Locking Intramedullary Nails Versus Locking Plates in the Treatment of 2-part and 3-part Proximal Humeral Surgical Neck Fractures in Elderly Patients: A Prospective Cohort Study

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Abstract

Background: Locking intramedullary nails and locking plates are most widely used in the treatment of 2-part and 3-part proximal humeral surgical neck fractures, however, the clinical outcomes are controversial. This study aimed to compare the clinical outcomes of treatment with these two implants in elderly patients.

Methods: In this prospective cohort study with a 24-month follow-up period, from June 2014 to November 2016, a total of 53 elderly patients with 2-part and 3-part proximal humeral surgical neck fractures treated with locking intramedullary nails and locking plates were included. We analyzed the intraoperative and radiographic parameters. The American Shoulder and Elbow Surgeons (ASES) score, Constant–Murley score and range of motion (ROM) were used to evaluate shoulder function. We also assessed the visual analog scale (VAS) score and complication rate.

Results: For both 2-part and 3-part proximal humeral surgical neck fractures, the nail group showed statistically significant superiority compared with the plate group in terms of the operative duration, incision length, blood loss, hemoglobin loss, neck-shaft angle (NSA) loss, time to bony union and pain. Good to satisfactory clinical outcomes were obtained with both types of implants. Significant differences were not found in the functional results or complication rate between the two groups at different time points during the follow-up period.

Conclusions: Treatment with both locking intramedullary nails and locking plates achieves similar and good to satisfactory clinical outcomes in elderly patients. We favor locking intramedullary nails, especially in the treatment of 2-part proximal humeral surgical neck fractures.

Trial registration: Medical Ethics Committee for Clinical Research of Zhongda hospital, ZDYJLY (2014) new No. 9. Registered 05 March 2014 <http://www.njzdyy.com>

Background

Proximal humeral fractures are one of the most common fractures of the upper extremity, accounting for approximately 5% of adult fractures [1]. The incidence of these fractures is increasing, as predicted by Palvanen et al., similar to the incidence of other osteoporosis-related fractures, as a result of the aging population [2]. Satisfactory outcomes can be achieved in patients with good compliance and nondisplaced or minimally displaced fractures through conservative treatment [3, 4]. However, patients with seriously displaced fractures always require open reduction and internal fixation, especially elderly patients with insufficient bone quality who require a better quality of life [5–7]. Locking intramedullary nails and locking plates are commonly used for the treatment of proximal humeral fractures. Several studies have compared the clinical efficacy of these two implants; however, the results are controversial [3, 8–11].

Locking plates are most commonly used as a standard treatment [8], but the incidence of complications is high [10–12]. Treatment with locking intramedullary nails is more consistent with the principle of minimally invasive surgery [13, 14]; however, this approach also has several disadvantages, such as the potential for screw displacement and iatrogenic rotator cuff tears [15, 16]. The improved 3rd generation locking intramedullary nails show better biomechanical advantages and a significantly reduced risk of rotator cuff tear because the nail entry point is in the muscle portion of the supraspinatus [17–19].

According to our working experience, clinical outcomes of using intramedullary nails seemed to be better than using locking plates. Thus, we hypothesized that, with proper surgical techniques, better clinical outcomes could be obtained with locking intramedullary nails in the treatment of 2-part and 3-part proximal humeral surgical neck fractures in elderly patients. The purpose of our study was to further verify which is more suitable in elderly patients.

Methods

Study design

The present study was a hospital-based, prospective cohort trial and was approved by the Medical Ethics Committee for Clinical Research of Zhongda hospital.

Inclusion criteria: (1) age $\geq$ 60 years; (2) 2-part or 3-part proximal humeral surgical neck fracture, according to the Neer system [20]; (3) fresh fracture $\leq$ 3 weeks old; and (4) systematic functional rehabilitation exercises performed after surgery.

Exclusion criteria: (1) pathological fracture; (2) humeral anatomical neck fracture; (3) concomitant humeral head fracture; (4) isolated tuberosity fracture; (5) fracture dislocation; (6) open fracture; (7) multiple fractures of the ipsilateral upper extremity; (8) previous or active infection in the shoulder; (9) frozen shoulder, irreparable rotator cuff tear, or plexus or nerve injury; (10) surgery history in ipsilateral shoulder; and (11) loss to follow-up.

Participants

From June 2014 to November 2016, 216 patients with a proximal humeral fracture were treated with surgery in our hospital, and 63 patients who were willing to participate and met the inclusion and exclusion criteria were divided into the nail group (TriGen[®], Smith & Nephew, London, UK) and the plate group (PHILOS[®], DePuySynthes, Oberdorf, Switzerland) at the discretion of the surgeon and finally of the patient.

Four patients were lost to follow-up at 12 months postoperatively. At 24 months postoperatively, 4 patients were lost to follow-up, and 2 patients died of a cause unrelated to the surgery. The flowchart is shown in Fig. 1.

Preoperative evaluation

We obtained a detailed medical history from every patient. All patients underwent an X-ray examination including an anteroposterior view of the shoulder and a lateral view of the scapular plane, as well as CT for 3D reconstruction to evaluate the fracture according to the Neer classification system.

Interventions and surgical procedures

All surgical procedures were performed by senior trauma surgeons with more than 15 years of clinical experience. All patients underwent general anesthesia combined with an interscalene brachial plexus block in the beach chair position. All patients received prophylactic intravenous antibiotics within 30 minutes before the surgery.

Nail group

We used a syringe needle to confirm the entry point preliminarily under C-arm guidance, and an approximately 4.5-cm-long incision was made parallel to Langer's line, lateral to the lower acromion. The deltoid was split between the anterior and middle thirds. We fixed and stretched the deltoid muscles to protect the axillary nerve. If necessary, the "joystick" technique [21] and Kirschner wires could be used to fix the fracture temporarily. Care was taken not to block the path of the nail. A 1-cm-long incision was made in the supraspinatus muscle close to the tendon in line with its muscle fiber orientation. The incision was optimized according to the position of the rotator cuff tear. Under radioscopic imaging, the entry point was located posterolateral to the long head of the biceps tendon in the sulcus between the greater tuberosity and the humeral head margin. The guidewire was introduced after the medullary canal was opened with an awl, and after the fracture was fully reduced, a medullary canal was reamed. The nail was inserted into the medullary cavity along with the guidewire until the nail was placed 4 mm below the cartilage. Then, at least 3 proximal locking screws and 2 distal locking screws were inserted. Additional tension band sutures were tied around the proximal screw heads to fix the rotator cuff if a comminuted tuberosity was observed, based on the so-called "rope-over-bitt" principle [22]. Finally, an end cap was screwed on, fracture reduction and accurate screw positioning were examined by radioscopic imaging, and a drainage tube was placed before wound closure.

Plate group

The fracture was exposed via the standard deltopectoral approach. A small bundle of deltoid muscles was first split and stretched to the internal side to wrap and protect the cephalic vein. The hematoma and embedded soft tissue were removed before fracture reduction. Kirschner wires were used to fix the fragments temporarily. Then, a locking plate was positioned on the proximal part of the humerus along the lateral side to the bicipital groove. To avoid subacromial impingement, the plate was placed

approximately 5 mm inferior to the tip of the greater tuberosity and 4 mm lateral to the bicipital groove. Next, a cortical screw was used for distal fixation, and the plate position was examined by radioscopic imaging. A minimum of 5 proximal locking screws and 3 distal locking screws were inserted. Here, a calcar screw could be used to provide medial column support. Radioscopic imaging was used to evaluate fracture reduction and implant position. Finally, the rotator cuff tear was carefully repaired with nonabsorbable tension band sutures through the proximal plate holes, and a drainage tube was placed before wound closure.

Postoperative procedures

Antibiotics were used continuously for 24 hours after surgery. Postoperative analgesia consisted of Celebrex at 400 mg the first time, followed by 200 mg twice daily for a minimum of 5 days. Narcotic analgesics could be used if necessary. The drainage tube was removed after 48 hours or if the drainage fluid volume was less than 50 ml within 24 hours after surgery.

Postoperative rehabilitation

Slings were used for 4 weeks. On the operative day and the first postoperative day, active exercises of the fingers, wrist and elbow were performed. Passive forward elevation and abduction were performed on the second postoperative day, and passive external and internal rotation were introduced gradually. Active-assisted exercises were started after 6 weeks, and active antigravity exercises were introduced when callus formation was observed on radioscopic imaging. Improved muscle-strengthening and active-resistance exercises were started after 12 weeks. Detailed rehabilitation protocol is given in a table [see Additional file 1].

Demographic characteristics

We recorded the sex, age, injured shoulder, Neer classification, coronal deviation, interval between injury and surgery, number of medial cortical comminutions and follow-up period.

Intraoperative parameters

The intraoperative parameters included the operative duration, incision length, blood loss, and hemoglobin loss at 24 hours postoperatively.

Postoperative radiographic parameters

Radiographs were obtained for the first time after the drainage tube was removed and at 1.5, 3, 6, 12 and 24 months postoperatively. The parameters included the neck-shaft angle (NSA) immediately postoperatively and at 24 months postoperatively, NSA loss, and time to callus formation and bony union. Bony union was defined upon the formation of callus bridging the main fracture fragments in 80% of the cortex.

Functional outcomes

Functional results were evaluated using the American Shoulder and Elbow Surgeons (ASES) score, Constant–Murley score, and visual analog scale (VAS) score at 3, 6, 12 and 24 months postoperatively. In addition, the VAS score was recorded on the first postoperative day. Forward elevation, abduction, and external rotation were measured by a goniometer and are expressed as an angle (°), and internal rotation was measured according to the height of the back touched by the thumb, which was ranked using a continuous number.

Complications included tuberosity resorption, loss of reduction of the greater tuberosity (≥ 0.5 cm), varus malunion (NSA $\leq 120^\circ$), screw penetration, subacromial impingement, humeral head avascular osteonecrosis, refracture, infection, iatrogenic nerve injury, iatrogenic rotator cuff tear and nonunion.

Statistical analysis

All data were analyzed using SPSS Statistics 20.0 (SPSS, IBM, New York, USA). Continuous variables are presented as the mean and standard deviation and were analyzed using Student's t-test when normally distributed or the Mann–Whitney U test when non-normally distributed. Categorical variables are presented as absolute numbers and were analyzed using the chi-squared test. In addition, internal rotation and the VAS scores are presented as the median and range and were analyzed using the Mann–Whitney U test. $P < 0.05$ was considered statistically significant.

Results

Demographic characteristics

A total of 53 patients were available for final evaluation. The average age was 71.6 ± 8.0 years in the nail group and 69.9 ± 8.5 years in the plate group. There were 25 patients in the nail group (12 with 2-part fractures and 13 with 3-part fractures) and 28 patients in the plate group (15 with 2-part fractures and 13 with 3-part fractures). Ten patients in the nail group and 12 patients in the plate group had valgus deformity, and 13 patients in both the nail group and the plate group had varus deformity. Medial cortical comminutions were found in 4 patients in the nail group and 6 patients in the plate group. The interval between injury and surgery was 4.6 ± 1.4 days in the nail group and 4.7 ± 1.3 days in the plate group. The average follow-up period was 26.0 ± 2.6 (range, from 24 to 29) months in the nail group compared with

27.0 ± 2.5 (range, from 24 to 30) months in the plate group. Each group had comparable demographic characteristics, and no significant differences were found (Table 1).

Table 1
Demographic Characteristics

	Nail group (n = 25)	Plate group (n = 28)	χ^2 / t	P-value
Sex ^a			0.121	0.728
Male	11	11		
Female	14	17		
Age (year) ^b	71.6 ± 8.0	69.9 ± 8.5	0.586	0.561
Injured shoulder ^a			0.191	0.662
Left	14	14		
Right	11	14		
Neer system ^a			0.164	0.685
2-part	12	15		
3-part	13	13		
Coronal deviation ^a			0.099	0.753
Valgus	10	12		
Varus	13	13		
Medial cortical comminution ^a	4	6	0.023	0.879
Interval between injury and surgery (day) ^b	4.6 ± 1.4	4.7 ± 1.3	-0.306	0.761
Follow-up period (month) ^b	26.0 ± 2.6	27.0 ± 2.5	-1.453	0.152
^a The values are presented as number of patients and analyzed using the Chi-square test.				
^b The values are presented as means and standard deviations and analyzed using Student's t-test.				

Intraoperative parameters

For both 2-part and 3-part proximal humeral surgical neck fractures, significant decreases in the operative duration ($P = 0.007$ in 2-part fractures, $P = 0.041$ in 3-part fractures), incision length ($P < 0.001$ in 2-part fractures, $P < 0.001$ in 3-part fractures), blood loss ($P < 0.001$ in 2-part fractures, $P < 0.001$ in 3-part fractures), and hemoglobin loss at 24 hours postoperatively ($P = 0.007$ in 2-part fractures, $P = 0.001$ in 3-part fractures) were observed in the nail group compared with the plate group (Table 2).

Table 2
Intraoperative parameters

	Nail group	Plate group	t	P-value
2-part				
Operative duration (minute)	82.5 ± 14.2	103.7 ± 22.5	-2.977	0.007
Incision length (cm)	6.3 ± 0.3	15.1 ± 2.1	-16.127	< 0.001
Blood loss (mL)	97.5 ± 12.9	178.7 ± 20.3	-12.021	< 0.001
Hemoglobin loss at 24 h (g/L)	11.9 ± 2.7	16.7 ± 5.4	-3.007	0.007
3-part				
Operative duration (minute)	104.6 ± 13.3	122.7 ± 26.4	-2.203	0.041
Incision length (cm)	7.2 ± 0.6	15.8 ± 2.7	-11.172	< 0.001
Blood loss (mL)	121.5 ± 12.8	209.2 ± 32.8	-8.984	< 0.001
Hemoglobin loss at 24 h (g/L)	13.5 ± 4.8	19.6 ± 3.7	-3.630	0.001
All values are presented as means and standard deviations and analyzed using Student's t-test.				

Radiographic parameters

For both 2-part and 3-part proximal humeral surgical neck fractures, there were no significant differences in the NSA immediately postoperatively or at 24 months postoperatively between the two groups. Significant decreases in NSA loss ($P = 0.029$ in 2-part fractures, $P = 0.037$ in 3-part fractures), and time to callus formation ($P = 0.001$ in 2-part fractures, $P = 0.007$ in 3-part fractures), and bony union ($P = 0.042$ in 2-part fractures, $P = 0.039$ in 3-part fractures) were observed in the nail group compared with the plate group (Table 3). Two typical cases are shown in Fig. 2.

Table 3
Radiographic parameters postoperatively

	Nail group	Plate group	t	P-value
2-part				
Immediate NSA (°)	137.0 ± 6.1	136.1 ± 5.7	0.381	0.706
NSA at 24 months (°)	133.9 ± 6.6	130.4 ± 6.4	1.397	0.175
NSA loss (°)	3.1 ± 1.6	5.7 ± 4.0	-2.365	0.029
Callus formation time (week)	5.3 ± 0.6	6.3 ± 0.7	-3.925	0.001
Bony union time (week)	11.6 ± 1.3	13.1 ± 2.1	-2.143	0.042
3-part				
Immediate NSA (°)	134.0 ± 8.3	136.2±6.1	-0.750	0.461
NSA at 24 months (°)	130.5 ± 8.4	129.2±8.5	0.372	0.713
NSA loss (°)	3.5 ± 2.6	6.9±4.8	-2.246	0.037
Callus formation time (week)	5.6 ± 1.0	6.8±1.1	-2.971	0.007
Bony union time (week)	13.0 ± 1.6	14.5±1.9	-2.187	0.039
All values are presented as means and standard deviations and analyzed using Student's t-test.				
NSA: Neck-shaft angle				

Functional scores

For 2-part proximal humeral surgical neck fractures, there were no significant differences in the ASES or Constant–Murley score between the nail and plate groups after 3, 6, 12, or 24 months (Table 4). Although both the ASES and Constant–Murley scores in the two groups continued to increase during the entire follow-up period, significant differences in the ASES and Constant–Murley score were found only between 3 and 6 months and were not found at 6, 12 or 24 months in the nail group. In the plate group, significant differences in the ASES and Constant–Murley scores were found at 3, 6 and 12 months and were not found between 12 and 24 months (Fig. 3).

Table 4
Clinical outcomes for 2-part proximal humeral surgical neck fractures

		Nail group	Plate group	Z / t	P-value
ASES score ^a	3 months	50.3 ± 13.9	45.4 ± 12.4	0.973	0.340
	6 months	66.2 ± 12.1	62.2 ± 12.3	0.841	0.409
	12 months	75.3 ± 9.6	73.0 ± 11.5	0.562	0.579
	24 months	79.1 ± 8.2	76.9 ± 9.4	0.642	0.527
Constant-Murley score ^a	3 months	53.4 ± 14.7	47.5 ± 13.1	1.114	0.276
	6 months	69.5 ± 12.5	65.5 ± 13.0	0.816	0.422
	12 months	77.5 ± 9.5	75.2 ± 11.5	0.557	0.582
	24 months	80.8 ± 8.0	79.1 ± 10.4	0.440	0.664
Forward elevation (°) ^a	3 months	84.8 ± 10.4	80.2 ± 7.9	1.290	0.209
	6 months	113.3 ± 12.7	110.8 ± 10.9	0.539	0.595
	12 months	137.9 ± 13.7	137.7 ± 12.4	0.050	0.961
	24 months	147.7 ± 11.9	146.1 ± 11.3	0.357	0.724
Abduction (°) ^a	3 months	69.5 ± 18.5	68.3 ± 13.3	0.191	0.850
	6 months	94.3 ± 14.9	91.1 ± 15.5	0.542	0.592
	12 months	118.2 ± 14.9	120.5 ± 14.1	-0.423	0.676
	24 months	129.8 ± 13.5	130.8 ± 14.5	-0.193	0.849
External rotation (°) ^a	3 months	20.4 ± 6.2	19.1 ± 5.7	0.590	0.560
	6 months	29.4 ± 8.1	27.3 ± 7.8	0.697	0.493
	12 months	39.4 ± 8.1	36.3 ± 9.0	0.939	0.356
	24 months	43.8 ± 7.4	41.8 ± 10.0	0.564	0.578
Internal rotation ^b	3 months	S3 (buttock-S3)	S5 (buttock-S1)	-0.753	0.452
	6 months	L4 (S5-L3)	L5 (S5-L3)	-1.104	0.270

^aThe values are presented as means and standard deviations and analyzed using Student's t-test.

^bThe values are presented as median with range in parentheses and analyzed using the Mann-Whitney U test.

ASES: American Shoulder and Elbow Surgeons; VAS: visual analog scale.

	12 months	T12 (S3-T11)	L2 (S3-T11)	-1.458	0.145
	24 months	T9 (S1-T7)	T10 (S3-T8)	-1.258	0.208
VAS score ^b	1 day	4.5 (2-5)	5 (4-8)	-2.620	0.009
	3 months	3 (1-4)	3 (2-4)	-1.491	0.136
	6 months	2 (1-3)	2 (1-4)	-0.772	0.440
	12 months	1 (0-2)	1 (1-2)	-0.168	0.867
	24 months	1 (0-2)	1 (0-2)	-0.445	0.656
^a The values are presented as means and standard deviations and analyzed using Student's t-test. ^b The values are presented as median with range in parentheses and analyzed using the Mann-Whitney U test. ASES: American Shoulder and Elbow Surgeons; VAS: visual analog scale.					

The trends in the statistical results for 3-part fractures agreed with those for 2-part fractures. In addition, significant differences in the ASES and Constant–Murley scores were found at 3, 6 and 12 months and were not found between 12 and 24 months in the two groups (Table 5, Fig. 3).

Table 5
Clinical outcomes for 3-part proximal humeral surgical neck fractures

		Nail group	Plate group	Z / t	P-value
ASES scor ^a	3 months	43.8 ± 11.4	40.3 ± 9.6	0.858	0.399
	6 months	57.2 ± 11.0	55.5 ± 11.0	0.640	0.528
	12 months	69.7 ± 11.6	68.4 ± 10.1	0.306	0.762
	24 months	74.0 ± 11.5	73.2 ± 10.6	0.178	0.860
Constant-Murley score ^a	3 months	45.6 ± 11.0	41.3 ± 8.7	1.106	0.280
	6 months	59.5 ± 10.7	57.6 ± 10.6	0.442	0.663
	12 months	72.1 ± 11.9	70.9 ± 9.9	0.268	0.791
	24 months	75.1 ± 10.7	74.5 ± 10.5	0.122	0.904
Forward elevation (°) ^a	3 months	74.5 ± 10.2	72.0 ± 7.4	0.725	0.476
	6 months	100.6 ± 11.7	104.4 ± 13.5	-0.760	0.454
	12 months	126.9 ± 11.9	125.5 ± 14.4	0.267	0.792
	24 months	135.8 ± 12.8	136.4 ± 13.5	-0.119	0.906
Abduction (°) ^a	3 months	58.5 ± 16.1	61.1 ± 13.3	-0.452	0.655
	6 months	81.6 ± 18.9	84.1 ± 14.4	-0.374	0.712
	12 months	107.4 ± 19.7	112.8 ± 12.6	-0.831	0.414
	24 months	115.9 ± 18.7	122.2 ± 13.0	-0.997	0.329
External rotation (°) ^a	3 months	17.5 ± 4.5	18.8 ± 4.6	-0.773	0.447
	6 months	28.1 ± 7.8	26.3 ± 6.3	0.641	0.528
	12 months	33.2 ± 8.9	33.9 ± 6.9	-0.247	0.807
	24 months	38.9 ± 9.2	37.5 ± 8.2	0.429	0.672
Internal rotation ^b	3 months	S5 (buttock-S1)	S5 (buttock-S5)	-0.730	0.465
	6 months	S1 (S5-L4)	S1 (S5-L5)	-0.943	0.346
	12 months	L3 (S3-T12)	L4 (S5-L2)	-1.021	0.307

^aThe values are presented as means and standard deviations and analyzed using Student's t-test.

^bThe values are presented as median with range in parentheses and analyzed using the Mann-Whitney U test.

	24 months	T12 (S1-T9)	L1 (S3-T10)	-1.012	0.311
VAS score ^b	1 day	5 (2-6)	6 (4-8)	-2.100	0.036
	3 months	3 (1-4)	3 (2-5)	-1.174	0.240
	6 months	2 (1-3)	2 (1-4)	-0.810	0.418
	12 months	1 (1-3)	2 (1-4)	-0.722	0.470
	24 months	1 (0-2)	1 (0-3)	-1.221	0.222
^a The values are presented as means and standard deviations and analyzed using Student's t-test.					
^b The values are presented as median with range in parentheses and analyzed using the Mann-Whitney U test.					

Range of motion (ROM)

For both 2-part and 3-part proximal humeral surgical neck fractures, as determined after 3, 6, 12, and 24 months, the ROM, including active forward elevation, abduction, external rotation, and internal rotation, continued to increase during the entire follow-up period. No significant differences were found between the two groups at the different time points during the follow-up period (Tables 4 and 5, Fig. 3).

VAS score

For both 2-part and 3-part humeral surgical neck fractures, the median VAS score was significantly lower in the nail group than in the plate group on the first postoperative day ($P = 0.009$ in 2-part fractures, $P = 0.036$ in 3-part fractures). Although the median VAS score was lower in the nail group than in the plate group after 3, 6, 12 and 24 months, there were no significant differences between the two groups (Tables 4 and 5). Here, the VAS score is also presented as the mean and standard deviation to show the decreasing trend in both groups (Fig. 4).

Complications

A total of 7 complications were recorded, 3 in the nail group (12.0%, 1 in 2-part fractures and 2 in 3-part fractures) and 4 in the plate group (14.3%, 1 in 2-part fractures and 3 in 3-part fractures). A significant difference was not found in the incidence of complications between the two groups ($P = 1.000$).

For 2-part proximal humeral surgical neck fractures, wound infection with *Staphylococcus epidermidis* was found in 1 patient at 3 days postoperatively in the nail group and was cured using intravenous vancomycin and dressing changes. Screw penetration beyond the subchondral bone was found in 1 patient in the plate group, and the penetrated screw was removed at 3 months postoperatively. For 3-part

fractures, in the nail group, there was 1 case of greater tuberosity resorption. Additionally, an 84-year-old female patient suffered from subacromial impingement in her left shoulder, and the patient refused to undergo implant removal because she said the condition had no serious impact on daily life. In the plate group, there was 1 case of loss of reduction of the greater tuberosity and 1 case of varus malunion (the NSA was 115° at 24 months). In addition, 1 patient suffered from humeral head avascular osteonecrosis (Cruess IV [23]) and underwent shoulder hemiarthroplasty at 24 months postoperatively (Table 6).

Table 6
Complications

	2-part		3-part	
	Nail group	Plate group	Nail group	Plate group
	(n = 12)	(n = 15)	(n = 13)	(n = 13)
Tuberosity resorption	-	-	1	-
Loss of reduction of the greater tuberosity	-	-	-	1
Varus malunion	-	-	-	1
Screw penetration	-	1	-	-
Subacromial impingement	-	-	1	-
Avascular osteonecrosis	-	-	-	1
Refracture	-	-	-	-
Infection	1	-	-	-
Iatrogenic nerve injury	-	-	-	-
Iatrogenic rotator cuff tear	-	-	-	-
Nonunion	-	-	-	-
All values are presented as number of patients.				

No cases of refracture, iatrogenic nerve injury, iatrogenic rotator cuff tear, or nonunion were found in any of the patients.

Discussion

In elderly patients with proximal humeral fractures, conservative treatment may result in severe complications, such as fracture nonunion, malunion, and traumatic arthritis [24]. Indications for surgical treatment include angulation $\geq 45^\circ$ between fracture fragments, displacement ≥ 1 cm of the humeral shaft against the humeral head or displacement ≥ 0.5 cm of the greater tuberosity [25]. As proximal

humeral fractures are intracapsular fractures, anatomical reduction must be achieved, while damage to the periosteum and soft tissue should be minimized, and the blood supply to the metaphysis should be protected as much as possible.

Locking plates are most widely used and can achieve good clinical outcomes. In a long-term study of 43 patients reported by Ockert et al., the absolute Constant–Murley score was 75.3; most of the patients showed good to excellent clinical outcomes 10 years after the surgery, with no relevant statistical decline in shoulder function compared with 1 year after surgery [8]. However, locking plates are associated with a greater incidence of complications. Hertel et al. reported that the integrity of the medial column was one of the most relevant predictors of ischemia [26]. Osterhoff et al. proved that the placement of calcar screws in the fixation of proximal humeral fractures could provide inferomedial support to reduce the risk of complications [27]. Cha et al. reported that fixation using a locking plate with an endosteal strut allograft can maintain anatomical reduction in elderly patients with comminuted proximal humeral fractures [28].

Intramedullary nails are effective in stabilizing proximal humeral fractures and conform more to the principle of minimal invasiveness. Unique advantages include a preservation effect on the blood supply around the fracture, central fixation, and advanced biomechanical properties [29, 30] (axial, torsional and bending loads). The early designs of 1st generation (unlocked) and 2nd generation (bent design) intramedullary nails had high rates of reoperations and complications, especially regarding the risk of underlying iatrogenic rotator cuff tear and chronic shoulder pain [31]. In addition, these nails were not recommended for patients with comminuted tuberosity fractures. The newly developed 3rd generation locking intramedullary nails (straight, multilocking, low-profile nails allowing tuberosity-based fixation) overcome these problems [18].

In our study, the operative duration was significantly shorter in the nail group. We have performed this kind of treatment for many years, and the surgeons involved in the surgeries were experienced and skilled, allowing the surgery to be finished in a short time. One study has suggested that the decreased operative duration may be related to the minimally invasive approach [9]. The application of this treatment could shorten the incision length, reduce bleeding, reduce soft tissue stripping, and protect blood vessels around the fracture and thus reduce the time to callus formation and bony union. However, the technique is difficult, and the learning curve is long. Therefore, it is recommended that beginners start with simple 2-part proximal humeral surgical neck fractures.

The functional scores and ROM were comparable between the two groups at different time points during the follow-up period in our study. Most researchers have reported good to satisfactory clinical outcomes after surgical treatment using these two implants. Ge et al. performed a prospective study to compare the clinical outcomes of treatment with intramedullary nails, locking plates and conservative treatment for 2-part and 3-part proximal humeral fractures in elderly patients, and the results suggested that similar functional outcomes can be achieved using locking intramedullary nails and locking plates [4]. In a randomized controlled trial, Gracitelli et al. also found that proximal humeral

surgical neck fracture fixation with these two implants produces similar results [32]. Xiang et al. concluded that 2-part proximal humeral fracture fixation with a locking intramedullary nail achieved superior functional scores and ROM [33]. The mean age of the patients was younger (57.2 ± 7.4 years), and young patients were also included in their study, which might have led to the divergence. In our study, for 2-part fractures, significant differences in functional scores were found only between 3 and 6 months and were not found at 6, 12 or 24 months in the nail group, which suggests that quick recovery could be achieved in patients with simple 2-part proximal humeral surgical neck fractures using locking intramedullary nails.

A significant difference was not found in the total complication rate between the two groups in our study, which is identical to the result of a meta-analysis based on 1384 individuals [34]. In the nail group, postoperative wound infection was found in one patient. Fortunately, it was cured without any serious consequences. The large diameter of the proximal locking screws was not suitable for small fragments of the greater tuberosity, which might result in tuberosity resorption. Regarding subacromial impingement, postoperative radiographs at 6 months suggested that the end cup was slightly higher than the humeral head, which caused the nail to collide with the acromion during abduction of the shoulder joint. This might have been the result of incorrect positioning of the C-arm during surgery. In addition, vertical reduction loss and humeral head subsidence might also result in upward movement of the nail. Furthermore, there were no cases of iatrogenic rotator cuff tear due to the use of 3rd generation intramedullary nails with an improved entry point, which is identical to Boileau's study [18]. In the plate group, a decrease in the screw holding strength decreasing and the loosening of internal fixation might have been the result of the loss of reduction of the greater tuberosity. The force on the screw tip was high, while the so-called "screw-bone interface" was weak, which might explain screw penetration in elderly patients with osteoporosis. We reconstructed the medial column with only one calcar screw but without autologous bone grafting to treat the medial cortical comminution, which might result in varusmalunion and avascular osteonecrosis. Damage to blood vessels and the periosteum caused by a wider approach might also result in avascular osteonecrosis.

Several limitations of this study should be considered. First, the patients were not randomly assigned, and the treatments were decided based on both the patients' choices and surgeons' advice, but the demographic characteristics were comparable. Second, the 24-month follow-up duration might result in an underestimation of the long-term complication rate. Another limitation was the small sample size. Therefore, validation by more multicenter, prospective, randomized controlled studies with larger sample sizes and longer-term follow-up periods is needed to confirm our findings.

Conclusions

With advanced surgical techniques and scientific postoperative rehabilitation methods, both locking intramedullary nails and locking plates could be used in the treatment of 2-part and 3-part proximal humeral surgical neck fractures in elderly patients with good to satisfactory clinical outcomes. We favor locking intramedullary nails due to the advantages of a reduced operative duration, incision length, blood

loss, hemoglobin loss, NSA loss, time to bony union and pain, especially in the treatment of 2-part proximal humeral surgical neck fractures.

List Of Abbreviations

ASES: American Shoulder and Elbow Surgeons; ROM: range of motion; VAS: visual analog scale; NSA: Neck-shaft angle;

Declarations

Ethics approval and consent to participate

The present study was approved by the Medical Ethics Committee for Clinical Research of Zhongda hospital (number: ZDYJLY (2014) new No. 9) and was in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written informed consent was obtained from all individuals.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to the study conception and design. Hao Wu, Yaliku Yusufu and Jihao Xu collected the data. Rui Geng and Qing Chang analyzed and interpreted the data. Rui Geng wrote the first

draft of the manuscript. Jun Lu and Ke Ren revised the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Flow chart for trial enrollment and analysis.

Figure 2

Two typical cases. Three-part proximal humeral surgical neck fracture (female, aged 70 years) treated with locking intramedullary nails (a, b and c). Two-part proximal humeral surgical neck fracture (female, aged 65 years) treated with locking plate (d, e and f). a and d Preoperative radiograph. b and e Preoperative CT 3D reconstruction. c and f Radiograph at 24 months postoperatively

Figure 3

Functional outcomes of locking intramedullary nails and locking plates for 2-part (a) and 3-part (b) proximal humeral surgical neck fractures. Internal rotation is presented as the median, and others are presented as the mean and standard deviation in the figure. ASES: American Shoulder and Elbow Surgeons

Figure 4

VAS scores of locking intramedullary nails and locking plates for 2-part (a) and 3-part (b) proximal humeral surgical neck fractures. VAS scores are presented as the mean and standard deviation in the figure. VAS: visual analog scale

Supplementary Files

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