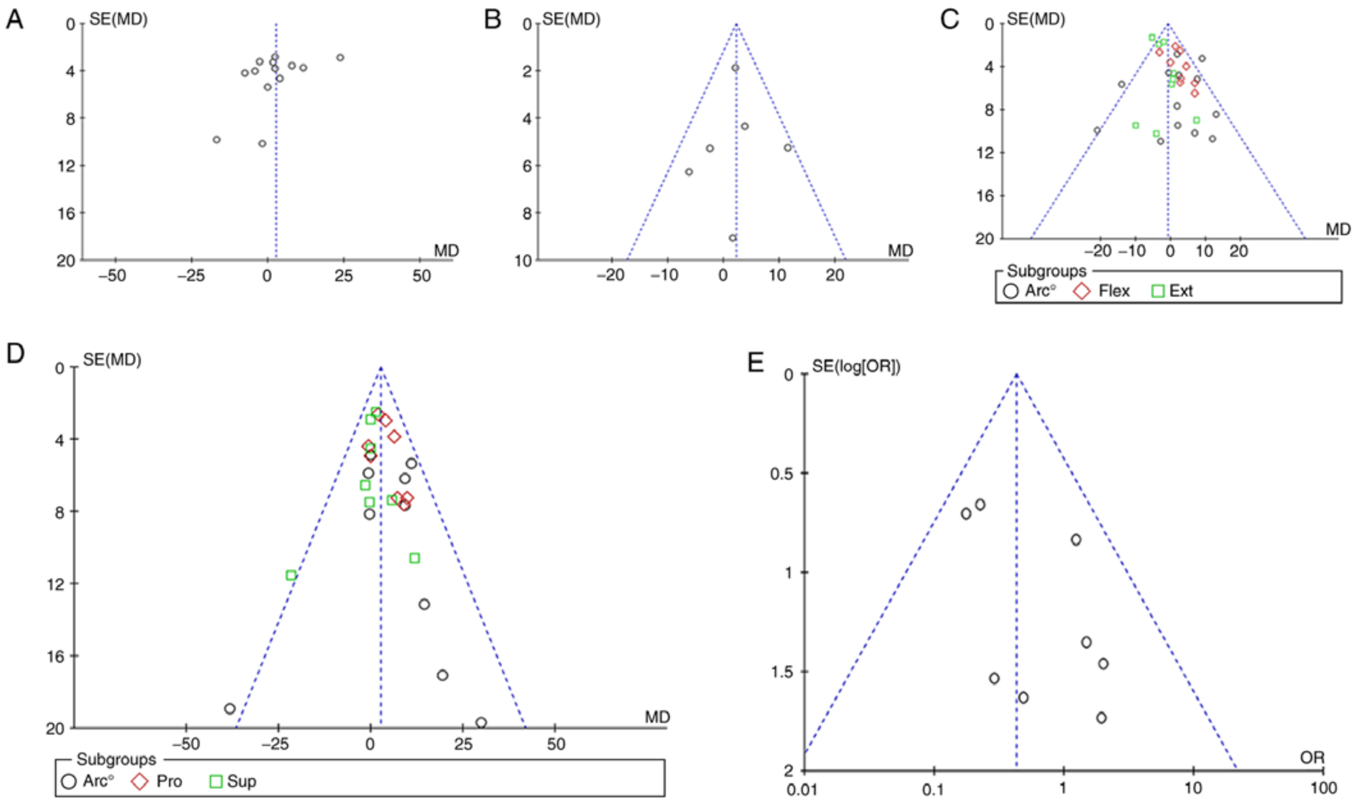

Figure 9. Funnel plots created to assess publication bias for (A) Mayo Elbow Performance Score, (B) disabilities of the arm, shoulder and hand score, (C) flexion-extension arc, (D) pronation-supination arc and (E) complications. SE, standard error; MD, mean difference; Flex, flexion; Ext, extension; Pro, pronation; Sup, supination; OR, odds ratio.

rotation [95% CI (0.28, 9.59); P=0.04] and maximum pronation range [95% CI (0.59, 6.33); P=0.02]. There was no significant difference in the maximum flexion angle [95% CI (-0.72, 3.75); P=0.18] and flexion-extension ROM [95% CI (-0.32, 5.51); P=0.08] between the two groups. Theoretically, the RHA group should achieve better ROM of the forearm during early functional exercise due to its better stability (39). However, this result shows that the ROM advantage of the RHA group is not evident compared with the ORIF group. We hypothesize that this may be related to the difficulty in choosing the ideal height and size of the prosthesis during RHA surgery. Inappropriate prosthesis may lead to changes in the alignment of the elbow joint, thereby limiting the ROM of the forearm (40).

In summary, although ORIF can achieve good functional scores after surgery, RHA can still achieve comparable functional scores even with poor soft tissue conditions, and leads to better forearm rotation ROM with fewer complications. Therefore, in the treatment of radial head fractures of TTIE, RHA is superior to ORIF.

The present study still has the following shortcomings, which need to be further investigated and improved: i) A total of 15 publications were included in the present meta-analysis and systematic review, of which no randomized controlled trials were included, and the number of studies was not sufficient; ii) the Jadad score was used to evaluate the included non-randomized controlled studies; iii) certain literature that met the inclusion criteria failed to provide detailed classification of radial head fractures, therefore conducting a detailed group study of the results according to fracture classification was not possible, and the surgical techniques varied between different literature, which would produce certain bias; iv) regarding outcome measures, a maximum of 13 articles and a minimum of 6 articles were included in the same evaluation method, thereby slightly increasing the heterogeneity between groups; v) furthermore, the difference in the final follow-up time within the literature may have a certain impact on the results, and the longer-term efficacy is unknown. Therefore, the above conclusions need to be further verified by more randomized controlled studies with large samples. Due to the lack of included literature, the conclusions of the present study may be different from the actual situation, thus further follow-up is needed. It would be beneficial if more literature reports were to emerge in the future to reduce bias, so that more authentic and reliable conclusions can be drawn.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

XYL and YLW were responsible for the design of the current study, and both performed the statistical analysis. XYL and YLW confirmed the authenticity of all the raw data. SY is responsible for the acquisition and sorting of data. PFH performed the interpretation of the data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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