

## Research Article

# Does Surgical Technique Influence Radial and Axillary Nerve Injury After Long PHILOS Plate Fixation in Proximally Extending Humeral Shaft Fractures?

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## ABSTRACT

**Background:** Proximally extending humeral shaft fractures (PEHSFs) pose significant surgical challenges due to the complex fracture anatomy and proximity to the axillary and radial nerves. While long proximal humeral internal locking system (PHILOS) plates are commonly used, the impact of surgical technique and implant length on neurological safety remains unclear. This study aimed to evaluate the relationship between surgical technique (Open Reduction-Internal Fixation [ORIF] versus Minimally Invasive Plate Osteosynthesis [MIPO]) and the occurrence of iatrogenic nerve palsy in patients with PEHSFs.

**Methods:** A retrospective study was conducted on 18 patients treated with long PHILOS plates for PEHSFs between January 2022 and January 2025. Patients were stratified into ORIF (n=10) and MIPO (n=8) groups. Axillary and radial nerve functions were assessed preoperatively, immediately postoperatively, and at the final follow-up. The impact of surgical approach, intraoperative nerve exploration, and plate length (9-, 11-, and 12-hole) on neurological outcomes was analyzed.

**Results:** The overall rate of immediate postoperative nerve palsy was 16.7% for the axillary nerve and 22.2% for the radial nerve. After a median follow-up of 8 months, persistent nerve palsy was observed in 3 patients (16.7%). Although the difference did not reach statistical significance (p=0.147), all permanent nerve injuries occurred in the ORIF group (30%), whereas no long-term deficits were observed in the MIPO group (0%). A statistically significant association was identified between plate length and persistent nerve palsy (p=0.002); all cases of permanent nerve palsy were associated with the use of 12-hole plates.

**Conclusion:** While MIPO demonstrated a favorable safety profile with no permanent nerve injuries, the use of 12-hole long locking plates was significantly associated with persistent neurological deficit in PEHSFs. These findings suggest that adopting soft-tissue-sparing techniques and selecting the shortest implant capable of providing adequate stability may reduce the risk of iatrogenic nerve injury

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## Introduction

Humeral shaft fractures exhibit a bimodal distribution and are becoming increasingly common (Bergdahl et al., 2016; Younis et al., 2024). Proximally extending humeral shaft fractures (PEHSFs) represent a more complex subgroup, as the fracture line spans a broad segment of the bone and lies in close proximity to intricate neurovascular structures (Cho et al., 2023). For the purposes of this study, PEHSFs were considered fractures extending into the proximal third of the humerus. In patients with high functional demands, the need for early mobilization and reliable union often favors surgical fixation. While intramedullary nailing is a potential option, it is frequently less preferred in PEHSFs due to difficulties in establishing a safe proximal entry point and limitations in controlling the proximal fragment (Boadi et al., 2024). Consequently, fixation with long proximal humeral internal locking system (PHILOS) plates has become a widely accepted treatment strategy (Yang et al., 2021).

Fixation with long plates can be performed using either Open Reduction-Internal Fixation (ORIF) or Minimally Invasive Plate Osteosynthesis (MIPO) (Jiamton et al., 2024).

ORIF offers the advantage of direct visualization and precise anatomical reduction but requires extensive dissection, which may increase the risk of soft-tissue injury (Esmailiejah et al., 2015). In contrast, MIPO preserves the biological environment through limited soft-tissue disruption (Yang et al., 2021; Aksu et al., 2012), although the indirect reduction technique and restricted visualization may introduce specific challenges in identifying neurovascular structures (Jiamton et al., 2024). Importantly, the current literature provides limited comparative evidence regarding which technique is safer with respect to neurological complications in PEHSFs, highlighting a notable gap in knowledge (Yang et al., 2021; Esmailiejah et al., 2015).

Neurological risk zones are particularly relevant during the application of long locking plates, with the axillary nerve being vulnerable proximally and the radial nerve distally. The axillary nerve curves around the surgical neck of the humerus, placing it at potential risk during proximal plate positioning and screw fixation (Saran et al., 2010). Distally, the radial nerve courses along the posterior humeral surface and penetrates the lateral intermuscular septum, where it may be susceptible to traction or entrapment, particularly during blind plate passage or distal screw insertion (Contreras et al., 2022; Rocchi et al., 2016; Zhang et al., 2024; Lietai., 2013).

Although minimally invasive plate osteosynthesis offers biological advantages, current literature suggests that humeral MIPO does not involve universally defined safe corridors, but rather region-specific anatomical danger zones (Zlotolow et al., 2006; Carlan et al., 2007; Contreras et al., 2022). Accordingly, various surgical approaches—including anterior and lateral techniques—have been described, and the optimal approach remains a subject of debate depending on fracture location, fracture extension, and the anticipated nerve at risk (Tubbs et al., 2001).

Given these anatomical and technical considerations, the impact of the chosen surgical technique on iatrogenic nerve injury remains unclear. The aim of this study was to evaluate the relationship between surgical technique (ORIF versus MIPO) using long PHILOS plates and the occurrence of iatrogenic axillary and radial nerve palsy in patients with proximally extending humeral shaft fractures.

## Materials and Methods

This retrospective study included patients who underwent surgical fixation for PEHSFs between January 2022 and 2025 in our orthopedic department. The study was performed in accordance with the Declaration of Helsinki and was approved by the Institutional Ethics Committee (Approval No: E1-22-2901). Patients aged 18 years or older who were treated with plate fixation for a PEHSF and who had preoperative and postoperative radiographs with a minimum clinical and radiological follow-up of six months were eligible for inclusion. All surgeries were performed by the same experienced orthopedic surgical team. Exclusion criteria included open or pathological fractures; polytrauma (Injury Severity Score >15); ipsilateral upper-extremity fractures; and fractures extending distally into the elbow joint. Furthermore, patients with documented preoperative radial or axillary nerve deficits were excluded to specifically isolate iatrogenic injuries. Patients who had previously undergone any surgical procedure on the same upper limb, as well as those with neurological or neuromuscular disorders that could affect upper-limb nerve function (e.g., peripheral neuropathy, brachial plexus pathology, motor neuron diseases) were also excluded. In addition, patients with fewer than six months of clinical or radiological follow-up were not included in the study. A total of 23 patients were initially assessed for eligibility, of whom 5 were excluded based on the predefined exclusion criteria, resulting in a final study cohort of 18 patients.

All procedures were performed under general anesthesia in the beach-chair position with fluoroscopic guidance. ORIF was performed through the deltopectoral approach, whereas MIPO was achieved via small anterolateral incisions (Jiamton et al., 2024; Rancan et al., 2010; Zlotolow et al., 2006). In the MIPO group, the plate was slid submuscularly from proximal to distal, ensuring the distal incision remained anterior to the spiral groove to minimize radial nerve risk (Jiamton et al., 2024; Wang et al., 2025). Long PHILOS plates with 9, 11, or 12 holes on the plate body were positioned along the lateral humeral cortex and secured using locking screws. When necessary, particularly in the ORIF group or complex MIPO cases, the axillary and radial nerves were identified and protected during exposure. Intraoperative identification and protection of the axillary and radial nerves were performed when predefined clinical or intraoperative risk factors were present. These included fracture patterns associated with an increased risk of nerve proximity or entrapment, difficulty in achieving or maintaining satisfactory reduction, and direct visualization requirements during plate positioning. The decision was based on intraoperative findings rather than surgeon preference.

Postoperatively, the operated side was immobilized in a standard shoulder sling. Passive range of motion and pendulum exercises were initiated on the first postoperative day as tolerated. Active mobilization was delayed until the 4th-to-6th week, contingent upon radiographic evidence of callus formation. In the event of immediate postoperative neurological deficits, a conservative management protocol was adopted, presuming neuropraxia. This regimen included observation, B-complex vitamin supplementation, and functional

splinting to prevent contractures. Electromyography (EMG) and surgical exploration were reserved for cases showing no clinical recovery after three months (Rocchi et al., 2016). Persistent nerve palsy was defined as a motor and/or sensory deficit related to the involved nerve that persisted at the final follow-up visit after at least 6 months of clinical follow-up, as determined by clinical examination. Patients with persistent palsy were followed clinically according to the clinical course. Routine postoperative ultrasonography was not performed; however, EMG was obtained during follow-up to evaluate neural recovery and guide further management.

Demographic data were collected from the hospital's electronic medical records, and radiological images used for analysis were obtained from the Sarus Picture Archiving and Communication System (Teknoritma, Ankara, Türkiye). Postoperative follow-up notes were reviewed to assess clinical and neurological outcomes, and operative reports were examined to determine the type of surgical approach and plate length used during fixation. Demographic characteristics (age, sex, and side), clinical variables (mechanism of trauma, time from admission to surgery, and postoperative hospitalization), and surgical parameters (ORIF or MIPO technique, plate length, and intraoperative exploration of the axillary and radial nerves) were recorded. Neurological assessments evaluating motor strength (specifically wrist/finger extension and deltoid function) and sensory deficits were performed at each outpatient follow-up visit, and long-term nerve recovery was determined based on the clinical findings of the final examination. Fractures were classified using the AO/OTA classification system, which categorizes humeral fractures into simple (type 12A), wedge (type 12B), and complex or multifragmentary patterns (type 12C) (Younis et al., 2024; Marmor et al., 2022). In fractures extending toward the proximal humeral segments, the Neer classification was also applied, dividing the proximal humerus into four parts based on displacement of more than 1 cm or angulation exceeding 45°. Fractures that did not extend to the humeral neck were classified as Neer Type 0 (Marmor et al., 2022). Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Normality was evaluated using both visual and analytical methods, and only age demonstrated a normal distribution. Therefore, age was reported as mean  $\pm$  standard deviation, while skewed continuous variables were expressed as median (interquartile range) and minimum–maximum values. Categorical variables were presented as frequencies and percentages. Student's t-test was used for normally distributed variables, the Mann–Whitney U test for skewed variables, and the  $\chi^2$  test for categorical comparisons; Fisher's exact test was applied when  $\chi^2$  assumptions were not satisfied. A p-value < 0.05 was considered statistically significant.

## Results

Among the 18 patients who underwent plate fixation for PEHSFs and were included in the study, the mean age was  $63.28 \pm 14.19$  years (range, 41–94 years), and 13 patients (72.2%) were female. The right side was affected in 11 patients (61.1%), and the most common injury mechanism was simple fall (66.7%). The median follow-up period for the study was 8 months (range, 6 to 26 months). The median time from injury to surgery was 3 days (range, 1–20), and the median total hospital stay was 4.5 days (range, 2–28). ORIF was performed in 10 patients (55.6%), while MIPO was performed in 8 patients (44.4%). Intraoperative axillary nerve exploration was carried out in 10 patients (55.6%), whereas radial nerve exploration was performed in 16 patients (88.9%). Long PHILOS plates of 9-hole, 11-hole, and 12-hole length were utilized in 9 (50%), 5 (27.8%), and 4 (22.2%) patients, respectively (see Table 1). Immediate postoperative axillary nerve palsy occurred in 3 patients (16.7%), and immediate postoperative radial nerve palsy in 4 patients (22.2%). As demonstrated in Table 2, a comprehensive analysis was conducted to investigate potential disparities between patients who did and did not experience immediate postoperative axillary palsy. The analysis revealed that there were no statistically significant differences ( $p > 0.05$  for each) in terms of age, sex, side, injury mechanism, AO/OTA or Neer type, time to surgery, hospital stay, surgical approach, or plate length (Table 2). In a similar manner, immediate postoperative radial nerve palsy exhibited no significant correlation with demographic or operative variables ( $p > 0.05$  for each) (Table 3).

**Table 1.** Demographic and clinical characteristics of the study population

Variables		Number of Patients (%) (n=18)
Age (years)		63.28 ± 14.191
Sex	Female	13 (72.2%)
	Male	5 (27.8%)
Side	Right	11 (61.1%)
	Left	7 (38.9%)
Injury Mechanism	Simple Fall	12 (66.7%)
	Fall from High	1 (5.6%)
	Vehicle Accident	5 (27.8%)
AO/OTA Classification (Type 12)	Type 12-A1	4 (22.2%)
	Type 12-A2	0
	Type 12-A3	0
	Type 12-B1	5 (27.8%)
	Type 12-B2	1 (5.6%)
	Type 12-B3	4 (22.2%)
	Type 12-C1	3 (16.7%)
	Type 12-C2	0
	Type 12-C3	1 (5.6%)
Neer Classification (Fractures not extending to humeral neck were defined as Type 0)	Type 0	6 (33.3%)
	Type 1	6 (33.3%)
	Type 2	4 (22.2%)
	Type 3	1 (5.6%)
	Type 4	1 (5.6%)
Time from Admission to Surgery (days)		3 (3) (1-20)
Postoperative Hospitalization (days)		4.5 (3) (2-28)
Surgical Approach	ORIF	10 (55.6%)
	MIPO	8 (44.4%)
Intraoperative Axillary Nerve Exploration	Yes	10 (55.6%)
	No	8 (44.4%)
Intraoperative Radial Nerve Exploration	Yes	16 (88.9%)
	No	2 (11.1%)
PHILOS Plate Length	9	9 (50%)
	11	5 (27.8%)
Immediate Postoperative Axillary Nerve Palsy	12	4 (22.2%)
	No	15 (83.3%)
Immediate Postoperative Radial Nerve Palsy	Yes	3 (16.7%)
	No	14 (77.8%)
Follow-up (months)		8 (6) (6-26)
Final Follow-up Axillary Nerve Palsy	No	17 (94.4%)
	Yes	1 (5.6%)
Final Follow-up Radial Nerve Palsy	No	16 (88.9%)
	Yes	2 (11.1%)

**Table 2.** Postoperative axillary nerve palsy in patients treated with long PHILOS plates

		Immediate Postoperative Axillary Nerve Palsy		P
		No (n=15)	Yes (n=3)	
Age (years)		63.07 ± 14.484	64.33 ± 15.535	0.893
Sex	Female	10 (76.9%)	3 (23.1%)	0.522
	Male	5 (100%)	0	
Side	Right	8 (72.7%)	3 (27.3%)	0.245
	Left	7 (100%)	0	
Injury Mechanism	Simple Fall	9 (75%)	3 (25%)	0.407
	Fall from High	1 (100%)	0	
	Vehicle Accident	5 (100%)	0	
AO/OTA Classification (Type 12)	Type 12-A1	4 (100%)	0	0.844
	Type 12-B1	4 (80%)	1 (20%)	
	Type 12-B2	1 (100%)	0	
	Type 12-B3	3 (75%)	1 (25%)	
	Type 12-C1	2 (66.7%)	1 (33.3%)	
	Type 12-C2	1 (100%)	0	
	Type 12-C3	1 (100%)	0	
Neer Classification (Fractures not extending to humeral neck were defined as Type 0)	Type 0	5 (83.3%)	1 (16.7%)	0.803
	Type 1	4 (66.7%)	2 (33.3%)	
	Type 2	4 (100%)	0	
	Type 3	1 (100%)	0	
	Type 4	1 (100%)	0	
Time from Admission to Surgery (days)		3 (3) (1-20)	3 (1-7)	0.912
Postoperative Hospitalization (days)		4 (3) (2-28)	5 (2-6)	0.738
Surgical Approach	ORIF	8 (80%)	2 (20%)	0.588
	MIPO	7 (87.5%)	1 (12.5%)	
Intraoperative Axillary Nerve Exploration	Yes	7 (70%)	3 (30%)	0.216
	No	8 (100%)	0	
PHILOS Plate Length	9	8 (88.9%)	1 (11.1%)	0.803
	11	4 (80%)	1 (20%)	
	Yes	3 (75%)	1 (25%)	

ORIF: Open Reduction Internal Fixation; MIPO: Minimally Invasive Plate Osteosynthesis

P: statistical significance value, ORIF: Open Reduction Internal Fixation; MIPO: Minimally Invasive Plate Osteosynthesis

**Table 3.** Postoperative radial nerve palsy in patients treated with long PHILOS plates

		Immediate Postoperative Radial Nerve Palsy		P
		No (n=15)	Yes (n=3)	
Age (years)		63.07 ± 14.746	64 ± 14.071	0.912
Sex	Female	9 (69.2%)	4 (30.8%)	0.278
	Male	5 (100%)	0	
Side	Right	9 (81.8%)	2 (18.2%)	0.515
	Left	5 (71.4%)	2 (28.6%)	
Injury Mechanism	Simple Fall	10 (83.3%)	0.155	0.155
	Fall from High	0	1 (100%)	
	Vehicle Accident	4 (80%)	1 (20%)	
AO Classification (Type 12)	Type 12-A1	3 (75%)	1 (25%)	0.547
	Type 12-B1	5 (100%)	0	
	Type 12-B2	1 (100%)	0	
	Type 12-B3	2 (50%)	2 (50%)	
	Type 12-C1	2 (66.7%)	1 (33.3%)	
	Type 12-C3	1 (100%)	0	
Neer Classification (Fractures not extending to humeral neck were defined as Type 0)	Type 0	5 (83.3%)	1 (16.7%)	0.243
	Type 1	4 (66.7%)	2 (33.3%)	
	Type 2	4 (100%)	0	
	Type 3	0	1 (100%)	
	Type 4	1 (100%)	0	
Time from Admission to Surgery (days)		3 (3) (1-20)	3.5 (5) (1-7)	0.959
Postoperative Hospitalization (days)		4 (3) (2-28)	6 (5) (2-8)	0.505
Surgical Approach	ORIF	7 (70%)	3 (30%)	0.588
	MIPO	7 (87.5%)	1 (12.5%)	
Intraoperative Axillary Nerve Exploration	Yes	12 (75%)	4 (25%)	0.595
	No	2 (100%)	0	
PHILOS Plate Length	9	8 (88.9%)	1 (11.1%)	0.295
	11	4 (80%)	1 (20%)	
	Yes	2 (50%)	2 (50%)	

**Table 4.** Persistent palsy following PHILOS plate fixation

		Final Follow-up Nerve Palsy		P
		No (n=15)	Yes (n=3)	
Age (years)		62.53 ± 15.212	67 ± 8.185	0.488
Sex	Female	10 (76.9%)	3 (23.1%)	0.522
	Male	5 (100%)	0	
Side	Right	10 (90.9%)	1 (9.1%)	0.528
	Left	5 (71.4%)	2 (28.6%)	
Injury Mechanism	Simple Fall	11 (91.7%)	1 (8.3%)	0.060
	Fall from High	0	1 (100%)	
	Vehicle Accident	4 (80%)	1 (20%)	
AO Classification (Type 12)	Type 12-A1	3 (75%)	1 (25%)	0.920
	Type 12-B1	4 (80%)	1 (20%)	
	Type 12-B2	1 (100%)	0	
	Type 12-B3	3 (75%)	1 (25%)	
	Type 12-C1	3 (100%)	0	
	Type 12-C3	1 (100%)	0	
Neer Classification (Fractures not extending to humeral neck were defined as Type 0)	Type 0	6 (100%)	0	0.078
	Type 1	4 (66.7%)	2 (33.3%)	
	Type 2	4 (100%)	0	
	Type 3	0	1 (100%)	
	Type 4	1 (100%)	0	
Time from Admission to Surgery (days)		3 (3) (1-20)	3 (2-5)	0.912
Postoperative Hospitalization (days)		4 (3) (2-28)	6 (5-8)	0.203
Surgical Approach	ORIF	7 (70%)	3 (30%)	0.147
	MIPO	8 (100%)	0	
Intraoperative Axillary Nerve Exploration	Yes	8 (80%)	2 (20%)	0.588
	No	7 (87.5%)	1 (12.5%)	
Intraoperative Radial Nerve Exploration	Yes	13 (81.3%)	3 (18.8%)	0.686
	No	2 (100%)	0	
PHILOS Plate Length	9	9 (100%)	0	0.002
	11	5 (100%)	0	
	12	1 (25%)	3 (75%)	
Immediate Postoperative Axillary Nerve Palsy	No	13 (86.7%)	2 (13.3%)	0.442
	Yes	2 (66.7%)	1 (33.3%)	
Immediate Postoperative Radial Nerve Palsy	No	13 (92.9%)	1 (7.1%)	0.108
	Yes	2 (50%)	2 (50%)	
Follow-up (months)		8 (6) (6-26)	7 (6-26)	0.654

P: statistical significance value, ORIF: Open Reduction Internal Fixation; MIPO: Minimally Invasive Plate Osteosynthesis

P: statistical significance value, ORIF: Open Reduction Internal Fixation; MIPO: Minimally Invasive Plate Osteosynthesis

At the final follow-up, 1 patient (5.6%) exhibited persistent axillary nerve palsy, and 2 patients (11.1%) demonstrated persistent radial nerve palsy, resulting in an overall persistent palsy rate of 3 patients (16.7%). In the analysis of long-term palsy, no significant associations were found with demographic factors, surgical approach, or intraoperative nerve exploration ( $p > 0.05$  for each). Although not statistically significant, the incidence of persistent palsy was found to be higher in patients who underwent ORIF (30%) compared with those treated by MIPO (0%) ( $p = 0.147$ ). A significant association was observed between plate length and persistent palsy, with a higher incidence of persistent palsy in cases treated with 12-hole plates ( $p = 0.002$ ) (Table 4).

## Discussion

Proximally extending humeral shaft fractures represent a formidable challenge due to the complex transition zone where the fracture lines traverse the anatomical risk areas of both the axillary and radial nerves (Cho et al., 2023; Saran et al., 2010; Rocchi et al., 2016). The principal finding of this study is that while the choice of surgical technique (ORIF vs. MIPO) shows a notable trend regarding safety, the length of the implant appears to be a statistically significant determinant of long-term neurological morbidity. To our knowledge, this is one of the first studies to explicitly demonstrate the association between using long (12-hole) proximal humeral locking plates and persistent nerve palsy in this specific fracture pattern.

The overall postoperative axillary (16.7%) and radial nerve palsy rates (22.2%) observed in our cohort align with the upper range of complications reported in the literature (10–30%) for fractures involving the proximal humerus–shaft junction (Hegeman et al., 2020; Shao et al., 2005). This high incidence reflects the "double jeopardy" of PEHSFs, where the axillary nerve is at risk proximally during plate positioning and the radial nerve is endangered distally during shaft fixation (Palm et al., 2013). Interestingly, our analysis revealed that demographic factors and fracture complexity (AO/OTA or Neer type) did not predict nerve injury. Furthermore, the finding that intraoperative nerve exploration did not reduce the rate of palsy supports the concept that visualization alone is insufficient to prevent neuropraxia. In fact, the dissection required to visualize the nerve may inadvertently necessitate greater retraction, contributing to traction-related microinjury (Esmailiejah et al., 2015).

Although the difference in persistent palsy rates between ORIF (30%) and MIPO (0%) did not reach statistical significance due to the limited sample size, the clinical divergence is striking. All permanent deficits occurred in the ORIF group, in contrast to the meta-analysis by Li et al. (2019), which reported a higher overall incidence of axillary nerve injury in patients treated with MIPO. This apparent discrepancy may be related to differences in the type of nerve at risk and the underlying injury mechanisms, as axillary nerve involvement in MIPO is mainly associated with proximal plate positioning and screw placement near the surgical neck, whereas persistent neurological deficits are more likely to result from extensive soft-tissue dissection and sustained retraction. This suggests that the extensive soft-tissue stripping and forceful retraction of the deltoid and triceps required for direct reduction in ORIF may compromise the vascular supply to the nerves or subject them to prolonged traction (Esmailiejah et al., 2015). In contrast, the MIPO technique, which relies on indirect reduction and creates a submuscular tunnel, appears to offer a "biological protection" effect (Yang et al., 2021; Aksu et al., 2012). By avoiding continuous retraction on the nerves and minimizing the dissection around the spiral groove, MIPO may reduce the risk of converting a transient neuropraxia into a permanent axonotmesis.

The most novel and statistically significant finding of this study ( $p = 0.002$ ) is the association between plate length and persistent neurological deficit. All cases of persistent palsy occurred in

patients treated with 12-hole PHILOS plates. While previous studies have reported successful outcomes with long PHILOS fixation for complex fractures (Jiamton et al., 2024; Pimple et al., 2010), our results suggest that plate length may be associated with an increased risk of persistent neurological deficit.

Biomechanically and anatomically, this is highly plausible, as a 12-hole PHILOS plate extends significantly down the humeral shaft. Its distal tip is likely to terminate in the distal third of the humerus, a critical zone where the radial nerve pierces the lateral intermuscular septum to enter the anterior compartment (Contreras et al., 2022; Wang et al., 2025). The insertion of distal screws in this zone, or the potential friction of the plate tip against the nerve during shoulder motion, may create a higher-risk environment for the radial nerve. Our results suggest that selecting the shortest plate capable of providing adequate mechanical stability (e.g., 9 or 11 holes) may be considered a simple yet effective strategy to mitigate this risk.

Although a significant association was observed between plate length and persistent nerve palsy, this finding should be interpreted with caution. In clinical practice, longer plates are typically selected for fractures with more extensive distal involvement. Such fracture patterns may place the radial nerve within the anatomical danger zone, thereby increasing the risk of nerve injury. Accordingly, plate length in this context may reflect the extent of fracture involvement rather than represent an independent risk factor.

This study has several limitations inherent to its retrospective design. First, the relatively small sample size limits the statistical power, particularly for the comparison between ORIF and MIPO techniques. A larger multicenter cohort might have yielded statistical significance for the trend observed in favor of MIPO. Second, the lack of routine postoperative electromyography (EMG) prevents the differentiation between axonotmesis and neurotmesis in recovering patients. Third, functional outcomes were not included, restricting our ability to correlate neurological recovery with overall limb function. Fourth, reliable data on surgery duration were not consistently available due to the retrospective nature of the study, which limited the assessment of its potential effect on soft tissue retraction and nerve-related outcomes. However, the homogeneity of the surgical team and the specific focus on the "grey zone" of PEHSFs strengthen the internal validity of our observations regarding plate length.

## Conclusion

This study highlights that iatrogenic nerve injury in proximally extending humeral shaft fractures is closely linked to technical factors rather than patient demographics or fracture pattern. While MIPO demonstrated a favorable safety profile with no permanent nerve injuries in a limited cohort, the use of 12-hole long locking plates emerged as a significant risk factor for persistent neurological deficit. Surgeons should exercise caution when using extensive plate lengths and acknowledge that increased plate length does not necessarily confer additional benefit. It is imperative that soft-tissue-sparing techniques are employed and that the optimal implant is selected to minimize the risk of permanent axillary and radial nerve palsy in complex humeral fractures.

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