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ORIGINAL ARTICLE

Meta-analysis comparing locking plate fixation with hemiarthroplasty for complex proximal humeral fractures

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Abstract
Background There remains no consensus on the surgical treatment of complex proximal humeral fractures. In this meta-analysis, we pool available trials to compare the clinical outcomes of locking plate fixation and hemiarthroplasty for this injury.
Methods A literature search between January 1990 and May 2012 in the main medical search engines (Pubmed, Medline, Embase search, and the Cochrane library) was included. We selected available trials that compared locking plate fixation and hemiarthroplasty in patients with complex proximal humeral fractures and that reported on functional outcomes, revisions, and method-related complications. The quality of the studies was assessed, and meta-analyses were performed with the Cochrane Collaboration's REVMAN 5.0 software.
Results A total of 567 patients from 9 trials were included in this meta-analysis (302 fractures treated with locking plate and 265 with hemiarthroplasty). In this comparison, we found that patients with locking plate fixation had better Constant–Murley score than with hemiarthroplasty, and hemiarthroplasty could reduce the rate of revisions and the method-related complications significantly.
Conclusions Compared with hemiarthroplasty, patients with locking plate fixation could obtain more favorable functional outcomes, but technical detail was critical to minimize the risk of implant failure, avascular necrosis, and re-operation. As the possible significant bias and inconclusive evidence arising from the included trials, further randomized trials and observational studies should be recommended to support these finding.

Keywords Locking plate fixation · Hemiarthroplasty · Complex proximal humeral fractures · Meta-analysis

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Introduction

Proximal humeral fracture is a quite common orthopedic injury and accounts for 6 % of all adult fractures [1]. Their incidence rapidly increases with age, and women are affected about three times as often as men [1, 2]. A proximal humeral fracture is a life-affecting event for any individual, and the risk of dysfunction and increased dependence is substantial.

Approximately 49–85 % of proximal humeral fractures are non- or minimally displaced [1, 3, 4], and conservative treatment is generally accepted. Conservative treatment usually includes a period of immobilization, such as in arm sling, followed by physiotherapy and exercises [5]. Surgery is recommended for displaced and unstable fractures and those with more complex fractures patterns to avoid painful and dysfunctional malunion. A various application of surgery strategies, including from closed reduction and percutaneous stabilization with pins or wires to hemiarthroplasty or reverse total shoulder replacement, has been reported. Besides a certain consensus on prosthetic therapy of 'head-split' fractures [6, 7], the surgical management is usually based on the personal experience and preference toward. Most complex proximal humeral fractures are presently being treated by hemiarthroplasty or open reduction and internal fixation with a locking plate, but the optimal choice remains challenging and controversial. With technique advances in the field of locking plating fixation, there is a clear trend toward ORIF with all displaced fractures of the proximal humerus [8, 9]; however, even a recent systematic review of the study was inefficient to determine a benefit from ORIF or hemiarthroplasty for treatment of these complex fracture patterns [5]. It becomes clearly apparent with the importance of this unresolved problem since revision prosthetic replacement for failed internal fixation has historically poor outcomes.

Randomized and comparative clinical studies have since been published to reach evidence-based conclusions, thus helping surgeons to make rational decisions. However, there still remains no clear consensus on the optimal treatment of these complex fracture patterns. We sought to perform a meta-analysis of these studies to evaluate the clinical results of locking plate fixation and hemiarthroplasty in the treatment of complex proximal humeral fracture, with regard to functional outcomes, revisions, and method-related complications.

Materials and methods

Search strategy

Computer literatures search was conducted to identify publications relating to compare locking plate fixation with hemiarthroplasty for the treatment of proximal humeral fractures. We conducted a Pubmed, Medline, and Embase search of the literature on proximal humeral fracture published between January 1990 and May 2012. A Cochrane database search revealed that no Cochrane review about comparing locking plate fixation with hemiarthroplasty for proximal humeral fracture had been performed. We combined search terms with 'proximal humeral/humerus fracture', 'internal fixation/locking plate fixation', and 'hemiarthroplasty/arthroplasty'. Additional strategies to identify relevant trails were supplement with Google Scholar. No language restriction was made.

Two authors (Dai J. Z. and Wang C. Y.) independently reviewed the following parameters for each trial: research design, population characteristics, intervention and outcomes, inclusion and exclusion criteria, matching criteria, number and length of cases follow-up. They analyzed the full text versions of these articles to determine whether they met the citation found. When the citation could not be excluded immediately, disagreements were resolved by debate with the senior investigator (Chai Y. M.).

Data extraction

Two authors (Dai J. Z. and Wang C. Y.) independently extracted data with a structured data collection form. Discrepancies were resolved by discussion with the senior investigator (Chai Y. M.). The following information was sought from each trial: first author, publication year and language, number of patients, mean age, sex ratio (male/female), fracture classification, study design, intervention and functional outcome, rate of complication and revision, and length of follow-up. There was 100 % agreement between the two authors.

Inclusion and exclusion criteria

The following eligibility criteria were performed in trials selection: (1) the research object was patients with complex proximal humeral fractures, (2) the intervention was ORIF with a locking plate compared with hemiarthroplasty (arthroplasty or total shoulder replacement), (3) studies included randomized trials and nonrandomized comparative studies (prospective and retrospective), (4) the outcome measures included functional outcomes, revisions, or method-related complication data, (5) skeletally mature patients, (6) a minimum cases of 10 patients, (7) studies in which a follow-up more than 6 months was involved. We excluded studies involving animal models, children, and open fractures and when it was impossible to extract or calculate the appropriate data from the published trials.

Outcomes of interest and definitions

The definition of ''method-related complications'' for locking plate fixation included infection, screw cutout, and avascular necrosis of the humeral head, postoperative pain and for hemiarthroplasty included infection, prosthesis loosening, and nonunion or malunion of the tuberosities; the definition of ''revisions'' included debridement after infection, the removal of hardware after fracture healing or screw cutout, or hemiarthroplasty after the implant failure or avascular necrosis.

Statistical analysis

The data from the studies were pooled together and analyzed using the Cochrane Collaboration's REVMAN 5.0 software. We pooled continuous variables across studies using the method of standard mean differences (SMD), and difference in means between intervention groups was shown in multitudes of a pooled standard deviation. Statistical analysis of dichotomous variables was carried out by using relative risks with associated 95 % confidence intervals (CIs). When the study reported continuous data with mean and range values, the standard deviations (SDs) were calculated using the method described by Hozo et al. [10]. Therefore, all continuous data were standardized for analysis. We performed a meta-analysis with a fixed-effect model when appropriate using the inverse-variance test for

Table 1 Characteristics of the included studies

Reference	No.		Follow-up (months)	Age (years)	Sex (m/f)	Classification	Level	Type of study	Language
	LPF	HAP							
Dietrich et al. [14]	52	59	12	80.9	17/94	Three-/four-part	3	Retrospective comparative	German
Bastian and Hertel [15]	44	33	60	59.1	N	Two-/three-/four-part	2	Prospective comparative	English
Solberg et al. [16]	38	48	36	67	26/60	Three-/four-part and dislocation	3	Retrospective comparative	English
Wang et al. [17]	12	10	20	49	10/8	Three-/four-part and dislocation	3	Retrospective comparative	Chinese
Zhang et al. [18]	28	30	28	67.7	24/34	Three-/four-part and dislocation	3	Retrospective comparative	Chinese
Kim et al. [19]	38	26	24	64.9	29/35	Three-/four-part	3	Retrospective comparative	Korean
Wild et al. [20]	42	15	35	59.4	15/42	Three-/four-part	3	Retrospective comparative	English
Spross et al. [22]	22	22	30	75.5	7/37	Neer VI	3	Retrospective comparative	English
Lu and Zhou [21]	26	22	>6	67	13/35	Four-part	3	Retrospective comparative	Chinese

LPF locking plate fixation group, *HAP* hemiarthroplasty group, *N* that means the result has not been mentioned

continuous variables and the Mantel–Haenszel test for dichotomous variables. Heterogeneity of effect size across studies was tested with the use of Q statistics at the $P < 0.05$ level of significance. We also calculated the I^2 statistic and a value >50 % indicated high heterogeneity. If there was significant result heterogeneity across studies, a random-effects model was used (DerSimonian–Laird test).

Assessment of methodological quality and publication bias

All studies that were nonrandomized trails were independently analyzed to check the methodological quality by two authors. It was evaluated in our meta-analysis by using MINORS score [11]. The methodological index for nonrandomized studies (MINORS) score was a valid instrument designed to assess the methodological quality of nonrandomized surgical studies. A MINORS score of more than 12 was considered the standard for inclusion.

Possible publication bias was evaluated by the Begg's rank correlation test and the Egger's regression test [12, 13]. Both analyses were performed using STATA 10.0 software. All statistical tests were two-sided, and a P value <0.05 was considered statistically significant.

Results

The literature search identified 2,682 relevant articles and 9 [14–22] papers met our inclusion criteria and reported results comparing locking plate fixation with hemiarthroplasty. There were a total of 302 fractures in the locking plate group and 265 in the hemiarthroplasty group. Among these trials, four papers were published in English, three were in Chinese, one was in German, and another was in Korean. There was no randomized trial, and we included 1 prospective comparative study and 8 retrospective comparative studies. Table 1 presents the characteristics and quality of the included studies, and Table 2 presents the clinical outcomes of the included studies.

Methodological quality and publication bias

Nine trials that included nonrandomized studies were assessed with MINORS score (Table 3). Two studies scored 13, one study scored 14, five studies scored 16, and one study scored 18. A moderate risk of bias was observed in all trials, and one prospective comparative study achieved higher score than others.

There was little evidence of publication bias with regard to complications in relation to risk of intervention, as indicated by the Begg's test ($P = 0.536$) and Egger's test ($P = 0.208$).

Results of meta-analysis

Nine articles, on a total of 501 patients, provided functional outcomes with the Constant–Murley score postoperatively. As we found significant heterogeneity ($P = 0.0001$) between studies, it was used as a random effect model. A meta-analysis showed that it had significant difference between various studies on the Constant–Murley score of locking plate fixation versus hemiarthroplasty (SMD = 0.68; 95 % CI = 0.31, 1.06; $P = 0.0001$; $I^2 = 74$ %) (Fig. 1). And it was clear that the Constant–Murley score of locking plate fixation is superior to hemiarthroplasty. Furthermore, subgroup analyses according to the language of paper published were made to eliminate all

Table 2 Clinical outcomes of the included studies

Reference	Constant–Murley score		Complication		Revision	
	LPF	HAP	LPF	HAP	LPF	HAP
Dietrich et al. [14][a]	71 ± 19.2	41 ± 18.3	23	19	13	1
Bastian and Hertel [15][b]	77.0 ± 19.2	70.0 ± 12.7	22	9	7	4
Solberg et al. [16]	68.6 ± 9.5	60.6 ± 5.9	19	10	11	8
Wang et al. [17]	69.6 ± 6.7	65.1 ± 5.3	2	0	N	N
Zhang et al. [18]	83.9 ± 6.8	85.5 ± 5.6	3	3	N	N
Kim et al. [19]	75 ± 6.5	70 ± 7.4	2	1	2	0
Wild et al. [20][c]	70.1 ± 21.8	44.8 ± 22.6	3	1	3	1
Spross et al. [22]	65.2 ± 18.5	54.4 ± 13.9	14	17	10	1
Lu and Zhou [21]	73.6 ± 11.0	70.4 ± 12.4	3	3	N	N

LPF locking plate fixation group, *HAP* hemiarthroplasty group, *N* result has not been mentioned

[a] The result of Constant–Murley score was assessed in 37/52 in LPF and in 43/59 in HAP

[b] The result of Constant–Murley score was assessed in 38/44 in LPF and in 28/33 in HAP

[c] The result of Constant–Murley score was assessed in 25/42 in LPF and in 8/15 in HAP

Table 3 Methodological items for nonrandomized studies

Study	Dietrich et al. [14]	Bastian and Hertel [15]	Solberg et al. [16]	Wang et al. [17]	Zhang et al. [18]	Kim et al. [19]	Wild et al. [20]	Spross et al. [22]	Lu and Zhou [21]
A clearly stated aim	2	2	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	1	2	2	2	2	1
Prospective collection of data	0	2	0	0	0	0	0	0	0
Endpoints appropriate to the aim of the study	1	2	2	2	2	2	2	2	1
Unbiased assessment of the study endpoint	0	0	0	0	0	0	0	0	0
Follow-up period appropriate to the aim of the study	2	2	2	2	2	2	2	2	1
Loss to follow-up <5 %	0	0	0	0	0	0	0	0	0
Prospective calculation of the study size	0	0	0	0	0	0	0	0	0
An adequate control group	2	2	2	2	2	2	2	2	2
Contemporary groups	0	2	2	2	2	2	2	2	2
Baseline equivalence of groups	2	2	2	2	2	2	2	2	2
Adequate statistical analyses	2	2	2	1	2	2	2	2	2
Total score	13	18	16	14	16	16	16	16	13

heterogeneity. The subgroup of English has shown better Constant–Murley scores significantly compared with hemiarthroplasty (SMD = 0.77; 95 % CI = 0.44, 1.10; $P = 0.25$; $I^2 = 27$ %) (Fig. 2), and the subgroup of Chinese had no significant difference between the two interventions (SMD = 0.16; 95 % CI = −0.36, 0.68; $P = 013$; $I^2 = 50$ %).

A total of 567 patients have covered method-related complications. The rate of method-related complications was the sum of all reported complications in the articles reviewed. There was no significant heterogeneity ($P = 0.15 > 0.05$) between studies; therefore, it was used as a fixed-effect model. We found it had significant difference between locking plate fixation with hemiarthroplasty (RR = 1.42; 95 % CI = 1.10, 1.83; $P = 0.15$; $I^2 = 33$ %) (Fig. 3).

The rates of surgical revision were analyzed and we found it had significant difference between studies on

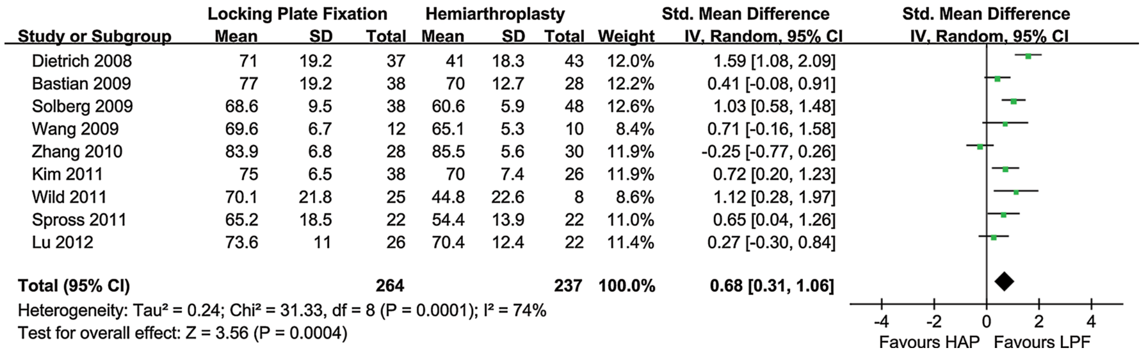

Fig. 1 Meta-analysis of Constant–Murley scores

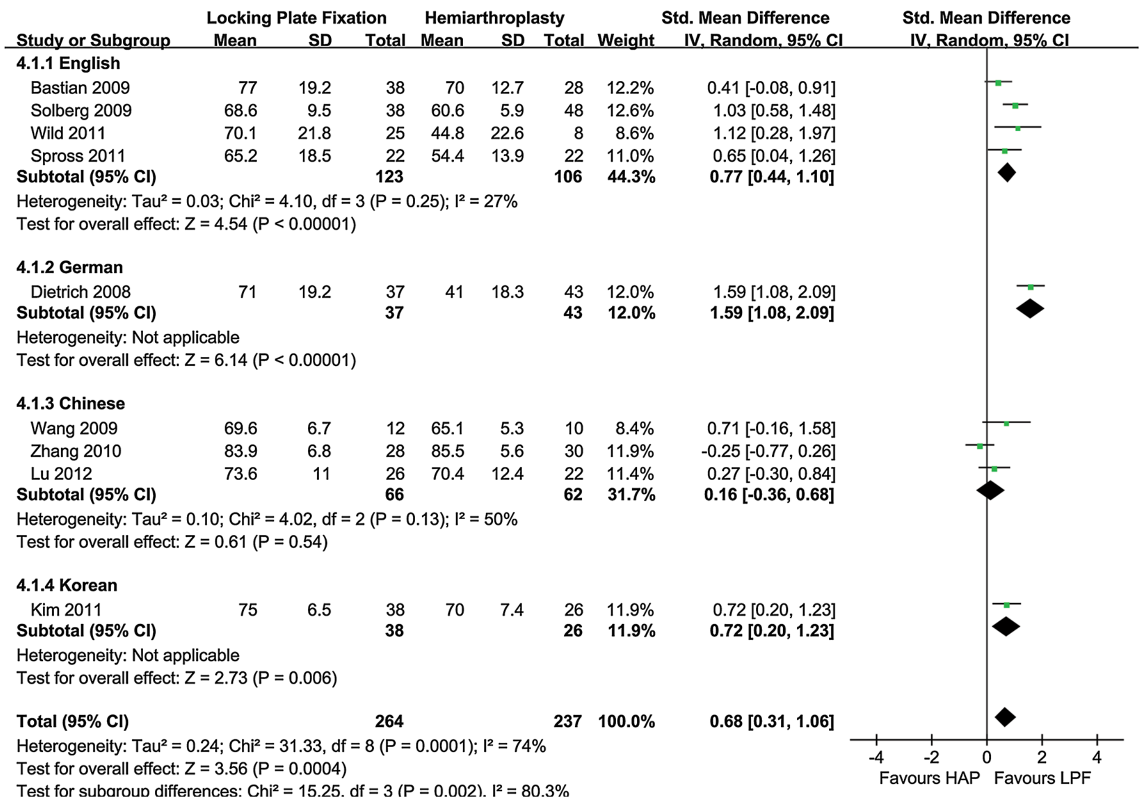

Fig. 2 Meta-analysis of Constant–Murley scores: subgroup analyses

reoperations rate of locking plate fixation versus hemiarthroplasty (RR = 2.92; 95 % CI = 1.71, 4.99; $P = 0.14$; $I^2 = 40$ %) (Fig. 4). The rate of surgical revision with hemiarthroplasty was lower than with locking plate fixation.

Discussion

Management of complex proximal humeral fracture remains challenging and controversial, and there is still little evidence and poor consensus focusing on the optimal technique [23]. In this systematic review of 9 articles comparing the clinical results of locking plate fixation with hemiarthroplasty, we tried to resolve the conflict and make any definitive conclusions about the optimal treatment of complex proximal humeral fracture. Our studies suggest that the locking plate fixation results in better outcome scores than hemiarthroplasty in similar patients with complex proximal humeral fractures, and hemiarthroplasty reduces the rate of surgical revisions and the method-related complications significantly.

Functional outcome is a major clinical evaluation criterion for comparing locking plate fixation with hemiarthroplasty, and the Constant–Murley score is the most frequently used shoulder outcome measures [24]. A controversy against primary hemiarthroplasty was the possibility of limited

Study or Subgroup	Locking Plate Fixation Events	Locking Plate Fixation Total	Hemiarthroplasty Events	Hemiarthroplasty Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Dietrich 2008	23	52	19	59	28.1%	1.37 [0.85, 2.22]
Bastian 2009	22	44	9	33	16.3%	1.83 [0.98, 3.44]
Solberg 2009	19	38	10	48	14.0%	2.40 [1.27, 4.54]
Wang 2009	2	12	0	10	0.9%	4.23 [0.23, 79.10]
Zhang 2010	3	28	3	30	4.6%	1.07 [0.24, 4.88]
Kim 2011	2	38	1	26	1.9%	1.37 [0.13, 14.32]
Wild 2011	3	42	1	15	2.3%	1.07 [0.12, 9.53]
Spross 2011	14	22	17	22	26.9%	0.82 [0.56, 1.21]
Lu 2012	3	26	3	22	5.1%	0.85 [0.19, 3.78]
Total (95% CI)		**302**		**265**	**100.0%**	**1.42 [1.10, 1.83]**
Total events	91		63			

Heterogeneity: Chi² = 12.00, df = 8 (P = 0.15); I² = 33%
Test for overall effect: Z = 2.72 (P = 0.006)

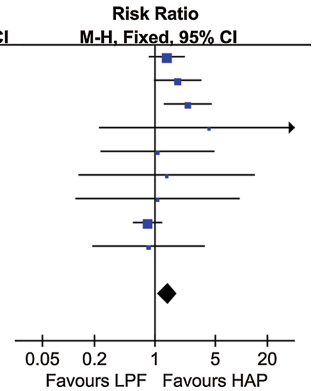

Fig. 3 Meta-analysis of the method-related complications

Study or Subgroup	Locking Plate Fixatioon Events	Locking Plate Fixatioon Total	Hemiarthroplasty Events	Hemiarthroplasty Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Dietrich 2008	13	52	1	59	6.0%	14.75 [2.00, 108.93]
Bastian 2009	7	44	4	33	29.2%	1.31 [0.42, 4.11]
Solberg 2009	11	38	8	48	45.2%	1.74 [0.78, 3.89]
Kim 2011	2	38	0	26	3.8%	3.46 [0.17, 69.28]
Wild 2011	3	42	1	15	9.4%	1.07 [0.12, 9.53]
Spross 2011	10	22	1	22	6.4%	10.00 [1.40, 71.62]
Total (95% CI)		**236**		**203**	**100.0%**	**2.92 [1.71, 4.99]**
Total events	46		15			

Heterogeneity: Chi² = 8.33, df = 5 (P = 0.14); I² = 40%
Test for overall effect: Z = 3.93 (P < 0.0001)

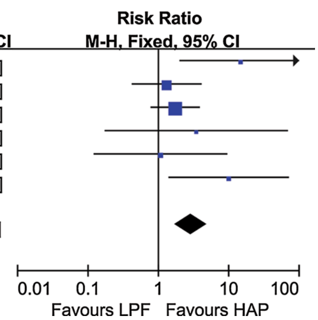

Fig. 4 Meta-analysis of revisions

function, which had influence on the quality of life in this elderly collective. Nijs and Broos [25] performed a meta-analysis (16 studies) on hemiarthroplasty in treatment of proximal humeral fracture, and the average Constant–Murley score for the entire review population (664 patients) was 53.9 with a mobility and strength limitation for patients. A systematic literature review (24 studies) compared the clinical outcome following treatment of three- and four-part fractures of the proximal humeral with conservative treatment, plate fixation and hemiarthroplasty, and found the range of motion was better in the hemiarthroplasty group [26]. However, the studies evaluated in this review were published between 1969 and 1999, and none of locking plate had been used in internal fixation group. Lanting et al. [27] found that hemiarthroplasty was less favorable regarding range of motion compared with plate fixation in their systematic review of treatment modalities for proximal humeral fracture, but the studies typically lack randomized and comparative evaluation. In our systematic review, it was the first time that a meta-analysis has pooled data from comparative studies on locking plate fixation versus hemiarthroplasty for complex proximal humeral fractures. The combined treatment result of the Constant–Murley scores indicated a significant difference favoring plate fixation.

Locking plate fixation was always associated with considerable complication [28]. The total complication rate of ORIF group in our study was 30.1 %, while a complication rate of 23.8 % in the hemiarthroplasty group. A systematic review has reported a high rate of complication (16–64 %) of locking plate treatment [29]. Brunner et al. [30] reported non-plate-related complications (e.g., avascular necrosis) in 35 % and plate-related complications (e.g., screw cutout) in 9 % of the 158 cases treated with PHILOS plating after a 1-year follow-up. Krappinger et al. [31] found that low bone mineral density and increasing age had positive correlation with the failure rate after ORIF of proximal humeral fractures. Avascular necrosis was a major complication in the plate fixation group and was strongly correlated with a great risk of an initial dislocation, which often resulted in painful dysfunction of the shoulder. Interestingly, some series reported favorable function despite osteonecrosis [32, 33]. It could be well tolerated by some cases and was not prerequisite for surgical revision. A review by Thanasas et al. [34] reported an avascular necrosis rate of 15 % after a locking plate therapy which was lower than traditional plating, but this result was based on short-time follow-up and it required further investigation. Screw cutout after loss of reduction was also found quite high, and the excessive rigidity of the plates increased the risk in patients with severe osteoporosis [34, 35].

Many surgeons preferred arthroplasty in the treatment of complex proximal humeral fracture as the association with osteonecrosis and the higher risk of complication for the ORIF surgery. In our meta-analysis, the risk ratio for method-related complications for locking plate fixation versus hemiarthroplasty was 1.10–1.83, which had significant difference between the two groups. Fialka et al. [36] reported the common complications of hemiarthroplasty were nonunion or malunion of the tuberosity, and the malunion rate has been found to be even worse with advanced age [37]. Malunion of the tuberosity was interrelated with fatty infiltration into the rotator cuff and disused the shoulder function finally [38]. Some surgeon's experience supported the findings that the fixation technique seemed to be crucial for anatomical tuberosity healing and apparently represented as the most important factors predicting function outcome [39, 40].

Although complications may cause severe clinical outcomes, it may not necessarily result in surgical revision. Our results found the hemiarthroplasty had a lower revision rate than locking plate fixation significantly (RR = 2.92; 95 % CI = 1.71, 4.99; $P = 0.14$; $I^2 = 40$ %). A previous review reported selection of individual patients for plate fixation or hemiarthroplasty based on their physical situation appeared promising as a lower revision rate was achieved [41]. When a successful reduction and fixation was performed, the failure of implant, nonunion, or osteonecrosis was still inevitable. Therefore, the patients were more likely to suffer a revision and had less satisfactory of daily life.

It was useful to integrate or combine the results of mutual independent clinical trials to enhance statistical power with meta-analysis, and it was an attractive option to answer clinical important questions [42]. However, our study had several limitations that should be taken into account when considering its results. Firstly, only 9 studies with 567 patients were included in this meta-analysis, and 8 of which were retrospective investigations with lower level of evidence. According to MINORS score, a moderate risk of bias was observed. It was too weak to attain sufficient statistical power to conclude the clinical important differences. Secondly, we tried to collect all relevant reports and retrieve additional unpublished data, but it was inevitable to miss some information. In particular, only four kinds of language papers were included in this study, it could not exclude the possibility that the estimates were biased. Moreover, three of the published clinical studies [14, 15, 22] only reported the median, range, and the size of the trials when we need the mean value and the standard deviation in order to pool data. In this meta-analysis, we used a simple method described by Hozo et al. [10] to calculate the SDs and certainly caused data bias. This available method widely improved the inclusiveness of all trials for the meta-analyses studies, and this bias can be lower with large samples. Finally, the existence of publication bias could also affect results of meta-analyses. To evaluate whether publication bias was present, the Begg's test and the Egger's test were performed. And minimal evidence of this bias was found in our meta-analysis.

Another handicap in comparative studies was a clear lack of long-term prospective randomized controlled trials. It was obviously that there was clinical bias as well, since the possible differences in the pre-intervention characteristics of the patients may cause some of the differences compared between the groups. A study by Deeks et al. [43] found that ‘results of randomized and nonrandomized studies sometimes, but not always, differ and that both similarities and differences may often be explicable by other confounding factors’. Thus, we believed the nonrandomized studies are helpful in the lack of randomized, controlled trials and to lead further researchers toward properly informed randomization in future studies [44].

In addition, the heterogeneity between the studies was large ($I^2 = 74$ %) when we pooled mean Constant–Murley scores across the nine studies. Subgroup analyses according to the language of paper published have shown that the difference was homogenous. The heterogeneity was probably due to the variability in the surgical techniques and postoperative care in the different regions. It was also affected by different ethnic populations. Furthermore, the different follow-up length of the different trials made the data conflict and contributed to the between-study variation. Although all but one subgroup analysis has been in favor of locking plate fixation with strong support, the generalizability of this difference was limited and required further discovery.

Conclusion

The present available evidence for surgical option of complex proximal humeral fracture has shown a significant difference in functional outcomes favoring locking plate fixation compared with hemiarthroplasty. Patients who are treated with locking plate fixation may truly expect functional outcomes. In comparison with locking plate fixation, hemiarthroplasty for the treatment of complex proximal humeral fractures significantly reduces the rate of revisions and method-related complications. However, this underpowered analysis requires strongly more randomized clinical trials with unselected patients in the future to certainly decide which intervention is better. We also call for a future study that includes a specific age cut off for locking plate fixation versus hemiarthroplasty.

Conflict of interest There are no disclosures or conflicts of interest for either author.

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