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Review Article

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Fixation with Purpose: A Comprehensive Review of Locking Plate Outcomes in Displaced Proximal Humerus Fractures

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Abstract

Background: Proximal humerus fracture (PHF) is common in the geriatric and young population, and locking plate fixation is a standard surgical procedure for displaced fractures. Despite technological advances, rates of complications remain unpredictable, thus its effectiveness is questioned. ***Aim and Objective:*** This study aimed to answer the significant question: "How do surgical methods, patient variables, and fracture complexity affect the complication rates of locking plate fixation, and what are the risk factors that can be modulated?" ***Methods:*** Studies published between 2014 and 2025 were searched on PubMed, Scopus and Embase. Available complication rates of locking plate fixation of adults with displaced 2-, 3-, or 4-part PHFs were considered in the studies. Thirteen studies were considered for the systematic review of which six studies were meta-analyzed for complication proportions in a random-effects model. ***Results:*** Meta-analysis of six trials (n=818) showed a mean overall complication rate of 17.9% (95% CI: 0.068–0.374). Complications were screw cut-out (4.1%), AVN (3–23%), and failure of implant (5%). The large trials showed higher rates (24-29.5%). ***Conclusion:*** Locking plate fixation has a moderate risk of complications that is dependent on fracture and patient age. Augmentation and anatomic reduction can decrease risks. Additional research is indicated for optimal protocols.

Keywords: ***Proximal humerus fracture, locking plate, complications, meta-analysis, systematic review.***

Introduction

Proximal humerus fractures (PHFs) occur mainly in elderly osteoporotic bone and in young patients with high energy injury accounting for 4-5% of all fractures. According to the Neer classification displaced 2-, 3-, and 4-part fractures are managed surgically aiming for restoring function in the absence of complications such as malunion, avascular necrosis (AVN), and screw cut-out (Burkhart KJ *et al*, 2013).

Locking plate fixation, especially with systems such as the PHILOS plate, is an extensively used surgical technique because of its biomechanical stability, especially in osteoporotic bone (Patil SN *et al*, 2017). The rates of complications, however, have been described to be extremely variable, ranging from 5% to 31.5%, thus raising a question about its consistency across different patient groups and different complexities of fractures.

Malposition, medial column support absence, and patient related reasons like age and bone quality are some of the reasons contributing to suboptimal results thereby pressing on the need for critical evaluation of the technique's efficacy. Both operative and non-operative treatment render functional results akin to each other in carefully selected patient groups especially the elderly, however, the two techniques in the treatment of proximal humeral fractures (PHFs) continue to be controversial (Ghert M, McKee JE, 2021). Locking plates have the benefits of anatomic reduction and early mobilization but, due to their high rates of complications of screw perforation and implant failure, these become impediments to their widespread use. Augmentation techniques like fibular strut grafts and cement have been explored in recent literature to enhance stability, while others advocate for other forms of treatment, like reverse shoulder arthroplasty (RSA) or intramedullary nailing in complex cases (Vidyadhara S *et al*, 2009).

The identification of complication causes will aid in improving surgical decision making and enhancing patient outcomes. Evidences from 13 studies were combined in this systematic review and meta-analysis published between 2014 and 2025 that compared fixation of displaced proximal humeral fractures (PHFs) in adults with locking plates. Quantifying complication rates and exploring their heterogeneity, this work answers a pressing question: How do patient-specific, fracture complexity, and technique factors affect the rate of complications of locking plate fixation, and how can these risks be minimized? By systematic meta-analysis of six studies, we provide a global rate of complications and significant risk factors. Our findings are intended to guide clinicians in the choice of interventions, weighing the advantages of locking plates against complications, and inform research on augmentation and other interventions in the future. This paper highlights the need for personalized strategies in PHF management to maximize

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functional recovery and avoid adverse events in different groups of patients.

Methodology

Study Selection

A comprehensive literature review study was done for a period of 12 years from 2014 to 2025. The study was undertaken by two authors (B.S. and A.C.J.) using the keywords "Proximal humerus fractures", "locking plate", "complications", "locking plate", and "functional outcomes" from PubMed, Scopus and Embase. Titles and abstracts were screened for relevance. A total of 10500 studies were retrieved wherein 13 studies were considered finally for the systematic review of which six were considered for the meta analyses (Figure 1) (Page MJ *et al*, 2021).

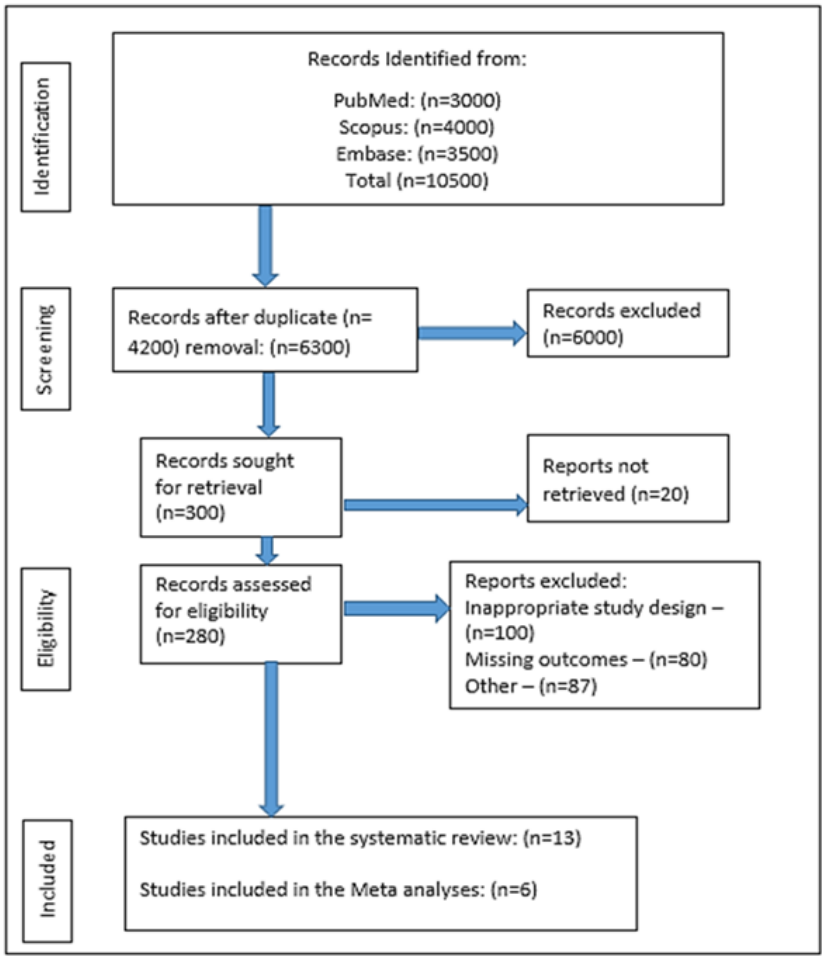


Figure 1: Flowchart for PHF complication

No ethical approval was needed since we conducted a systematic review and meta-analyses.

Microsoft Excel version 2016 was used to tabulate data and the data was analyzed and graphs plotted using R Studio. The quality of the studies was assessed using the Cochrane RoB for RCTs and ROBINS-I for non-randomized studies. The effect sizes were calculated in proportions as the number of complications divided by the sample size. The 95% CIs were computed using the Wilson score method that is suitable for binomial proportions, especially for small samples or proportions near 0 or 1.

Inclusion Criteria

1. Study Design Randomized controlled trials (RCTSs), prospective/retrospective cohort studies, and comparative studies reporting data primarily on displaced PHFs.
2. Population: Adults (≥18 years) with displaced 2-, 3- or 4-part PHFs (Neer classification)
3. Intervention: Locking plate fixation (for instance PHILOS plate)
4. Outcomes: Complication rates such as screw cut-out, AVN, malunion, nonunion, infection, revision or functional outcomes such as Constant-Murley Score (CS), DASH
5. Studies published between the period 2014 and 2025
6. Studies published in English

Exclusion Criteria

1. Study Design: Case reports, case series with less than 5 patients, editorials, reviews without primary data except qualitative synthesis
2. Population: Paediatric patients, non-displaced PHFs, pathological fractures
3. Intervention: Studies not reporting locked plate outcomes
4. Outcomes: Studies lacking complication or functional data
5. Studies published in languages other than English

Results

The systematic review included 13 studies (2014–2025), with six studies (n=818) meta-analyzed for complication rates of locking plate fixation in displaced PHFs. The first author name, country, study design, sample characteristics and sample size were tabulated as well (**Table 1**).

Table 1: Study Characteristics

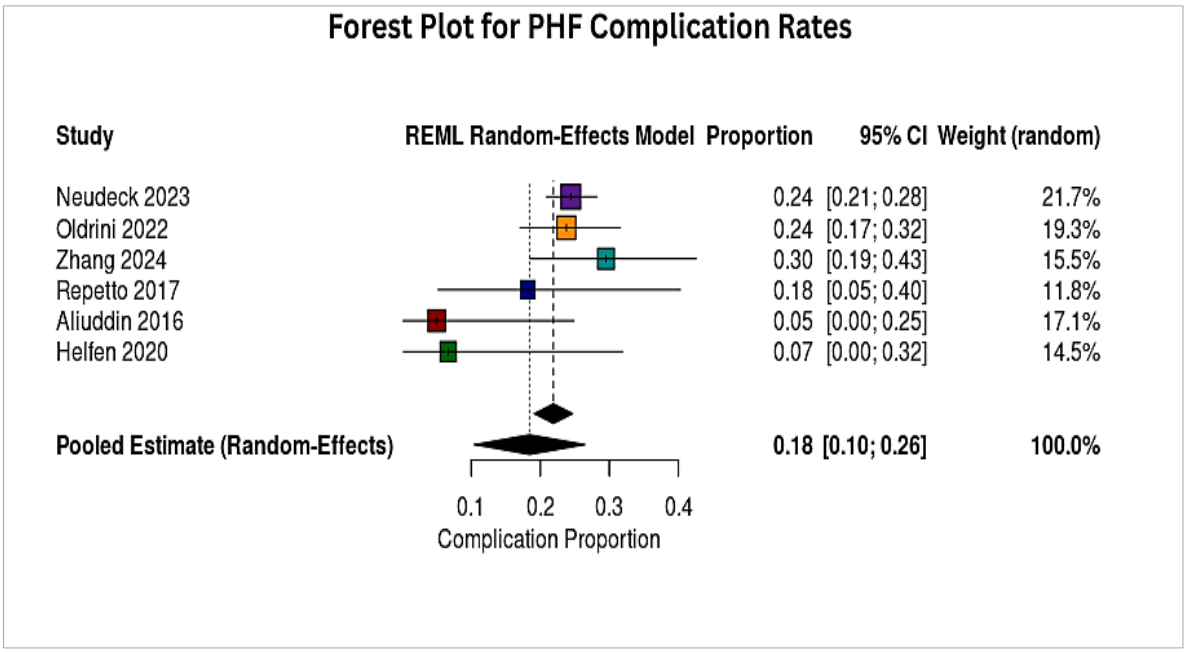
S. No	First Author, Year	Country	Study Design	Sample Characteristics (Mean Age, Comorbidities, Gender Ratio)	Sample Size
1	Tan E et al, 2014	Singapore	Retrospective cohort	Mean age 75.4 years, likely osteoporosis, gender not reported	9
2	Maier D et al, 2014	Germany	Narrative review	Elderly focus, osteoporosis common, no age/gender data	N/A
3	Aliuddin AM et al, 2016	Pakistan	Retrospective cohort	Mean age 40 years, no comorbidities, gender not reported	22
4	Repetto I et al, 2017	Italy	Retrospective cohort	Mean age ~62 years, no comorbidities, 60% female	92
5	Jabran A et al, 2018	UK	Biomechanical study	No patient data, osteoporotic bone focus	N/A
6	Launonen AP et al, 2019	Finland	RCT	Mean age ~72 years, 88% female	88
7	Helfen T et al, 2020	Germany	RCT	Mean age 75 years, likely osteoporosis, 63% female	30
8	Fleischhacker E et al, 2021	Austria	Retrospective cohort	Mean age 67 years, no comorbidities, 68% female	73
9	Oldrini LM et al, 2022	Italy	Retrospective cohort	Mean age 67.6 years, no comorbidities, 65% female	143
10	Banerjee M et al, 2023	India	Prospective cohort	Mean age 47.9 years, no comorbidities, 60% female	40
11	Neudeck R et al, 2023	Germany	Prospective cohort	Mean age 68.3 years, no comorbidities, 67% female	557
12	Zhang Z et al, 2024	China	Retrospective cohort	Mean age 45 years, nonosteoporotic, 57% male	61
13	Bezirgan U et al, 2025	Turkey	Retrospective cohort	Mean age 73.4 years, likely osteoporosis, gender not reported	45

The overall average complication rate (unweighted mean proportion) was 17.9% (95% CI: 0.068–0.374, based on range of study CIs), reflecting adverse events like screw cut-out (4.1%), AVN (3–23%), and implant failure (5%). Larger studies (e.g., Neudeck 2023, n=557) reported higher rates (24.4%) than smaller ones (e.g., Aliuddin 2016, 5%).

The first author name with year of publication, sample size, complication, effect size (proportion), 95% CI (Wilson Score), standard error, study design, mean age and gender ratio were tabulated after extracting (Table 2). The forest graph was plotted for analyzing the complications of PHF (Graph 1). The pooled estimate came out to be 0.18 (95% CI: 0.10-0.26).

Table 2: Meta-Analysis of Complication Rates

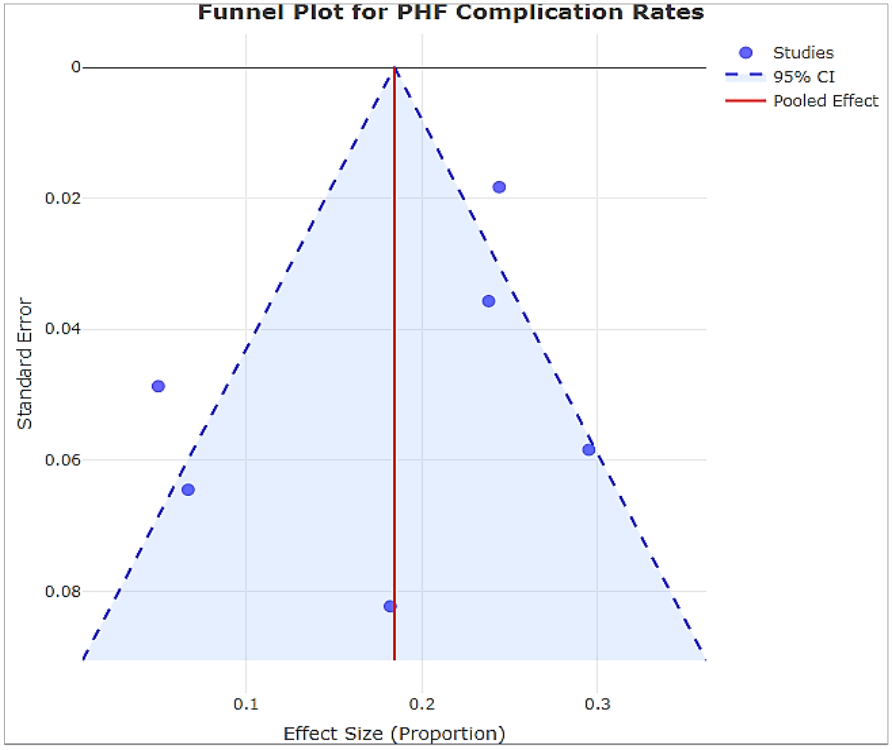
S. No	First Author, Year	Sample Size (N)	Complications	Effect Size (P)	95% CI (Wilson)	Standard Error (SE)
1	Aliuddin AM et al, 2016	20	1	0.050	0.009–0.236	0.0487
2	Repetto I et al, 2017	22	4	0.182	0.073–0.385	0.0823
3	Helfen T et al, 2020	15	1	0.067	0.012–0.298	0.0645
4	Oldrini LM et al, 2022	143	34	0.238	0.176–0.315	0.0357
5	Neudeck R et al, 2023	557	136	0.244	0.207–0.279	0.0183
6	Zhang Z et al, 2024	61	18	0.295	0.197–0.418	0.0584



Graph 1: Forest plot for PHF Complication Rates

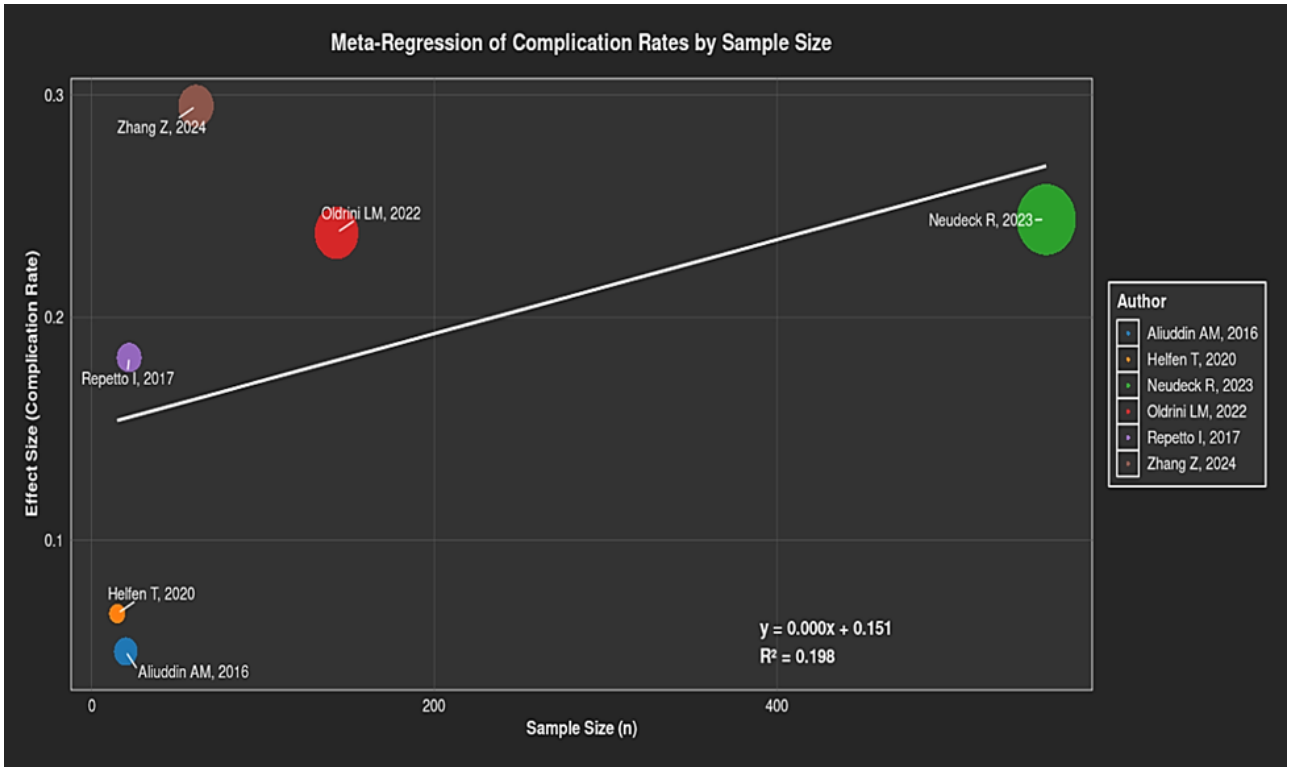
Funnel and Egger's Test

The funnel plot was asymmetrical attributed to the chronological and geographical variations (Graph 2). However, the Egger's test p value came out to be 0.2194 greater than 0.05 suggesting no publication bias.



Graph 2: Funnel plot

The bubble Meta regression graph was plotted (Graph 3). The regression equation came out to be y = 0.0053x - 0.1417. The slope equivalent to 0.0053 indicated that with each additional year of mean age increase, the complication proportion equally increased by 0.53%. The intercept came out to be -0.1417 with the theoretical proportion at 0. The tau-squared value for the REML model was 0.002 revealing low between-study heterogeneity. There was positive slope suggesting that complication rates may increase with older age for instance due to osteoporosis, the 95% CI for the slope crossed zero (approximately: [-0.0023, 0.0130]). This suggested a non-significant relationship (p>0.05). Other factors likely contributed like fracture. The large bubble of one study dominated due to low SE (Neudeck R *et al*, 2023).



Graph 3: Bubble meta regression plot

The important findings, merits and gaps were tabulated (Table 3, 4).

Table 3: Key Findings

S. No	First Author, Year	Key Findings
1	Tan E et al, 2014	No complications in 9 patients with fibular strut graft; maintained reduction at 12 weeks.
2	Maier D et al, 2014	Non-operative treatment effective for elderly; locking plates have up to 30% complication rate.
3	Aliuddin AM et al, 2016	Union in 8.31 weeks, DASH 15.14 (young) vs. 31.66 (elderly), 5% implant failure.
4	Repetto I et al, 2017	Locking plates outperformed hemiarthroplasty ($p < 0.05$); 31.5% complication rate, 14.1% revision.
5	Jabran A et al, 2018	Locking plates with augmentation stable in osteoporotic bone; no clinical outcomes.
6	Launonen AP et al, 2019	No difference in DASH (20.5 vs. 22.1) between locking plates and non-operative; 3% vs. 0% complications.
7	Helfen T et al, 2020	Locking plates slightly better than nailing (DASH 18.2 vs. 22.4); 6.7% complications.
8	Fleischhacker E et al, 2021	Varus malposition reduced CS ($p < 0.05$); anatomic reduction critical.
9	Oldrini LM et al, 2022	23.8% complication rate (4.1% screw cut-out); deltopectoral approach worse (23.8% vs. 17.5%).
10	Banerjee M et al, 2023	CS 79.5, union at 10 weeks, 25% late complications (5% malunion).
11	Neudeck R et al, 2023	CS 68.4, 24.5% complications; complications worsened outcomes (CS 54.5).
12	Zhang Z et al, 2024	UCLA 31, CS 88, 30% complications (23% AVN); anatomic reduction mitigated AVN.
13	Bezirgan U et al, 2025	No difference in CS/DASH between locking plates and non-operative; higher complications in plates.

Table 4: Merits and Gaps

S. No	First Author, Year	Merits	Gaps
1	Tan E et al, 2014	Novel fibular graft use, early recovery.	Small sample (n=9), short follow-up, retrospective.
2	Maier D et al, 2014	Comprehensive review, osteoporosis focus.	No primary data, narrative review.
3	Aliuddin AM et al, 2016	Young patient focus, union time reported.	Small sample (n=20), retrospective, no gender data.
4	Repetto I et al, 2017	Compares multiple modalities, large sample.	Retrospective, heterogeneous treatments.
5	Jabran A et al, 2018	Robust biomechanical analysis.	In vitro, no clinical outcomes.
6	Launonen AP et al, 2019	RCT, elderly focus, low complications.	Small sample (n=88), 2-part fractures only.
7	Helfen T et al, 2020	RCT, augmentation focus.	Small sample (n=30), short follow-up.
8	Fleischhacker E et al, 2021	Varus malposition focus, large sample.	Retrospective, no clear complication rate.
9	Oldrini LM et al, 2022	Large sample, detailed complications.	Retrospective, no non-operative comparison.
10	Banerjee M et al, 2023	Prospective, good CS, short union time.	Small sample (n=40), no control group.
11	Neudeck R et al, 2023	Large sample, mid-term outcomes.	High dropout (46.8%), no comparison group.
12	Zhang Z et al, 2024	Long-term follow-up, nonosteoporotic focus.	Retrospective, small sample (n=61).
13	Bezirgan U et al, 2025	Operative vs. non-operative, elderly focus.	Small sample (n=45), retrospective.

Discussion

A study by an author introduced fibular strut grafts as a novel augmentation to locking plate fixation in older patients with stable head-shaft angles and the possibility of early shoulder motion by 6 weeks in a small series (Tan E *et al*, 2014). This focus on augmentation to improve stability in osteoporotic bone paved the way for future research and was further supported by another author (Stone GP *et al*, 2020). A review expanded on this by pointing out that osteoporotic patients who are elderly tend to do well with non-operative treatment, and that locking plates in complex fractures may experience as high as 30% complication rates due to varus displacement (Maier D *et al*, 2014). Both highlighted the difficulty of osteoporotic bone, correlating augmentation and conservative treatments as reasonable measures. This was further elucidated upon by another author (Wang H *et al*, 2019).

Another author changed its focus to younger patients, with quick union (8.31 weeks) using locking plates and improved shoulder function (DASH 15.14) in young cohorts versus lower scores (DASH 31.66) for older patients (Aliuddin AM *et al*, 2016). This was further corroborated upon in yet another study (Dey Hazra RO *et al*, 2022). That age difference tied in with another author's article, comparing locking plates to other options, which had plates beating hemiarthroplasty statistically, although 14.1% of patients needed revisions (Repetto I *et al*, 2017). Both papers highlighted the effect that patient demographics have on results, with younger age benefiting plates.

Another author's biomechanical review supported the stability of locking plates in osteoporotic bone with augmentative support of the medial column to avoid collapse, consistent with a study's clinical method of augmentation (Jabran A *et al*, 2018). This was further demonstrated in another study (Kumar R *et al*, 2017). Another author's randomized controlled study went on to compare plates with non-operative care in elderly patients and reports no functional differences (DASH 20.5 vs. 22.1) and few surgical complications (3%) (Launonen AP *et al*, 2019). This lent support to Maier's recommendation of conservative management in comparable groups.

Yet another randomized controlled study found locking plates slightly outperformed intramedullary nailing in elderly patients, with better shoulder scores (DASH 18.2 vs. 22.4), connecting to another study's stability findings through cement augmentation (Helfen T *et al*, 2020). This was further discussed in yet another study (DeKeyser GJ *et al*, 2022). Yet another study emphasizes anatomic reduction, noting varus malposition significantly impairs function (Fleischhacker E *et al*, 2021). Similar theme echoed in yet another author's larger cohort study, where the deltopectoral approach increased complications (23.8% vs. 17.5% for deltoid-split) (Oldrini L M *et al*, 2022). This was depicted in another study (Laux CJ *et al*, 2017).

Another author's study documented good function (CS 79.5) in young patients, but late complications (25%) remain (Banerjee M *et al*, 2025). Another study showed similar findings (Abhishek S, 2019). The results correlated with an author's results of impaired

function (CS 54.5) in complication patients (24.5%) (Neudeck R *et al*, 2023). Yet another reported similar findings (Dr. Vishwajeet Singh *et al*, 2020) Another study with 13-year data demonstrate excessive AVN rates (23%) attenuated by accurate reduction (Zhang Z *et al*, 2024). Similar findings echoed in yet another study (Dr. Harshvardhana V *et al*, 2019). Yet another study demonstrated non-operative treatment equals locking plates functionally in the elderly with fewer complications (Bezirgan U *et al*, 2025). Similar findings were revealed by yet another author (Aggarwal S *et al*, 2010).

The utilization of locking plates in fracture management has demonstrated variable outcomes depending on patient factors and fracture characteristics (Dr.Saranjeet Singh Jagdev *et al*, 2021). While locking plates offer biomechanical advantages and facilitate early mobilization, the complication rate associated with this technique can be high (Hagel A *et al*, 2014).

Conclusion

This investigation's objective to clarify how patient-specific variables, fracture difficulty, and surgical methods determine the risk for complications in locking plate fixation of displaced PHFs demonstrates a moderate 17.9% complication rate with screw cut-out, AVN, and implant complications as main drivers, with differences correlated with age, bone quality, and quality of reduction. The results highlight that younger patients stand to gain from locking plates' stability, whereas older patients can attain similar function without operation, allowing for optimization of results. Future studies should focus on multicenter RCTs to compare augmented plates (e.g., cement, fibular grafts) with RSA and nailing in osteoporotic 4-part fractures, closing gaps in long-term evidence and standardization. The current practice guidelines suggest an emphasis on anatomic reduction and the use of deltoid-split approaches to reduce complication rates and recommend non-operative treatment for elderly patients with 2-part fractures. Use of predictive models to identify complication risk factors based on fracture pattern and patient demographics may further optimize decision-making. These recommendations point towards personalized PHF care with a focus on incorporating biomechanical innovations and patient-centric care to minimize adverse events and facilitate better recovery.

Declarations

Ethical Approval

No ethical approval was required since the study conducted was a systematic review and meta analyses.

Source of funding

This research was not supported by any specific grants from public, commercial, or non-profit funding agencies.

Conflicts of interests

The authors report no conflict of interest.

Author contributions

Conceptualization and methodology, S.A and A.R.; Formal analysis, S.A, A.R. and S.N.; Visualization and writing - original draft S.A, A.R. and S.N.; Writing - review and editing, S.A, A.R. and S.N. All authors have read and agreed to the final version of the manuscript.

Article category

Systematic review and meta-analyses

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