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Research Article

Comparison of Functional and Clinical Outcomes Following Intramedullary Nailing versus Plate Fixation for Humeral Shaft Fractures: A Prospective Study

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Abstract

Background: The optimal fixation method for humeral shaft fractures remains debated. This study compared functional and clinical outcomes after intramedullary nailing (IMN) and open reduction and internal fixation (ORIF) with plate fixation.
Methods: In this prospective, observational, comparative cohort study, 85 adults with Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association (AO/OTA) type 12-B or 12-C humeral shaft fractures were enrolled at a tertiary orthopedic trauma center in Tehran, Iran, between April 2020 and April 2024. Patients underwent IMN (n = 43) or plate ORIF (n = 42) according to the treating surgeon's judgment. The primary outcome was the 12-month Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) score; secondary outcomes included shoulder and elbow function, pain, union, hospital stay, return to work, and complications.
Results: Mean age was higher in the IMN group compared to the ORIF group (41.53 ± 14.12 vs. 35.83 ± 11.82 years; P = 0.047). The duration of hospital stay was shorter after IMN in the unadjusted comparison (2.07 ± 0.34 vs. 2.26 ± 0.59 days; P = 0.043). Nonunion occurred in 2 patients in each group (4.7% vs. 4.8%, P > 0.999), and no statistically significant difference was observed in the unadjusted QuickDASH scores (10.93 ± 11.33 vs. 16.48 ± 15.23; P = 0.060). In an exploratory model adjusted only for age and sex, IMN was associated with a modestly lower QuickDASH score [B = −6.22, 95% confidence interval (CI): −12.20 to −0.25; P = 0.041]; this association remains susceptible to residual confounding. Both techniques achieved high union rates and favorable 12-month outcomes. The unadjusted QuickDASH comparison was not significant, and the modest association in a partially adjusted exploratory model should not be interpreted as clinical superiority of IMN. Treatment selection should remain individualized.

Keywords: Humeral Shaft Fracture; Intramedullary Nailing; Bone Plates; Fracture Fixation; Recovery of Function; Disability Evaluation

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Background

Humeral shaft fractures account for 1-3 percent of all fractures, and the annual incidence is 13-20 per 100000 population. They have a bimodal age distribution with a predominance in young men following high-energy trauma and the elderly women following low-energy falls (1, 2). Most fractures are treated non-operatively with functional bracing. However, surgical therapy is required for open fractures, polytrauma, neurovascular damage, pathological fractures, and failed conservative treatment (3).

There are two main surgical choices: intramedullary nailing (IMN) and open reduction and internal fixation (ORIF) using plates. IMN is minimally invasive and preserves the soft tissues and blood supply around the bone. Furthermore, it has biomechanical advantages due to its central placement within the marrow canal (4). However, antegrade IMN requires transection of the rotator cuff, which causes persistent shoulder pain and dysfunction in over half of patients (5). ORIF, on the other hand, allows accurate visualization of the fracture, allowing proper reduction without damaging the shoulder joint. Nevertheless, this method generally involves considerable tissue dissection, thereby increasing the risk of nerve injury and the likelihood of infection (6, 7).

Despite extensive research, consensus has yet to be reached regarding which technique is more effective. Recent meta-analyses of randomized controlled studies have yielded conflicting results, with some showing superior shoulder outcomes and faster union with plate fixing (8, 9), while others report no significant differences in union rates or overall functional outcomes between the methods (10). The treatment selection should be made considering the patient's specific circumstances, including fracture site, age, and bone quality. However, the existing studies are constrained by variable outcome measures and short follow-up periods, emphasizing the need for future research to inform clinical practice (3, 4).

We hypothesized that while both IMN and ORIF would result in comparable union rates, IMN would be associated with shorter hospital stay and lower patient-reported disability scores due to its minimally invasive nature. Accordingly, this study aimed to compare the functional and clinical outcomes between IMN and ORIF for humeral

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shaft fractures in an Iranian population, with a comprehensive assessment of shoulder and elbow function, disability scores, union rates, and complications.

Methods

Study Design and Setting: This prospective, observational, comparative cohort study was carried out at a tertiary orthopedic trauma center in Tehran, Iran, to evaluate the functional and clinical outcomes of humeral shaft fracture treatments using IMN and plate fixation. Ethical approval was obtained from the Ethics Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran (approval code: IR.SBMU.MSP.REC.1404.474). Written informed consent was obtained from all participants before enrollment in the study.

Study Population and Eligibility Criteria: The study consecutively enrolled patients who presented to the orthopedic department between April 2020 and April 2024 with humeral shaft fractures requiring surgical fixation. Eligible patients were adults aged 18–65 years with isolated, displaced, or unstable diaphyseal humeral shaft fractures classified as Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association (AO/OTA) type 12-B or 12-C, including closed fractures and Gustilo type I or II open fractures, with injury occurring within 14 days before presentation. All patients were required to provide written informed consent and be able to comply with scheduled postoperative follow-up visits. Surgical intervention—either IMN or ORIF with plate fixation—was determined by the treating surgeon's clinical judgment. Treatment selection was not randomized and was based on fracture morphology, fracture location, soft-tissue condition, patient-related factors, and surgeon preference. Exclusion criteria included proximal or distal humeral fractures, Gustilo type III open fractures, severe associated vascular or neurological injuries, neuromuscular disorders affecting upper-limb function, pathological fractures, inability to attend follow-up visits, pregnancy or lactation, and active substance abuse or alcoholism. Age, sex, and AO/OTA morphology were sufficiently complete for group comparison. Certain variables, including fracture level within the shaft, open versus closed status, injury mechanism, side and limb dominance, smoking status, comorbidities, and specific implant subtype, were not recorded consistently enough for reliable group-level analysis and were not imputed.

Sample Size Calculation: The calculation of the sample size was based on the Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) score, which served as the primary measure of functional outcome. Assuming a significance level of 0.05, a power of 80%, a standard deviation (SD) of 12 points, and a minimal clinically important difference (MCID) of 8 points between groups, an initial sample size of 36 patients per group was calculated. To account for an expected 15% loss to follow-up, this number was increased to 42 patients per group, resulting in a minimum required sample size of 84 participants.

Surgical Techniques: All surgical procedures were carried out by a senior orthopedic surgeon under general anesthesia. The IMN group underwent antegrade locked humeral nailing in the beach-chair position. Through a deltoid-splitting approach, a limited longitudinal split was made in the supraspinatus tendon, and a standard proximal humeral entry site was established under fluoroscopic guidance. The fracture was reduced fluoroscopically, and a size-appropriate locked humeral nail was inserted with proximal and distal locking screws. The cuff split was repaired at closure. The nail manufacturer or model, reamed versus unreamed preparation, specific cuff-suture material or configuration, and standardized quantitative measurements of proximal nail prominence were not consistently available in the study dataset and were not imputed.

In the ORIF group, fractures were treated through an anterolateral approach. The radial nerve was identified and protected when encountered. Reduction was obtained under direct visualization, and fixation was performed with a 4.5-mm narrow dynamic compression plate (DCP) or locking compression plate (LCP), with at least six cortices engaged proximally and distally (11). Both DCP and LCP constructs were used, but the specific distribution of these two plate types was not consistently documented in the study dataset; therefore, it could not be reported reliably.

Postoperative Management: All patients were managed postoperatively with a consistent protocol to ensure uniformity between the groups. In the early phase of recovery, a simple arm sling was utilized for comfort. Active and active-assisted shoulder and elbow range of motion (ROM) exercises were initiated within the first postoperative week, as tolerated by pain. Lifting and weight-bearing on the affected limb was limited to less than 1 kg until radiographic evidence of fracture union was confirmed. Moreover, a uniform physiotherapy protocol was recommended to all patients, starting from the early postoperative period for optimal recovery.

Outcome Measures

Patients were examined at baseline and at routine intervals of 6 weeks, 3 months, 6 months, and 12 months postoperatively. Functional and clinical outcomes were evaluated at each visit.

Functional and Clinical Outcomes

Elbow function was assessed using the Mayo Elbow Performance Score (MEPS), which evaluates pain, ROM, stability, and activities of daily living (ADLs) on a 0-100 scale, with higher scores indicating better function (12). Shoulder function was evaluated using the Constant-Murley Score (CMS), which assesses pain, daily activities, ROM, and strength on a 0-100 scale (13). Upper-extremity disability was measured using the 11-item QuickDASH questionnaire, transformed to a 0-100 scale, where higher scores indicate greater disability (14). Pain intensity was assessed using a 10-cm visual analog scale (VAS). Clinical outcomes included hospital stay, time to radiographic union, return to previous activity or work, union status, and complications. At follow-up visits, wound status and signs of superficial or deep infection were documented; motor and sensory radial nerve functions were examined; and patients were asked about shoulder pain, weakness, impingement-type symptoms, and implant-related complaints. Shoulder pain, motion, and strength were also evaluated using the CMS. Standard anteroposterior (AP) and lateral radiographs were reviewed for bridging callus, alignment, implant breakage or displacement, screw back-out, and other nail- or plate-related problems. Reoperations and revision procedures were identified from clinical and operative records. As rotator cuff pathology after antegrade nailing was not evaluated via routine ultrasonography, magnetic resonance imaging (MRI), or a separate cuff-specific instrument, this study focused on clinically apparent shoulder morbidity and could not exclude asymptomatic or subclinical cuff lesions. Union was defined as bridging callus across the fracture site with absence of pain or abnormal motion, whereas nonunion was defined as absence of progressive healing at 9 months with no radiographic progression over three consecutive months (15).

Data Collection and Statistical Analysis: Data were collected prospectively through patient examinations, medical record review, radiographic assessment, and standardized questionnaires. Baseline variables were recorded at enrollment, and outcomes were assessed at predefined follow-up visits by trained evaluators. Continuous variables were reported as mean ± SD and categorical variables as frequencies and percentages. Normality was assessed via the Shapiro-Wilk test. For continuous variables, between-group comparisons were performed using independent samples t-tests or Mann–Whitney U tests, while categorical variables were compared using chi-square or Fisher's exact tests, as appropriate. Exploratory multiple linear regression models included surgical technique, age, and sex. These models were only partially adjusted: fracture location, open-fracture status, injury mechanism, smoking status, comorbidities, implant subtype, and other factors related to treatment selection were unavailable or incomplete, and AO/OTA subtype was not included in the original model. Accordingly, adjusted estimates were interpreted as exploratory associations rather than causal treatment effects. Furthermore, Pearson correlation analysis was utilized to examine associations between continuous variables. All tests were two-tailed, and P-values < 0.05 were considered statistically significant.

Results

Study Population and Demographics: A total of 85 patients with humeral shaft fractures were included in the final analysis, comprising 43 treated with IMN and 42 managed via ORIF. The available baseline characteristics are summarized in table 1. Sex distribution, age categories, and AO/OTA fracture morphology were comparable between groups, although mean age was higher in the IMN group (41.53 ± 14.12 vs. 35.83 ± 11.82 years; P = 0.047). Fracture level, open versus closed status, injury mechanism, limb dominance, smoking status, comorbidities, and specific implant subtype could not be systematically categorized for tabular presentation, because these variables were incompletely or inconsistently documented in the study dataset.

Table 1. Available baseline demographic and fracture characteristics

Variable	Subgroup	IMN (n = 43)	ORIF (n = 42)	Total (n = 85)	P-value
Gender	Men	27 (62.8)	30 (71.4)	57 (67.1)	0.538
	Women	16 (37.2)	12 (28.6)	28 (32.9)	
Age (year)		41.53 ± 14.12	35.83 ± 11.82	38.72 ± 13.27	0.047*
Age category (year)	≤30	11 (25.6)	16 (38.1)	27 (31.8)	0.238
	31–45	13 (30.2)	16 (38.1)	29 (34.1)	
	46–60	18 (41.9)	9 (21.4)	27 (31.8)	
	≥61	1 (2.3)	1 (2.4)	2 (2.4)	
AO/OTA fracture type	12-B	30 (69.8)	31 (73.8)	61 (71.8)	0.679
	12-C	13 (30.2)	11 (26.2)	24 (28.2)	

Data are presented as mean ± standard deviation (SD) or n (%); P-values were calculated using the t-test, chi-square test, or Fisher's exact test, as appropriate. Variables not shown were not consistently available for reliable group-level analysis.
*P < 0.05
AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; IMN: Intramedullary nailing; ORIF: Open reduction and internal fixation

Clinical Outcomes and Complications: Clinical outcomes and complications are summarized in table 2.

Table 2. Clinical outcomes and complications in the intramedullary nailing (IMN) and open reduction and internal fixation (ORIF) groups

Outcome	IMN (n = 43)	ORIF (n = 42)	Total (n = 85)	P-value
Length of hospital stay (day)	2.07 ± 0.34	2.26 ± 0.59	2.16 ± 0.48	0.043*
Time to union (month)	2.98 ± 0.69	3.11 ± 0.59	3.04 ± 0.64	0.355
Return to work (month)	3.03 ± 0.85	3.30 ± 0.84	3.16 ± 0.85	0.138
Nonunion	2 (4.7)	2 (4.8)	4 (4.7)	> 0.999
New postoperative radial nerve palsy	1 (2.3)	3 (7.1)	4 (4.7)	0.360

Data are presented as mean ± standard deviation (SD) or n (%); P-values were calculated using Student's t-test, Mann–Whitney U test, chi-square test, or Fisher's exact test, as appropriate.
*P < 0.05
IMN: Intramedullary nailing; ORIF: Open reduction and internal fixation

The IMN group had a shorter hospital stay in the unadjusted comparison (2.07 ± 0.34 vs. 2.26 ± 0.59 days, P = 0.043). Time to union, return to work, and union rate were comparable between groups. Nonunion occurred in 2 patients in each group. No instances of clinically detected superficial or deep infection, implant failure or displacement, symptomatic hardware-related complications (including screw, nail, or plate issues), persistent shoulder symptoms or impingement, clinically apparent rotator cuff-related impairments, or revision surgery were documented in either group during the follow-up period. Regarding neurological outcomes, no preoperative radial nerve palsy was observed; however, postoperative radial nerve palsy occurred in one IMN patient and three ORIF patients (P = 0.360), with all cases resolving within 6 months. The absence of clinically apparent shoulder complications should be interpreted in light of the lack of routine cuff imaging or a separate cuff-specific assessment protocol.

Functional Outcomes and Pain Scores: Functional outcomes and pain scores are summarized in table 3. Although MEPS scores were numerically higher in the IMN group compared to the ORIF group, the difference was not statistically significant (87.12 ± 9.40 vs. 83.21 ± 10.70; P = 0.077). Similarly, QuickDASH scores were lower in the IMN group, but this unadjusted comparison also did not reach statistical significance (10.93 ± 11.33 vs. 16.48 ± 15.23; P = 0.060). CMS and VAS pain scores were comparable between groups.

Table 3. Functional outcomes and pain scores at 12-month follow-up in the intramedullary nailing (IMN) and open reduction and internal fixation (ORIF) groups

Outcome measure	IMN (n = 43)	ORIF (n = 42)	Total (n = 85)	P-value
MEPS	87.12 ± 9.40	83.21 ± 10.70	85.19 ± 10.19	0.077
CMS	84.77 ± 10.91	83.36 ± 12.22	84.07 ± 11.53	0.576
QuickDASH	10.93 ± 11.33	16.48 ± 15.23	13.67 ± 13.61	0.060
VAS	1.33 ± 1.60	1.64 ± 1.51	1.48 ± 1.56	0.350

Data are presented as mean ± standard deviation (SD). P-values were calculated using the Student's t-test or the Mann–Whitney U test, as appropriate.
CMS: Constant-Murley score; IMN: Intramedullary nailing; MEPS: Mayo Elbow Performance Score; ORIF: Open reduction and internal fixation; QuickDASH: Quick Disabilities of the Arm, Shoulder, and Hand; VAS: Visual analog scale

Multivariate Regression Analyses: Exploratory multivariable regression analyses adjusted for age and sex are shown in table 4. In this partially adjusted model, IMN was associated with a 6.22-point lower QuickDASH score [95% confidence interval (CI): -12.20 to -0.25; P = 0.041]. Because the unadjusted QuickDASH comparison was not statistically significant and clinically relevant treatment-selection variables were not included, this estimate was interpreted as a cautious association rather than evidence of treatment superiority. The association between IMN and MEPS approached statistical significance (B = 4.42, 95% CI: -0.06 to 8.91; P = 0.053).

Table 4. Exploratory multiple linear regression models adjusted for age and sex

Outcome	Independent variable	B	SE	95% CI	P-value	R^2
MEPS score	Surgical technique	4.42	2.25	−0.06 to 8.91	0.053	0.050
	Age	−0.08	0.09	−0.25 to 0.09	0.375	
	Gender	0.99	2.36	−3.70 to 5.68	0.674	
CMS score	Surgical technique	2.12	2.59	−3.03 to 7.26	0.415	0.022
	Age	−0.10	0.10	−0.30 to 0.09	0.299	
	Gender	1.41	2.70	−3.97 to 6.79	0.603	
QuickDASH score	Surgical technique	−6.22	3.00	−12.20 to −0.25	0.041*	0.054
	Age	0.11	0.11	−0.12 to 0.34	0.341	
	Gender	−0.53	3.14	−6.77 to 5.72	0.868	
VAS pain score	Surgical technique	−0.47	0.34	−1.15 to 0.22	0.177	0.057
	Age	0.03	0.01	0.00 to 0.05	0.052	
	Gender	−0.04	0.36	−0.75 to 0.67	0.910	
Length of hospital stay	Surgical technique	−0.21	0.11	−0.42 to 0.01	0.058	0.049
	Age	0.00	0.00	−0.01 to 0.01	0.787	
	Gender	−0.09	0.11	−0.31 to 0.13	0.422	
Time to union	Surgical technique	−0.24	0.14	−0.52 to 0.03	0.081	0.145
	Age	0.01	0.01	0.00 to 0.02	0.015*	
	Gender	−0.32	0.14	−0.61 to −0.03	0.030*	
Return to work	Surgical technique	−0.35	0.19	−0.72 to 0.02	0.065	0.064
	Age	0.01	0.01	0.00 to 0.03	0.088	
	Gender	−0.06	0.20	−0.45 to 0.33	0.753	

Surgical technique was coded as intramedullary nailing (IMN) = 1 and open reduction and internal fixation (ORIF) = 0; sex was coded as men = 1 and women = 0. The models did not account for several treatment-selection variables and should not be interpreted causally.
*$P < 0.05$
CI: Confidence interval; CMS: Constant-Murley score; MEPS: Mayo Elbow Performance Score; QuickDASH: Quick Disabilities of the Arm, Shoulder, and Hand; SE: Standard error; VAS: Visual analog scale

Age showed a borderline association with VAS pain score (B = 0.03, 95% CI: 0.00 to 0.05; P = 0.052). For clinical endpoints, time to union increased with age (B = 0.01 months per year; P = 0.015) and was shorter in men (B = −0.32; P = 0.030). Associations of surgical technique with hospital stay and return to work did not reach statistical significance after adjustment. Due to the low frequency of nonunion events (n = 4), no multivariable model was fitted for union status.

Union Outcomes and Correlation Analysis: Union outcomes were comparable between the two treatment groups. Nonunion occurred in 2 patients in the IMN group and 2 patients in the ORIF group, with no statistically significant between-group difference. Given the small number of nonunion events, no multivariable predictor analysis was performed for union status. Pearson correlation analysis demonstrated strong correlations among functional outcome measures (Table 5). MEPS and CMS scores exhibited strong positive correlations, whereas both were negatively correlated with QuickDASH and VAS scores. Additionally, a strong positive correlation was observed between QuickDASH and VAS pain scores; however, age and length of hospital stay showed no significant correlation with functional outcomes.

Table 5. Pearson correlation coefficients among age, functional outcome scores, and hospital stay

Variable	Age	MEPS	CMS	Quick DASH	VAS	Hospital stay
Age	1.00	−0.06	−0.11	0.06	0.19	−0.01
MEPS	−0.06	1.00	0.90*	−0.90*	−0.80*	−0.09
CMS	−0.11	0.90*	1.00	−0.87*	−0.80*	−0.15
QuickDASH	0.06	−0.90*	−0.87*	1.00	0.81*	0.06
VAS	0.19	−0.80*	−0.80*	0.81*	1.00	0.04
Hospital stay	−0.01	−0.09	−0.15	0.06	0.04	1.00

Values represent Pearson correlation coefficients.
*$P < 0.05$
CMS: Constant-Murley score; MEPS: Mayo Elbow Performance Score; QuickDASH: Quick Disabilities of the Arm, Shoulder, and Hand; VAS: Visual analog scale

Discussion

This prospective, observational, comparative cohort study evaluated functional and clinical outcomes after IMN and ORIF with plate fixation for AO/OTA type 12-B and 12-C humeral shaft fractures. Both techniques were followed by high union rates and favorable 12-month functional outcomes. Hospital stay was shorter after IMN in the unadjusted analysis. The unadjusted QuickDASH comparison was not statistically significant; a modest association favoring IMN appeared only in an exploratory model adjusted for age and sex. Other functional outcomes, pain, time to union, return to work, nonunion, and radial nerve palsy did not differ significantly.

The present findings suggest that both IMN and plate fixation are effective surgical options for selected cases of humeral shaft fractures. Contemporary systematic reviews have shown that operative treatment of humeral shaft fractures generally achieves high union rates, although the optimal fixation method remains debated because studies vary in fracture patterns, surgical approaches, implants, and outcome measures (3-6, 8, 16). Recent meta-analyses comparing IMN and ORIF have also reported broadly comparable overall union and functional outcomes, with differences between techniques often depending on the specific endpoint analyzed. Therefore, the absence of a clear overall superiority of either technique in our cohort is consistent with the current literature (5, 6, 8, 16, 17).

Fracture union was achieved in the majority of patients in both groups, with no significant difference in nonunion rates between IMN and ORIF cohorts. This finding is consistent with recent evidence indicating that both IMN and plating can provide adequate mechanical stability and biological conditions for healing when appropriate reduction and fixation are achieved (3, 5, 6, 8, 16). Van Bergen et al. reported generally favorable union outcomes after operative treatment of humeral shaft fractures, although direct comparison between techniques remains limited by heterogeneity among studies (3). Similarly, Beeres et al. (6) and Hurley et al. (8) found no consistent clinically decisive difference in nonunion rates between IMN and plate fixation across pooled studies. In our study, the comparable time to union between groups further suggests that both fixation strategies can provide sufficient stability for AO/OTA 12-B and 12-C fractures when applied in appropriately selected patients.

The low overall nonunion rate in this cohort should also be interpreted in relation to patient selection and surgical standardization. Humeral shaft nonunion is influenced by both biological and mechanical factors, including fracture pattern, patient comorbidities, infection, smoking status, alcohol abuse, and adequacy of fixation (18). Olson et al. identified alcohol abuse, chronic liver disease, and deep infection as important risk factors for nonunion after traumatic humeral shaft fractures (18). Because the present study excluded pathological fractures, severe neurovascular injuries, and patients unable to comply with follow-up, the relatively low nonunion rate may partly reflect a more controlled surgical population.

Functional outcomes were favorable in both groups. QuickDASH scores were numerically lower after IMN, but the unadjusted comparison did not reach statistical significance. An exploratory age- and sex-adjusted model yielded an approximately 6-point lower QuickDASH score in the IMN group. This finding should be interpreted cautiously because the model did not include fracture location, open-fracture status, injury mechanism, smoking status, comorbidities, implant subtype, or other determinants of treatment selection. Moreover, published estimates of clinically meaningful changes in Disabilities of the Arm, Shoulder, and Hand (DASH) and QuickDASH scores vary significantly across different populations and contexts (19-21). The obtained results represent a modest adjusted association, and do not establish clinical superiority or a causal relationship for IMN. Antegrade nailing may reduce soft-tissue exposure at the fracture site, but proximal entry can affect the rotator cuff or shoulder if entry position, nail prominence, or cuff repair is suboptimal (2, 5, 8). No difference in CMS was observed in this cohort; however, routine cuff imaging and a dedicated cuff-specific assessment were not performed; therefore, subclinical pathology cannot be excluded.

Shoulder and elbow functional scores did not differ significantly between groups. Concerns regarding antegrade IMN have historically focused on postoperative shoulder pain and impaired motion (2, 5), whereas ORIF requires greater soft-tissue dissection and radial nerve identification or protection (2, 6, 7). In this study, shoulder pain, motion, and strength were assessed both clinically and via the CMS. While the lack of symptomatic shoulder morbidity is reassuring, these findings should not be interpreted as an absence of structural rotator cuff changes, as systematic ultrasound or MRI was not performed.

Pain outcomes were also similar between the two groups. VAS pain scores were low at final follow-up in both IMN and ORIF patients, indicating satisfactory pain control after either fixation method. Recent comparative reviews of surgical treatment for humeral shaft fractures have generally shown no consistent long-term pain advantage for one fixation method over another (3, 6, 8, 16, 17). The strong positive correlation between VAS and QuickDASH in our cohort is clinically plausible because pain is a major contributor to patient-reported upper-extremity disability (10, 19-21). This association reinforces the importance of including both pain and functional disability measures when evaluating humeral shaft fracture outcomes (22).

Hospital stay was significantly shorter in the IMN group in the unadjusted analysis, which is consistent with the less invasive nature of nailing and its reduced need for extensive soft-tissue exposure compared with open plating (2, 5, 8). However, the absolute difference was small, and the adjusted analysis showed only a near-significant association. Return to work was also comparable between groups, in line with the similar union, pain, and functional outcomes observed at 12 months. Although shorter hospitalization may have practical and economic value, cost-effectiveness and return-to-work outcomes are influenced by multiple factors, including operative and implant expenses, complications, reoperations, occupational demands, rehabilitation access, and socioeconomic context (3, 10, 23, 24). Therefore, these findings should be interpreted cautiously, and dedicated economic and work-related analyses are needed before firm conclusions can be drawn.

Radial nerve palsy was infrequent and showed no significant difference between groups. All cases of postoperative palsy recovered during follow-up, consistent with the generally favorable prognosis associated with radial nerve palsy in humeral shaft fractures (25). Recent propensity score-matched data comparing short-term complications after plate fixation and IMN also underscore the importance of accounting for patient selection when interpreting complication profiles (26). Infection, nonunion, implant-related problems, and revision procedures were assessed through clinical records, serial examination, radiographs, and operative documentation. Nevertheless, the sample was too small to compare uncommon complications reliably, and shoulder complications after antegrade nailing were assessed clinically rather than through routine imaging. Accordingly, the low observed adverse-event rate should not be interpreted as proof that the procedures have equivalent complication profiles.

Age differed significantly between groups, with older patients more frequently treated with IMN. This imbalance is important because age may influence fracture healing, bone quality, rehabilitation capacity, and surgeon decision-making (1, 2, 18). Gallusser et al. noted that age and fracture characteristics could influence the risk of nonunion and treatment selection in humeral shaft fractures (2). In exploratory analysis, older age was associated with a longer time to radiographic union, but this finding should be interpreted cautiously because the study was not primarily powered to evaluate predictors of fracture healing (2, 18). Due to the non-randomized nature of the treatment allocation, this age difference may reflect a clinical preference for a less invasive fixation method in older patients.

These findings support individualized fixation rather than a routine preference for either technique. Both IMN and ORIF produced similar union, pain, shoulder and elbow function, return to work, and radial nerve outcomes in this cohort. The shorter unadjusted hospital stay and the modest, partially adjusted QuickDASH association are hypothesis-generating and do not establish clinical superiority of IMN. Surgical selection should continue to reflect fracture characteristics, soft-tissue condition, patient factors, implant availability, and surgeon experience, consistent with recent comparative and network meta-analytic evidence (27, 28).

This study has several limitations. First, the prospective nonrandomized design creates substantial potential for confounding by indication and selection bias. Treatment was chosen by the surgeon, but the study dataset did not reliably capture fracture level, open versus closed status, injury mechanism, dominant side, smoking status, comorbidities, exact nail system, reaming status, or DCP-versus-LCP distribution. AS the exploratory regression model was adjusted only for age and sex and did not include AO/OTA subtype or other clinically important treatment-selection variables, the potential for residual confounding remains high. Second, the sample was not large enough to compare uncommon complications such as nonunion, infection, implant failure, revision, or radial nerve palsy. Third, clinically apparent shoulder symptoms were assessed, but no routine rotator cuff imaging or dedicated cuff-specific instrument was used; thus, subclinical cuff pathology could have been missed. Fourth, follow-up was limited to 12 months and may not have captured late implant-related or shoulder complications. Finally, economic outcomes, occupational demands, and quality-adjusted life-years (QALYs) were not evaluated.

Future research should focus on adequately powered multicenter randomized studies comparing current IMN against conventional ORIF and minimally invasive plate osteosynthesis. Furthermore, subsequent studies should stratify patients by fracture location, pattern, bone quality, age, smoking status, and occupational demands. Standardized reporting of patient-reported outcome measures (PROMs), complications, reoperations, return to work, and cost-effectiveness would improve comparability across studies (29). A longer follow-up is needed to determine whether early differences in disability or hospital stay translate into durable functional or economic advantages.

Conclusion

In this prospective, observational, comparative cohort of selected AO/OTA type 12-B and 12-C humeral shaft fractures, both IMN and plate fixation yielded high union rates and generally favorable 12-month outcomes. While unadjusted QuickDASH scores showed no statistically significant differences between groups, a modest association favoring IMN was observed in an exploratory model adjusted for age and sex. However, these findings should be interpreted cautiously due to the incomplete control of treatment-selection factors. Shoulder or elbow function, pain, time to union, return to work, nonunion, and radial nerve palsy did not differ significantly. Consequently, these results do not establish the superiority of either technique and support individualized fixation based on fracture, soft-tissue, patient, and surgeon factors.

Conflict of Interest

The authors declare no conflict of interest in this study.

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