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Improved Outcomes for Proximal Humerus Fracture Open Reduction Internal Fixation Augmented with a Fibular Allograft in Elderly Patients: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: To date, no meta-analysis has been performed on the efficacy of fibular allograft augmentation for the management of proximal humerus fractures. The purpose of this study was to evaluate the radiographic and clinical outcomes of proximal humerus fractures treated with a locking compression plate (LCP) with or without fibular allograft augmentation. **Methods:** The Cochrane Database of Systematic Reviews, the Cochrane Register of Controlled Trials, PubMed, MEDLINE, Web of Science, and SCOPUS were queried in June of 2021 for literature comparing the radiographic and clinical outcomes for patients with proximal humerus fractures that were treated with a LCP only or a LCP augmented with a fibular allograft. Data describing study design, level of evidence, demographic information, final follow-up, radiographic changes in humeral head height (HHH), radiographic changes in neck shaft angle (NSA), final American Shoulder and Elbow Surgeons (ASES) scores, final Constant-Murley scores, and major complications were collected. Risk of bias was assessed using the Methodological Index for Non-Randomized Studies (MINORS) criteria. A meta-analysis was performed using pooled weighted mean differences (WMD) to compare changes in HHH, NSA, final ASES and final Constant-Murley scores between the two groups; a pooled odds ratio was used to compare complications between the groups. **Results:** Ten studies with a total of 802 patients were identified. There was a significant difference that favored patients augmented with a fibular allograft for change in HHH (WMD = -2.40; 95% CI, -2.49 to -2.31; $p < 0.00001$), change in NSA (WMD = -5.71; 95% CI, -6.69 to -4.72; $p < 0.00001$), final ASES scores (WMD = 5.08; 95% CI, 3.69 to 6.48; $p < 0.00001$), and odds ratio for developing a major complication (OR = 0.37; 95% CI, 0.23 to 0.59; $p < 0.0001$). There was no significant difference in final Constant-Murley scores (WMD = 3.36; 95% CI, -0.21 to 6.93; $p = 0.06$) or revision surgery rate (p =

0.182) between the two groups. **Conclusion:** The pooled WMD and prediction interval suggest that 95% of patients with proximal humerus fractures treated with a LCP augmented with a fibular allograft will have improved radiographic outcomes, improved ASES clinical outcome scores, and decreased odds of a major complication when compared to patients treated with a LCP alone. Limitations of this study include a relatively short average final follow-up time (< 2 years) and a potential lack of standardization for radiographic outcomes among included studies.

Level of Evidence: Level III; Systematic Review/Meta-Analysis

Keywords: Fibular Allograft, Proximal Humerus Fracture, Locking Compression Plate, Strut Allograft, Endosteal Graft, Meta-Analysis

Proximal humerus fractures are the third most common fracture in the elderly patient population.[17] The relatively high incidence of this fracture can be attributed to decreasing bone quality and the resulting osteoporosis or osteopenia associated with increasing age.[30] Consequently, these injuries usually occur as a result of minimal trauma such as a ground-level fall.[6, 32] The economic impact of these injuries on the health care system is significant, estimating 185,000 visits to the emergency department in the United States per year.[15] Additionally, those who suffer these fractures may suffer from significant morbidity, with a 10% mortality rate at one-year post-injury.[24]

A variety of treatment options are available for proximal humerus fractures and are predominately guided by the fracture pattern and the patients' pre-injury level of activity.[32] The most common options include nonoperative management with a sling, open reduction and internal fixation (ORIF), or shoulder arthroplasty.[13] However, the best treatment option for displaced fractures remains controversial.[11] Unfortunately, regardless of the treatment option selected, many studies report poor clinical outcomes for these injuries, including residual shoulder pain, limited shoulder range of motion, and decreased quality of life.[32]

With the increasing use of proximal humeral locking compression plates (LCP), studies have demonstrated relative ineffectiveness in preventing varus collapse of the fracture with this technique.[28] When managing these injuries, medial column restoration is an important consideration to minimize varus malalignment.[16] One strategy to address medial column stability is the use of a fibular allograft augment, first introduced by Gardner *et al* in 2008.[9] Subsequent studies have demonstrated excellent postoperative radiographic and clinical outcomes following the use of a LCP with fibular allograft augmentation.[12, 21, 26]

In an effort to analyze the available data, two recent systematic reviews have examined the use of fibular allograft augmentation in the treatment of proximal humeral fractures.[1, 30] In 2016, Saltzman *et al* conducted a systematic review of four studies that reported therapeutic clinical outcome scores following fibular strut allograft adjunct to a LCP.[30] Biermann *et al* performed a similar study in 2019 that included 15 biomechanical and 30 clinical studies that investigated fibular allograft augmentation for proximal humerus fractures.[1] With the data available at that time, neither of these systematic reviews were able to conduct a meta-analysis. Most of the studies included in those reviews were either biomechanical or level of evidence IV and V. Furthermore, since the publication by Biermann *et al*, nine additional studies have been published that directly compare a LCP augmented with a fibular allograft to a LCP alone.

The purpose of this study was to systematically review all available studies that directly compared a LCP augmented with a fibular allograft to a LCP alone. By incorporating only comparative clinical studies, a meta-analysis was conducted to compare radiographic outcomes, clinical outcomes, and complication rates between the two groups. The authors hypothesized that intramedullary fibular allograft augmentation of a LCP will lead to superior radiographic outcomes, superior clinical outcomes, and a reduced rate of major complications relative to a LCP alone for the management of proximal humerus fractures in the elderly population.

METHODS

Article Identification and Selection

This meta-analysis was conducted in accordance with the 2009 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement (**Figure 1**).[23] The Cochrane Database of Systematic Reviews, the Cochrane Register of Controlled Trials, PubMed, MEDLINE, Web of Science, and SCOPUS were queried on June 14th 2021 for literature comparing the radiographic and clinical outcomes for patients with proximal humerus fractures that were treated with a locking compression plate (LCP) only or a LCP augmented with a fibular allograft. The following search terms were used: "fibular allograft AND proximal humerus" OR "strut allograft AND proximal humerus" OR "fibular graft AND proximal humerus" OR "endosteal strut AND proximal humerus" OR "endosteal graft AND proximal humerus." Inclusion criteria were as follows: directly compared a LCP only against a LCP augmented only with a fibular allograft, clinical and/or radiographic outcomes, patients treated for a proximal humerus fracture, clinical study, and English language literature. Exclusion criteria included non-fibular grafts, cadaveric studies, in-vivo animal studies, in-vitro studies, editorial articles, surveys, letters to the editor, special topics, expert reviews, and non-comparative studies (level of evidence IV or V). Three investigators (S.P.D., B.K., P.R.) independently screened articles by title, abstract, and full text, when appropriate. For any disagreements, these three authors discussed the study and a consensus decision was made.

Outcome Measures and Data Extraction

The primary outcome measures evaluated in this meta-analysis were (1) change in humeral head height (HHH) in mm, (2) change in neck shaft angle (NSA) in degrees, (3) patient reported American Shoulder and Elbow Surgeons (ASES) scores, (4) patient reported Constant-Murley scores, and (5) major complications, which were defined as malunions, avascular necrosis, screw perforation, screw cutout, or major adverse events subjectively defined and reported by respective authors. Humeral head height is defined radiographically as the distance between the upper end of the plate to the upper end of the humeral head, while the measured NSA is defined as the angle between the humeral head and the shaft in an anteroposterior view.[34] A customized data extraction spreadsheet was created to record all relevant data from the included studies including publication information, study design, level of evidence, demographic information (age, gender), time until final follow-up, and the aforementioned outcome scores. Prior to inclusion, all data was qualitatively analyzed based on their methods, results, discussion, and conclusion.

Risk of Bias Assessment

Two investigators (L.M.F. and B.K.) independently assessed risk of bias using the MINORS criteria.[31] Any disagreements between the two reviewers were resolved by consensus. To summarize, the numerical scale is composed of 12 questions for non-randomized studies. Items are scored as 0 for not reported, 1 for reported but inadequate, and 2 for reported and adequate. For a comparative study, an ideal score would be 24 points.

Statistical Analysis

Regardless of the variance among the data extracted from the included studies, a random effects model was chosen based on the design of the studies included and the methodology used for sampling the data.[2] This model was used to compare five outcomes: change in HHH (mm) between initial postoperative radiographs and radiographs at final follow-up, change in NSA (degrees) between initial postoperative radiographs and radiographs at final follow-up, patient reported ASES at final follow-up, patient reported Constant-Murley at final follow-up, and complications as defined previously. A weighted mean difference (WMD) and 95% confidence interval (CI) were used to assess the average and range of true means for each respective outcome measure based on the studies included. An alpha < 0.001 was assigned as significant. The percentage of variance in the true effect value and the percentage of variance from sampling error was determined using I-squared tests (I^2). The true effect size in 95% of the population (95% prediction interval or PI) was calculated using the variance of true effects (T^2) and thus the standard deviation of true effects (T).

Among each set of outcomes, the age, follow-up, gender distribution, and Neer classification fracture distribution were compared between the LCP only group and the LCP augmented with a fibular allograft group. For continuous numerical variables, a Shapiro-Wilk test was performed to determine distribution of the variables. For variables with a normal distribution, an unpaired two-tailed Student's *t* test was used to compare differences between the groups. For variables with an abnormal distribution, a Mann-Whitney U test was used for the same purpose. Gender and fracture distribution were compared using a $\chi 2$ test with 1 or 2 degrees of freedom, respectively. Alpha was set at 0.05 for these outcomes. Statistical analysis was performed using Review Manger 5 (The Nordic Cochrane Center, Copenhagen, Denmark) and IBM SPSS Statistics for Macintosh (Version 28.0; IBM, Armonk, NY, USA).

RESULTS

Study Characteristics

The database query yielded a total of 241 studies after duplicates were removed (**Figure 1**). Ten studies satisfied all prespecified inclusion criteria. All studies were cross-referenced, and there was no potential for duplicate data on the same patients presented across different studies. Study characteristics of all studies that met the inclusion criteria, even those with data that was not used for meta-analysis, are presented in **Table 1**. All ten studies were retrospective cohort studies (level of evidence III). When combining the patients from all studies included in this systematic review, there was a total of 436 proximal humerus fracture patients that were treated with a LCP only and a total of 366 patients that were treated with a LCP augmented with a fibular allograft. The mean age of patients treated with a LCP only was 65.76 ±6.74 years (range, 54.30 to 73.30 years), while the mean age of patients treated with a LCP augmented with a fibular allograft was 68.24 ±4.88 years (range, 59.90 to 75.60 years). The mean follow-up for patients treated with a LCP only was 17.70 ±8.45 months (range, 6.50 to 35.70 months), and the mean follow-up for patients in the LCP augmented with a fibular allograft group was 18.28 ±8.14 months (range, 7.83 to 33.50 months).

The risk of bias assessment was performed using the MINORS criteria and is presented in **Table 2**. Of the ten included retrospective cohort studies, seven had a total MINORS score of 16. The studies by Wang et al and Cha et al had a total MINORS score of 18.[3, 34] The study by Lee et al had a total MINORS score of 19, which was the highest among the included studies in this meta-analysis.[19]

Outcome Measures

Humeral Head Height

Five studies assessed the difference in change in HHH from initial postoperative radiographs to radiographs on final follow-up between the LCP group (162 patients) and the LCP augmented with a fibular allograft group (154 patients) (**Figure 2**). The mean age for the LCP only group and the LCP group that was augmented with a fibular allograft was 69.33 ±3.72 years (range, 64.10 to 73.30 years) and 70.59 ±4.40 years (range, 64.10-75.60 years), respectively. This difference was not significant ($p = 0.638$). The mean follow-up for the LCP only group was 17.95 ±8.14 months (range, 12.00 to 32.23 months) compared to 18.29 ±7.90 months (range, 12.00 to 31.56 months) for the group augmented with a fibular allograft. The difference was not significant ($p = 1.000$). There were no differences in gender ($p = 0.592$) or in the distribution of Neer type 2/3/4 fracture patterns ($p = 0.665$) between the two groups.

There was a smaller change in HHH in the LCP groups augmented with fibular allografts compared to groups that were treated with a plate alone: this difference was statistically significant (WMD = -2.40; 95% CI, -2.49 to -2.31; $p < 0.00001$). Thus, the null hypothesis can be rejected, and it can be concluded that, on average, in a universe of populations comparable to the studies sampled in this analysis, there was a reduced change in HHH for patients treated with a LCP augmented with a fibular allograft compared to a LCP alone. For this set of data, the variance of true effects (T^2) was 0.00, and the I^2 is 0%, indicating that variance is estimated to be 0.

To put this measurement into clinical context, several of the included studies defined a loss of anatomic fixation as a change in HHH of over 3 mm.[3, 7, 19, 26] The weighted mean for change in HHH in the groups augmented with the fibular allograft was 1.5 mm compared to 4.1 mm in the groups treated with a LCP alone. This suggests that, on average, the groups augmented with a fibular allograft did not lose anatomic fixation at final follow-up. This is further supported by the finding that all five included studies reported a change in HHH less than 3 mm for groups augmented with a fibular allograft. Conversely, the groups treated with a LCP alone had an average change in HHH that exceeded 3 mm, suggesting that this treatment option was more likely to result in a loss in anatomic fixation. Furthermore, in each individual study, the LCP alone group consistently demonstrated an average change in HHH that was greater than 3 mm.

Neck Shaft Angle

Seven studies assessed the difference in change in NSA from initial postoperative radiographs to radiographs on final follow-up between the LCP group (280 patients) and the LCP augmented with a fibular allograft (254 patients) (**Figure 3**). The mean age for the LCP only group was 67.64 ±6.72 years (range, 54.30 to 73.30 years) and was 69.34 ±4.87 years (range, 62.30-75.60 years) for the LCP group that was augmented with a fibular allograft. This difference was not significant (p = 0.798). The mean follow-up for the LCP only group was 16.46 ±7.97 months (range, 6.50 to 32.23 months) compared to 16.90 ±7.59 months (range, 7.83 to 31.56 months) for the group augmented with a fibular allograft. The difference was not significant (p = 0.918). There were no differences in gender (p = 0.339) or in the distribution of Neer type 2/3/4 fracture patterns (p = 0.609) between the two groups.

There was a smaller change in NSA in the LCP groups augmented with fibular allografts (weighted mean: 5 degrees) compared to groups that were treated with a LCP alone (weighted mean: 10 degrees). This difference was statistically significant (WMD = -5.71; 95% CI, -6.69 to -4.72; $p < 0.00001$). Thus, the null hypothesis can be rejected, and it can be concluded that, on average, in a universe of populations comparable to the studies sampled in this analysis, there was a reduced change in neck shaft angle for patients treated with a LCP augmented with a fibular allograft compared to a LCP alone.

For this set of data, the I^2 is 80%, indicating that only 20% of the variance between the true mean difference and the observed mean difference was due to standard error. More importantly, the variance of true effects (T^2) was 0.98 with a standard deviation of true effects (T) of 0.990. This suggests that in 95% of patients from a population comparable to those involved in this data set, the true mean difference for the change in neck shaft angle would be smaller in the LCP groups augmented with fibular allografts relative to the LCP only groups (95% PI, -7.69 to -3.73).

American Shoulder and Elbow Surgeons (ASES) Score

Four studies assessed the difference in ASES scores on final follow-up between the LCP group (154 patients) and the LCP augmented with a fibular allograft (132 patients) (**Figure 4**). The mean age for the LCP only group and the LCP group that was augmented with a fibular allograft was 71.82 ±1.92 years (range, 69.00 to 73.30 years) and 72.44 ±2.82 years (range, 68.80 to 75.60 years), respectively. This difference was not significant (p = 1.00). The mean follow-up for the LCP only group was 19.36 ±9.06 months (range, 12.00 to 32.23 months) compared to 19.04 ±8.87 months (range, 12.00 to 31.56 months) for the group augmented with a fibular allograft. The difference was not significant (p = 0.962). There were no differences in gender (p = 0.671) or in the distribution of Neer type 2/3/4 fracture patterns (p = 0.981) between the two groups.

LCP groups augmented with a fibular allograft (weighted mean: 84.3) reported mean ASES scores that were higher than those reported by the LCP only groups (weighted mean: 78.7). This difference was statistically significant (WMD = 5.08; 95% CI, 3.69 to 6.48; $p <$ 0.00001). Based on these results, it can be concluded that in a universe of populations comparable to the studies included in this analysis, there were higher average ASES value reported by patients treated with a LCP augmented with a fibular allograft compared to LCP only groups. For this set of data, the variance of true effects (T^2) was 0.00, and the I^2 was 0%, indicating that variance is estimated to be 0.

Constant-Murley Score

Five studies assessed the difference in Constant-Murley scores on final follow-up between the LCP group (169 patients) and the LCP augmented with a fibular allograft (172 patients) (**Figure 5**). The mean age for the LCP only group and the LCP group that was augmented with a fibular allograft was 69.39 ±3.69 years (range, 64.10 to 73.30 years) and 70.29 ±4.39 years (range, 69.10-75.60 years), respectively. This difference was not significant (p = 0.735). The mean follow-up for the LCP only group was 18.13 ±8.06 months (range, 12.00 to 32.23 months) compared to 18.73 ±7.73 months (range, 12.00 to 31.56 months) for the group augmented with a fibular allograft. The difference was not significant (p = 0.834). There were no differences in gender (p = 0.413) or in the distribution of Neer type 2/3/4 fracture patterns (p = 0.753) between the two groups.

The weighted mean for the Constant-Murley score at final follow-up was 81.9 in the group augmented with a fibular allograft and 79.9 in the group treated with a LCP alone. While the weighted mean difference favored the group augmented with a fibular allograft, this difference was not statistically significant (WMD = 3.36; 95% CI, -0.21 to 6.93; p = 0.06). The null hypothesis could not be rejected, and no conclusions can be made regarding comparisons in Constant-Murley scores between the two groups. Additionally, only 25% of the variance between true and observed mean differences can be attributed to sampling error (I^2 = 75%). The variance of true effects (T^2) was 12.08 with a standard deviation of true effects (T) of 3.476. The

95% prediction interval was -3.592 to 10.312, indicating that it is unclear if there was any benefit to fibular allograft augmentation for LCP in the context of the Constant-Murley score.

Major Complications

The reported major complications included in this meta-analysis included malunions, avascular necrosis, screw perforation, screw cutout, or complications subjectively defined and reported by respective authors. Eight studies reported major complications as defined by this study (**Figure 6**). One study by Kim *et al* reported zero complications for patients treated with a LCP augmented with a fibular allograft. A fixed value of 0.5 was assigned for this zero-count cell, which introduced an undesirable bias toward no difference between the groups.

There were 32 reported complications in 296 total patients treated with LCP augmented with a fibular allograft. There were 87 reported complications in 349 patients treated with LCP only. The mean age for the LCP only group was 65.60 ±5.92 years (range, 54.30 to 72.50 years) and was 67.13 ±4.47 years (range, 59.90-72.20 years) for the LCP group that was augmented with a fibular allograft. This difference was not significant (p = 0.571). The mean follow-up for the LCP only group was 17.12 ±8.25 months (range, 6.5 to 35.20 months) compared to 17.68 ±7.48 months (range 7.83 to 33.50 months) for the group augmented with a fibular allograft. The difference was not significant (p = 0.903). There were no differences in gender (p = 0.130) or in the distribution of Neer type 2/3/4 fracture patterns (p = 0.388) between the two groups.

There was a statistically significant decrease in the odds ratio for complications in the LCP augmented with a fibular allograft group compared with the LCP alone group (OR = 0.37;

95% CI, 0.23 to 0.59; $p < 0.0001$). 95% of variance between the observed odds ratio and the true odds ratio can be attributed to sampling error ($I^2 = 5\%$). The variance of true effects (T^2) was 0.03 with a standard deviation of true effects (T) of 0.173. The 95% prediction interval for the odds ratio of complications ranged from 0.014 to 0.716. This suggests that augmentation of a LCP with a fibular allograft was associated with a reduction in the odds of a major complication relative to patients treated with a LCP alone for 95% of patients drawn from a population similar to the study populations sampled.

When examining the rate of revision surgery, only three studies reported the number of patients who underwent a subsequent surgical intervention for the affected shoulder.[8, 25, 34] There was a slightly lower rate of revision surgeries in the groups augmented with a fibular allograft (6.2%) compared to the groups treated with a LCP alone (9.8%); however, this difference was not statistically significant ($p = 0.182$).

DISCUSSION

This study included ten papers published between 2017 and 2020 evaluating the outcomes of fibular allograft augmentation in addition to a LCP compared to a LCP alone in proximal humeral fractures. Neither of the previous two recent systematic reviews on this technique directly compared the outcomes of plating alone to plating augmented with a fibular allograft.[1, 30] The major findings of this meta-analysis were as follows: 1) radiographic changes in NSA and HHH were significantly lower for patients treated with fibular allograft augmentation; 2) functional outcome scoring for ASES was significantly higher with the fibular allograft augmentation group, while a nonsignificant difference was demonstrated for Constant-

Murley scoring between the two groups; 3) complication rates were significantly lower with the application of fibular allograft augmentation.

Radiographic Findings

The radiographic measurements for change in HHH and change in NSA were reported in five and seven of the analyzed studies, respectively. Both HHH and NSA were found to have a statistically significant reduction in change from postoperative radiographs to final follow-up radiographs for the group augmented with a fibular allograft. Cha *et al* evaluated the radiographic outcomes after surgical management for 52 patients with proximal humeral fractures.[3] The authors reported a significantly lower change in HHH and NSA for groups augmented with a fibular allograft relative to groups treated with a LCP alone. Two other publications included in this meta-analysis demonstrated that regardless of the Neer classification fracture pattern, the addition of a fibular allograft showed superior radiographic results in both NSA and HHH than plating alone.[7, 35] Similar to Cha *et al*, Tuerxun *et al* reported that three of the 22 patients who underwent LCP alone had changes in NSA greater than 10° and six patients had changes in HHH greater than 3 mm.[33] Additionally, Lee *et al* determined the rate of varus malignment and loss of HHH were significantly decreased to 8.9% and 4.4%, respectively, when a fibular allograft was used during plate fixation.[19]

Noncomparative studies examining the use of fibular allograft augmentation in ORIF of proximal humerus fractures have reported similar radiographic outcomes, further supporting the potential benefit of this surgical technique. An interesting study by Gardner *et al* examined 35 patients who underwent plating alone and found that patients who had adequate mechanical medial support had an average loss of HHH of 1.2 mm, whereas those without adequate medial support had an average HHH loss of 5.8 mm ($p < 0.001$).[10] These results drove the authors to propose augmentation with a fibular allograft for medial support in their subsequent 2008 publication, where they initially introduced the technique.[9]

From a biomechanical standpoint, the addition of a fibular allograft complex is potentially beneficial with comminuted fracture patterns, especially those involving loss of medial calcar support. This is because the increased purchase and head support with grafting allows for increased stiffness of the bone-implant interface, increased test load failure, and improved osteosynthesis in complex proximal humeral fractures.[5, 18, 22, 27]

Functional Outcomes

In the present study, functional outcome ASES scoring was significantly higher with fibular allograft augmentation, while nonsignificant results were demonstrated for Constant-Murley scoring amongst the publications that reported functional outcomes. Kim *et al* deduced that the application of a minimally invasive plate osteosynthesis with a fibular graft demonstrated no significant differences in scores for visual analog score (VAS) or Constant-Murley scores at one year postoperatively in comparison to ORIF alone.[14] Comparatively, Zhao *et al* retrospectively looked at 21 elderly patients who received a fibular allograft in addition to plating as well as 21 patients with ORIF alone and reported that Constant-Murley scores were significantly higher for those in the augmentation group and DASH scores were significantly lower for the augmentation group.[35]

The functional outcomes reported in the present study are on par with the heterogeneity of the previously mentioned studies. The impact of clinical outcomes, such as ASES and Constant-Murley, must be put in context of total follow-up time and correlated to improvements in range of motion. Given that the follow-up time varied drastically amongst the studies reporting ASES and Constant scores, ranging from an average of 13.6 to 32.23 months, the nonsignificant changes in Constant scores between the groups may not allow for adequate conclusions to be made. It is imperative that surgeons who are assessing the efficacy of surgical techniques for proximal humeral fractures take note of the variability in follow-up time and initial morbidity investigated in previous studies, as the functional outcomes in their own patients may reflect certain subgroups of the population that have been previously studied.

Complication Rates

Complication rates were significantly lower with the application of fibular allograft augmentation in this meta-analysis. Myers *et al* determined that despite a decrease in overall total fluoroscopy time (63 vs. 83 seconds; $p = 0.04$) with fibular allograft use, the length of operation and blood loss were similar. They also found a statistically significant decrease in the need for revision surgery in Neer 3 or 4-part fractures (16% vs 0%; $p < 0.01$) for the fibular allograft group.[25] Chen *et al*, Zhao *et al*, and Tuerxun *et al* also reported statistically significant decreases in complication rates observed for the group augmented with a fibular allograft.[4, 33, 35] Other studies were not able to find a significant difference between the two groups. For example, when Davids *et al* stratified for both age (<65 years vs >65 years) and gender they still were not able to parse out significant differences in complication rates of ORIF alone compared to ORIF augmented with a fibular allograft.[8]

While the data presented in this meta-analysis suggests that fibular allograft augmentation reduces major complications, it is important to emphasize that the majority of complications reported were subjectively defined by authors and were not uniform between studies. Additionally, this study did not address complications associated with the need for future surgery such as conversion to total shoulder arthroplasty (TSA). Revision surgery can be challenging after failed ORIF augmented with a fibular allograft because ingrowth leads to the formation of an intramedullary canal that is resistant to reaming and prosthesis stem placement during a salvage procedure.[20, 29] Despite this, there have been reports of successful reverse TSA with improvements in pain, patient satisfaction, and ASES scores for these complex cases of humeral head collapse and screw penetration secondary to AVN.[20, 29] The fibular allograft also has disadvantages related to its high cost and, like other allografts, its risk for disease transmission.[7] Neither of these disadvantages were adequately explored in this study.

Limitations

This systematic review is not without limitations. The average final follow-up time was relatively short (< 2 years), and there was significant heterogeneity in the presentation of both subjective outcomes and objective outcomes. Several studies emphasized physical exam/functioning outcomes such as range of motion changes while others focused heavily on radiographic differences in the two groups. Additionally, despite finding a statistically significant difference in ASES scores between the two groups, the minimal clinically important difference for ASES scores does not currently exist in the literature for ORIF of proximal humerus fractures. This made it challenging to place these findings in the appropriate clinical context.

Another major limitation of this study is that the HHH radiographic outcome may not have been standardized between studies and may differ based on the view, rotation, and magnification of the radiographs. Given the inherent design of systematic reviews, it is possible that relevant papers were not included in this study based on how search terms were defined during the initial database query. Furthermore, the retrospective nature of this meta-analysis and included studies limits the generalizability that can be extrapolated. While the results presented are promising, a randomized controlled trial is needed to determine the true efficacy of fibular allograft augmentation in the management of proximal humerus fractures treated with a LCP.

CONCLUSION

The results of this meta-analysis favored the use of fibular allograft augmentation for the management of proximal humerus fractures treated with a LCP. When generalizing the results of this study, this data set would suggest that 95% of patients sampled from populations representative of those included in this study would experience improved radiographic outcomes, improved ASES clinical outcome scores, and decreased odds of a major complication if treated with a LCP augmented with a fibular allograft compared to patients treated with a LCP alone. Limitations of this study include the relatively short final follow-up time and a potential lack of standardization for radiographic outcome measures among the included studies.

FIGURE LEGENDS

Figure 1: PRISMA flowchart of the study selection criteria.

Figure 2: Forest plot demonstrating the mean difference for change in humeral head height from initial postoperative radiographs to radiographs at final follow-up for patients treated with either a LCP alone or a LCP augmented with a fibular allograft. This includes a summary estimate

(center of the diamond) and a 95% confidence interval (width of the diamond) for the true mean difference. The size of each square represents the relative weight given to each respective study.

Figure 3: Forest plot demonstrating the mean difference for change in neck shaft angle from initial postoperative radiographs to radiographs at final follow-up for patients treated with either a LCP alone or a LCP augmented with a fibular allograft. This includes a summary estimate (center of the diamond) and a 95% confidence interval (width of the diamond) for the true mean difference. The size of each square represents the relative weight given to each respective study.

Figure 4: Forest plot demonstrating the mean difference between ASES scores on final follow-up for patients treated with either a LCP alone or a LCP augmented with a fibular allograft. This includes a summary estimate (center of the diamond) and a 95% confidence interval (width of the diamond) for the true mean. The size of each square represents the relative weight given to each respective study.

Figure 5: Forest plot demonstrating the mean difference between Constant-Murley scores on final follow-up for patients treated with either a LCP alone or a LCP augmented with a fibular allograft. This includes a summary estimate (center of the diamond) and a 95% confidence interval (width of the diamond) for the true mean. The size of each square represents the relative weight given to each respective study.

Figure 6: Forest plot demonstrating the odds ratio for reported major complications in patients treated with either a LCP alone or a LCP augmented with a fibular allograft. This includes a summary estimate (center of the diamond) and a 95% confidence interval (width of the diamond). The size of each square represents the relative weight given to each respective study. Complications were defined as malunions, avascular necrosis, screw perforation, screw cutout, or subjectively by respective authors.

Table 1: Study characteristics table. M = Male; F = Female; LCP = Locking Compression Plate; FA = Locking Compression Plate Augmented with a Fibular Allograft

Table 2: Methodological Index for Non-Randomized Studies (MINORS) criteria. For this bias assessment, an ideal score would be 24 points.

REFERENCES

1. Biermann N, Prall WC, Böcker W, Mayr HO, Haasters F. Augmentation of plate osteosynthesis for proximal humeral fractures: a systematic review of current biomechanical and clinical studies. Archives of Orthopaedic and Trauma Surgery 2019;139(8):1075-99. doi:10.1007/s00402-019-03162-2
2. Borenstein M, Hedges LV, Higgins JP, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. Res Synth Methods 2010;1(2):97-111. doi:10.1002/jrsm.12
3. Cha H, Park K-B, Oh S, Jeong J. Treatment of comminuted proximal humeral fractures using locking plate with strut allograft. Journal of Shoulder and Elbow Surgery 2017;26(5):781-5. doi:10.1016/j.jse.2016.09.055
4. Chen H, Yin P, Wang S, Li J, Zhang L, Khan K, et al. The Augment of the Stability in Locking Compression Plate with Intramedullary Fibular Allograft for Proximal Humerus Fractures in Elderly People. BioMed Research International 2018;2018:1-8. doi:10.1155/2018/3130625
5. Chow RM, Begum F, Beaupre LA, Carey JP, Adeeb S, Bouliane MJ. Proximal humeral fracture fixation: locking plate construct ± intramedullary fibular allograft. J Shoulder Elbow Surg 2012;21(7):894-901. doi:10.1016/j.jse.2011.04.015
6. Court-Brown CM, Garg A, McQueen MM. The epidemiology of proximal humeral fractures. Acta Orthop Scand 2001;72(4):365-71. doi:10.1080/000164701753542023
7. Cui X, Chen H, Ma B, Fan W, Li H. Fibular strut allograft influences reduction and outcomes after locking plate fixation of comminuted proximal humeral fractures in elderly patients: a retrospective study. BMC Musculoskeletal Disorders 2019;20(1). doi:10.1186/s12891-019-2907-3
8. Davids S, Allen D, Desarno M, Endres NK, Bartlett C, Shafritz A. Comparison of Locked Plating of Varus Displaced Proximal Humeral Fractures With and Without Fibula Allograft Augmentation. J Orthop Trauma 2020;34(4):186-92. doi:10.1097/bot.0000000000001679

9. Gardner MJ, Boraiah S, Helfet DL, Lorich DG. Indirect medial reduction and strut support of proximal humerus fractures using an endosteal implant. J Orthop Trauma 2008;22(3):195-200. doi:10.1097/BOT.0b013e31815b3922

10. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. J Orthop Trauma 2007;21(3):185-91. doi:10.1097/BOT.0b013e3180333094

11. Handoll HH, Ollivere BJ, Rollins KE. Interventions for treating proximal humeral fractures in adults. Cochrane Database Syst Rev 2012;12:Cd000434. doi:10.1002/14651858.CD000434.pub3

12. Hinds RM, Garner MR, Tran WH, Lazaro LE, Dines JS, Lorich DG. 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(6):889-96. doi:10.1016/j.jse.2014.10.019

13. Kelly BJ, Myeroff CM. Reverse Shoulder Arthroplasty for Proximal Humerus Fracture. Curr Rev Musculoskelet Med 2020;13(2):186-99. doi:10.1007/s12178-020-09597-0

14. Kim JY, Lee J, Kim S-H. Comparison between minimally invasive plate osteosynthesis and the deltopectoral approach with allogenous fibular bone graft in proximal humeral fractures. Clinics in Shoulder and Elbow 2020;23(3):136-43. doi:10.5397/cise.2020.00199

15. Kim SH, Szabo RM, Marder RA. Epidemiology of humerus fractures in the United States: nationwide emergency department sample, 2008. Arthritis Care Res (Hoboken) 2012;64(3):407-14. doi:10.1002/acr.21563

16. Krappinger D, Bizzotto N, Riedmann S, Kammerlander C, Hengg C, Kralinger FS. Predicting failure after surgical fixation of proximal humerus fractures. Injury 2011;42(11):1283-8. doi:10.1016/j.injury.2011.01.017

17. Lauritzen JB, Schwarz P, Lund B, McNair P, Transbøl I. Changing incidence and residual lifetime risk of common osteoporosis-related fractures. Osteoporos Int 1993;3(3):127-32. doi:10.1007/bf01623273

18. Laux CJ, Grubhofer F, Werner CML, Simmen HP, Osterhoff G. Current concepts in locking plate fixation of proximal humerus fractures. J Orthop Surg Res 2017;12(1):137. doi:10.1186/s13018-017-0639-3

19. Lee SH, Han SS, Yoo BM, Kim JW. Outcomes of locking plate fixation with fibular allograft augmentation for proximal humeral fractures in osteoporotic patients: comparison with locking plate fixation alone. Bone Joint J 2019;101-b(3):260-5. doi:10.1302/0301-620x.101b3.Bjj-2018-0802.R1

20. Manzi JE, Ruzbarsky JJ, Rauck RC, Gulotta LV, Dines JS, Dines DM. Failed Proximal Humerus Osteosynthesis Using Intramedullary Fibular Strut Allograft Conversion to Reverse Shoulder Arthroplasty. Techniques in hand & upper extremity surgery 2020;24(1):7-12. doi:10.1097/BTH.0000000000000260

21. Matassi F, Angeloni R, Carulli C, Civinini R, Di Bella L, Redl B, et al. Locking plate and fibular allograft augmentation in unstable fractures of proximal humerus. Injury 2012;43(11):1939-42. doi:10.1016/j.injury.2012.08.004

22. Mathison C, Chaudhary R, Beaupre L, Reynolds M, Adeeb S, Bouliane M. Biomechanical analysis of proximal humeral fixation using locking plate fixation with an intramedullary fibular allograft. Clin Biomech (Bristol, Avon) 2010;25(7):642-6. doi:10.1016/j.clinbiomech.2010.04.006

23. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009;339(jul21 1):b2535-b. doi:10.1136/bmj.b2535

24. Myeroff CM, Anderson JP, Sveom DS, Switzer JA. Predictors of Mortality in Elder Patients With Proximal Humeral Fracture. Geriatr Orthop Surg Rehabil 2018;9:2151458517728155. doi:10.1177/2151458517728155

25. Myers DM, Triplet JJ, Warmoth PJ, Passias BJ, McGowan SP, Taylor BC. Improved Outcomes Using a Fibular Strut in Proximal Humerus Fracture Fixation. Orthopedics 2020;43(5):262-8. doi:10.3928/01477447-20200721-02

26. Neviaser AS, Hettrich CM, Beamer BS, Dines JS, Lorich DG. Endosteal strut augment reduces complications associated with proximal humeral locking plates. Clin Orthop Relat Res 2011;469(12):3300-6. doi:10.1007/s11999-011-1949-0

27. Osterhoff G, Baumgartner D, Favre P, Wanner GA, Gerber H, Simmen HP, et al. Medial support by fibula bone graft in angular stable plate fixation of proximal humeral fractures: an in vitro study with synthetic bone. J Shoulder Elbow Surg 2011;20(5):740-6. doi:10.1016/j.jse.2010.10.040

28. Owsley KC, Gorczyca JT. Displacement/Screw Cutout After Open Reduction and Locked Plate Fixation of Humeral Fractures. Journal of bone and joint surgery American volume 2008;90(2):233-40. doi:10.2106/JBJS.F.01351

29. Polisetty T, Devito P, Judd H, Malarkey A, Levy JC. Reverse Shoulder Arthroplasty for Failed Proximal Humerus Osteosynthesis With Intramedullary Allograft: A Case Series. Journal of Shoulder and Elbow Arthroplasty 2020;4:247154922092546. doi:10.1177/2471549220925464

30. Saltzman BM, Erickson BJ, Harris JD, Gupta AK, Mighell M, Romeo AA. Fibular Strut Graft Augmentation for Open Reduction and Internal Fixation of Proximal Humerus Fractures. Orthopaedic Journal of Sports Medicine 2016;4(7):232596711665682. doi:10.1177/2325967116656829

31. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. ANZ J Surg 2003;73(9):712-6. doi:10.1046/j.1445-2197.2003.02748.x

32. Slobogean GP, Johal H, Lefaivre KA, MacIntyre NJ, Sprague S, Scott T, et al. A scoping review of the proximal humerus fracture literature. BMC Musculoskelet Disord 2015;16:112. doi:10.1186/s12891-015-0564-8

33. Tuerxun M, Tuxun A, Zeng L, Wang Q, Chen Y. Locking Plate Combined With Endosteal Fibular Allograft Augmentation for Medial Column Comminuted Proximal Humeral Fracture. Orthopedics 2020;43(6):367-72. doi:10.3928/01477447-20200827-06

34. Wang H, Rui B, Lu S, Luo C, Chen Y, Chai Y. Locking Plate Use with or without Strut Support for Varus Displaced Proximal Humeral Fractures in Elderly Patients. JB JS Open Access 2019;4(3). doi:10.2106/jbjs.Oa.18.00060

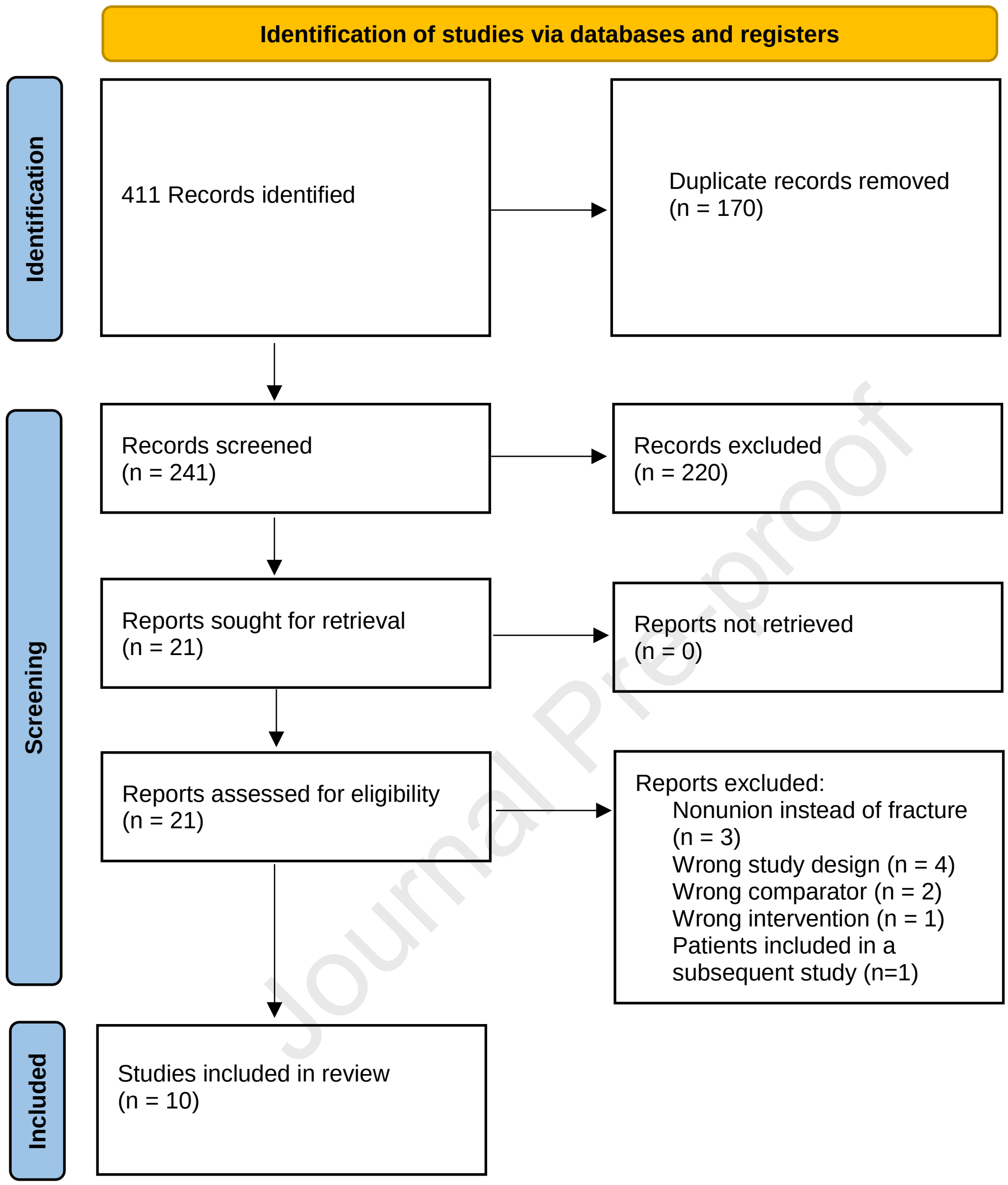
35. Zhao L, Qi YM, Yang L, Wang GR, Zheng SN, Wang Q, et al. Comparison of the Effects of Proximal Humeral Internal Locking System (PHILOS) Alone and PHILOS Combined with Fibular Allograft in the Treatment of Neer Three- or Four- part Proximal Humerus Fractures in the Elderly. Orthopaedic Surgery 2019;11(6):1003-12. doi:10.1111/os.12564

Table 1: Study Characteristics

Author	Year	Study Design	Level of Evidence	Intervention	Patient (Sex)	Mean Age (Years)	Follow-up (Months)	Neer Classification (2/3/4)
Davids[9]	2020	Retrospective Cohort	III	LCP	75 (N/A)	59.9	17.6	40/35/0
				FA	27 (N/A)	59.9	17.6	13/14/0
Kim[15]	2020	Retrospective Cohort	III	LCP	39 (32F, 7M)	68.1	15.9	20/19/0
				FA	38 (33F, 5M)	69.8	17.2	24/14/0
Myers[25]	2020	Retrospective Cohort	III	LCP	72 (41F, 31M)	54.3	6.5	47/25/0
				FA	61 (45F, 16M)	62.3	7.83	35/26/0
Tuerxun[34]	2020	Retrospective Cohort	III	LCP	22 (13F, 9M)	64.1	16.3	3/10/09
				FA	41 (29F, 12M)	64.1	19.3	6/19/16
Cui[8]	2019	Retrospective Cohort	III	LCP	35 (24F, 11M)	72.46	32.23	0/25/10
				FA	25 (18F, 7M)	73.16	31.56	0/17/8
Lee[20]	2019	Retrospective Cohort	III	LCP	52 (38F, 14M)	73.3	14.2	25/22/5
				FA	45 (33F, 12M)	75.6	13.6	21/20/4
Wang[35]	2019	Retrospective Cohort	III	LCP	46 (33F, 13M)	72.5	19	0/0/46
				FA	39 (23F, 16M)	72.2	19	0/0/39
Zhao[36]	2019	Retrospective Cohort	III	LCP	21 (9F, 12M)	69	12	0/15/6
				FA	23 (12F, 11M)	68.8	12	0/14/7
Chen[5]	2018	Retrospective Cohort	III	LCP	42 (27F, 15M)	69.12	35.2	0/10/32
				FA	47 (35F, 12M)	68.6	33.5	0/12/35
Cha[4]	2017	Retrospective Cohort	III	LCP	32 (24F, 8M)	67.8	15	8/21/03
				FA	20 (15F, 5M)	71.3	15	3/15/02

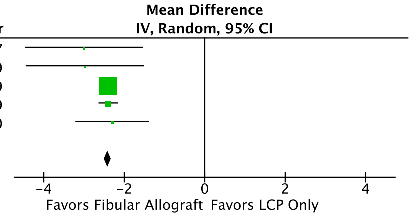
Table 2: MINORS Bias Score

Author	Year	Title	Study Design	Total Score
Davids[9]	2020	Comparison of Locked Plating of Varus Displaced Proximal Humeral Fractures With and Without Fibula Allograft Augmentation.	Retrospective Cohort	16
Kim[15]	2020	Comparison between MIPO and the deltopectoral approach with allogenous fibular bone graft in proximal humeral fractures.	Retrospective Cohort	16
Myers[25]	2020	Improved Outcomes Using a Fibular Strut in Proximal Humerus Fracture Fixation.	Retrospective Cohort	16
Tuerxun[34]	2020	Locking Plate Combined With Endosteal Fibular Allograft Augmentation for Medial Column Comminuted Proximal Humeral Fracture.	Retrospective Cohort	16
Cui[8]	2019	Fibular strut allograft influences reduction and outcomes after locking plate fixation of comminuted proximal humeral fractures in elderly patients: a retrospective study.	Retrospective Cohort	16
Lee[20]	2019	Outcomes of locking plate fixation with fibular allograft augmentation for proximal humeral fractures in osteoporotic patients: comparison with locking plate fixation alone.	Retrospective Cohort	19
Wang[35]	2019	Locking Plate Use with or without Strut Support for Varus Displaced Proximal Humeral Fractures in Elderly Patients.	Retrospective Cohort	18
Zhao[36]	2019	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.	Retrospective Cohort	16
Chen[5]	2018	The Augment of the Stability in Locking Compression Plate with Intramedullary Fibular Allograft for Proximal Humerus Fractures in Elderly People.	Retrospective Cohort	16
Cha[4]	2017	Treatment of comminuted proximal humeral fractures using locking plate with strut allograft.	Retrospective Cohort	18


Identification of studies via databases and registers
Identification
411 Records identified
Duplicate records removed
(n = 170)
Screening
Records screened
(n = 241)
Records excluded
(n = 220)
Reports sought for retrieval
(n = 21)
Reports not retrieved
(n = 0)
Reports assessed for eligibility
(n = 21)
Reports excluded:
Nonunion instead of fracture
(n = 3)
Wrong study design (n = 4)
Wrong comparator (n = 2)
Wrong intervention (n = 1)
Patients included in a
subsequent study (n=1)
Included
Studies included in review
(n = 10)

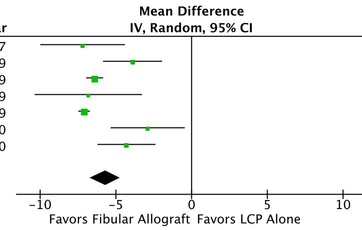
Study or Subgroup	Fibular Allograft Mean [mm]	SD [mm]	Total	LCP Only Mean [mm]	SD [mm]	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Cha 2017	1	1	20	4	4	32	0.4%	−3.00 [−4.45, −1.55]	2017
Cui 2019	1.18	1.08	25	4.16	4.2	35	0.4%	−2.98 [−4.43, −1.53]	2019
Lee 2019	1.8	0.2	45	4.2	0.3	52	81.9%	−2.40 [−2.50, −2.30]	2019
Zhao 2019	2.14	0.33	23	4.54	0.42	21	16.3%	−2.40 [−2.62, −2.18]	2019
Tuerxun 2020	1.1	1.1	41	3.4	2	22	1.0%	−2.30 [−3.20, −1.40]	2020
Total (95% CI)			**154**			**162**	**100.0%**	**−2.40 [−2.49, −2.31]**	

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.31$, df = 4 (P = 0.86); $I^2 = 0\%$
Test for overall effect: Z = 51.90 (P < 0.00001)



Study or Subgroup	Fibular Allograft Mean [Degrees]	Fibular Allograft SD [Degrees]	Fibular Allograft Total	LCP Only Mean [Degrees]	LCP Only SD [Degrees]	LCP Only Total	Weight	Mean Difference IV, Random, 95% CI	Year
Cha 2017	3	3	20	10.2	7	32	8.5%	−7.20 [−9.96, −4.44]	2017
Wang 2019	14.7	3.1	39	18.6	5.7	46	13.1%	−3.90 [−5.81, −1.99]	2019
Zhao 2019	3.42	0.71	23	9.82	1.02	21	24.0%	−6.40 [−6.92, −5.88]	2019
Cui 2019	3.12	3.13	25	9.94	9.92	35	6.0%	−6.82 [−10.33, −3.31]	2019
Lee 2019	3.2	0.6	45	10.3	1.1	52	25.0%	−7.10 [−7.45, −6.75]	2019
Myers 2020	1.8	5.6	61	4.7	8.5	72	10.1%	−2.90 [−5.31, −0.49]	2020
Tuerxun 2020	3.3	2.2	41	7.6	4.2	22	13.3%	−4.30 [−6.18, −2.42]	2020
Total (95% CI)			**254**			**280**	**100.0%**	**−5.71 [−6.69, −4.72]**	

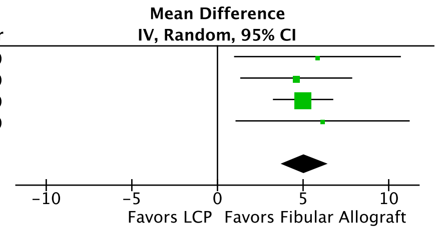
Heterogeneity: $Tau^2 = 0.98$; $Chi^2 = 30.50$, $df = 6$ ($P < 0.0001$); $I^2 = 80\%$
Test for overall effect: $Z = 11.35$ ($P < 0.00001$)



Study or Subgroup	Fibular Allograft Mean	SD	Total	LCP Only Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Cui 2019	78.64	9.18	25	72.8	9.73	35	8.3%	5.84 [1.01, 10.67]	2019
Lee 2019	83.1	8.5	45	78.5	7.6	52	18.6%	4.60 [1.37, 7.83]	2019
Wang 2019	87.2	3.6	39	82.2	4.5	46	65.4%	5.00 [3.28, 6.72]	2019
Zhao 2019	87.76	7.15	23	81.62	9.62	21	7.6%	6.14 [1.09, 11.19]	2019
Total (95% CI)			**132**			**154**	**100.0%**	**5.08 [3.69, 6.48]**	

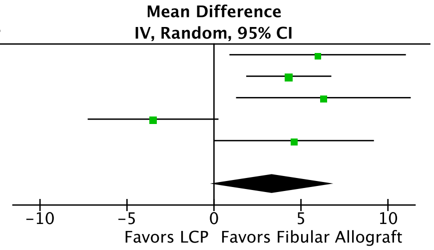
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.36$, df = 3 (P = 0.95); $I^2 = 0\%$

Test for overall effect: Z = 7.15 (P < 0.00001)



Study or Subgroup	Fibular Allograft Mean	Fibular Allograft SD	Fibular Allograft Total	LCP Only Mean	LCP Only SD	LCP Only Total	Weight	Mean Difference IV, Random, 95% CI	Year
Cui 2019	78.96	9.71	25	73	9.94	35	17.7%	5.96 [0.93, 10.99]	2019
Lee 2019	87.8	5.6	45	83.5	6.5	52	24.4%	4.30 [1.89, 6.71]	2019
Zhao 2019	86	7.56	23	79.71	9.14	21	17.9%	6.29 [1.31, 11.27]	2019
Kim 2020	78.3	7.5	38	81.8	9.1	39	21.1%	−3.50 [−7.22, 0.22]	2020
Tuerxun 2020	83.7	8.6	41	79.1	8.9	22	18.9%	4.60 [0.04, 9.16]	2020
Total (95% CI)			**172**			**169**	**100.0%**	**3.36 [−0.21, 6.93]**	

Heterogeneity: $Tau^2 = 12.08$; $Chi^2 = 16.25$, df = 4 (P = 0.003); $I^2 = 75\%$
Test for overall effect: Z = 1.85 (P = 0.06)



Study or Subgroup	Fibular Allograft Events	Fibular Allograft Total	LCP Only Events	LCP Only Total	Weight	Odds Ratio IV, Random, 95% CI	Year
Cha 2017	1	20	4	32	4.4%	0.37 [0.04, 3.56]	2017
Chen 2018	8	47	17	42	21.5%	0.30 [0.11, 0.80]	2018
Wang 2019	3	39	5	46	9.7%	0.68 [0.15, 3.06]	2019
Zhao 2019	1	23	7	21	4.6%	0.09 [0.01, 0.82]	2019
Davids 2020	6	27	16	75	18.5%	1.05 [0.36, 3.05]	2020
Kim 2020	0	38	3	39	2.5%	0.14 [0.01, 2.71]	2020
Myers 2020	10	61	29	72	29.1%	0.29 [0.13, 0.66]	2020
Tuerxun 2020	3	41	6	22	9.7%	0.21 [0.05, 0.95]	2020
Total (95% CI)		**296**		**349**	**100.0%**	**0.37 [0.23, 0.59]**	
Total events	32		87				

Heterogeneity: $Tau^2 = 0.03$; $Chi^2 = 7.40$, df = 7 (P = 0.39); $I^2 = 5\%$
Test for overall effect: Z = 4.10 (P < 0.0001)