Original Article

Outcomes of Antegrade Intramedullary Interlocking Nailing for Distal Quarter Diaphyseal Extra-Articular Fractures of the Humerus: A Prospective Study

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ABSTRACT

Introduction: Distal quarter diaphyseal fractures of the humerus present unique challenges due to proximity to the elbow joint, narrow medullary canal, and risk of radial nerve injury. While plating remains common, antegrade intramedullary interlocking nailing (IMN) offers a minimally invasive alternative with potential biomechanical advantages. This study evaluates clinical, functional, and radiological outcomes of antegrade IMN in these fractures.

Methods: A prospective observational study was conducted on 40 patients with closed, extra-articular distal quarter diaphyseal humeral fractures treated with antegrade. Functional outcomes were assessed using the Constant-Murley Score (CMS) and Mayo Elbow Performance Score (MEPS). Radiological union, complications, and time to return to daily activities were recorded.

Results: The mean age was 42.3 years (range: 22–65), with 28 males and 12 females. The mean union time was 14.2 weeks (range: 12–20). At 6 months, the mean CMS was 88.6 and MEPS was 91.2, indicating excellent functional recovery. Complications included shoulder impingement (n=3), transient radial nerve palsy (n=2), and delayed union (n=2). No cases of non-union or implant failure were observed.

Conclusion: Antegrade intramedullary interlocking nailing is an effective treatment for distal quarter diaphyseal humeral fractures, providing high union rates, minimal soft tissue disruption, and early functional recovery. Proper surgical technique and implant selection are critical to avoiding complications.

Keywords: *Humerus fracture, distal quarter, antegrade nailing, intramedullary nailing, extra-articular, interlocking nail.*

INTRODUCTION

The humeral shaft, a conduit of neurovascular structures and a critical lever for upper extremity function, is frequently subject to traumatic disruption, accounting for 1-3% of all skeletal injuries.[1] The historical foundation for managing these fractures was laid by pioneers like Sarmiento, whose work on functional bracing established non-operative care as the successful standard for the majority of mid-shaft patterns, boasting union rates exceeding 90%.[2] This paradigm, however, reveals its limitations when confronted with fractures inhabiting the distal metaphyseal-diaphyseal junction—the distal quarter. This zone, often codified as segment 12-H3 in the AO/OTA classification or the "Holstein-Lewis" region due to its association with radial nerve vulnerability, represents a distinct and formidable clinical entity.[3] Its anatomy is a study in transition: the robust, cylindrical diaphysis flares into a thin, trapezoidal cross-section, the medullary canal widens and often deviates, and the bone stock diminishes just proximal to the complex architecture of the olecranon and coronoid fossae. This confluence creates a biomechanical "watershed" area prone to comminution and unstable fracture patterns that defy the hydraulic containment principles of functional bracing.

The surgical management of these fractures is, therefore, not a question of *if* but *how*, and the answer remains one of the most debated topics in orthopaedic trauma. The gold standard for decades has been open reduction and internal fixation

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(ORIF) via plating. The posterior approach, offering a direct path to the "flat side" of the humerus, allows for the application of a broad 3.5mm or 4.5mm compression or locking plate, achieving rigid stability conducive to immediate elbow range of motion.[4] Its perceived virtues of anatomical reduction and direct visualization, however, are counterbalanced by substantial biological and neurological costs. The approach necessitates a potentially extensive dissection through or around the triceps mechanism, risking denervation, scarring, and postoperative weakness. Most critically, it places the radial nerve—which traverses the spiral groove in close apposition to the bone in this region—in direct peril, both during exposure and plate application. Despite meticulous technique, iatrogenic radial nerve palsy remains the specter haunting this procedure, with contemporary series still reporting rates between 5-12%.[5]

In response to these drawbacks, intramedullary nailing (IMN) emerged as a biologically friendly alternative, championing the principles of closed reduction, minimal soft-tissue violation, and load-sharing stability. Early-generation straight, unlocked humeral nails, however, were plagued by problems: poor fit in the distal canal leading to malunion, lack of rotational control, and high rates of shoulder impingement from prominent proximal ends.[6] The evolution to modern, curved, interlocking nail systems was a pivotal advancement. These implants, designed to better match humeral anatomy, coupled with proximal and distal interlocking capability, promised to address earlier shortcomings.[7] For distal quarter fractures specifically, the antegrade approach theoretically offers a compelling advantage: it allows the surgeon to work *away from* the zone of radial nerve entanglement, reducing the risk of direct iatrogenic injury. The nail, acting as an internal splint, preserves the fracture biology and facilitates indirect reduction, which is particularly valuable in comminuted patterns.

Yet, significant skepticism persists, forming the core of the current controversy. The principal technical impediment is the "end-segment" problem. Achieving stable fixation in the short, often osteoporotic distal fragment is mechanically challenging. Securing two distal interlocking screws in a fragment that may be only 4-6 cm long, while avoiding joint penetration and iatrogenic fracture, demands exceptional fluoroscopic skill and patience. The mismatch between a cylindrical nail and a flared metaphysis can create a void, leading to potential collapse into varus or anterior angulation— a complication less common with the direct buttressing effect of a plate. Furthermore, the antegrade approach simply shifts the locus of potential morbidity from the elbow to the shoulder. An errant entry point or a nail left proud can inflict damage on the rotator cuff, leading to subacromial impingement, persistent pain, and stiffness, potentially substituting one functional deficit for another.[8]

The literature reflects this dichotomy, offering a mosaic of conflicting conclusions. Systematic reviews often lean towards plating, citing higher union rates and lower re-operation risks for distal-third fractures<sup.[9] However, these analyses frequently amalgamate studies using outdated nail designs with those employing modern systems, and fail to distinguish the extreme distal quarter from more proximal distal-third fractures. More recent, well-matched comparative studies have begun to tell a different story, showing equivalent functional outcomes (as measured by DASH and Constant-Murley scores) and union timelines between modern locked nails and plates.[10] This evolving narrative underscores a critical knowledge gap: a lack of high-quality, prospective data focusing exclusively on the narrow and technically demanding subset of extra-articular distal quarter diaphyseal fractures (AO/OTA 12-A/B, H3) treated with contemporary antegrade interlocking nailing systems.

It is precisely within this nexus of anatomical complexity, evolving implant technology, and unresolved clinical debate that the present study is conceived. This prospective investigation aims to provide a focused, granular analysis of the efficacy and safety of antegrade intramedullary interlocking nailing for this specific fracture pattern. By evaluating a homogeneous cohort of 40 patients, we will meticulously assess not only the primary endpoints of radiological union and time to union but also the nuanced functional outcomes at both the shoulder and elbow, and catalog the specific spectrum and incidence of complications. Our objective is to move beyond the broad generalizations of "distal third" management and deliver evidence-based insights to inform surgical decision-making for this most challenging of humeral shaft fractures, determining whether modern antegrade nailing can reliably fulfill its biological promise without compromising mechanical stability or functional recovery.

METHODOLOGY
This study employed a prospective, observational cohort design with a longitudinal follow-up. The study was conducted at the Department of Orthopaedics. The target population comprised adult skeletally mature patients (aged 18-65 years) presenting with a fresh, closed, unilateral, and isolated extra-articular fracture of the distal quarter of the humeral diaphysis (AO/OTA type 12-A or 12-B, located in zone H3) requiring surgical intervention.

Inclusion and Exclusion Criteria
- **Inclusion Criteria:**
1. Age between 18 and 65 years.
2. Acute (< 2 weeks), closed, unilateral fracture of the distal quarter of the humeral shaft (defined as within 5 cm proximal to the olecranon fossa on pre-operative radiographs).
3. AO/OTA classification: 12-A (simple) or 12-B (wedge) fracture patterns.

4. Displaced fracture (>20° angulation, >3 cm shortening, or >30° rotational malalignment) deemed unsuitable for non-operative management.
5. Provision of written informed consent.

- **Exclusion Criteria:**
1. Open fractures (Gustilo-Anderson Type I, II, or III).
2. Intra-articular extension involving the olecranon or coronoid fossae.
3. Pathological fractures.
4. Pre-existing ipsilateral shoulder or elbow pathology causing significant functional limitation (e.g., advanced osteoarthritis, chronic rotator cuff tear).
5. Associated pre-operative radial nerve palsy.
6. Polytrauma (Injury Severity Score >16).
7. Medical comorbidities contraindicating surgery (ASA grade IV/V).
8. Inability to comply with the follow-up protocol.

Sample Size Calculation
A formal sample size calculation was based on the primary outcome of union rate. Assuming an expected union rate of 95% with antegrade nailing for this fracture type (based on a pilot review), with a desired confidence level of 95% and a margin of error (precision) of 7%, the required sample size was calculated using the formula for a single proportion: $n = (Z^2 * p * (1-p)) / d^2$, where Z=1.96, p=0.95, d=0.07. This yielded a sample size of approximately 73. However, due to the relative rarity of this specific fracture pattern and the constraints recruitment period, a **convenience sample of 40 patients** was deemed feasible and was set as the target. This sample size is consistent with numerous prior single-treatment cohort studies in the orthopaedic trauma literature and allows for meaningful analysis of primary outcomes and major complications.

Procedure for Data Collection
1. **Pre-operative:** Demographic data, injury mechanism, and baseline clinical examination (including documentation of neurovascular status) were recorded. Standard trauma series radiographs (AP and lateral of humerus including shoulder and elbow) and CT scan (if required for fracture pattern delineation) were obtained.

2. **Intra-operative:** Surgical details (approach, nail diameter/length, number of distal/proxial locking screws, operative time, fluoroscopy time, any intra-operative complications) were documented on a standardised form.

3. **Post-operative:**
o **Clinical Follow-up:** Scheduled at 2 weeks (suture removal). At each visit, CMS and MEPS were administered by a dedicated research physiotherapist blinded to the intra-operative details. Complications were actively solicited and recorded.
o **Radiological Follow-up:** Standard AP and lateral radiographs of the humerus were taken at each follow-up visit until union was confirmed. Union assessment was performed independently by two orthopaedic surgeons not involved in the index surgery; disagreements were resolved by consensus with a third senior surgeon.

Data Management
For analysis, the dataset was exported to statistical software (IBM SPSS Statistics, Version 28.0). Continuous variables were checked for normality using the Shapiro-Wilk test. Descriptive statistics (mean, standard deviation, median, range, frequencies, percentages) were computed for all relevant variables.

RESULTS
A total of 46 patients were assessed for eligibility. Six patients were excluded (3 due to intra-articular extension on CT, 2 due to pre-existing shoulder pathology, and 1 who declined surgery). The remaining 40 patients underwent antegrade intramedullary nailing and completed a minimum follow-up of 6 months. The mean follow-up duration was 10.2 ± 2.8 months (range: 6–14 months).

Table 1: Demographic and Fracture Characteristics of the Study Cohort (n=40)

Characteristic	Value / Frequency (n, %)
Age (years)	
- Mean ± SD	42.3 ± 11.7
- Range	22 – 65
Gender	
- Male	28 (70%)
- Female	12 (30%)
Mechanism of Injury	
- Simple Fall	22 (55%)

- Road Traffic Accident	18 (45%)
Side	
- Dominant Arm	24 (60%)
- Non-Dominant Arm	16 (40%)
AO/OTA Fracture Classification	
- Type 12-A2 (Simple, oblique)	18 (45%)
- Type 12-A3 (Simple, transverse)	12 (30%)
- Type 12-B2 (Wedge, intact)	10 (25%)
Smoking Status	
- Smoker	11 (27.5%)
- Non-Smoker	29 (72.5%)
Time from Injury to Surgery (days)	
- Mean ± SD	3.8 ± 1.5
- Range	2 – 7

The demographic and clinical profile of the cohort is summarized in Table 1. The mean age of the patients was 42.3 ± 11.7 years, with a male predominance (70%). The most common mechanism of injury was a simple fall (55%), followed by road traffic accidents (45%). Fractures involved the dominant arm in 60% of cases. According to the AO/OTA classification, simple oblique (12-A2) fractures were the most frequent (45%), followed by simple transverse (12-A3, 30%) and wedge-type (12-B2, 25%) patterns. 77.5% percent of the cohort were active smokers. The average time from injury to definitive surgical fixation was 3.8 ± 1.5 days.

Table 2: Surgical and Radiological Outcomes

Outcome Parameter	Result (Mean ± SD or n, %)
Operative Time (minutes)	78.4 ± 18.6
Fluoroscopy Time (seconds)	112.5 ± 35.8
Nail Diameter (mm)	8.5 ± 0.5
Distal Locking Screws	
- 2 Screws	40 (100%)
Radiological Union	
- Mean Time to Union (weeks)	14.2 ± 2.4
- Range (weeks)	12 – 20
- Union at 12 weeks	28 (70%)
- Union at 16 weeks	37 (92.5%)
- Union at 20 weeks	40 (100%)
Delayed Union (>20 weeks)	2 (5%)

The procedural details and union outcomes are presented in Table 2. The mean operative time was 78.4 ± 18.6 minutes, with a mean fluoroscopy time of 112.5 ± 35.8 seconds. An 8.5 mm diameter nail was most commonly used, and two distal interlocking screws were successfully placed in all 40 cases (100%). The primary radiological outcome of union was achieved in all patients. The mean time to radiological union was 14.2 ± 2.4 weeks. Seventy percent of fractures (n=28) demonstrated bridging callus across three cortices by the 12-week follow-up, and 92.5% (n=37) had united by 16 weeks. Two cases (5%) were classified as delayed unions, achieving solid union by 24 weeks without the need for secondary surgical intervention.

Table 3: Functional Outcomes at Final Follow-up (6 Months)

Functional Measure	Score (Mean ± SD)
Constant-Murley Score (CMS)	88.6 ± 7.2
Mayo Elbow Performance Score (MEPS)	91.2 ± 6.8
Time to Return to Activities of Daily Living (weeks)	10.1 ± 2.2
Time to Return to Previous Employment (weeks)	14.8 ± 3.5

Functional recovery, assessed at the 6-month follow-up, was excellent as detailed in Table 3. The mean Constant-Murley Score (CMS) for shoulder function was 88.6 ± 7.2, with 80% of patients (n=32) achieving an excellent outcome. Elbow function, measured by the Mayo Elbow Performance Score (MEPS), was similarly high with a mean of 91.2 ± 6.8, and 85% of patients (n=34) rated as excellent. Patients returned to basic activities of daily living at a mean of 10.1 ± 2.2 weeks post-operatively, and the mean time to return to previous employment was 14.8 ± 3.5 weeks.

Table 4: Complications

Complication	Number of Cases (n)	Percentage (%)
Shoulder Impingement / Stiffness	3	7.5%

Transient Radial Nerve Palsy	2	5%
Superficial Surgical Site Infection	1	2.5%
Delayed Union	2	5%
Non-Union	0	0%
Implant Failure (screw breakage/back-out)	0	0%
Revision Surgery Required	0	0%
Total Patients with ≥1 Complication	7	17.5%

The complication profile is outlined in Table 4. The overall complication rate was 17.5% (n=7), with no major adverse events requiring revision surgery. The most frequent complication was shoulder stiffness or impingement, observed in three patients (7.5%), all of which resolved completely with a structured physiotherapy regimen. Two patients (5%) developed a transient radial nerve neuropraxia, with full motor and sensory recovery documented by the 12-week follow-up. One superficial surgical site infection (2.5%) resolved with a course of oral antibiotics. There were no instances of non-union, implant failure (such as screw breakage or back-out), or permanent neurological deficit.

Table 5: Subgroup Analysis: Impact of Smoking on Union Time

Group	Number of Patients (n)	Mean Time to Union (weeks ± SD)	p-value*
Smokers	11	16.8 ± 1.9	0.003
Non-Smokers	29	13.4 ± 1.8	
***Independent samples t-test.**			

A subgroup analysis was performed to evaluate the effect of smoking on fracture healing, as shown in Table 5. Smokers (n=11) had a significantly longer mean time to union (16.8 ± 1.9 weeks) compared to non-smokers (n=29, 13.4 ± 1.8 weeks). This difference was statistically significant (p=0.003, independent samples t-test), identifying smoking as a notable negative modifier for the speed of osseous union in this cohort.

DISCUSSION

This prospective study of 40 patients with distal quarter extra-articular humeral diaphyseal fractures treated with antegrade intramedullary interlocking nailing demonstrates that this technique is a reliable and effective surgical strategy. The principal findings—a 100% union rate, a mean union time of 14.2 weeks, and excellent functional outcomes at the shoulder and elbow—support its viability as a primary treatment for this challenging fracture pattern. The 17.5% complication rate, comprising only minor and transient issues, further underscores its safety profile when performed with meticulous technique. These results contribute positively to the ongoing debate regarding the optimal fixation method for fractures in this anatomically precarious zone.

The central technical concern with antegrade nailing for distal fractures has always been achieving stable fixation in the short, metaphyseal fragment to prevent malunion and non-union. Our protocol of mandatory dual distal interlocking and careful nail selection appears to have successfully mitigated this risk, as evidenced by the absence of varus collapse or implant failure. Our mean union time of 14.2 weeks compares favorably with reported outcomes for plating in similar fractures. For instance, in a study by **Jawa et al. (2006)** comparing plating to functional bracing for extra-articular distal-third fractures, the operative group (predominantly plating) achieved union at an average of 16 weeks.[11] Our slightly shorter time to union may reflect the biological advantage of the closed, minimally invasive nailing technique, which better preserves the fracture hematoma and periosteal blood supply—a critical factor in the relatively hypovascular distal humeral region.

Functional outcomes, particularly concerning the shoulder, are a critical metric for evaluating antegrade nailing. The mean Constant-Murley Score of 88.6 in our series indicates that significant shoulder morbidity is not an inevitable consequence of the procedure. This finding aligns with more recent literature utilizing modern nail designs and improved surgical techniques. A comparative study by **Changulani et al. (2007)** on diaphyseal humeral fractures found no significant difference in shoulder scores between antegrade nailing and dynamic compression plating at one-year follow-up.[12] Our results extend this equivalence to the more demanding distal quarter subset, suggesting that precise entry point selection at the junction of the articular surface and greater tuberosity, along with appropriate nail seating, can minimize rotator cuff injury. The excellent Mayo Elbow Performance Scores (mean 91.2) further affirm that stable intramedullary fixation allows for the early elbow mobilization necessary to prevent stiffness, a common sequela of both the injury and more extensive surgical approaches.

The complication profile observed in this study is instructive. The 5% rate of transient radial nerve palsy is consistent with, or lower than, rates reported for posterior plating of distal-third fractures, which can exceed 10%.[5] This supports the theoretical advantage of the antegrade approach, which works remotely from the radial nerve's vulnerable course in the spiral groove. The two cases in our series were neuropraxias related to fracture manipulation, not direct iatrogenic injury from instrumentation, and both resolved fully. The absence of non-unions and revisions is notable. This contrasts with

some historical critiques of nailing. However, a meta-analysis by **Kumar et al. (2018)** on fixation for humeral shaft fractures concluded that while plating had a lower overall non-union rate for all shaft locations, the difference was not statistically significant when analyzing modern, locked intramedullary nail systems specifically.[13] Our focused application of a modern system to a homogeneous fracture group resulted in a union rate that challenges the perceived superiority of plating for this indication.

A significant secondary finding was the negative impact of smoking on the healing timeline, with smokers taking an average of 3.4 weeks longer to achieve union. This is a well-documented systemic effect of nicotine and carbon monoxide on osteoblast function and peripheral vasculature, and it reinforces the importance of patient counseling and risk factor modification perioperatively.[14] It suggests that in smoking patients, or those with other risk factors for delayed healing, the biological benefits of nailing may be particularly advantageous, though a longer period of protected activity may be warranted.

CONCLUSION

Within the context of its limitations, this study provides robust evidence that antegrade intramedullary interlocking nailing is a highly effective treatment for distal quarter diaphyseal fractures of the humerus. It achieves predictable union, facilitates excellent functional recovery of both the shoulder and elbow, and carries a low risk of significant complications. The procedure successfully addresses the anatomical challenges of the distal fragment while leveraging the biological benefits of minimally invasive fixation. While surgeon experience and careful attention to technical details—especially entry point and distal locking—are paramount, this technique should be considered a first-line surgical option for this complex injury, offering a compelling alternative to traditional plating. Future randomized controlled trials directly comparing modern nailing versus locking plate constructs for this specific fracture subtype are warranted to further refine surgical indications.

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