

# Dual plate fixation of unstable proximal humerus fractures: A Narrative review

Lyubomir Rusimov<sup>1</sup>

<sup>1</sup> University Multiprofile Hospital for Active Treatment and Emergency Medicine “N.I.Pirogov”, Sofia, Bulgaria

**Corresponding author:** Lyubomir Rusimov, University Multiprofile Hospital for Active Treatment and Emergency Medicine “N.I.Pirogov”, Sofia, Bulgaria; E-mail: [lyubomirrusimov@gmail.com](mailto:lyubomirrusimov@gmail.com)

**Academic editor:** Margarita Kateva-Vrabccheva

**Received:** 19 December 2024 ♦ **Accepted:** 27 March 2025 ♦ **Published:** 19 May 2025

**Citation:** Rusimov L. Dual plate fixation of unstable proximal humerus fractures: A Narrative review. Bulgarian Society of Medical Sciences Journal 2025;7:e144938. doi: 10.3897/bsms.7.144938.

## Abstract

**Introduction:** Medial column instability has been identified as a key factor contributing to the increased failure rates observed after locking plate (LP) fixation for unstable proximal humerus fractures (PHFs). Recent studies have reported promising biomechanical and clinical outcomes with the use of LP fixation augmented by an additional plate for medial column stabilization.

The current article provides an overview of the available clinical literature for dual plate fixation of unstable PHFs with medial column instability.

**Materials and methods:** For the arrangement of this narrative, non-systematic review, an exploratory search in the MEDLINE (via PubMed) database using the keywords combinations: “proximal humerus fracture” and “dual plate”; “proximal humerus fracture” and “double plate”; “proximal humerus fracture” and “additional plate” was conducted.

**Results:** The initial search in Pubmed yielded 24 studies, but only 9 studies satisfied the inclusion criteria and were subject to further analysis. There were 165 patients with PHFs in the nine included studies. The average age was 57 years (range 18–84 years). The average follow-up was 21.8 months (range 12–52 months). The average Constant-Murley Score at the final follow-up was 79.9 (71.5–90.4). There were a total of 12 (7.3%) reported clinically relevant complications and 15 (9.1%) re-interventions. Various plates were used as additional fixation to the PHLP: 1/3 tubular plate; a Variable Angle Locking Compression Plate (Distal Radius System); non-locking 3-hole T-plate; 2.7-mm T-shaped locking plate; anatomical medial locking plate; 2.7-mm micro-locking plate;

**Conclusion:** Adding a second plate to PHLP fixation for unstable PHFs with medial column insufficiency has shown promising clinical outcomes with a relatively low complication rate, despite the additional soft tissue dissection required. The anterior placement of the secondary plate is less technically demanding and can serve as a temporary reposition tool. However, anterior plating has been associated with a higher risk of avascular necrosis compared to medial plating. The variability in techniques and implants used for dual plating complicates drawing definitive conclusions. Moreover, the current evidence is limited, and additional studies with a higher level of evidence are needed to support the efficacy and routine application of the dual plating technique for unstable PHFs.

## Keywords

Proximal humeral fractures, Medical column insufficiency, Dual plating, Additional plate, Double plate

## Introduction

Medial column instability has been identified as a key factor contributing to the increased failure rates observed after locking plate (LP) fixation for unstable proximal humerus fractures (PHFs) [1,2,3]. Medial column instability, primarily characterized by calcar comminution, is particularly severe in patients with osteoporosis [4]. Over the past decade, numerous augmentation strategies have been introduced to enhance medial column stabilization and improve outcomes in LP fixation including calcar screws [5], allogenic or autologous bone grafting [6,7], and cement augmentation [8]. Recent studies have reported promising biomechanical [9,10] and clinical outcomes [11,12] with the use of LP fixation augmented by an additional plate for medial column stabilization.

The current article provides an overview of the available clinical literature for dual plate fixation of unstable PHFs with medial column instability. To our knowledge, this is the first review article addressing the current topic.

## Materials and methods

For the arrangement of this narrative non-systematic review, an exploratory search in the MEDLINE (via PubMed) database using the keywords combinations: “proximal humerus fracture” and “dual plate”; “proximal humerus fracture” and “double plate”; “proximal humerus fracture” and “additional plate” was conducted. The search was originally performed in November 2024 to include the most recent literature. The selected studies were limited to English only. The results of the search were critically evaluated and clinical studies were included in a detailed review. Reference lists from the articles retrieved were further examined to identify any additional studies of interest. Inclusion criteria for the study were: clinical studies with proximal humerus fractures due to trauma; patients older than 18 years of age; more than 6 patients included in the study; at least 12 months follow-up; studies with fractures having medial column instability; patients treated only with proximal humerus locking plate (PHLP) and additional plate; Exclusion criteria considered: biomechanical (experimental) studies; studies on pathological fractures; patients younger than 18 years of age; studies with less than 6 included patients; studies with patient follow-up of less than 12 months; studies with fractures without having medial column instability; patients treated with proximal humerus locking plate (PHLP), additional plate and other augmentation, such as structural allograft or cement;

## Results

The initial search in Pubmed yielded 24 studies. 15 studies did not meet the inclusion criteria: 8 were biomechanical experiments; 1 study did not use PHLP; 3 studies had less

than six patients; one study was available only in Mandarin; one study used PHLP, additional plate and structural allograft; One study had a follow-up period of just 6 months. As a result only 9 studies satisfied the inclusion criteria and were subject to further analysis. Two studies were performed prospectively [11,13] while the other seven studies were conducted retrospectively.

There were 165 patients with PHFs in the nine included studies. The average age was 57 years (range 18–84 years). The average follow-up was 21.8 months (range 12–52 months). By fracture type, there were 32 (19.4%) two-part fractures, 64 (38.8%) three-part fractures, 61 (37%) four-part fractures and 8 (4.8%) fracture-dislocations.

Various plates were used as additional fixation to the PHLP: three studies employed a 1/3 tubular plate for supplementary fixation [14–16] with one study also using either a 2.4/2.7 mm reconstruction plate or a 1/3 tubular plate [15]. One study utilized a Variable Angle Locking Compression Plate (Distal Radius System, Synthes, Switzerland) [13], another study reported the use of a non-locking 3-hole T-plate (Zimmer or Synthes) [17], and a 2.7 mm T-shaped locking plate was employed in one study [18]. One study used an anatomical medial locking plate (Waston, China) [19], and a 2.7 mm micro-locking plate (Synthes Inc., Paoli, PA, USA) was used in one study [12]. Finally, a locking three-hole T-plate (Zimmer, Inc Warsaw, IN or Synthes) plate was described in one study [20].

Eight authors used the delto-pectoral approach and one author used anterolateral (MIPO) approach with a “novel” medial approach [19].

In all 9 studies, rehabilitation with passive and/or active-assisted range of motion began as soon as patients were comfortable and pain-free.

Absolute Constant-Murley Score (CMS) was used for functional evaluation in 8 out of 9 studies. Relative CMS calculated by using reference values of the respective age and gender group described by Constant and Murley was used in 1 study [14]. The average CMS at the final follow-up for the patients who had undergone dual plate fixation for PHFs was 79.9 (71.5–90.4).

There were a total of 12 (7.3%) reported clinically relevant complications and 15 (9.1%) re-interventions.

The results and complications for each separate study are detailed in Table 1.

## Discussion

The medial calcar support consists of two main components: the length of the posteromedial metaphyseal extension and the integrity of the medial hinge [21].

According to Gardner et al., positioning a locking plate along the lateral cortex of the proximal humerus creates a mechanical construct that acts as a tension band. When the rotator cuff activates and exerts varus-deforming forces on the humeral head, these forces can be redirected into medial compression forces. This process effectively re-

**Table 1.** Results and complications of the studies using dual plate fixation for unstable PHFs.

Author, year	Number of patients	Mean Age (years)	Mean follow-up (months)	Fracture type/ Neer	Suture type	Functional outcome	Complications/re-interventions – in number of patients
Theopold <sup>[16]</sup> 2016	7	50	25.4	3(11B2.3) 3(11C2.1) 1(11C2.2)	<b>1/3 tubular plate</b> in inverted position into bicipital groove	CMS <sup>abs</sup> – 80	1 incomplete AVN with SP 3 elective implant removals
Choi <sup>[13]</sup> 2019	21	62.3	25.1	8(11A3.3) 13(11B2.3)	<b>VA-LCP</b> for Distal Radius posterior or anterior to GT	UCLA – 23 CMS <sup>abs</sup> – 90.4	1 SAI 1 AVN 1 Frozen shoulder
Park <sup>[17]</sup> 2019	17	62.5	30	3 (2-part) 7 (3-part) 4 (4-part) 3 (fracture-dislocations)	<b>3-hole T- non-locking plate</b> medially as a buttress	ASES – 74 DASH – 26.6 CMS <sup>abs</sup> – 70	2 AVN of GT
2021	25	53.1	21.8	3 (3-part) 17 (4-part) 5 (fracture-dislocations)	<b>1/3 tubular plate</b> ventrally at the LT	CMS <sup>rel</sup> – 77	1 nonunion 2 AVN 1 SAI 9 implant removal + arthroscopic arthrolysis 3 secondary arthroplasties
Zhang <sup>[18]</sup> 2021	15	61.5	18.5	5 (3-part) 10 (4-part)	<b>2.7-mm T- locking plate</b> ventrally at the LT	CMS <sup>abs</sup> – 79.8	1 AVN + SP
Wang <sup>[19]</sup> 2021	8	54.1	18.1	4 (3-part) 4 (4-part)	<b>Anatomical locking plate for medial proximal humerus</b> medially as a buttress	CMS <sup>abs</sup> – 82.8	0 complications
Liu <sup>[12]</sup> 2022	37	54.9	21.8	11 (2-part) 22 (3-part) 4 (4-part)	<b>2.7-mm micro-locking plate</b> under the medial LT as a buttress	ASES – 86.6 CMS <sup>abs</sup> – 88.8	0 complications
Alquahtani <sup>[15]</sup> 2023	9	46.2	12	9 (4-part)	<b>2.7/2.4 mm reconstruction plate</b> or <b>1/3 tubular plate</b> into bicipital groove	CMS <sup>abs</sup> – 78.9	0 complications
Seok <sup>[20]</sup> 2023	26	68.9	23.8	10 (2-part) 7 (3-part) 9 (4-part)	<b>3-hole T-shaped locking plate</b> medially on the latissimus dorsi tendon as a buttress	ASES – 78.5 CMS <sup>abs</sup> – 71.5	1 AVN of GT 1 Reduction loss

AVN\* – avascular necrosis; SP\* – screw perforation; CMS<sup>abs</sup>\* – Absolute Constant-Murley Score; CMS<sup>rel</sup>\* - Relative Constant-Murley Score calculated by using reference values of the respective age and gender group described by Constant and Murley; GT\* - greater tuberosity; LT\* - lesser tuberosity; SAI\* – subacromial impingement;

duces the load on the implant, promoting a load-sharing mechanism between the implant and the bone. However, the mechanical stability of the construct depends on the integrity and alignment of the medial cortex, which must be capable of effectively transmitting the load [22,23]. Beyond its mechanical function, the medial calcar plays a crucial role in bone biology by supporting blood flow to the humeral head through the vessels of the posteromedial hinge [22,24].

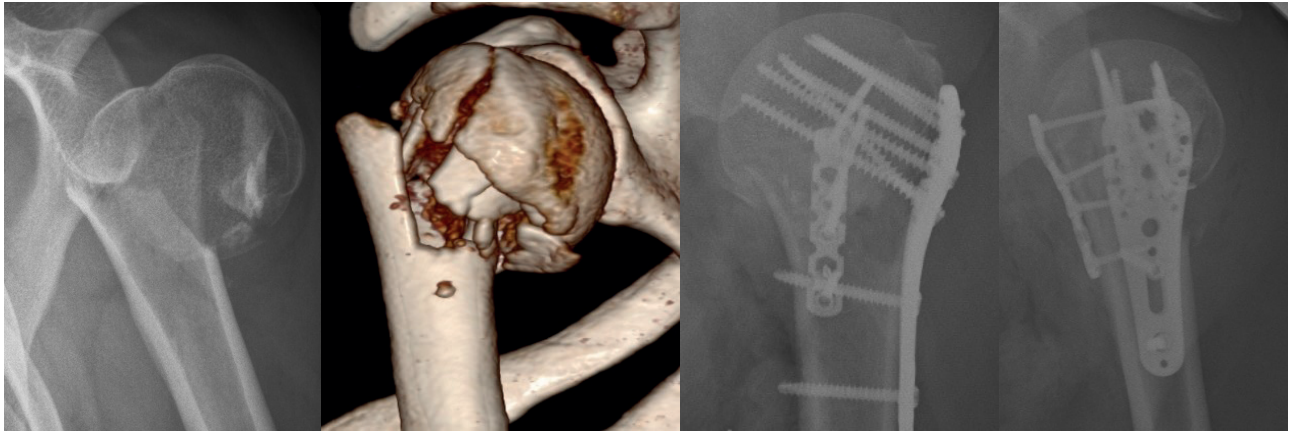
In an experimental study by Ponce et al., medial comminution was found to reduce the load to failure by 48% compared to cadaveric specimens with an intact medial cortex [25]. In a clinical study Osterhoff compares the functional outcomes between patients with PHFs with and without metaphyseal comminution treated with LP. Patients with medial cortex comminution exhibit lower absolute CMS (CSabs < 65) compared to the average for both groups (72.4) [26].

The simplest approach of achieving medial support is by medializing the diaphysis and laterally impacting the humeral head, or simply fixing it in varus [23]. Although biomechanically justified, these techniques could theoretically lead to complications, pain, and impaired shoulder func-

tion [25]. The other simple method involves placing locking screws in the inferomedial quadrant (calcar screws) of the humeral head [23]. However, Gardner reports a 29% complication rate, despite the use of calcar screws [23].

Supplemental fibular allograft augmentation for medial column insufficiency has been shown to improve both radiological and clinical outcomes while reducing the rate of complications [27,28]. However, fibular allograft carries potential risks, including infection, disease transmission, and the possibility of fracture during insertion. Despite its benefits, its high cost and availability constraints may make it less accessible in all healthcare settings [29–31].

Cement augmentation for PHFs, especially in elderly patients, can provide enhanced stability, but it does carry several risks. Potential complications include cement leakage, which can lead to adjacent joint or soft tissue damage, and the risk of thermal injury due to the high temperatures generated during cement setting, which may cause necrosis of the bone tissue. Additionally, while cement augmentation may improve fixation in osteoporotic bone, its use remains controversial, with concerns about the long-term effectiveness and the risk of fractures or delayed healing in some cases [8,32].



**Figure 1.** Preoperative X-ray and 3D CT imaging of a four-part proximal humerus fracture with medial comminution in a 33-year-old patient. The fracture was stabilized using a proximal humeral locking plate supplemented by a 2.7 mm reconstructive plate positioned anteriorly. This case is presented courtesy of the Second Clinic of Trauma and Orthopaedic Surgery at UMHATEM “N. I. Pirogov” in Sofia, Bulgaria.

To address the limitations of previously mentioned techniques, several authors have proposed using an additional plate to augment medial column insufficiency [12–20] (Fig. 1). Warner et al. introduced double-plate fixation for unstable proximal PHFs, utilizing a 1/3 tubular plate placed laterally and another positioned ventrally at a 90° angle to the first. This configuration demonstrated high internal stability, enabling early shoulder mobilization in all patients treated with this method [33]. However, subsequent biomechanical study comparing the use of two 1/3 tubular plates with a proximal humeral locking plate (PHLP) found that the PHLP offers superior mechanical stability, providing significantly greater stiffness and exhibited less irreversible deformation [34]. Further biomechanical studies comparing PHLP alone to PHLP combined with a second plate have demonstrated that the additional medial column support provided by the second plate enhances stability in the proximal humerus [9,10,35–38].

The majority of authors who use an additional plate to the PHLP for treating unstable PHFs with medial column instability report good clinical results with little or no complications (Table 1). As shown in Table 1, the positioning of plates varies between studies, with each placement requiring additional soft tissue dissection regardless of its location [14,18]. A ventrally positioned plate carries the risk of compromising the blood flow through the anterior circumflex humeral artery (ACHA). Similarly, a medially positioned plate may endanger the blood supply to the humeral head by compressing branches of the anterior or posterior circumflex humeral arteries, both of which are vital for maintaining its vascular integrity [19,39]. Anyway, the rate of avascular necrosis (AVN) in the studies of dual plating is relatively low. The highest incidence of AVN was reported in the study by Warnhoff et al., where the complication occurred in 2 (8%) out of 25 patients treated with a PHLP combined with an additional anterior one-third tubular plate [14]. The authors attributed this outcome primarily to the destruction of the medial calcar and the more complex fracture morphology observed in all cases [14]. Zhang et al. reported one case of AVN among 15

patients treated with an additional 2.7 mm locking T-plate positioned ventrally at the lesser tuberosity [18]. The authors highlighted a potential advantage of the locking mechanism of the anteromedial plate, which minimizes pressure on the periosteum, thereby preserving the remaining blood supply to the humeral head. This contrasts with the one-third tubular plate, which may exert greater pressure and potentially compromise vascular integrity [18]. In the study by Liu et al., which included the largest patient cohort, the authors reported that no complete AHCA was found beneath the lesser tuberosity, before plate fixation in the 37 patients. According to the authors, microplate fixation beneath the lesser tuberosity offers a distinct advantage in preventing excessive medial placement, which could otherwise further compromise the blood supply to the comminuted bone fragments of the medial calcar and the posterior circumflex humeral artery (PCHA). As a final result none of the patients had humeral head necrosis at the last follow-up visit. In contrast, a study by Wang et al., which utilized a medial plate in eight patients, reported no complications, including AVN [19]. This clinical study was preceded by a biomechanical experiment using the same anatomically designed plate and an anatomical study for a newly developed medial approach [35]. The authors observed that there are no communicative branches between the PCHA and the ACHA. Additionally, beneath the humeral head, the distance between the PCHA and ACHA was approximately 25–30 mm. This anatomical gap allows for the use of an interval plane to avoid both arteries while providing sufficient space to position the plate along the medial column [19]. Seok et al. utilized a locking three-hole T-plate, contoured to the medial cortex, to buttress the medial metaphyseal head extension in 26 PHFs with medial comminution and varus deformity in patients with osteoporosis. To minimize the risk of ACHA injury during bone exposure, the plate was placed on the latissimus dorsi tendon. The authors reported that the plate’s position did not significantly affect postoperative function or range of motion, with a mean CMS of 71.5. Furthermore, no cases of iatrogenic nerve injury, vascular injury, or AVN were

observed. In comparison, functional outcomes were worse and complication rates were higher in similar fractures and patient characteristics treated with PHLP alone [15].

As a conclusion from the studies in the present review, the anterior position of the second plate could possibly be more dangerous for the humeral head supply.

Another potential drawback of dual plate fixation for PHFs is the possible restriction in range of motion, primarily due to mechanical impingement and, secondly, muscle violation, particularly with anterior or posterior plate placement. In the study by Choi et al., the authors dissected the subscapularis or supraspinatus muscles to position the VA-LCP distal radius plate anteriorly or posteriorly, respectively, as a buttress to prevent anterior-posterior angulation of the humeral head. The muscle tendons were reattached to the plate after its fixation. However, the functional results were excellent with CMS of 90.4 points [13]. Zhang et al. stripped the attachment of pectoralis major for 2–3 cm and repaired it by suturing to the plate or by drilling the humeral cortical bone after fracture reconstruction. If necessary, the subscapularis tendon was also partially released from the lesser tuberosity. The CMS was good – 79.8 [18].

One advantage of the anterior plate, compared to the medial and posterior plates, is that it is easier to place and can serve as a temporary fixation method before the placement of the PHLP [12,16].

The present study has some limitations. First, it was limited by its narrative design, which may have introduced selection bias. Second, the number of included studies was relatively small. Third, the majority of the studies included in the final analysis were retrospective case series, and further research with higher levels of evidence is needed to confirm these findings. However, this study also has several strengths. One strength is the strict inclusion criteria used, which helped minimize potential bias. Another strength is the large total number of patients, which is adequate for a meaningful analysis of the results. Lastly, the mean follow-up period in the included studies is sufficient to objectively assess functional outcomes and detect any subsequent complications.

## Conclusions

Adding a second plate to PHLP fixation for unstable PHFs with medial column insufficiency has shown promising clinical outcomes with a relatively low complication rate, despite the additional soft tissue dissection required. The anterior placement of the secondary plate is less technically demanding and can serve as a temporary reposition tool. However, anterior plating has been associated with a higher risk of AVN compared to medial plating. The variability in techniques and implants used for dual plating complicates drawing definitive conclusions. Moreover, the current evidence is limited, and additional studies with a higher level of evidence are needed to support the efficacy and routine application of the dual plating technique for unstable PHFs.

## Additional information

### Conflict of interest

The author has declared that no competing interests exist.

### Ethical statements

The authors declared that no clinical trials were used in the present study.

The authors declared that no experiments on humans or human tissues were performed for the present study.

The authors declared that no informed consent was obtained from the humans, donors or donors' representatives participating in the study.

The authors declared that no experiments on animals were performed for the present study.

The authors declared that no commercially available immortalised human and animal cell lines were used in the present study.

### Funding

No funding was reported.

### Author contributions

The author solely contributed to this work.

### Author ORCIDs

Lyubomir Rusimov  <https://orcid.org/0009-0000-6868-497X>

### Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

## References

1. Jung WB, Moon ES, Kim SK, Kovacevic D, Kim MS. Does medial support decrease major complications of unstable proximal humerus fractures treated with locking plate?. *BMC Musculoskelet Disord.* 2013;14:102. <https://doi.org/10.1186/1471-2474-14-102>
2. Jung SW, Shim SB, Kim HM, Lee JH, Lim HS. Factors that Influence Reduction Loss in Proximal Humerus Fracture Surgery. *J Orthop Trauma.* 2015;29(6):276-282. <https://doi.org/10.1097/BOT.0000000000000252>
3. McMillan TE, Johnstone AJ. Primary screw perforation or subsequent screw cut-out following proximal humerus fracture fixation using locking plates: a review of causative factors and proposed solutions. *Int. Orthop.* 2018;42(8):1935-1942. <https://doi.org/10.1007/s00264-017-3652-6>
4. Carbone S, Mezzoprete R, Papalia M, Arceri V, Carbone A, Guminia S. Radiographic patterns of osteoporotic proximal humerus fractures. *Eur J Radiol.* 2018;100:43-48. <https://doi.org/10.1016/j.ejrad.2017.12.025>
5. Lim JH, Hwang J, Kim S, Kim MS. Clinical and radiographic results of locking plate with medial support screw in Proximal Humerus fracture - the more, the better?. *BMC Musculoskelet Disord.* 2024;25(1):580. Published 2024 Jul 24. <https://doi.org/10.1186/s12891-024-07700-x>
6. Kim SH, Lee YH, Chung SW, et al. Outcomes for four-part proximal humerus fractures treated with a locking compression plate and an

- autologous iliac bone impaction graft. *Injury*. 2012;43(10):1724-1731. <https://doi.org/10.1016/j.injury.2012.06.029>
7. Wang Q, Sheng N, Huang JT, et al. Effect of Fibular Allograft Augmentation in Medial Column Comminuted Proximal Humeral Fractures: A Randomized Controlled Trial. *J Bone Joint Surg Am*. 2023;105(4):302-311. <https://doi.org/10.2106/JBJS.22.00746>
  8. Hristov S, Visscher L, Winkler J, et al. A Novel Technique for Treatment of Metaphyseal Voids in Proximal Humerus Fractures in Elderly Patients. *Medicina (Kaunas)*. 2022;58(10):1424. <https://doi.org/10.3390/medicina58101424>
  9. Patel R, Brown JR, Miles JW, et al. Preventing varus collapse in proximal humerus fracture fixation: 90-90 dual plating versus endosteal fibular allograft strut. *Arch Orthop Trauma Surg*. 2023;143(8):4653-4661. <https://doi.org/10.1007/s00402-022-04738-1>
  10. Xiao G, Zhang X, Duan A, Li J, Chen J. Impact of augmentation strategy variations on the mechanical characteristics of patients with osteoporotic proximal humerus fractures with medial column instability. *Front Bioeng Biotechnol*. 2024;12:1463047. <https://doi.org/10.3389/fbioe.2024.1463047>
  11. Zhang Y, Wan L, Zhang L, Yan C, Wang G. Reduction and fixation of proximal humeral fracture with severe medial instability using a small locking plate. *BMC Surg*. 2021;21(1):387. Published 2021 Oct 31. <https://doi.org/10.1186/s12893-021-01388-9>
  12. Liu J, Cui P, Wu X, Han L, Wang G, Dong J. Short-term Clinical Outcome of Dual Plate Fixation in the Treatment of Proximal Humerus Fractures with Calcar Comminution. *Orthop Surg*. 2023;15(8):1990-1996. <https://doi.org/10.1111/os.13601>
  13. Choi S, Seo KB, Kwon YS, Kang H, Cho C, Rho JY. Dual plate for comminuted proximal humerus fractures. *Acta Orthop Belg*. 2019;85(4):429-436
  14. Warnhoff M, Jensen G, Dey Hazra RO, Theruvath P, Lill H, Ellwein A. Double plating - surgical technique and good clinical results in complex and highly unstable proximal humeral fractures. *Injury*. 2021;52(8):2285-2291. <https://doi.org/10.1016/j.injury.2021.05.047>
  15. Alqahtani SM, Aljamaan Y, Abusultan A, Alzahrani MM. Dual plate fixation of proximal humerus fractures: Retrospective review and surgical technique. *Shoulder Elbow*. 2023;15(6):641-646. <https://doi.org/10.1177/17585732231158798>
  16. Theopold J, Marquäß B, Fakler J, Steinke H, Josten C, Hepp P. The bicipital groove as a landmark for reconstruction of complex proximal humeral fractures with hybrid double plate osteosynthesis. *BMC Surg*. 2016;16:10. doi:10.1186/s12893-016-0125-6
  17. Park SG, Ko YJ. Medial Buttress Plating for Humerus Fractures With Unstable Medial Column. *J Orthop Trauma*. 2019;33(9):e352-e359. <https://doi.org/10.1097/BOT.0000000000000151>
  18. Zhang Y, Wan L, Zhang L, Yan C, Wang G. Reduction and fixation of proximal humeral fracture with severe medial instability using a small locking plate. *BMC Surg*. 2021;21(1):387. Published 2021 Oct 31. <https://doi.org/10.1186/s12893-021-01388-9>
  19. Wang F, Wang Y, Dong J, et al. A novel surgical approach and technique and short-term clinical efficacy for the treatment of proximal humerus fractures with the combined use of medial anatomical locking plate fixation and minimally invasive lateral locking plate fixation. *J Orthop Surg Res*. 2021;16(1):29. <https://doi.org/10.1186/s13018-020-02094-7>
  20. Seok HG, Park SG. Dual-Plate Fixation for Proximal Humerus Fractures With Unstable Medial Column in Patients With Osteoporosis. *J Orthop Trauma*. 2023;37(10):e387-e393. <https://doi.org/10.1097/BOT.0000000000002645>
  21. Lin SJ, Tsai YH, Yang TY, Shen SH, Huang KC, Lee MS. Medial calcar support and radiographic outcomes of plate fixation for proximal humeral fractures. *Biomed Res Int*. 2015;2015:170283. <https://doi.org/10.1155/2015/170283>
  22. Gardner MJ, Lorich DG, Werner CM, Helfet DL. Second-generation concepts for locked plating of proximal humerus fractures. *Am J Orthop (Belle Mead NJ)*. 2007;36(9):460-465.
  23. 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):185-191. <https://doi.org/10.1097/BOT.0b013e3180333094>
  24. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg*. 2004;13(4):427-433. <https://doi.org/10.1016/j.jse.2004.01.034>
  25. Ponce BA, Thompson KJ, Raghava P, et al. The role of medial comminution and calcar restoration in varus collapse of proximal humeral fractures treated with locking plates. *J Bone Joint Surg Am*. 2013;95(16):e113(1-e113(7. <https://doi.org/10.2106/JBJS.K.00202>
  26. Osterhoff G, Hoch A, Wanner GA, Simmen HP, Werner CM. Calcar comminution as prognostic factor of clinical outcome after locking plate fixation of proximal humeral fractures. *Injury*. 2012;43(10):1651-1656. <https://doi.org/10.1016/j.injury.2012.04.015>
  27. Segarra B, Molina M, Aguilera L. Role of Fibular Allograft in Proximal Humerus Fractures: A Systematic Review. *J Orthop Trauma*. 2022;36(11):e425-e430. <https://doi.org/10.1097/BOT.0000000000002404>
  28. Dasari SP, Kerzner B, Fortier LM, et al. Improved outcomes for proximal humerus fracture open reduction internal fixation augmented with a fibular allograft in elderly patients: a systematic review and meta-analysis. *J Shoulder Elbow Surg*. 2022;31(4):884-894. <https://doi.org/10.1016/j.jse.2021.11.004>
  29. 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 Musculoskelet Disord*. 2019;20(1):511. <https://doi.org/10.1186/s12891-019-2907-3>
  30. Wei Y, Lin T, Liu Y, Chen Z, Zhou C. Fibula allograft with cannulated screw fixation versus ordinary cannulated screw fixation for femoral neck fractures: a 10-year retrospective comparative study. *J Orthop Surg Res*. 2023;18(1):570. <https://doi.org/10.1186/s13018-023-04002-1>
  31. Nie W, Wang Z, Gu F, et al. Effects of fibular strut augmentation for the open reduction and internal fixation of proximal humeral fractures: a systematic review and meta-analysis. *J Orthop Surg Res*. 2022;17(1):322. <https://doi.org/10.1186/s13018-022-03211-4>
  32. Peng CC, Tai TH, Chen CY. Locking Plate Fixation with Calcium Phosphate Bone Cement Augmentation for Elderly Proximal Humerus Fractures-A Single-Center Experience and Literature Review. *J Clin Med*. 2024;13(17):5109. Published 2024 Aug 28. <https://doi.org/10.3390/jcm13175109>
  33. Wanner GA, Wanner-Schmid E, Romero J, et al. Internal fixation of displaced proximal humeral fractures with two one-third tubular plates. *J Trauma*. 2003;54(3):536-544. <https://doi.org/10.1097/01.TA.0000052365.96538.42>

34. Hessmann MH, Korner J, Hofmann A, Sternstein W, Rommens PM. Osteosynthese am proximalen Humerus mittels winkelstabiler Platte oder Doppelplatte: eine vergleichende biomechanische Untersuchung [Angle-fixed plate fixation or double-plate osteosynthesis in fractures of the proximal humerus: a biomechanical study]. *Biomed Tech (Berl)*. 2008;53(3):130-137. <https://doi.org/10.1515/BMT.2008.018>
35. He Y, He J, Wang F, et al. Application of Additional Medial Plate in Treatment of Proximal Humeral Fractures With Unstable Medial Column: A Finite Element Study and Clinical Practice. *Medicine (Baltimore)*. 2015;94(41):e1775. <https://doi.org/10.1097/MD.0000000000001775>
36. He Y, Zhang Y, Wang Y, Zhou D, Wang F. Biomechanical evaluation of a novel dual plate fixation method for proximal humeral fractures without medial support. *J Orthop Surg Res*. 2017;12(1):72. <https://doi.org/10.1186/s13018-017-0573-4>
37. Theopold J, Schleifenbaum S, Müller M, et al. Biomechanical evaluation of hybrid double plate osteosynthesis using a locking plate and an inverted third tubular plate for the treatment of proximal humeral fractures. *PLoS One*. 2018;13(10):e0206349. <https://doi.org/10.1371/journal.pone.0206349>
38. Kotler JA, Zuppke JN, Abraham VM, et al. Biomechanical Analysis of Combined Medial Calcar and Lateral Locked Plating Versus Isolated Lateral Locked Plating of Proximal Humerus Fractures. *J Orthop Trauma*. 2023;37(9):e355-e360. <https://doi.org/10.1097/BOT.0000000000002619>
39. Hettrich CM, Boraiah S, Dyke JP, Neviaser A, Helfet DL, Lorich DG. Quantitative assessment of the vascularity of the proximal part of the humerus. *J Bone Joint Surg Am*. 2010;92(4):943-948. <https://doi.org/10.2106/JBJS.H.01144>