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ORIGINAL ARTICLE • ELBOW - FRACTURES

Comparison between radial head arthroplasty and open reduction and internal fixation in patients with radial head fractures (modified Mason type III and IV): a meta-analysis

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Abstract

Purpose Open reduction and internal fixation (ORIF) and radial head arthroplasty (RHA) are the most common operative treatments in patients with radial head fractures. The purpose of this study was to determine the efficacy of RHA and ORIF treatments in patients with radial head fractures (modified Mason type III and IV).

Methods We conducted a computerized search of five electronic databases from their inception to July 2015. All clinical trials comparing ORIF versus RHA treatment in patients with radial head fractures were included. We evaluated the primary outcomes included elbow functional evaluation criteria by Broberg and Morrey, elbow score (Broberg and Morrey), Mayo Elbow Performance Score (MEPS) and QuickDASH score. Secondary outcomes included Visual Analog Scale (VAS), range of motion, operation time and complications. The “assessing risk of bias” table was applied to assess the risk of bias of the included studies.

Result Eight studies were included in this meta-analysis, which consisted of 138 cases of ORIF and 181 RHA. Methodological quality of the studies was moderate to low. RHA afforded significantly higher satisfaction rate, better elbow score (Broberg and Morrey) and MEPS, shorter operation time, lower incidence of bone nonunion or absorption and internal fixation failure when compared to ORIF. There were no significantly differences in QuickDASH score and other complications.

Conclusions RHA has better outcome in patients with radial head fractures (modified Mason type III and IV) than ORIF with medium-short-term follow-up period, but longer-term studies will be required to ascertain whether the apparent benefits of RHA were offset by late complications.

Level of evidence Therapeutic decision analysis; a meta-analysis, Level III.

Keywords Radial head fracture · Terrible triad injuries · Radial head fixation · Radial head arthroplasty · Meta-analysis

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Introduction

Radial head fractures occur in approximately 4 % of all fractures and 33 % of elbow fractures [1]. A retrospective epidemiological study from the Netherlands noted that the incidence of radial head fractures was 2.8 per 10,000 inhabitants per year [2]. The modified Mason classification system is commonly used to describe radial head fractures and guide the clinical treatment. The types of Mason I and II fractures are treated with nonoperative therapy or by ORIF [3, 4]. The modified Mason type III radial head fractures are comminuted fracture, and the modified Mason type IV are radial head fractures with dislocation. These two kinds of fractures are difficult to treat, and the prognosis is unsatisfactory [5].

Proper treatment is essential in order to regain the stability and functional activities of the elbow and minimize the sequelae. The treatment included traditional resection, ORIF and RHA. Resection is an option in Mason type III without valgus instability, but some studies showed resection had less satisfactory joint motion, strength and function than ORIF and RHA, so it was not recommended [6].

Another treatment ORIF is utilized to perform operations of the displaced, noncomminuted fractures and part of the complex, unstable fracture dislocations. The goals of ORIF treatment are to obtain a anatomic reduction and stable fixation [7]. Bone nonunion and internal fixation failure are the most common complications which can lead to chronic pain and dysfunction of the elbow joint [8]. While RHA is made use of managing comminuted displaced fractures or other failed treatments [9]. The main complications are implant loosening, overstuffed, etc. [5]. Each treatment has its own advantages and disadvantages. Therefore, management of radial head fractures is still a matter of debate.

The clinical outcomes of ORIF and RHA have been compared in a few studies. Although a meta-analysis was earlier performed by Li [10], there are some new studies in recent years. Therefore, we performed a meta-analysis to evaluate the clinical outcomes and complications of ORIF and RHA in patients with radial head fractures (modified Mason type III or IV).

Materials and methods

Our meta-analysis was conducted following the guidelines provided by the Cochrane Handbook and according to the PRISMA guideline.

Study selection

Studies were included if they met the following criteria: (1) randomized controlled trials (RCT) or nonrandomized controlled trials (nRCT) comparing ORIF versus RHA for the treatment of radial head fractures, and (2) studies reporting at least one of the following outcomes: elbow functional evaluation criteria by Broberg and Morrey, elbow score (Broberg and Morrey), MEPS, QuickDASH score, VAS, range of motion (ROM), operation time, etc. The exclusion criteria were reviews, case series and cadaver studies.

Literature search

A computerized search of five electronic databases (OVID, PubMed, EMBASE, Cochrane Central Register of Controlled Trials and MANTIS) was conducted from the inception to July 2015. Search terms were selected in order to maximize the search sensitivity and specificity. The key words of searching included "radial head fractures," "terrible triad injuries," "radial head reconstruction," "radial head dislocation," "radial head resection," "open reduction and internal fixation/radial head fractures," "radial head replacement," "radial head arthroplasty" and radial head prosthesis." Unpublished findings were not considered in this study. Two reviewers independently assessed the publications for inclusion in this meta-analysis. Any discrepancies were resolved through discussion between the reviewers.

Data abstraction

Two independent reviewers extracted trial details and collated onto a predefined database. From each study, the data extracted included sample size, patient age, gender, sides of operation, fixation, follow-up period, clinical outcomes and complications.

Quality assessed

In order to adopt the same method to evaluate the RCTs and nRCTs, two reviewers independently applied the "assessing risk of bias" table to assess the risk of bias of the studies included. The evaluation also included allocation concealment, participant, personnel, outcome assessor blinding, attrition bias, incomplete outcome data, selective outcome reporting and other sources of bias. Discrepancies were resolved through discussion between the reviewers.

Data analysis

Continuous data were assessed using mean difference (MD) with corresponding 95 % confidence interval (95 % CI). Dichotomous data were assessed using relative risk (RR) and 95 % CI. $p < 0.05$ was regarded as statistically significant. If a standard error was seen in the final outcome value, we calculated the z-score with the formula: z = mean difference/standard error [11].

The heterogeneity of the studies was assessed by the Cochrane Q test. For statistical heterogeneity with a χ^2 heterogeneity of $p > 0.10$ and the I^2 statistic <50 %, a fixed-effects model was adopted; otherwise, a random-effects model was chosen. The review manager 5.3 was used to perform this analysis.

Additional analyses were performed according to different age (the younger or the elder), study design (RCT or nRCT) and different modified Mason classification (III or IV).

Results

Identification and selection of studies

A total number of 2184 records and abstracts were extracted from five electronic databases, of which 1439 duplicates records were excluded. Ten studies comparing ORIF with RHA were identified, while two of them were excluded because they were biomechanical or cadaver studies (Fig. 1). Finally, two RCTs [13, 19] and six nRCTs [12, 14–18] were included in this review (Table 1).

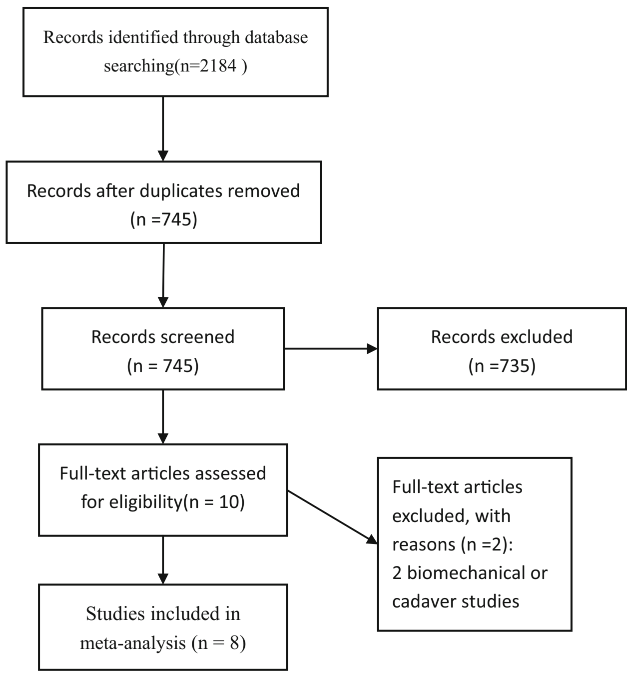

Fig. 1 Flow diagram of included and excluded studies

Study characteristics and quality

There were 138 ORIF cases and 181 RHA cases in eight studies. Five studies [12, 14, 17–19] reported the gender of the patients. A total number of 48 males and 42 females underwent ORIF as compared to 59 males and 62 females who underwent RHA. Two studies [14, 17] reported the side of operation, which included 18 left elbows and 14 right elbows for ORIF as compared to 17 left elbows and 11 right elbows for RHA. The internal fixations of ORIF were plate and screws but one [12], and the RHA adopts the prosthesis of radial head. The maximum follow-up period was >3 years [14], and the minimum period was approximately 1 year [12, 18], Table 1. All the studies used the Mason classification system or modified Mason classification system to evaluate the severity of the radial head fractures. Four studies [12–14, 18] used the Mason classification, two studies [15, 17] used the modified Mason classification while the other two [16, 19] used both. According to the modified Mason classification, patients were classified again. Four studies [12, 13, 17, 18] were classified as Mason type III totally, and the other four studies [14–16, 19] were classified as Mason type IV totally.

Quality appraisal

The “assessing risk of bias” was applied to assess the risk of bias of the eight studies. All the studies had one or more limitations in study design (Fig. 2). The methodological quality of the eligible trials was moderate to low. Two RCTs had higher quality than six nRCTs (Fig. 2).

Primary outcomes

Four kinds of overall evaluation were adopted by eight studies. The elbow functional evaluation criteria (Broberg

Table 1 Description of the studies included in the meta-analysis

Study	Design	Caseload		Mean age		Gender (m/f)		Side (left/right)		Follow-up (months)	Fixation (ORIF/RHA)
		ORIF	RHA	ORIF	RHA	ORIF	RHA	ORIF	RHA		
Ruan et al. (2009) [12]	nRCT	8	14	40.1	37.4	5/3	8/6	NS	NS	10–27	Cannulated screws and K wires/bipolar prosthesis
Chen et al. (2010) [13]	RCT	23	22	37		34/11		NS	NS	33	Plate and screws/monopolar prosthesis
Leigh et al. (2012) [14]	nRCT	13	11	42.2	45.5	6/7	6/5	5/8	5/6	41	Plate and screws/not stated
Watters et al. (2014) [15]	nRCT	9	30	48		21/18		19/20		24	Plate or screws/not stated
Schnetzke et al. (2014) [16]	nRCT	12	30	42.1	50.7	NS	NS	NS	NS	12–60	Plates or tension band/monopolar prosthesis
Burdeni et al. (2015) [17]	nRCT	19	17	34.1	38.1	17/2	15/2	13/6	12/5	15	Not stated
Liu et al. (2015) [18]	nRCT	35	37	65.5	68.7	19/18	19/16	NS	NS	10–18	Plate and screws/not stated
Yan et al. (2015) [19]	RCT	19	20	35.5	36.5	7/12	11/9	NS	NS	36	Plate and screws/monopolar prosthesis

ORIF Open reduction and internal fixation, *RHA* radial head arthroplasty, *NS* not stated

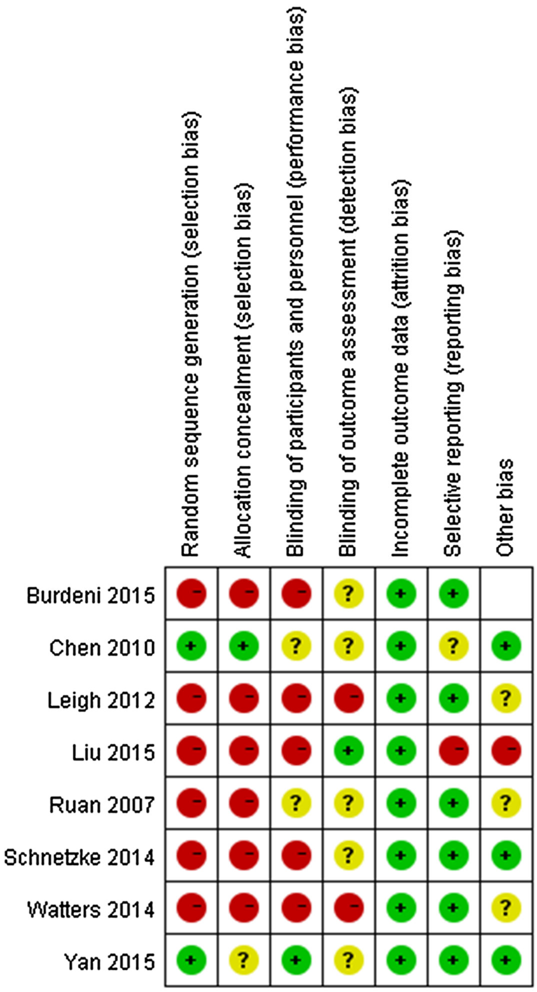

Fig. 2 Risk of bias assessment of included studies

and Morrey) were assessed in four studies [12, 13, 18, 19]. One hundred and seventy-eight elbows (85 ORIF and 93 RHA, respectively) were available. The outcome of satisfaction rate was 94.6 % in RHA group and 72.9 % in ORIF group, which showed no significantly difference (RR = 0.72; 95 % CI 0.44, 1.18, $p = 0.20$). Heterogeneity was high ($I^2 = 89$ %, $\chi^2 = 28.01$, $p < 0.001$), as shown in Fig. 3.

For QuickDASH score, 99 elbows were evaluated in three studies [14, 15, 17] (41 ORIF and 58 RHA, respectively). No significant difference was observed between the two treatments (MD = 0.73; 95 % CI −1.50, 2.95, $p = 0.52$). Meta-analysis showed a high heterogeneity ($I^2 = 77$ %, $\chi^2 = 8.68$, $p = 0.52$).

MEPS was evaluated in two studies [16, 19], with 78 elbows (31 in ORIF and 47 in RHA). A significantly higher score in RHA group was shown in the meta-analysis (MD = −7.08; 95 % CI −12.93, −1.24, $p = 0.02$). The heterogeneity was low ($I^2 = 0$ %, $\chi^2 = 0.16$, $p = 0.69$).

The elbow score (Broberg and Morrey) was assessed in two studies [13, 18]. One hundred and seventeen elbows (58 ORIF and 59 RHA, respectively) were available for meta-analysis. There were statistically significant differences between two groups (MD = −15.53; 95 % CI −23.16, −7.91, $p < 0.001$). The heterogeneity was high ($I^2 = 93$ %, $\chi^2 = 13.86$, $p < 0.001$).

Secondary outcomes

There was a statistically significant difference in operation time and VAS. The ORIF group showed significantly longer operation time (MD = 33.78; 95 % CI 26.59, 40.97, $p < 0.001$) and higher VAS than RHA group (MD = −0.58; 95 % CI −0.66, −0.49, $p < 0.001$) (Table 2).

For range of motion, the degree of flexion (MD = −1.94; 95 % CI 1.31, 2.58, $p < 0.001$), pronation (MD = −2.63; 95 % CI −3.17, −2.08, $p < 0.001$) and supination (MD = 1.43; 95 % CI 0.78, 2.08, $p < 0.001$) showed statistically significant differences between two groups. There was no statistically significant difference in the degree of extension (MD = 1.52; 95 % CI −2.53, 5.58, $p = 0.46$) (Table 2).

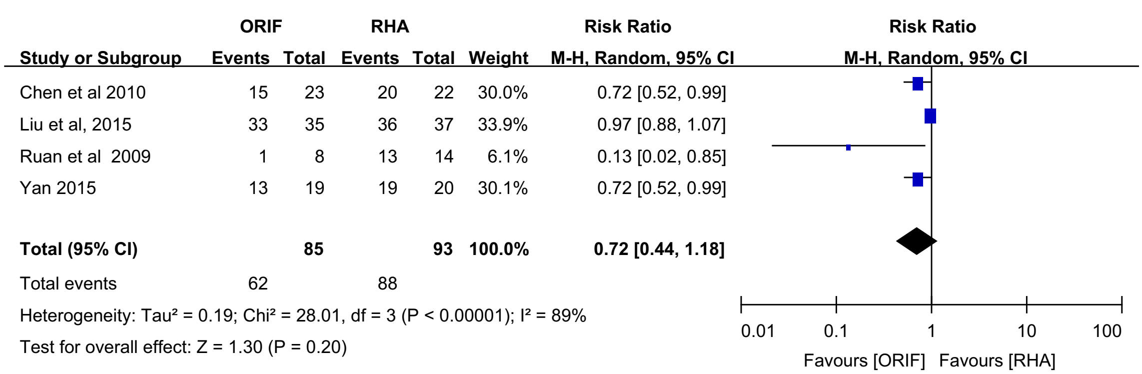

Fig. 3 Forest plot. Outcome: elbow functional evaluation criteria (Broberg and Morrey)

Table 2 Results of the secondary outcomes

Outcome	Studies	Sample size		Mean difference/RR (95 % CI)	*p* value	Heterogeneity	
		ORIF0	RHA			I^2	χ^2 (*P*)
Clinical outcomes							
Operation time	[1]	38	37	33.78 (26.59, 40.97)	<0.001	0	0.49
VAS	[15, 16]	47	67	−0.58 (−0.66, −0.49)	<0.001	0	0.44
ROM of elbow							
Extension	[1, 14–16, 23]	88	128	1.52 (−2.53, 5.58)	0.46	90	<0.001
Flexion	[1, 14–16, 23]	88	128	1.94 (1.31, 2.58)	<0.001	41	0.14
Pronation	[1, 14–16]	67	68	−2.63 (−3.17, −2.08)	<0.001	0	0.38
Supination	[1, 14–16]	67	68	1.43 (0.78, 2.08)	<0.001	12	0.32
Complications							
Revision	[1, 14, 16, 23]	72	108	1.76 (0.94, 3.27)	0.08	0	0.67
Internal fixation failure	[5, 14, 16, 19, 23, 24]	84	127	7.93 (2.51, 25.01)	<0.001	0	0.93
Overstuffed	[1, 16, 23]	40	80	0.31 (0.06, 1.67)	0.17	0	0.94
Bone nonunion or absorption	[5, 14, 16, 19, 23]	56	77	6.70 (1.59, 28.16)	<0.001	0	0.88
Heterotopic ossification	[1, 5, 16, 19]	62	86	1.17 (0.35, 3.84)	0.80	0	0.50
Stiffness	[1, 5]	61	59	1.98 (0.52, 7.52)	0.31	0	0.40
Infection	[5, 14, 16]	48	63	0.73 (0.15, 3.56)	0.70	0	0.56
Nerve palsy	[16]	12	30	0.42 (0.06, 3.10)	0.39		
Arthrosis	[23]	9	30	0.13 (0.01, 2.09)	0.15		

VAS Visual Analog Scale, *ROM* range of motion

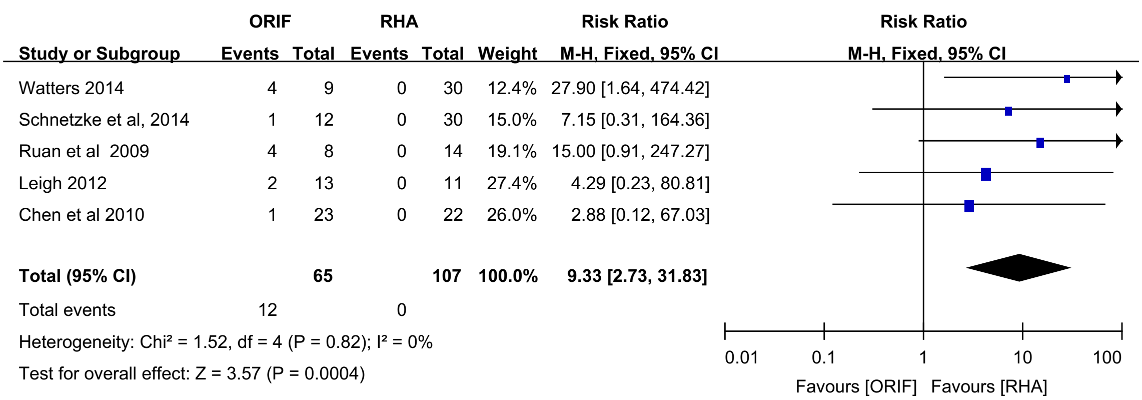

Fig. 4 Forest plot. Outcome: bone nonunion or absorption

Complications

There was significantly higher incidence of bone nonunion or absorption (RR $= 6.70$; 95 % CI 1.59, 28.16, $p < 0.001$) and internal fixation failure (RR $= 7.03$; 95 % CI 2.51, 25.01, $p < 0.001$) in the ORIF groups as compared to the RHA groups (Fig. 4). Other complications were reported in different studies, with each study reporting different complications. There were no significant differences in infection, overstuffed, heterotopic ossification, stiffness, nerve palsy, arthrosis and revision, as shown in Table 2 and Fig. 5.

Risk of bias and publication bias assessment

Two RCTs and six nRCTs were included in this study. Outcomes were analyzed both separately and together when being reported in RCTs and nRCTs. There were statistical differences in the elbow functional evaluation criteria (Broberg and Morrey) in the RCTs, but not in the nRCTs. In contrast, there were statistical differences in the incidence of internal fixation failure in the nRCTs, but not in the RCTs. Other outcomes were coincidental in the RCTs and nRCTs (Table 3).

Study or Subgroup	ORIF Events	ORIF Total	RHA Events	RHA Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Burdeni et al, 2015	1	19	0	17	4.8%	2.70 [0.12, 62.17]
Leigh 2012	5	13	1	11	9.8%	4.23 [0.58, 30.99]
Schnetzke et al, 2014	4	12	10	30	51.7%	1.00 [0.39, 2.58]
Watters 2014	4	9	7	30	29.3%	1.90 [0.72, 5.06]
Yan 2015	1	19	0	20	4.4%	3.15 [0.14, 72.88]
Total (95% CI)		**72**		**108**	**100.0%**	**1.76 [0.94, 3.27]**
Total events	15		18			

Heterogeneity: Chi² = 2.34, df = 4 (P = 0.67); I² = 0%
Test for overall effect: Z = 1.78 (P = 0.08)

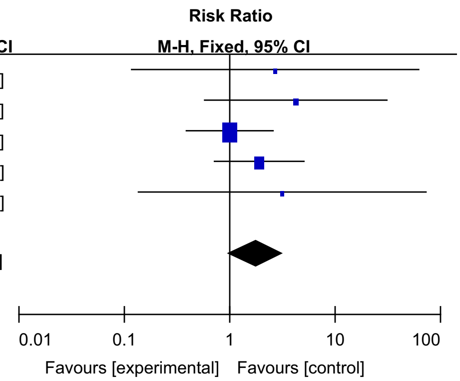

Fig. 5 Forest plot. Outcome: revision

The average age of one study [18] was more than 65 years old, and the others were less than 51 years of age (Table 1). So we divided the studies into two groups according to age. The average age of the elder group was more than 65 years old, and the younger group was less than 51 years old. All outcomes were coincidental between two groups (Table 3).

According to the modified Mason classification, four studies [12, 13, 17, 18] were classified as Mason type III totally, and other four studies [14–16, 19] were classified as Mason type IV totally. So we divided the studies into two groups according to modified Mason classification (Mason III group and Mason IV group). There were statistical differences in the Elbow extension and flexion in the RCTs, but not in the nRCTs. In contrast, there were statistical differences in Mason III group, but not in Mason IV group. Other outcomes were coincidental between two groups (Table 3).

Discussion

This is a quantitative comparative meta-analysis comparing ORIF and RHA for the treatment of radial head fractures. Ultimately, two RCTs and six nRCTs were included in this meta-analysis.

In overall evaluation, the elbow score (Broberg and Morrey) [13, 18] and MEPS [16, 19] of RHA groups was significantly higher than ORIF group. The elbow functional evaluation criteria (Broberg and Morrey) were considered to be satisfactory if the result was good or excellent and unsatisfactory if it was fair or poor. The satisfaction rate of RHA groups was higher than ORIF groups, though there was no statistically significant difference between them. The elbow functional evaluation criteria (Broberg and Morrey) are a widespread used overall evaluation for elbow, which consists of the motion, strength, stability and pain. Recent studies [12, 13, 18] suggested that the better outcomes of medium-short-term in RHA groups could be explained that radial head prosthesis might provide early stability, allowing early rehabilitation and avoiding the failure of internal fixation.

In complications, five studies reported the incidence of revision. The outcome of revision rate was 16.7 % in RHA group and 20.1 % in ORIF group, which showed no significant difference. Internal fixation failure (9/15) and bone nonunion (4/15) were the main reasons for revision in ORIF. Six studies [12–16, 19] reported the incidence of internal fixation failure. The ORIF groups (15.5 %) had significantly higher incidence than RHA groups (0 %). Five studies [12–16] reported the incidence of bone nonunion or absorption. The ORIF groups (18.5 %) had significantly higher incidence than RHA groups (0 %). In our meta-analysis, all the studies are fixed with plate and screws but one [12]. However, there were still some fragments which were unable to be stably fixed and lack of blood supply due to the primary injury and iatrogenic factors. It gave rise to an increase in the incidence of internal fixation failure. Stable fixation and the protection of the blood supply of the fractures were needed, but it was difficult for severe comminuted fractures [15, 17, 18].

Overstuffed of prosthesis (8/18) and subluxation (4/18) were the main reasons for revision in RHA. Overstuffed of prosthesis was defined by prosthesis over lengthening $\geq$2 mm [20]. This highlights the need for proper diameter and length of the prosthesis. While the excised radial head can be used for diameter determination, length determination should be made using prostheses models repeatedly during the operation to determine the position for the radial head amputation [21]. A retrospective study [22] about RHA showed that there were 11 cases of overstuffed in 47 cases with revision, but the most common indication for revision was painful loosening (31/47). The subluxation was the secondary important reason of revision in the studies included in our meta-analysis. Watters et al. [15] suggested that lateral ulnar collateral ligament (LUCL)

Table 3 Additional analyses

Outcomes	All studies				RCTs				nRCTs			
	n	MD (95 % CI)	*p*	Heterogeneity (I^2/p)	*n*	MD (95 % CI)	*p*	Heterogeneity (I^2/p)	*n*	MD (95 % CI)	*p*	Heterogeneity (I^2/p)
Broberg and Morrey evaluation criteria	4	0.72 (0.44, 1.18)	0.20	89/<0.01	2	0.72 (0.57, 0.90)	<0.01	0/0.99	2	0.38 (0.01, 23.30)	0.64	95/<0.01
Internal fixation failure	6	7.93 (2.51, 25.01)	<0.01	0/0.93	2	4.97 (0.60, 41.24)	0.14	0/0.73	4	9.96 (2.48, 40.04)	<0.01	0/0.81
Revision	5	1.76 (0.94, 3.27)	0.08	0/0.67	1	3.15 (0.14, 72.88)	0.47	NA	4	1.69 (0.90, 3.18)	0.10	0/0.54
Heterotopic ossification	4	1.17 (0.35, 3.84)	0.80	0/0.50	2	3.03 (0.50, 18.48)	0.23	0/0.67	2	0.38 (0.05, 2.91)	0.35	0/0.57

Outcomes	All studies				Younger patients				Elderly patients			
	n	MD (95 % CI)	*p*	Heterogeneity (I^2/p)	*n*	MD (95 % CI)	*p*	Heterogeneity (I^2/p)	*n*	MD (95 % CI)	*p*	Heterogeneity (I^2/p)
Broberg and Morrey evaluation criteria	4	0.72 (0.44, 1.18)	0.20	89/<0.01	3	0.66 (0.31, 1.44)	0.30	92/<0.01	1	0.72 (0.52, 0.99)	0.05	NA
Elbow score	2	−15.5 (−23.2, −7.9)	<0.01	93/<0.01	1	−19.7 (−23.8, −15,6)	<0.01	NA	1	−11.9 (−12.5, −11.3)	<0.01	NA

Outcomes	All studies				Mason III				Mason IV			
	n	MD (95 % CI)	*p*	Heterogeneity (I^2/p)	*n*	MD (95 % CI)	*p*	Heterogeneity (I^2/p)	*n*	MD (95 % CI)	*p*	Heterogeneity (I^2/p)
Broberg and Morrey evaluation criteria	4	0.72 (0.44, 1.18)	0.20	89/<0.01	3	0.66 (0.31, 1.44)	0.30	92/<0.01	1	0.72 (0.52, 0.99)	0.05	NA
Internal fixation failure	6	7.93 (2.51, 25.01)	<0.01	0/0.93	2	8.81 (1.17, 66.12)	0.03	0/0.79	4	7.43 (1.86, 29.61)	<0.01	0/0.74
Revision	5	1.76 (0.94, 3.27)	0.08	0/0.67	1	2.70 (0.12, 62.17)	0.53	NA	4	1.71 (0.91, 3.21)	0.10	0/0.53
Heterotopic ossification	4	1.17 (0.35, 3.84)	0.80	0/0.50	2	0.98 (0.20, 4.81)	0.98	51/0.15	2	1.48 (0.24, 9.08)	0.67	0/0.62
Elbow extension	5	1.52 (−2.53, 5.58)	0.46	90/<0.01	1	1.80 (0.87, 2.73)	<0.01	NA	4	1.26 (−5.81, 8.33)	0.73	92/<0.01
Elbow flexion	5	1.94 (1.31, 2.58)	<0.01	41/0.14	1	2.0 (1.35, 2.65)	<0.01	NA	4	0.86 (−3.69, 5.4)	0.71	51/0.10

Younger patients, <51 years old; elderly patients, >65 years old needed to be repaired in both ORIF and RHA, and then, the hanging arm test was performed to assess stability of elbow joint. If instability persisted, repairing of the medial collateral ligament (MCL) or external fixator was necessary. A retrospective study [23] of 258 patients with RHA for more than 10 years of follow-up showed that 62 patients needed revision, and the primary reason for revision was heterotopic ossification (53.2 %). Duckworth et al. [1] reported lower age was increased risk of revision in RHA. Four studies [12, 13, 16, 19] reported the types of prosthesis, with one bipolar and three monopolar. A cadaveric test showed a similar biomechanics outcomes between bipolar prosthesis and monopolar prosthesis [24].

Two studies [17, 19] reported the operation time, and meta-analysis showed ORIF group had longer operation time. The reduction and fixation in ORIF were more difficult than RHA with radial head resection and prosthesis installation, so loner operation time was needed. Five studies [14–16, 18, 19] reported the range of motion. Although there were significant differences, the clinical significance was not obvious. The maximum value of mean difference was less than three degrees. Three studies [13, 17, 19] reported the incidence of stiffness. The incidence of stiffness in ORIF group (8.2 %) was higher than that in RHA group (3.4 %) but no statistically significant differences. Finally, only one study [16] reported the iatrogenic nerve injury. The incidence of RHA groups (20.0 %) was higher than ORIF groups (8.3 %) but no statistically significant differences.

However, there were three limitations in this meta-analysis. First, two RCTs and six nRCTs were included. Therefore, the nRCTs had a greater caseload and were more likely to suffer from various biases. The additional analysis showed different results between the RCTs and nRCTs. Secondly, all the studies used the Mason classification system or modified Mason classification system to evaluate the severity of the radial head fractures. However, a marginal fracture with displacement >2 mm and dislocation was classified as modified Mason type IV but Mason Type II. Although all the cases can be classified as modified Mason type III and IV, the bias persisted. Thirdly, in terms of follow-up period, none was more than 5 years in this study. Although the longest follow-up period was up to three and a half years, there were a few complications which required longer period of follow-up to obtain accurate results. Therefore, the outcomes in this study might exist inaccurate.

In conclusions, radial head arthroplasty afforded higher satisfaction rate, better elbow score (Broberg and Morrey) and MEPS, shorter operation time, lower incidence of bone nonunion or absorption and internal fixation failure when compared to open reduction and internal fixation. As the follow-up period of all the studies in this meta-analysis were medium-short-term, longer-term studies will be required to ascertain whether the apparent benefits of RHA will be offset by late complications.

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Compliance with ethical standards There was no fund support in our study. The authors declare that they have no competing interests. This article does not contain any studies with human participants performed by any of the authors.

Conflict of interest None.

References

1. Duckworth AD, Clement ND, Jenkins PJ, Aitken SA, Court-Brown CM, McQueen MM (2012) The epidemiology of radial head and neck fractures. J Hand Surg Am 37(5):112–119. doi:10.1016/j.jhsa.2011.09.034
2. Kaas L, van Riet RP, Vroemen JP, Eygendaal D (2010) The epidemiology of radial head fractures. J Shoulder Elbow Surg 19(6):520–523. doi:10.1016/j.jse.2009.10.015
3. Kaas L, Struijs PA, Ring D, van Dijk CN, Eygendaal D (2012) Treatment of Mason type II radial head fractures without associated fractures or elbow dislocation: a systematic review. J Hand Surg Am 37(1):1416–1421. doi:10.1016/j.jhsa.2012.03.042
4. Bruinsma W, Kodde I, de Muinck Keizer RJ, Kloen P, Lindenhovius AL, Vroemen JP (2014) A randomized controlled trial of nonoperative treatment versus open reduction and internal fixation for stable, displaced, partial articular fractures of the radial head: the RAMBO trial. BMC Musculoskelet Disord 6(15):140–147. doi:10.1186/1471-2474-15-147
5. Delclaux S, Lebon J, Faraud A, Toulemonde J, Bonnevialle N, Coulet B (2015) Complications of radial head prostheses. Int Orthop 39(7):907–913. doi:10.1007/s00264-015-2689-7
6. Hall JA, McKee MD (2008) Posterolateral rotatory instability of the elbow following radial head resection. J Bone Joint Surg Am 8(3):1571–1579. doi:10.2106/jbjs.d.02829
7. Allieu Y, Winter M, Pequignot JP (2006) Radial head replacement with a pyrocarbon head prosthesis: preliminary results of a multicentric prospective study. Eur J Orthop Surg Traumatol 16(1):1–9. doi:10.1007/s00590-005-0041-4
8. Ring D (2004) Open reduction and internal fixation of fractures of the radial head. Hand Clin 20(4):415–427. doi:10.1016/j.hcl.2004.06.001
9. Ring D (2011) Radial head fracture: open reduction-internal fixation or prosthetic replacement. J Shoulder Elbow Surg 20(8):107–112. doi:10.1016/j.jse.2010.11.011
10. Li N, Chen S (2014) Open reduction and internal-fixation versus radial head replacement in treatment of Mason type III radial head fractures. Eur J Orthop Surg Traumatol 24(6):851–855. doi:10.1007/s00590-013-1367-y
11. Higgins JP, Thompson SG, Deeks JJ, Altman DG (2013) Measuring inconsistency in meta-analyses. BMJ Br Med J 327(2):557. doi:10.1136/bmj.327.7414.557
12. Ruan HJ, Fan CY, Liu JJ, Zeng BF (2009) A comparative study of internal fixation and prosthesis replacement for radial head fractures of Mason type III. Int Orthop 33(7):249–253. doi:10.1007/s00264-007-0453-3
13. Chen X, Wang SC, Cao LH, Yang GQ, Li M, Su JC (2011) Comparison between radial head replacement and open reduction

and internal fixation in clinical treatment of unstable, multi-fragmented radial head fractures. Int Orthop 35(2):1071–1076. doi:10.1007/s00264-010-1107-4
14. Leigh WB, Ball CM (2012) Radial head reconstruction versus replacement in the treatment of terrible triad injuries of the elbow. J Shoulder Elbow Surg 21(6):1336–1341. doi:10.1016/j.jse.2012.03.005
15. Watters TS, Garrigues GE, Ring D, Ruch DS (2014) Fixation versus replacement of radial head in terrible triad: Is there a difference in elbow stability and prognosis? Clin Orthop Relat Res 472(3):2128–2135. doi:10.1007/s11999-013-3331-x
16. Schnetzke M, Aytac S, Deuss M, Studier-Fischer S, Swartman B, Muenzberg M (2014) Radial head prosthesis in complex elbow dislocations: effect of oversizing and comparison with ORIF. Int Orthop 38(4):2295–2301. doi:10.1007/s00264-014-2478-8
17. Al-Burdeni S, Abuodeh Y, Ibrahim T, Ahmed G (2015) Open reduction and internal fixation versus radial head arthroplasty in the treatment of adult closed comminuted radial head fractures (modified Mason type III and IV). Int Orthop. doi:10.1007/s00264-015-2755-1
18. Liu R, Liu P, Shu H, Gong J, Sun Q, Wu J (2015) Comparison of primary radial head replacement and ORIF (open reduction and internal fixation) in Mason type III fractures: a retrospective evaluation in 72 elderly patients. Med Sci Monit 21(5):90–93. doi:10.12659/msm.893048
19. Yan M, Ni J, Song D, Ding M, Liu T, Huang J (2015) Radial head replacement or repair for the terrible triad of the elbow: which procedure is better? ANZ J Surg. doi:10.1111/ans.13060
20. Athwal GS, Frank SG, Grewal R, Faber KJ, Johnson J, King GJ (2010) Determination of correct implant size in radial head arthroplasty to avoid over lengthening surgical technique. J Bone Joint Surg Am. doi:10.2106/jbjs.j.00356
21. Van Glabbeek F, Van Riet RP, Baumfeld JA, Neale PG, O'Driscoll SW, Morrey BF (2004) Detrimental effects of over-stuffing or understuffing with a radial head replacement in the medial collateral-ligament deficient elbow. J Bone Joint Surg Am 86(4):2629–2635
22. van Riet RP, Sanchez J, Morrey BF (2010) Failure of metal radial head replacement. J Bone Joint Surg Br 92(3):661–667. doi:10.1302/0301-620x.92b5.23067
23. Ha AS, Petscavage JM (2012) Radial head arthroplasty: a radiologic outcome study. AJR Am J Roentgenol 199:1078–1082. doi:10.2214/ajr.11.7674
24. Hartzler RU, Morrey BF, Steinmann SP, Llusa-Perez M, Sanchez-Sotelo J (2014) Radial head reconstruction in elbow fracture-dislocation: Monopolar or bipolar prosthesis? Clin Orthop Relat Res 472(3):2144. doi:10.1007/s11999-014-3672-0