Role of Fibular Allograft in Proximal Humerus Fractures: A Systematic Review

Borja Segarra, MD, Marta Molina, MD, and Luis Aguilella, MD, PhD

Objectives: To analyze the outcomes and complication rates of fibular allografts (FA) as an augmentation technique for proximal humeral fractures and determine their appropriate indications.

Data Sources: English- and Spanish-language articles in PubMed, MEDLINE, Embase, Web of Science (Core Collection), and Google Scholar databases were systematically reviewed with the Preferred Reporting Items for Systematic Reviews guidelines on April 10, 2020.

Study Selection: Studies of patients with proximal humeral fractures treated primarily with FA and locking compression plates and with a minimum follow-up of 6 months were included, and presenting results with standardized clinical scales, radiological values, and operative complications.

Data Extraction: Two authors independently extracted data from the selected studies with a standardized data collection form. Subsequently, each extracted data set was consolidated on the agreement of authors.

Data Synthesis: From the initial screening of 361 articles, 5 case series and 6 retrospective cohort studies were included. A meta-analysis was not performed.

Conclusions: FA improved the clinical and radiological results, thereby reducing complications. The optimal indication for this procedure may be a 4-part fracture with medial column disruption in younger adults.

Key Words: fibular allograft, augmentation, fibular strut, endosteal augmentation, proximal humeral fracture, shoulder fracture

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

(*J Orthop Trauma* 2022;36:e425–e430)

Accepted for publication May 13, 2022.

From the Department of Orthopaedic Surgery, Hospital Universitario de La Ribera, Alzira, Valencia, Spain.

The authors report no conflict of interest.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.jorthotrauma.com).

Reprints: Borja Segarra, MD, Hospital Universitario de La Ribera, Ctra. de Corbera Km.1, Alzira, Valencia 46600, Spain (e-mail: borsemu@gmail.com).

Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.

DOI: 10.1097/BOT.0000000000002404

INTRODUCTION

Locking compression plates (LCP) have been widely used in the primary treatment of proximal humeral fractures (PHF), providing a rigid and stable construct.[1,2] However, because this type of fracture is more prevalent in patients with poor bone quality[3] and bone support, primary repair with LCP may fail because of fracture comminution,[4] leading to complications such as screw cutout, loss of reduction, and high reoperation rates.[5]

To provide greater stability to osteosynthesis, various alternatives have been suggested, such as the addition of a structured bone graft[6] or cement to screws.[7] Gardner et al proposed the use of fibular allografts (FA) as a structural augmentation method.[8] The technique consists of intramedullary placement of a 5- to 6-cm diaphyseal fragment of the fibula, facilitating the reduction and support of the humeral head. The allograft is incorporated into osteosynthesis by LCP, thus strengthening its fixation. The initial clinical outcomes of this technique were satisfactory[9] and were maintained in subsequent studies conducted at the same institution.[10–15] Although there are some systematic reviews on this technique,[16,17] none of them have been conducted with rigorous inclusion criteria. In addition, new comparative studies of fibular augmentation with other techniques[18,19] have been published in recent years. In light of these observations, there is an urgent need for a new systematic review of this topic.

Given the increasing popularity of this treatment in recent years, we have performed a systematic review of the literature on the use of FA as an augmentation technique for osteosynthesis of PHF. The purpose of this study was to review the applicable indications for FA and to determine whether its clinical outcomes and complications justify the use of this technique for PHF.

MATERIAL AND METHODS

Data Sources

A systematic review was performed with the Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines under the advice of an experienced librarian. No ethical approval was required for the study. The review was performed with the Google Chrome browser (Version 81, Google Inc.) in Incognito mode. To minimize selection bias, 2 reviewers independently conducted the search on April 10, 2020. The search databases included PubMed, MEDLINE, Embase, Web of Science (Core Collection), and Google Scholar, the latter in its 200 most relevant results. Articles in English and Spanish

Copyright © 2022 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

were selected with no temporary filter. Whenever an option was presented, the "human" filter was included.

The search algorithm for the study was as follows: [Fracture Fixation, Internal AND (Humeral Fractures OR Shoulder Fractures)] AND [(Fibula AND Bone Transplantation) OR Fibula Strut OR Endosteal Augmentation OR Allograft Fibula)]. MeSH terms were used along with all their synonyms for "Fracture Fixation, Internal," "Humeral Fractures," "Shoulder Fractures," "Fibula," and "Bone Transplantation." Free texts that include "Fibula Strut," "Endosteal Augmentation," and "Allograft Fibula" were also examined because these terms were reported in the existing literature but did not match any MeSH.

Study Selection

All titles and abstracts were screened for duplicates. We then classified and removed biomechanical and cadaveric studies, review articles, clinical cases, research of other augmentation techniques, and articles describing unrelated pathologies. The inclusion criteria for the final selection were as follows: articles containing patients with PHF treated primarily with LCP and FA, minimum follow-up of 6 months, standardized scale for measuring clinical outcomes, and recorded complications. Both reviewing authors subsequently agreed on the studies selected. In the absence of selection consensus by the reviewing authors, the senior author would determine whether a particular study met inclusion criteria. If a duplicate population was observed, only the study with the largest sample size was included.

In each article, we extracted the number of patients, their age and average follow-up, type of fracture treated according to Neer's classification,[20] clinical outcome using scales, radiological outcome, range of motion obtained, and complications. The clinical scales were either generic, such as the Disability of the Arm, Shoulder, and Hand (DASH) scale, 36-Item Short Form (SF-36) scale, and Visual Analog Scale (VAS), or specific to the shoulder, such as the Constant-Murley Score (CMS), American Shoulder and Elbow Surgeons (ASES) scale, and University of California at Los Angeles scale. Radiological results were analyzed by the neck-shaft angle (NSA), which assesses the varus or valgus consolidation of the fracture, and humeral head height (HHH) loss, which measures the loss of reduction by measuring the height of the humeral head relative to the plate. In addition, we extracted data regarding the rehabilitation protocol and technical details of surgery. The Center for Evidence-Based Medicine external scale was used to calculate the level of evidence for each included study.[21] The Coleman methodology score was used to evaluate the quality of the studies.[22] The final score was defined as excellent (85–100 points), good (70–84 points), fair (50–69 points), and poor (<50 points).

Data Extraction

Data were extracted and transferred independently by both researchers on forms specifically designed for this task. On reaching selection consensus by the authors, the data were entered into a Microsoft Word table (version 2011; Microsoft).

RESULTS

Of the 361 studies identified, 11 were included in the final analysis (Fig. 1[23]). Table, **Supplemental Digital Content 1** (see **Table**, http://links.lww.com/JOT/B728) presents the main characteristics of the selected studies. Five studies had a level of evidence of IV (case series studies), and 6 had a level of evidence of IIIB (cohort retrospective studies). Of the latter 6, 4 studies compared the combined use of FA with LCP versus LCP alone. The fifth study from this group compared the use of LCP with inferomedial screws versus FA without inferomedial screws, whereas the last study compared the use of FA in geriatric and nongeriatric cohorts. According to the Coleman methodology score, 5 studies were conducted with a poor methodology, whereas the other 6 studies followed a fair methodology.

The most frequently accepted indication was disruption of the medial column, defined as metaphyseal comminution and loss of medial column support. These criteria were applied to 2-, 3-, or 4-part fractures. Of the 685 patients included in the studies, 455 were treated by FA. Among the FA patients, 224 (49%) had 3-part fractures, 138 (30%) had 4-part fractures, and 92 (20%) had 2-part fractures. The average age of the patients was 69 years with the minimum of 50 years, except in 2 studies[14,24] that were conducted without lower age limit. Hinds et al[15] studied the differences between the geriatric and nongeriatric cohorts. The developers of the technique[14,15] used a transdeltoid approach, whereas others used a deltopectoral approach. Postoperatively, most authors used a sling to progressively facilitate mobilization.

The average follow-up period was 27 months. Clinical results were assessed by validated scales, with CMS being the most common. The details of the average scores are shown in Table 1. Regarding studies comparing LCP versus FA, Chen et al[25] demonstrated higher scores for the FA group in both the CMS (74 vs. 70; $P = 0.02$) and DASH (36 vs. 49; $P = 0.001$) scales. Kim et al[26] showed similar outcomes in both the Constant scale and VAS for 3-part fractures. However, 4-part fractures obtained better outcomes in the FA group in the CMS scale (78 vs. 69; $P = 0.038$) and VAS (1.4 vs. 2.8; $P = 0.045$). Cui et al[18] demonstrated better results in patients treated with FA for the CMS (79 vs. 73; $P = 0.024$) and ASES (79 vs. 73; $P = 0.022$) scales. Similar results were obtained in Zhao et al[19] for the CMS (86 vs. 80; $P = 0.02$), ASES (88 vs. 82; $P = 0.024$), and DASH (18 vs. 28; $P < 0.001$) scales. Besides these studies, Lee et al[27] also revealed better results in FA group on the Constant scale, ASES scale, and VAS, without reaching statistical significance.

Two comparative studies[18,27] highlighted the advantages of range of motion (ROM) when using fibular support. Lee et al[27] demonstrated better mean flexion (149 vs. 125 degrees; $P = 0.042$) and similar external rotation for both groups (59 vs. 53 degrees). In the study of Cui et al,[18] the FA group exhibited a better flexion (144 degrees vs. 128 degrees; $P = 0.01$) and abduction (141 vs. 122 degrees; $P = 0.002$). Hinds et al[15] showed a significant result of 10 degrees more mobility for shoulder flexion in a nongeriatric cohort. No study has collected the ROM associated with each type of fracture according to Neer et al[20]

Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2022 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

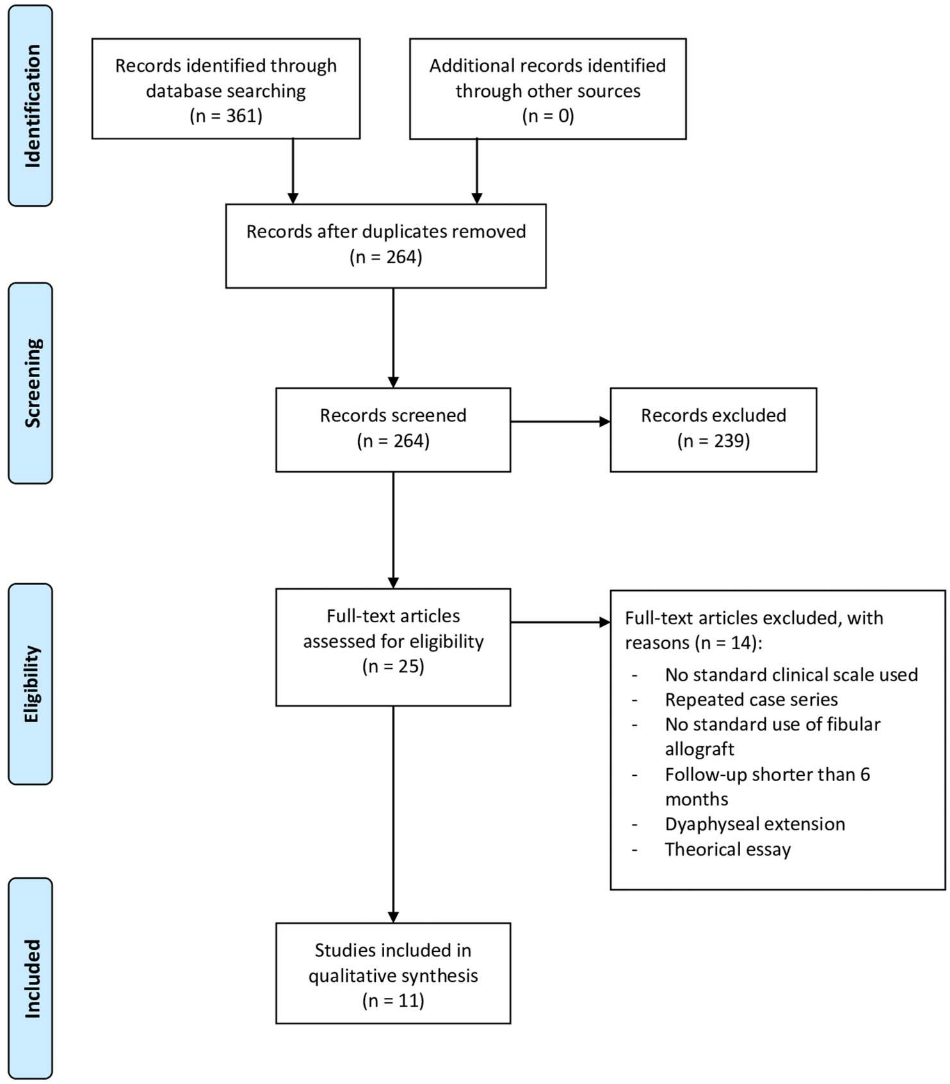

FIGURE 1. Flowchart of literature search and study selection.

All studies used plain x-rays to perform measurements during follow-up. The HHH loss was collected as an absolute value in 7 articles.[14,15,18,19,24,27,28] In 3 of them, the mean HHH loss of the FA group (1.3 mm) was significantly shorter than that of the LCP group (4.3 mm) (Lee et al[27]: $P = 0.021$; Cui et al[18]: $P < 0.001$; Zhao et al[19]: $P < 0.001$). Some authors defined loss of reduction as an HHH loss greater than 3 mm[18,24,27] or 5 mm.[25]

TABLE 1. Average Scores for Patients Treated With Fibular Allograft

CMS	81/100
ASES	82/100
UCLA	29/35
DASH	27/100
VAS	1.7
SF-36	81/100

SF-36, 36-Item Short Form.

The first scenario occurred in 10 (7%) patients treated with FA[18,24,27] and 46 (53%) patients treated only with LCP.[18,27] The second scenario occurred in 2 (4%) patients treated with FA and 9 (21%) patients treated only with LCP ($P = 0.022$).[25]

The NSA was collected as an absolute value in 7 articles.[14,19,24–26,29,30] Three articles were comparative[19,25,26] with an average result of 131 degrees for patients with FA and 127 degrees for the patients treated only with LCP.[19,25,26] These differences were significantly enhanced for 3- and 4-part fractures in the study by Kim et al[26] when using FA. Some studies measured the change in the NSA instead of the absolute value.[14,18,19,27,29,30] These analyses showed a value of 3-degree change for patients treated with FA, which was significantly lower than the 10-degree change for those treated only with LCP.[18,19,27] Two authors[18,27] interpreted a statistically significant change greater than 5 degrees as varus collapse of the fracture, which occurred in 8 (11%) patients with FA and 51 (59%) patients treated only with LCP.

All the studies reported complications related to the technique. According to the studies comparing FA versus

Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2022 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

LCP only,[18,19,25–27] a total of 82 complications were described. Patients treated with LCP within the 5 comparative studies[18,19,25–27] suffered 64 complications versus 18 for those treated with the addition of FA. Significantly higher complications in the LCP group were found in 3 studies.[19,25,26] Hinds et al[15] reported no complications in the nongeriatric cohort compared with the 2 complications described in the geriatric cohort.

The most common complication in this systematic review was screw cutout. Nine cases were present in patients with FA (2%), whereas 18 cases (12%) among patients treated only with LCP. In all the comparative studies,[18,19,25–27] screw cutout was lower with the use of FA and reached statistical significance in Chen et al[25] (P = 0.049). Twenty-one cases of avascular necrosis of the humeral head (AVN) were described. Thirteen cases of AVN (3%) were present in the FA group, whereas 8 cases (3%) were detected in the LCP group. Patients who developed AVN either refused treatment[15,24] or followed conservative treatment.[27] The remaining studies did not provide further details on the follow-up of these patients.[14,18,19,25]

DISCUSSION

Optimal selection of surgical treatment for PHF remains a topic of debate. Widely used techniques such as LCP[31] are not exempt from a high rate of complications, which include screw cutout and AVN, accounting for approximately 52% of reoperations.[5,32] This complication rate justifies the current increasing trend for indication of reverse arthroplasty in older patients[33] and conservative treatment.[34,35] Augmentation techniques such as FA addition have been shown to provide greater rigidity and load resistance in biomechanical studies.[36] Its purpose is to provide medial support to prevent frequent complications.

We used a database selection method that has proven to be the most comprehensive[37] because it allows for the inclusion of both accepted and published articles.[38] Nevertheless, publication bias may have affected our search. The extracted articles, which did not include any prospective studies or clinical trials, were categorized according to their level of evidence and evaluated for their quality. The main limitation of this systematic review is the low level of evidence in the published studies. Our study may have been affected by the region setting in Google Chrome, which can alter the order of the results obtained, even in the Incognito mode. Similarly, the studies did not specify whether the CMS had been adjusted for age. Some studies did not consider the presence of some complications, which could be inferred by poor radiological results. Although studies with repeated patient series were excluded, we included the studies by Little et al[14] and Hinds et al[15] because their cohorts overlap just partially.

Five articles with large cohorts of at least 40 patients compared FA augmentation with the classical technique of LCP. The use of FA obtained better outcomes in the clinical scales in all comparative studies, with statistical significance observed in 4 of them.[18,19,25,26] Kim et al[26] also compared the results by fracture type and concluded that 4-part fractures with absence of medial support obtained greater clinical benefit with FA addition. This finding can be explained by the greater instability of this type of fracture, with the differences being less pronounced in 2- and 3-part fractures. Similarly, patients treated with FA improve their range of motion by an average of 21 degrees for flexion[18,27] and 19 degrees for abduction.[18] The nongeriatric cohort study by Hinds et al[15] also obtained better forward flexion, which deserves additional clinical attention and further assessment.

Regarding the radiological results, the loss of reduction measured by the HHH was mitigated with the use of FA, which can be explained by the support provided in the axial plane to prevent the fracture from collapsing. According to the absolute value of NSA, most patients obtained an optimal radiological result with anatomical reduction,[39,40] which was improved in both 3- and 4-part fractures treated with FA.[26] Similarly, according to the criteria used by some authors, FA prevented varus collapse of the fracture, decreasing changes in the NSA throughout the follow-up.[18,19,27]

In comparative studies, fewer complications were observed with the addition of FA.[19,25,26] From example, screw cutout, one of the main complications of the LCP technique, decreases with the use of FA. This finding can be explained by the greater stability and stiffness of the construction provided by FA addition. Unlike screw cutout, similar rates of AVN were observed in the FA and LCP groups. The lack of reduction in AVN rate may be related to the treatment indication from the selected studies (ie, disruption of the medial column and a critical area for vascularization of the humeral head[41]). Hinds et al[15] did not report any complications in a nongeriatric cohort, indicating that the technique is safer in this age group. This finding may be explained by the need for less bone augmentation, given the better bone quality.

The benefit of using an FA is contrasted by the difficulty of performing reverse total shoulder arthroplasty (rTSA) because of failure of the technique. This technical difficulty and the number of cases converted to arthroplasty have not been mentioned in any of the articles. Nevertheless, this is one of the reasons why experienced shoulder surgeons might not use this technique. By the time AVN is established and revision surgery is indicated, the allograft is already integrated in 80% of the cases.[42] Plain x-rays may give a misleading appearance of integration because the allograft still exhibits well-defined contours. In such cases, magnetic resonance imaging (MRI) provides the most valuable information.[43]

Articles published to date suggest conversion into rTSA should be addressed as a revision arthroplasty through a deltopectoral approach.[42] The removal of the strut is crucial to its performance. The strut can be removed by separating the allograft from the surrounding bone with flexible osteotomes. A tap can then be inserted into the medullary canal to complete the extraction.[44] When this is not possible, a reamer may be used to gradually allow a small stem to fit. During the reaming process, the strut might break into smaller extractable pieces. Because the allograft is usually integrated, extraction is challenging. The loss of metaphyseal bone also poses a risk of humeral fracture. Whenever possible, press-fit humeral

Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2022 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

stems are preferred to avoid leakage of cement through the holes resulting from implant removal.[42]

Current evidence shows that the clinical and radiological outcomes of patients treated with FA are better than those treated with LCP alone. A reduction in the rate of complications, particularly in screw cutout, is also observed with the use of FA. This systematic review suggests that 4-part humeral fractures with disruption of the medial column or metaphyseal comminution may receive the optimal clinical benefit with the introduction of this technique to avoid replacement, maintain reduction, and preserve the bone. Given the lower number of complications, the application of FA in younger patients should be considered. Other considerations include the economic cost, additional surgical time, and possible conversion to rTSA.

ACKNOWLEDGMENTS

The authors thank Editage [http://www.editage.com] for editing and reviewing this manuscript for English language.

REFERENCES

1. Südkamp N, Bayer J, Hepp P, et al. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. Results of a prospective, multicenter, observational study. *J Bone Jt Surg Am*. 2009;91:1320–1328.
2. Hirschmann MT, Fallegger B, Amsler F, et al. Clinical longer-term results after internal fixation of proximal humerus fractures with a locking compression plate (PHILOS). *J Orthop Trauma*. 2011;25:286–293.
3. Wang MQ, Youssef T, Smerdely P. Incidence and outcomes of humeral fractures in the older person. *Osteoporos Int.* 2018;29:1601–1608.
4. Laux CJ, Grubhofer F, Werner CML, et al. Current concepts in locking plate fixation of proximal humerus fractures. *J Orthop Surg Res.* 2017; 12:137.
5. Sproul RC, Iyengar JJ, Devcic Z, et al. A systematic review of locking plate fixation of proximal humerus fractures. *Injury*. 2011;42:408–413.
6. Robinson CM, Wylie JR, Ray AG, et al. Proximal humeral fractures with a severe varus deformity treated by fixation with a locking plate. *J Bone Jt Surg Br*. 2010;92:672–678.
7. Katthagen JC, Lutz O, Voigt C, et al. Cement augmentation of humeral head screws reduces early implant-related complications after locked plating of proximal humeral fractures. *Obere Extrem*. 2018;13: 123–129.
8. Gardner MJ, Lorich DG, Werner CMC, et al. Second-generation concepts for locked plating of proximal humerus fractures. *Am J Orthop (Belle Mead NJ)*. 2007;36:460–465.
9. Gardner MJ, Boraiah S, Helfet DL, et al. Indirect medial reduction and strut support of proximal humerus fractures using an endosteal implant. *J Orthop Trauma*. 2008;22:195–200.
10. Neviaser AS, Hettrich CM, Beamer BS, et al. Endosteal strut augment reduces complications associated with proximal humeral locking plates. *Clin Orthop Relat Res.* 2011;469:3300–3306.
11. Neviaser AS, Hettrich CM, Dines JS, et al. , . Rate of avascular necrosis following proximal humerus fractures treated with a lateral locking plate and endosteal implant. *Arch Orthop Trauma Surg.* 2011;131:1617–1622.
12. Hettrich CM, Neviaser A, Beamer BS, et al. Locked plating of the proximal humerus using an endosteal implant. *J Orthop Trauma*. 2012; 26:212–215.
13. Berkes MB, Little MTM, Lazaro LE, et al. Intramedullary allograft fibula as a reduction and fixation tool for treatment of complex proximal humerus fractures with diaphyseal extension. *J Orthop Trauma*. 2014; 28:e56-64.
14. Little MTM, Berkes MB, Schottel PC, et al. The impact of preoperative coronal plane deformity on proximal humerus fixation with endosteal augmentation. *J Orthop Trauma*. 2014;28:338–347.
15. Hinds RM, Garner MR, Tran WH, et al. Geriatric proximal humeral fracture patients show similar clinical outcomes to non-geriatric patients after osteosynthesis with endosteal fibular strut allograft augmentation. *J Shoulder Elbow Surg.* 2015;24:889–896.
16. Saltzman BM, Erickson BJ, Harris JD, et al. Fibular strut graft augmentation for open reduction and internal fixation of proximal humerus fractures: a systematic review and the authors' preferred surgical technique. *Orthop J Sports Med.* 2016;4:2325967116656829.
17. Biermann N, Prall WC, Böcker W, et al. Augmentation of plate osteosynthesis for proximal humeral fractures: a systematic review of current biomechanical and clinical studies. *Arch Orthop Trauma Surg.* 2019; 139:1075–1099.
18. Cui X, Chen H, Ma B, et al. Fibular strut allograft influences reduction and outcomes after locking plate fixation of comminuted proximal humeral fractures in elderly patients: a retrospective study. *BMC Musculoskelet Disord.* 2019;20:511.
19. Zhao L, Qi YM, Yang L, et al. Comparison of the effects of proximal humeral internal locking system (PHILOS) alone and PHILOS combined with fibular allograft in the treatment of neer three- or four-part proximal humerus fractures in the elderly. *Orthop Surg.* 2019;11:1003–1012.
20. Neer CS II. Displaced proximal humeral fractures. I. Classification and evaluation. *J Bone Jt Surg Am*. 1970;52:1077–1089.
21. Centre for Evidence-based Medicine (CEBM). *Levels of Evidence*; 2009. Available at: https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009. Accessed December 7, 2020.
22. Coleman BD, Khan KM, Maffulli N, et al. Studies of surgical outcome after patellar tendinopathy: clinical significance of methodological deficiencies and guidelines for future studies. Victorian Institute of Sport Tendon Study Group. *Scand J Med Sci Sports*. 2000;10:2–11.
23. Moher D, Liberati A, Tetzlaff J, Altman D G, et al; Group PRISMA. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 2009;6:e1000097.
24. Panchal K, Jeong JJ, Park SE, et al. Clinical and radiological outcomes of unstable proximal humeral fractures treated with a locking plate and fibular strut allograft. *Int Orthop.* 2016;40:569–577.
25. Chen H, Yin P, Wang S, et al. The augment of the stability in locking compression plate with intramedullary fibular allograft for proximal humerus fractures in elderly people. *Biomed Res Int.* 2018;2018: 3130625.
26. Kim DS, Lee DH, Chun YM, et al. Which additional augmented fixation procedure decreases surgical failure after proximal humeral fracture with medial comminution: fibular allograft or inferomedial screws? *J Shoulder Elbow Surg.* 2018;27:1852–1858.
27. Lee SH, Han SS, Yoo BM, et al. Outcomes of locking plate fixation with fibular allograft augmentation for proximal humeral fractures in osteoporotic patients: comparison with locking plate fixation alone. *Bone Jt J.* 2019;101-B:260–265.
28. Matassi F, Angeloni R, Carulli C, et al. Locking plate and fibular allograft augmentation in unstable fractures of proximal humerus. *Injury.* 2012;43:1939–1942.
29. Kim YK, Kang SW, Kim JW. Preventing varus deformity in senile patients with proximal humerus fractures and poor medial support. *Clin Shoulder Elb*. 2016;19:216–222.
30. Noh YM, Kim DR, Kim CH, et al. Minimally invasive percutaneous plate osteosynthesis via a deltoidsplitting approach with strut allograft for the treatment of displaced 3- or 4-part proximal humeral fractures. *Clin Shoulder Elb*. 2018;21:220–226.
31. Brunner F, Sommer C, Bahrs C, et al. Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. *J Orthop Trauma*. 2009;23: 163–172.
32. Thanasas C, Kontakis G, Angoules A, et al. Treatment of proximal humerus fractures with locking plates: a systematic review. *J Shoulder Elbow Surg.* 2009;18:837–844.
33. Jauregui JJ, Nadarajah V, Shield WP III, et al. Reverse shoulder arthroplasty: perioperative considerations and complications. *JBJS Rev.* 2018; 6:e3.
34. Rangan A, Handoll H, Brealey S, et al. Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. *JAMA*. 2015;313:1037–1047.

Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2022 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.

35. Soler-Peiro M, García-Martínez L, Aguilella L, et al. Conservative treatment of 3-part and 4-part proximal humeral fractures: a systematic review. *J Orthop Surg Res.* 2020;15:347.
36. Bae JH, Oh JK, Chon CS, et al. The biomechanical performance of locking plate fixation with intramedullary fibular strut graft augmentation in the treatment of unstable fractures of the proximal humerus. *J Bone Jt Surg Br*. 2011;93:937–941.
37. Bramer WM, Rethlefsen ML, Kleijnen J, et al. Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. *Syst Rev.* 2017;6:245.
38. Duffy S, de Kock S, Misso K, et al. Supplementary searches of PubMed to improve currency of MEDLINE and MEDLINE In-Process searches via Ovid. *J Med Libr Assoc.* 2016;104:309–312.
39. Paavolainen P, Björkenheim JM, Slätis P, et al. Operative treatment of severe proximal humeral fractures. *Acta Orthop Scand.* 1983;54:374–379.
40. Schnetzke M, Bockmeyer J, Porschke F, et al. Quality of reduction influences outcome after locked-plate fixation of proximal humeral type-C fractures. *J Bone Jt Surg Am*. 2016;98:1777–1785.
41. Hertel R, Hempfing A, Stiehler M, et al. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg.* 2004;13:427–433.
42. Manzi JE, Ruzbarsky JJ, Rauck RC, et al. Failed proximal humerus osteosynthesis using intramedullary fibular strut allograft conversion to reverse shoulder arthroplasty. *Tech Hand Up Extrem Surg.* 2020;24:7–12.
43. Lazaro LE, Birnbaum JF, Farshad-Amacker NA, et al. Endosteal biologic augmentation for surgical fixation of displaced femoral neck fractures. *J Orthop Trauma*. 2016;30:81–88.
44. Amini MH. Managing the endosteal fibula during arthroplasty for proximal humeral fracture sequelae. *J Orthop Trauma*. 2019;33(suppl 1):S1–S2.

Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2022 Wolters Kluwer Health, Inc. Unauthorized reproduction of this article is prohibited.