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Outcomes After Minimally Invasive Intramedullary Nail Fixation and Locking Plate Fixation Among Patients With Proximal Humerus Fractures

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Minimally invasive intramedullary nail (IMN) fixation has gained increasing attention for proximal humerus fractures. We compared operative time, intraoperative blood loss, postoperative pain, and functional outcomes between minimally invasive IMN fixation and locking plate fixation.

Material/Methods: This prospective study enrolled 61 patients from January 2019 to January 2024: 36 treated via IMN (Group A) and 25 treated via locking plates (Group B). Operative time, incision length, blood loss, visual analog scale (VAS) scores, complication rates, and postoperative shoulder function were analyzed.

Results: Group A had a shorter operative time, smaller incision length, less blood loss (all P=0.001); shorter hospital stay (P=0.006); lower VAS scores (P=0.04); and fewer complications (P=0.03) than Group B. Group A demonstrated better shoulder flexion at 1, 3, and 6 months (P<0.001; =0.003, 0.029). At 1, 3, 6, and 12 months, Group A showed superior external rotation, internal rotation, and abduction versus Group B (all P<0.05). The neck-shaft angle was greater and loss of humeral head height was lower in Group A at 3, 6, and 12 months (all P<0.05). Constant-Murley scores were higher in Group A at 1 and 3 months (P=0.008, 0.032); DASH scores were lower in Group A at 3 and 12 months (P=0.002, 0.009).

Conclusions: IMN fixation for proximal humerus fractures offers shorter operative time, fewer complications, and improved postoperative shoulder function, indicating superior clinical efficacy relative to locking plate fixation.

Keywords: **Fracture Fixation • Intramedullary Nailing • Minimally Invasive Surgical Procedures • Orthopedics • Proximal Humeral Fractures**

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Introduction

Proximal humeral fractures represent 4% to 10% of all fractures in adults and are the third most common fracture in this population [1,2]. The most widely used clinical classification system is that proposed by Charles S. Neer, which divides the proximal humerus into 4 anatomical components: greater tuberosity, lesser tuberosity, humeral head, and humeral shaft. Displacement exceeding 1 cm or angulation greater than 45 degrees defines the threshold for classification. Fractures are categorized as 1-, 2-, 3-, or 4-part types based on the extent of displacement and anatomical segments involved [3]. Management of proximal humeral fractures is primarily determined by fracture type and patient-specific factors [4]. For stable fractures, conservative treatment is typically recommended [4,5]. However, for unstable or substantially displaced fractures, such as Neer type II, III, and IV fractures, the optimal treatment strategy remains controversial. Most clinicians recommend surgical intervention, which is believed to facilitate better functional recovery than conservative management [6,7]. Common surgical techniques include K-wire fixation, locking plate fixation, intramedullary nail fixation, and shoulder arthroplasty [8-12]. Locking plate fixation is considered the gold standard for treating proximal humeral fractures; however, it is associated with a higher incidence of complications, including infection, nonunion, and limited shoulder function [13,14]. With the development of minimally invasive techniques and widespread use of intramedullary nails, intramedullary nail fixation for proximal humeral fractures has become increasingly common and has demonstrated favorable clinical outcomes [15-17]. There is evidence that intramedullary nails are effective for treating proximal humeral fractures, yielding favorable early radiographic and functional outcomes, even in patients with comminuted humeral calcar fractures [18]. Although both methods achieve favorable clinical outcomes, characterized by high success rates and acceptable complication profiles, controversy persists regarding the choice between intramedullary nails and locking plates for the treatment of proximal humeral fractures. This debate primarily centers on differences in complication rates, surgical complexity, and recovery time [19,20]. The suitability of using a locking intramedullary nail alone for initial varus proximal humeral fractures has not been reported in the literature. Thus, the present prospective pilot study aimed to evaluate the feasibility of using a locking intramedullary nail alone for the treatment of initial varus proximal humeral fractures. To determine whether intramedullary nail fixation yields superior outcomes compared with locking plate fixation for proximal humeral fractures, we compared operative time, intraoperative blood loss, and postoperative pain and functional outcomes between patients undergoing minimally invasive intramedullary nail fixation and those undergoing locking plate fixation.

Material and Methods

This study was approved by the Ethics Committee of Shenzhen Hospital (Guangming), affiliated with the University of Chinese Academy of Sciences (approval number: LL-KT-2018128). All patients provided written informed consent for participation in the study and for the surgical procedure.

Inclusion and Exclusion Criteria

Eligible patients were those with proximal humeral fractures undergoing surgical treatment between January 2019 and January 2024, aged 18 to 70 years, with injury occurring up to 14 days before surgery, and without concomitant fractures at other sites. Patients were required to have no systemic or local infections, no major vascular injuries, and no other conditions that would preclude surgery.

Patients were excluded if they did not voluntarily accept intramedullary nailing treatment; had concomitant fractures at other sites; had massive, irreparable rotator cuff tears; had systemic or local infections; had clinically significant vascular or nerve injuries in the affected limb; had open fractures; were unable to tolerate surgery; had clinically significant preoperative limitations in shoulder function due to autoimmune or other shoulder disorders; had severe osteoporosis; or had pathological fractures.

Clinical Data

All patients underwent routine blood tests, chest X-rays, and electrocardiograms after admission. Additionally, anteroposterior X-rays of the affected shoulder, computed tomography with 3-dimensional reconstruction, magnetic resonance imaging, and bone density measurements were performed. Patients were selected according to the aforementioned inclusion and exclusion criteria, then randomly assigned to groups. Fractures were classified according to the Neer system by 2 independent physicians. Surgical management followed generally accepted principles for proximal humerus fracture fixation. The choice between intramedullary nail and plate fixation was based on fracture pattern, bone quality, and surgeon experience, in accordance with contemporary practice guidelines [4].

Preoperative Preparation

Patients fasted and abstained from water for 8 hours before surgery; they received a broad-spectrum antibiotic 30 minutes prior to the procedure.

Surgical Methods

All surgeries were performed by a single surgeon while patients were under general anesthesia with tracheal intubation

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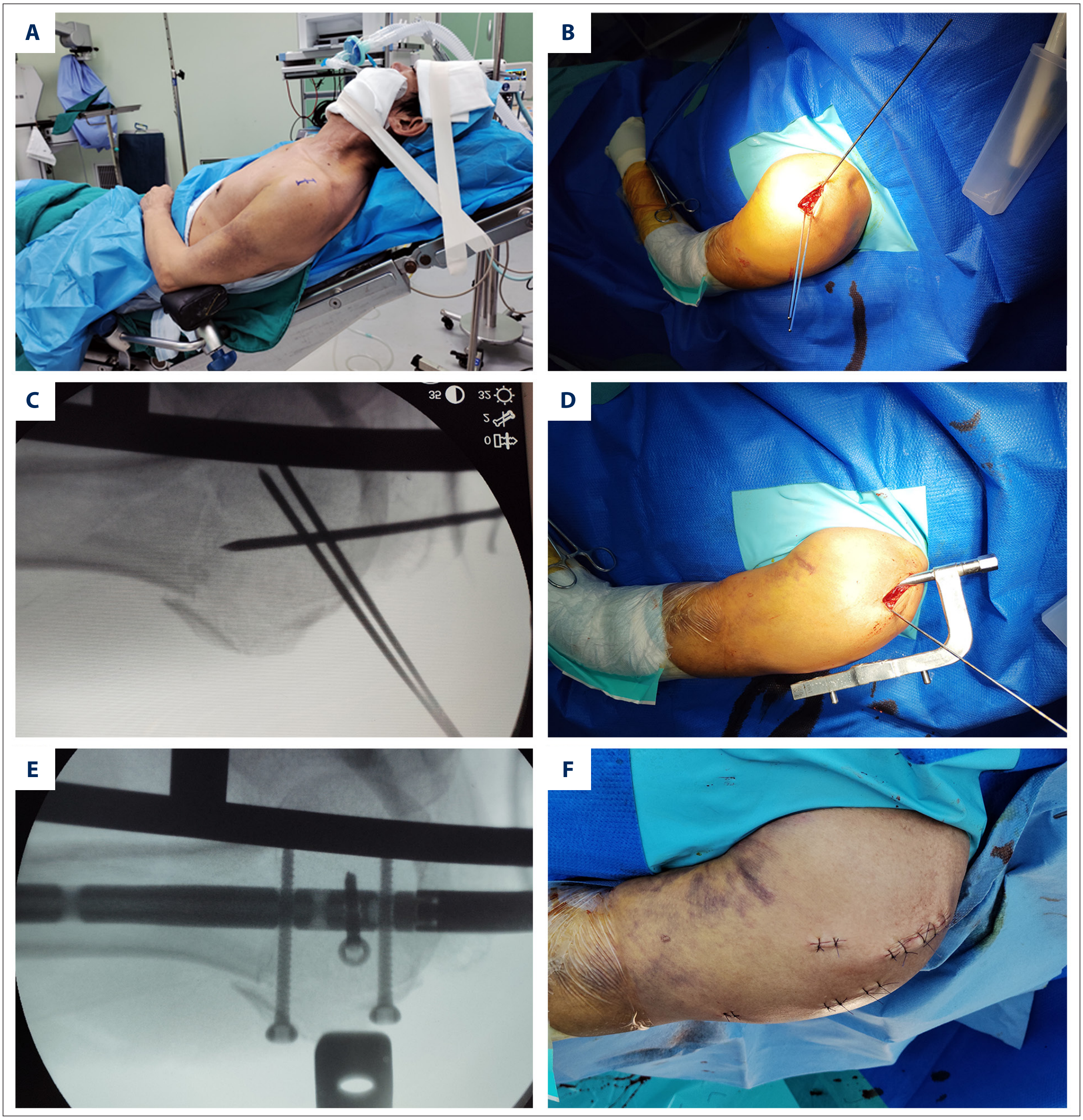

Figure 1. Intramedullary nail fixation surgical procedure. (**A**) Patient positioning and incision; (**B**) fracture reduction and guide pin placement using a Kirschner wire; (**C**) confirmation of fracture reduction and guide pin position via fluoroscopy; (**D**) insertion of the intramedullary nail; (**E**) confirmation of intramedullary nail and screw placement via fluoroscopy; (**F**) wound closure.

or brachial plexus anesthesia; each patient was positioned in the beach-chair position.

Intramedullary Nail Fixation Group

For Neer type II fractures, closed reduction was performed using traction techniques. For Neer type III and IV fractures, K-wire manipulation was used. A shoulder anterolateral incision of approximately 1 to 3 cm was made (**Figure 1A**); this was followed by deltoid splitting to expose the greater tuberosity of the humerus. The upper limb was maintained in a neutral position, with the elbow flexed at 90 degrees and shoulder extended at 45 to 60 degrees, allowing exposure of the supraspinatus tendon above the humeral head. The entry point for the intramedullary nail was established approximately 1 cm posterior to the bicipital groove and about 1 cm medial to the greater tuberosity (at the highest point of the humeral head), where a 2.0-mm guide pin was inserted (**Figure 1B**).

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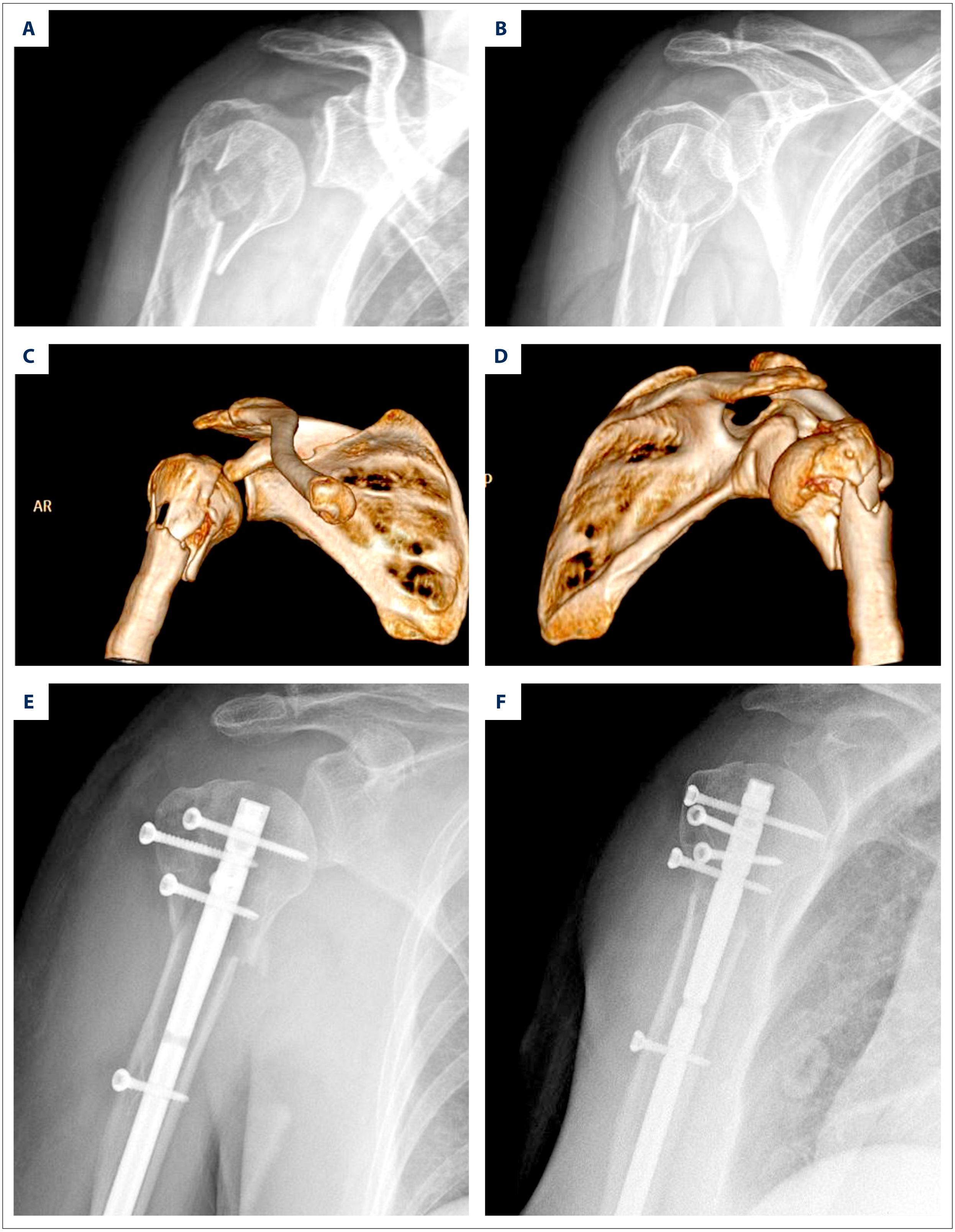

Figure 2. Imaging data for a Neer type IV fracture. (**A, B**) Preoperative X-ray images; (**C, D**) preoperative computed tomography images; (**E, F**) postoperative X-ray images.

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C-arm fluoroscopy was used to confirm fracture reduction and guide pin position (**Figure 1C**). An incision was made along the direction of the muscle fibers at the guide pin entry site, and a 4.5-mm cannulated drill was used to create the entry hole. The medullary canal was sequentially reamed, and an appropriately sized intramedullary nail was inserted based on the canal diameter (**Figure 1D**). After satisfactory fracture reduction and nail position had been confirmed under fluoroscopy, the proximal end of the nail was positioned 3 to 5 mm below the articular surface of the humeral head. For Neer type II fractures, 2 to 3 proximal locking screws were inserted; for Neer type III and IV fractures, 3 to 4 proximal locking screws were used (**Figure 1E**). In cases of comminuted greater tuberosity fractures, high-strength sutures were used to repair the rotator cuff and secure it to the proximal locking screws, facilitating reduction and fixation. One to 2 distal locking screws were then placed. Final fluoroscopy confirmed satisfactory fracture reduction and implant positioning. The incision was closed in layers (**Figure 1F**).

Locking Plate Group

For Neer type II fractures, closed reduction was achieved using traction applied to the affected limb. After fluoroscopic confirmation of satisfactory reduction, minimally invasive internal fixation was performed. An anterolateral shoulder incision of approximately 5 cm was made, along with a 3-cm longitudinal incision at the deltoid insertion to separate the anterior and middle bundles of the deltoid muscle. A periosteal elevator was used to detach the periosteum from proximal to distal along the subdeltoid tunnel, with careful protection of the axillary nerve. A proximal humeral locking plate was inserted along the periosteum from proximal to distal. The plate was positioned with its proximal end approximately 8 mm below the highest point of the greater tuberosity and its anterior edge 3 to 5 mm from the intertubercular groove. Fluoroscopy confirmed satisfactory fracture reduction and plate positioning. At the distal incision, 1 appropriately sized cortical screw was placed to secure the plate, followed by 5 to 6 proximal locking screws and 2 distal locking screws. Fluoroscopy was used to verify fracture reduction, plate placement, and screw length, ensuring that no screws penetrated the joint cavity. The incision was then closed in layers.

For Neer type III and IV fractures, a deltopectoral approach was used, with an incision of approximately 10 to 12 cm. The cephalic vein was identified and protected; the interval between the pectoralis major and deltoid muscles was developed to expose the proximal humerus for open reduction. Locking plate fixation was then performed using the same technique. Placement of a drain was determined based on intraoperative bleeding and swelling. The incision was closed in layers.

Postoperative Treatment and Follow-Up

Antibiotics were administered immediately after surgery to prevent infection. X-ray imaging was repeated 1 to 2 days postoperatively to evaluate fracture reduction (**Figure 2**). Functional exercises were initiated on the first postoperative day. During the first week, patients were instructed to perform upper limb muscle exercises combined with passive, limited-range shoulder movements. During weeks 2 and 3, active range-of-motion exercises with limited flexion and rotation were introduced, along with upper limb strengthening. By week 4, active exercises involving shoulder abduction, elevation, and rotation were initiated. Resistance exercises were introduced at week 6. Patients were allowed to return to normal work approximately 8 weeks after surgery. Fracture healing was monitored to determine when patients could gradually resume upper limb strength training, typically around 6 months postoperatively.

The follow-up period ranged from 1 to 2 years. Patients were evaluated at 1, 3, 6, 9, and 12 months postoperatively, followed by visits every 6 months thereafter.

Observation Indicators

Outcome measures included operative time, incision length, intraoperative blood loss, number of fluoroscopic exposures, fracture reduction status, postoperative pain, and functional recovery. Pain was assessed using the visual analog scale (VAS) on postoperative days 3 and 7. Radiographic evaluations were performed at 1, 3, 6, and 12 months. Two senior physicians independently assessed radiographic parameters, including fracture reduction, healing time, neck-shaft angle, and loss of humeral head height. Functional outcomes were evaluated using the Constant-Murley score and the Disabilities of the Arm, Shoulder and Hand (DASH) score. Shoulder range of motion, including flexion, extension, internal rotation, and external rotation, was measured using a goniometer.

Statistical Methods

All analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including means and standard deviations, were calculated for each group. Differences between groups were assessed using independent-samples t-tests for continuous variables and χ^2 tests for categorical variables. The statistical significance threshold was set at α=0.05.

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Table 1. General patient characteristics.

Item	Intramedullary nail (n=36)	Locking plate (n=25)	P value
Sex, male/female (n)	21/15	10/15	0.796
Age (years)	46.2±11.9	48.4±12.9	0.719
Neer fracture classification, type 2/3/4 (n)	10/20/6	11/12/2	0.726
Cause of injury, fall/fall from height/traffic accident (n)	17/3/16	12/1/12	0.793
Time from injury to surgery (days)	5.0±2.6	5.5±2.2	0.144

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables and chi-square test for categorical variables. *P*<0.05 was considered statistically significant.

Table 2. Hospitalization and surgery-related data.

Item	Intramedullary nail (n=36)	Locking plate (n=25)	P value
Incision length (cm)	6.13±1.58	10.33±2.01	0.001
Intraoperative blood loss (mL)	32.08±14.80	179.00±139.70	0.001
Operative time (min)	84.64±11.99	116.76±35.99	0.001
Intraoperative fluoroscopic exposures (n)	4.69±0.71	10.20±1.63	0.001
VAS score on postoperative day 3	2.64±1.20	6.16±0.80	0.040
VAS score on postoperative day 7	2.03±0.66	4.36±0.86	0.020
Hospital stay (days)	7.03±1.59	11.48±3.54	0.003
Fracture healing time (months)	2.39±0.80	3.80±0.91	0.642
Complications (cases)	0.00±0.00	0.13±0.34	0.030

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant. VAS, visual analog scale.

Results

Participants' General Information

Between January 2019 and January 2024, 61 cases of proximal humeral fractures were treated using either intramedullary nails or proximal humeral plates. The patients were divided into 2 groups: Group A, which received intramedullary nail fixation, and Group B, which received plate fixation. Group A included 36 patients (21 men and 15 women) with a mean age of 46.2±11.9 years. According to the Neer classification, there were 10 two-part fractures, 20 three-part fractures, and 6 four-part fractures. Causes of injury included falls (n=17), falls from height (n=3), and traffic accidents (n=16). The mean time from injury to surgery was 5.0±2.6 days. Group B included 25 patients (10 men and 15 women) with a mean age of 48.4±12.9 years. According to the Neer classification, there were 11 two-part fractures, 12 three-part fractures, and 2 four-part fractures. Causes of injury included falls (n=12), falls from height (n=1), and traffic accidents (n=12). The mean time from injury to surgery was 5.5±2.2 days. There were no statistically significant differences in baseline characteristics between the 2 groups (*P*>0.05) (**Table 1**). All cases were followed for more than 1 year.

Hospitalization and Surgery-Related Results

The intramedullary nail group showed significantly lower values than the locking plate group for incision length, intraoperative blood loss, operative time, number of intraoperative fluoroscopic exposures, length of hospital stay, postoperative pain scores on days 3 and 7, and incidence of complications (*P*<0.05). However, there was no significant difference in fracture healing time between the groups (*P*>0.05) (**Table 2**).

Table 3. Postoperative shoulder flexion (degrees).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	139.61±4.24	121.76±7.67	<0.001
3 months postoperatively	161.53±4.94	137.32±2.34	0.003
6 months postoperatively	172.36±4.30	153.76±2.86	0.029
12 months postoperatively	177.25±4.07	169.68±5.39	0.195

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Table 4. Postoperative shoulder extension (degrees).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	50.39±3.75	43.72±2.21	0.062
3 months postoperatively	54.61±3.79	47.08±1.84	0.002
6 months postoperatively	58.75±1.79	52.84±3.82	0.020
12 months postoperatively	59.47±1.84	59.04±2.13	0.536

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Table 5. Postoperative shoulder abduction (degrees).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	120.17±13.65	88.8±4.94	<0.001
3 months postoperatively	147.81±10.24	117.36±4.82	<0.001
6 months postoperatively	171.92±3.65	137.32±5.37	0.027
12 months postoperatively	176.61±3.66	169.24±5.58	0.027

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Table 6. Postoperative shoulder external rotation (degrees).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	53.69±3.62	36.00±1.35	0.003
3 months postoperatively	60.67±6.13	54.20±2.12	<0.001
6 months postoperatively	76.42±1.59	64.60±7.64	0.020
12 months postoperatively	88.25±1.68	83.96±7.39	0.001

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Incidence of Complications

Neither group experienced complications such as neurovascular injury, fixation-related fracture, internal fixation failure, screw cut-out, or fracture nonunion. The locking plate group had 3 complications (12%): 2 surgical site infections, which resolved after 3 weeks of antibiotic therapy and dressing changes, and 1 case of avascular necrosis of the humeral head, which required humeral head replacement 1 year after surgery. The

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Table 7. Postoperative shoulder internal rotation (degrees).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	59.94±6.46	55.08±3.67	<0.001
3 months postoperatively	70.19±9.21	58.00±4.61	<0.001
6 months postoperatively	80.97±7.02	63.76±4.81	0.013
12 months postoperatively	88.44±3.69	81.72±7.55	0.002

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Table 8. Postoperative humeral neck-shaft angle (degrees).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	133.69±1.47	130.24±2.05	0.238
3 months postoperatively	132.86±1.29	128.24±2.01	0.005
6 months postoperatively	132.00±1.76	126.52±2.80	0.027
12 months postoperatively	131.39±1.50	124.28±2.89	0.009

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Table 9. Postoperative humeral head height loss (mm).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	1.03±0.24	1.58±1.79	0.697
3 months postoperatively	1.09±1.26	2.12±0.34	0.016
6 months postoperatively	1.13±0.14	2.40±0.42	<0.001
12 months postoperatively	1.22±0.17	2.62±0.38	<0.001

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

complication rate was significantly lower in the intramedullary nail group than in the locking plate group (*P*=0.03) (**Table 2**).

Shoulder Joint Function

At 1, 3, and 6 months after surgery, the intramedullary nail group demonstrated significantly greater shoulder flexion compared with the locking plate group (*P*<0.05). No significant difference was observed at 12 months postoperatively (*P*>0.05). The intramedullary nail group also showed significantly better external rotation, internal rotation, and abduction at 1, 3, 6, and 12 months postoperatively (*P*<0.05) (**Tables 3-7**).

No significant differences were observed between groups in humeral neck-shaft angle or loss of humeral head height at 1 month postoperatively (*P*>0.05). However, at 3, 6, and 12 months postoperatively, the intramedullary nail group demonstrated a significantly greater neck-shaft angle compared with the locking plate group (*P*<0.05). Additionally, loss of humeral head height was significantly lower in the intramedullary nail group than in the locking plate group (*P*<0.05) (**Tables 8, 9**).

Comparison of Constant-Murley scores showed that, at 1 and 3 months postoperatively, the intramedullary nail group had significantly higher scores compared with the locking plate group (*P*<0.05); no significant differences were observed at 6 and 12 months (*P*>0.05) (**Table 10**).

Comparison of DASH scores showed no significant differences between groups at 1 and 6 months postoperatively (*P* > 0.05). However, at 3 and 12 months, the intramedullary nail group had significantly lower scores relative to the locking plate group (*P*<0.05) (**Table 11**).

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Table 10. Postoperative shoulder Constant-Murley score (points).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	74.17±3.35	60.00±5.03	0.008
3 months postoperatively	79.89±2.97	66.00±1.84	0.032
6 months postoperatively	87.81±2.35	70.20±1.83	0.146
12 months postoperatively	91.81±2.55	82.72±2.26	0.667

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Table 11. Postoperative upper limb disability (DASH) score (points).

Time	Intramedullary nail (n=36)	Locking plate (n=25)	P value
1 month postoperatively	15.78±0.93	32.72±1.14	0.270
3 months postoperatively	13.42±1.29	20.48±2.71	0.002
6 months postoperatively	11.31±1.47	18.88±1.92	0.333
12 months postoperatively	9.28±1.26	13.68±2.36	0.009

Values are presented as mean±standard deviation. P values were calculated using the independent-samples t-test for continuous variables. *P*<0.05 was considered statistically significant.

Discussion

Compared with locking plate fixation, minimally invasive intramedullary nailing for displaced proximal humeral fractures was associated with less surgical trauma, reduced intraoperative blood loss, lower postoperative pain, shorter hospital stay, a lower complication rate, faster functional recovery, and more favorable early- to mid-term radiographic and functional outcomes.

Advantages of Surgical Methods

Intramedullary nailing for proximal humeral fractures is less invasive than locking plate fixation, requiring only 5 to 6 small incisions. This technique uses closed reduction, which minimizes soft tissue damage and preserves blood supply. It also shortens operative time and reduces intraoperative blood loss. During intramedullary nail fixation, fluoroscopy is primarily required for fracture reduction, guide pin insertion, and nail placement. Consequently, fewer fluoroscopic exposures are needed compared with locking plate fixation, reducing intraoperative radiation exposure. Li et al [21] studied 37 older patients with proximal humeral fractures receiving intramedullary nail or locking plate fixation; they concluded that both methods yield good outcomes, but intramedullary nailing offers advantages such as shorter operative time, less postoperative pain, and faster recovery. Hu et al [22] also reported that intramedullary nail fixation outperformed locking plate fixation in terms of operative time, intraoperative blood loss, and postoperative infection rates. In the present study, the intramedullary nail group demonstrated significantly shorter incision length, reduced intraoperative blood loss, shorter operative time, fewer intraoperative fluoroscopic exposures, and lower postoperative pain scores than the locking plate group. These findings are consistent with previous studies and highlight the minimally invasive advantages of intramedullary nail fixation. Sigterman et al [23] evaluated intramedullary nailing for proximal humeral fractures in older patients and concluded that it is a viable treatment option with advantages over plating, including reduced invasiveness and a lower complication rate. Zhu et al [24] reported similar findings in a cohort of 60 patients, demonstrating a lower incidence of complications with intramedullary nail fixation. Consistent with these reports, we identified a significantly lower postoperative complication rate in the intramedullary nail group. At 1, 3, and 6 months postoperatively, the intramedullary nail group demonstrated significantly greater shoulder flexion compared with the locking plate group. These findings support previous evidence that intramedullary nail fixation offers advantages over locking plate fixation, including faster functional recovery and lower complication rates.

Functional Recovery

Functional recovery is a key indicator of treatment effectiveness in proximal humeral fractures. Fan et al [25] conducted a comparative study involving 86 older patients, revealing that intramedullary nail fixation was less invasive and associated with faster recovery. Previous studies indicate that the minimally invasive nature of intramedullary nails reduces postoperative

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pain and shortens recovery time, thereby promoting functional recovery [20,26]. In the present study, VAS scores on postoperative days 3 and 7 were significantly lower in the intramedullary nail group than in the locking plate group, suggesting that the minimally invasive approach reduces postoperative pain and facilitates earlier functional recovery of the shoulder joint. Within the first 3 postoperative months, patients treated with intramedullary nails demonstrated more rapid functional recovery than those treated with locking plates, allowing earlier return to daily activities. Previous research has shown that patients treated with intramedullary nails achieve significantly higher shoulder function scores, including Constant-Murley and DASH scores, particularly in flexion and abduction [27,28]. Consistent with these findings, our results showed that at 1, 3, and 6 months postoperatively, the intramedullary nail group demonstrated significantly greater shoulder flexion relative to the locking plate group. Additionally, shoulder abduction, external rotation, and internal rotation were significantly better in the intramedullary nail group at 1, 3, 6, and 12 months. Constant-Murley scores were significantly higher in the intramedullary nail group at 1 and 3 months postoperatively. Similarly, DASH scores, which assess upper limb functional impairment, were significantly lower in the intramedullary nail group at 3 and 12 months postoperatively. These findings are consistent with previous studies and indicate that intramedullary nail fixation results in superior shoulder functional recovery relative to locking plate fixation.

Biomechanical Stability and Radiographic Evaluations

Locking plates use an eccentric fixation method, which can lead to stress concentration and increase the risk of complications such as plate fracture [29]. Among patients with osteoporosis, the plate position may predispose to upward displacement or malunion of greater tuberosity fractures. Because locking plates cannot effectively stabilize small fracture fragments of the tuberosity, nonabsorbable sutures are often used to secure these fragments to surrounding soft tissue or the plate, which may increase the risk of fixation failure. Previous research has demonstrated that locking plates for proximal humeral fractures are associated with complications, including loss of humeral head height, subsidence, and loss of reduction [7]. In the present study, at 3, 6, and 12 months postoperatively, losses of neck-shaft angle and humeral head height were significantly greater in the plate group than in the intramedullary nail group, consistent with previous findings.

Intramedullary nails provide central fixation, offering biomechanical advantages such as improved load sharing and a shorter lever arm [30]. Deng et al [31] reported that intramedullary nail fixation has advantages over locking plate fixation, including better prevention of varus deformity and reduced surgical trauma. In a study of 83 patients, Fu et al [18] demonstrated that intramedullary nail fixation yields favorable early radiographic and functional outcomes. In our study, no significant differences were evident concerning humeral head height loss or neck-shaft angle at 1 month postoperatively. However, at 3, 6, and 12 months, loss of humeral head height was significantly lower and the neck-shaft angle was significantly greater in the intramedullary nail group than in the locking plate group. These findings suggest that intramedullary nail fixation provides superior biomechanical stability, with improved resistance to compressive forces, prevention of varus deformity, and better maintenance of the neck-shaft angle, resulting in improved radiographic outcomes.

Limitations

This study has some limitations. First, the sample size was small and the follow-up period was relatively short, which may limit the ability to fully evaluate the efficacy, safety, and incidence of postoperative complications associated with the 2 surgical approaches. Given the mean follow-up duration of approximately 12 months, the long-term incidence of complications and long-term shoulder function may be underestimated. Second, in the intramedullary nail group, partial incision of the supraspinatus tendon was required during surgery; however, postoperative magnetic resonance imaging or ultrasonography was not performed to assess rotator cuff integrity. Therefore, the incidence of iatrogenic rotator cuff injury in this cohort remains unclear. Third, the small number of 4-part fractures may affect the generalizability of the findings for this fracture type.

Conclusions

Compared with locking plate fixation, intramedullary nailing for proximal humeral fractures offers advantages such as minimal invasiveness, ease of operation, shorter operative time, reduced intraoperative blood loss, high safety, reliable fixation, and favorable functional recovery. Additionally, this technique is associated with a low complication rate and favorable clinical outcomes.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During preparation of this work, the authors used DeepSeek to improve language and readability. After using this tool, the authors reviewed and edited the content as needed; they take full responsibility for the content of the publication.

Data Availability

The data used in this analysis may be made available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

This study was approved by the ethics committee of the authors' institution (No. 2018128) and was conducted in accordance with the principles of the World Medical Association Declaration of Helsinki (1964). All patients provided informed consent for publication of their relevant clinical data and images for scientific research.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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