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Anatomic locking plates for complex proximal humeral fractures: anatomic neck fractures versus surgical neck fractures

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Background: Continued debate exists on the management of displaced 3- or 4-part proximal humeral fractures. Only a few studies have compared the efficacy of proximal humeral locking plates (PHLPs) for treating anatomic neck fractures (ANFs) and surgical neck fractures (SNFs).
Methods: The medical data of 31 consecutive patients with displaced 4-part proximal humeral fractures treated with PHLPs between May 2013 and April 2015 were reviewed retrospectively. We divided the patients into the ANF and SNF groups and assessed the neck-shaft angle (NSA), sum of the screw tip–articular surface distance, and other parameters postoperatively at 3 days and at 12 months using shoulder radiographs. The Constant-Murley scores were assessed at 3 days, 12 months, and last follow-up.
Results: The ANF group had a significantly lower mean age and significantly greater mean operative duration, estimated blood loss, and rate of bone grafting. Full or partial osteonecrosis of the humeral head developed in 7 patients and 1 patient in the ANF and SNF groups, respectively. Screw cutout and/or pullout complications occurred in 8 cases in the ANF group but not in the SNF group. In the ANF group, the values for NSA and the sum of the screw tip–articular surface distance changed significantly from 3 days to 12 months postoperatively. There were no significant correlations among the tested parameters.
Conclusion: ANFs resulted in more complications at a younger age than SNFs. ANF treatment using PHLPs is more prone to a decreased NSA and humeral head osteonecrosis and has poorer clinical outcomes than SNF treatment using PHLPs.
Level of evidence: Level III; Retrospective Cohort Design; Treatment Study

Keywords: Anatomic neck fracture; proximal humeral fracture; proximal humeral locking plate; surgical neck fracture; osteonecrosis; Constant-Murley score

The Institutional Review Board of Zhoupu Hospital, Shanghai University of Medicine & Health Sciences, approved this study (No. ZPYYL-2016-09).

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Proximal humeral fractures (PHFs) are relatively frequent, accounting for 4%-5% of all fractures, and are the second most common upper-limb fracture and the third most common type of fracture in patients older than 75 years.[8,10,26] Most PHFs are caused by low-energy falls[15] and have a female-to-male predominance of 2-3 to 1.[24]

Nondisplaced or 2-part PHFs are typically treated conservatively, and clinical results are satisfactory.[15] However, continued debate exists regarding the management of displaced 3- or 4-part PHFs. Common techniques include open reduction with locking plate fixation,[25] intramedullary nailing,[9,18] and arthroplasty.[3,19]

Currently, locking plates for displaced PHFs are widely recommended and used,[14,21] even for complex fracture patterns such as type C fractures, according to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA), and 3- or 4-part PHFs. The treatment of these types of fractures using open reduction with angular stable fixation plates and screws is associated with good clinical outcomes[25] and represents a significant advancement in treatment, as it provides a more secure fixation for osteoporotic fractures. However, some complications exist, such as varus malalignment, penetration of screws into the articular surface of the humeral head, humeral head osteonecrosis, subacromial impingement, and loss of screw purchase, which can lead to poor clinical outcomes and revision surgery.[2]

On the basis of our observations, most anatomic neck fractures (ANFs), which are a subset of PHFs with a unique anatomic configuration, are 4-part fractures and are classified as AO/OTA type C fractures. Although surgical treatment for 4-part surgical neck fractures (SNFs) is associated with good clinical outcomes,[23,25] to date, only a few studies have evaluated the surgical treatment outcomes of using proximal humeral locking plates (PHLPs) for ANFs. We hypothesized that the treatment of ANFs and SNFs with PHLPs would have different outcomes. Therefore, the purpose of this study was to compare the efficacy of PHLPs for the treatment of ANFs and SNFs using an open reduction and internal fixation technique.

Materials and methods

We conducted a retrospective study of 36 consecutive patients with displaced 4-part PHFs who underwent surgery in a single institution from May 2013 to April 2015. All PHFs were classified as ANFs or SNFs based on imaging documentation performed in the emergency department. The study included patients 18 years or older with no pathologic fractures, primary or metastatic tumors, or previous surgery on the affected shoulder. All fractures were treated within 2 weeks of injury. All participating patients provided informed consent.

Preoperative true anteroposterior radiographs and computed tomography scans with 3-dimensional reconstructions based on 2-dimensional reconstructions of the shoulder were reviewed to determine the fracture type. The fracture patterns were classified according to the AO/OTA system[23] and Neer criteria (fracture displacement ≥ 1 cm and angulation ≥ 45°).[17]

Four senior surgeons used either the deltopectoral or deltoid-splitting surgical approach with the patient placed in the beach-chair position, according to preference.[1] After reduction, all fractures were fixed using PHLPs (Double Medical Technology, Xiamen, China) with at least 1 medial calcar screw if the patient's medial bone cortex was incomplete and lacked support. When fracture stability could not be maintained, the collapsed humeral head underwent implantation of autogenous iliac bone grafts, bone allografts, or Osteoset (medical-grade calcium sulfate; Wright Medical Technology, Memphis, TN, USA). The type of bone graft used depended on the clinical needs and the patient's choice. The rotator cuff was grasped with sutures near the insertion at the tuberosities to correct varus malalignment.[7] Physiotherapy (passive-assisted movements) was started on the second day after surgery. Active range-of-motion exercises were initiated 2-4 weeks postoperatively, depending on the stability of the osteosynthesis and bone quality.

Data regarding demographic characteristics, trauma mechanism, dislocation or subluxation, bone grafting, estimated blood loss (EBL), surgical time, osteonecrosis, and screw perforation or loss of fixation were obtained from medical records. Radiographic measurements, including the neck-shaft angle (NSA),[1] sum of the screw tip–articular surface distance (SD), tuberosity–to–humeral head height, humeral head thickness (HT), and humeral head offset,[13] were assessed postoperatively at 3 days and at 12 months using true anteroposterior radiographs of the shoulder (Figs. 1 and 2). The modified SD was measured digitally for each screw located in the humeral head based on a previous report,[1] that is, the total distance of each screw to the articular surface (Fig. 2). All radiographic measurements were performed by 2 independent blinded observers using Image-Pro Plus (Media Cybernetics, Rockville, MD, USA). Measurements were standardized for magnification using the known screw

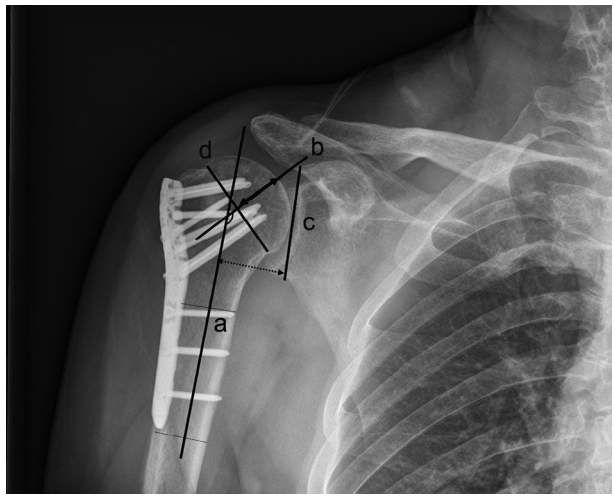

Figure 1 Radiographic measurements on anteroposterior view of shoulder. Line *a* bisects the humeral shaft. Line *d* is the line between the superior and inferior borders of the articular surface. Line *b* is the line perpendicular to line *d*. Line *c* is the line parallel to line *a* and is the tangent line of the articular surface. The angle between lines *a* and *b* was defined as the neck-shaft angle (*semicircle*). The humeral head offset is the distance between lines *a* and *c* (*dotted arrow*). The longest line from the articular surface to line *d* is the humeral head thickness (*solid arrow*).

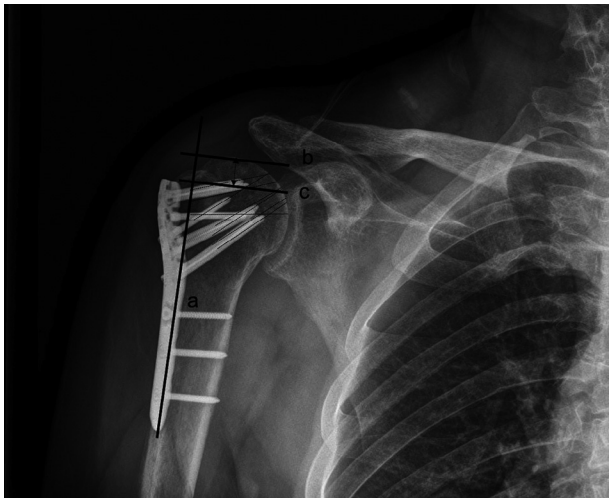

Figure 2 Line *a* is the axis of the locked plate. Line *b* is the line perpendicular to line *a* and is on top of the humeral head. Line *c* is the line perpendicular to line *a* and is on the top plate. The distance between lines *b* and *c* is the humeral head height (*arrow*). The sum of the screw tip to the articular surface distance was also measured for each screw head.

diameter (3.5 mm). Radiographic assessments were performed by 1 orthopedic surgeon and 1 senior radiologist; when they classified fractures differently, the fracture classification was ultimately determined by 1 senior surgeon. Postoperatively, clinical assessments using the Constant-Murley score (CMS)[6] were performed by a single orthopedic surgeon at 3 months, at 12 months, and at the last follow-up visit.

Statistical analyses

Statistical analyses were performed using SPSS software (version 23; IBM, Armonk, NY, USA). Age, operative duration, EBL, SD, NSA, humeral head height, HT, humeral head offset, and CMS were analyzed using independent-samples *t* tests (between groups) or paired-samples *t* tests (within groups). The Student-Newman-Keuls multiple comparisons test was used when multiple groups were compared (eg, CMS). Group differences in sex, injury side, injury type, bone grafts, dislocation or subluxation, osteonecrosis, and screw perforation or loss of fixation were evaluated using χ^2 tests. For the age-adjusted CMS, a linear regression analysis was performed to determine the correlation between age and the CMS in patients with ANFs and SNFs. In addition, logistic regression analyses were used to calculate the odds ratio and 95% confidence interval for osteonecrosis of the humeral head with a decreased NSA. Data are presented as mean ± standard deviation. $P < .05$ was considered statistically significant.

Results

Among the 36 patients with 4-part PHFs, there were 19 ANF cases (52.8%) and 17 SNF cases (47.2%); however, we excluded 3 cases from the ANF group (2 because of incomplete follow-up data and 1 because of treatment with hemiarthroplasty) and 2 cases from the SNF group (because of incomplete follow-up). A total of 31 patients (7 men and 24 women; 16 ANFs and 15 SNFs; average age, 70 years; age range, 56-82 years) were included in this analysis.

There were no significant between-group differences in sex ($P = .394$), injured limb side ($P = .066$), high- versus low-energy fractures ($P > .999$), mean waiting time for surgery ($P = .290$), or shoulder dislocation or subluxation ($P = .083$, Fisher exact test) (Table I). Patients in the ANF group were significantly younger than those in the SNF group (60.7 ± 10.3 years [range, 44-79 years] vs 69.5 ± 9.1 years [range, 56-82 years]; $P = .017$). The mean operative duration was significantly longer in the ANF group than in the SNF group (115.8 ± 28.6 minutes vs 93.2 ± 20.0 minutes, $P = .017$). In addition, the mean operative EBL was significantly higher in the ANF group than in the SNF group (239.4 ± 109.5 mL vs 165.3 ± 70.4 mL, $P = .034$). A total of 11 ANF patients (68.8%) and 3 SNF patients (20.0%) needed bone grafting during surgery ($P = .011$). Full or partial osteonecrosis of the humeral

Table I Demographic and clinical characteristics

Parameters	ANFs (n = 16)	SNFs (n = 15)	*P* value
Total patients	16	15	
Age, yr	60.7 ± 10.3	69.5 ± 9.1	.017
Male/female sex	5/11	2/13	.394
Follow-up duration, mo	25.6 ± 7.8	25.5 ± 5.3	.960
Left/right side	3/13	8/7	.066
Waiting time for surgery, d	1.9 ± 1.2	2.5 ± 1.8	.290
High-/Low-energy injury	2/14	2/13	>.999
Operative duration, min	115.8 ± 28.6	93.2 ± 20.0	.017
Operative EBL, mL	239.4 ± 109.5	165.3 ± 70.4	.034
Bone graft	11	3	.011
Dislocation and/or subluxation	6	1	.083
Osteonecrosis	7	1	.037
Screw perforation and/or loss of fixation	3/5	0/0	.043

ANF, anatomic neck fracture; *SNF*, surgical neck fracture; *EBL*, estimated blood loss.
Data are presented as mean ± standard deviation or number of patients. Differences are considered significant at $P < .05$.

Table II Postoperative radiographic parameters in patients with ANFs

Parameter	3 d postoperatively	12 mo postoperatively	*P* value
NSA, °	140.7 ± 13.6	134.2 ± 10.4	.038
Humeral head offset, mm	23.4 ± 4.8	24.5 ± 6.7	.216
SD, mm	68.9 ± 26.1	59.6 ± 25.6	.047
HT, mm	19.7 ± 3.2	18.1 ± 4.4	.101
HH, mm	11.8 ± 2.6	11.3 ± 4.0	.572

ANF, anatomic neck fracture; *NSA*, neck-shaft angle; *SD*, sum of screw tip–articular surface distance; *HT*, head thickness; *HH*, humeral head height. Data are presented as mean ± standard deviation. Differences are considered significant at $P < .05$.

Table III Postoperative radiographic parameters in patients with SNFs

Parameter	3 d postoperatively	12 mo postoperatively	*P* value
NSA, °	139.8 ± 8.8	136.0 ± 8.6	.071
Humeral head offset, mm	24.4 ± 3.8	25.5 ± 3.98	.241
SD, mm	60.7 ± 13.1	54.2 ± 18.3	.059
HT, mm	18.3 ± 3.3	17.4 ± 2.7	.269
HH, mm	10.3 ± 3.9	10.2 ± 4.0	.872

SNF, surgical neck fracture; *NSA*, neck-shaft angle; *SD*, sum of screw tip–articular surface distance; *HT*, head thickness; *HH*, humeral head height. Data are presented as mean ± standard deviation. Differences are considered significant at $P < .05$.

head developed in 7 patients in the ANF group (43.8%), whereas osteonecrosis of the humeral head developed in only 1 patient in the SNF group (6.7%) ($P = .037$, Fisher exact test). Screw cutout and/or screw pullout complications occurred in 8 cases in the ANF group (50.0%) but none in the SNF group ($P = .043$, Fisher exact test).

There were no cases of infection, reoperation, or nonunion. The mean follow-up duration was 27.5 months (range, 25-39 months).

The postoperative radiographic parameters for the ANF group are shown in Table II. In the ANF group, the NSA ($P = .038$) and SD ($P = .047$) values changed significantly from 3 days to 12 months postoperatively. However, the humeral head offset, HT, and humeral head height values did not significantly change over time. The same relevant postoperative radiographic parameters for the SNF group did not significantly change over time (Table III).

There were no significant group differences in the average CMS at 3 months ($P = .136$) and 12 months ($P = .065$) (Supplementary Table S1). At last follow-up, the CMS was significantly lower in the ANF group than in the SNF group ($P = .042$). There were no significant correlations between age and the CMS or between the osteonecrosis rate and the NSA. Additional results are shown in Supplementary Tables S2-S6.

Discussion

When deciding the surgical approach for PHF treatment, one must consider several parameters, such as age, daily activities before the injury, and especially fracture pattern. Certain fracture patterns are better suited to different surgical methods. Conservative treatment remains the gold standard for nondisplaced or minimally displaced PHFs, with satisfactory results.[27] Most 2- and 3-part fractures are well suited for treatment with locking plates or proximal humeral nails.[22,27] However, the surgical treatment of displaced 4-part fractures remains challenging.

Compared with SNFs, the treatment of ANFs is more complex because it has a longer operative duration, results in more EBL, and needs more bone graft. The treatment of ANFs with PHLPs also frequently results in osteonecrosis of the humeral head and poor clinical outcomes. Meanwhile, accurate data regarding ANF treatment are lacking. On the basis of the model of Hertel et al,[12] ANFs include types 2, 7, 8, 9, 10, and 12, most of which are AO/OTA type C fractures. In contrast, SNFs are a common type of PHF, most of which are AO/OTA type B fractures. Classic ANFs include fractures in the anatomic neck of the proximal humerus and humeral heads compacted with the metaphysis of the proximal humerus, with fracture and displacement of the greater and lesser tubercles (also called "ice cream fractures") (Fig. 3).

Unexpectedly, the number of patients with ANFs in our clinic was not lower than that of patients with other types of PHFs, such as SNFs. Thus, the morbidity of ANFs may be undervalued. In this study, ANFs were diagnosed based on findings from plain radiographs as well as from computed tomography scans with 3-dimensional reconstructions of the shoulder (Fig. 3). ANFs usually cannot be diagnosed precisely based on plain radiographs alone.

Patients in the ANF group were younger than those in the SNF group by 8.84 years on average. However, there were no significant differences in the type of injury (high vs low energy) between the groups. A similar finding has been reported for femoral neck fractures versus intertrochanteric fractures of the proximal femur: Patients with intertrochanteric

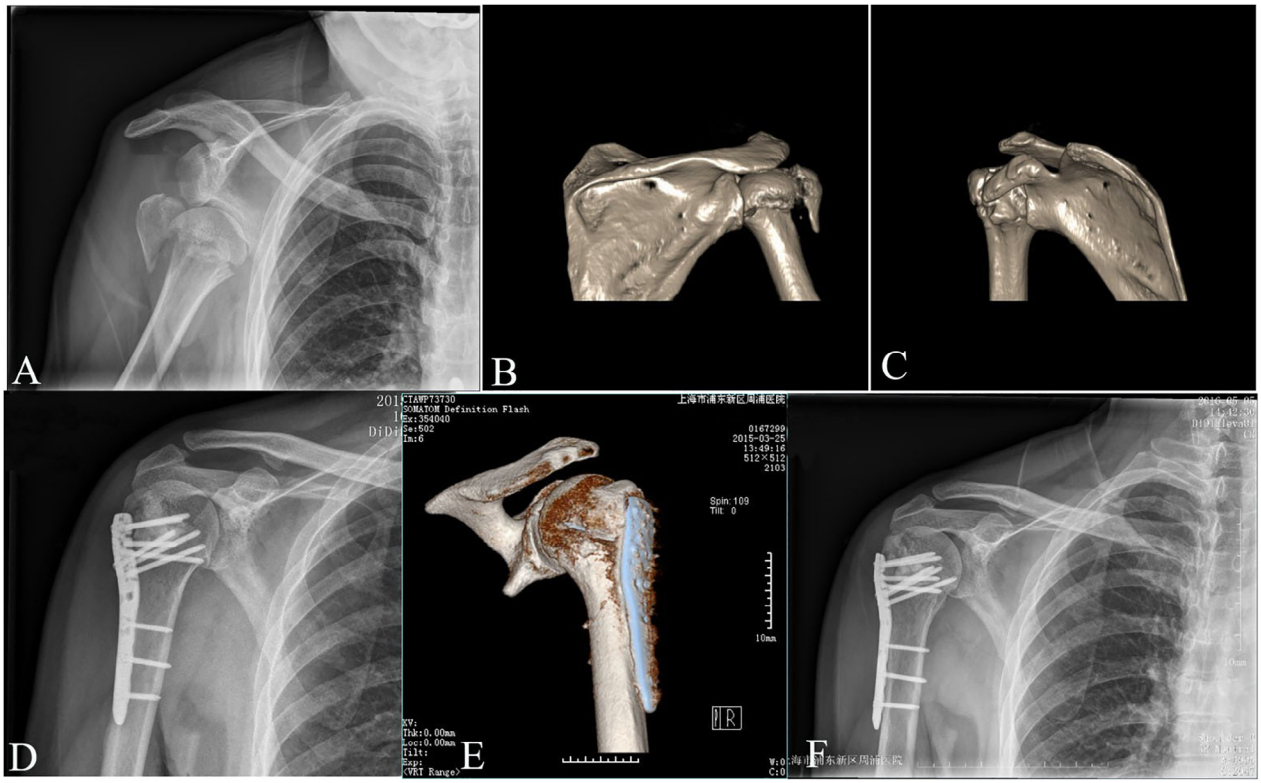

Figure 3 Imaging findings of a 58-year-old male patient with an ice cream anatomic neck fracture (ANF) and Constant-Murley score of 59 points at 3 months, 77 points at 12 months, and 73 points at the last follow-up visit. (**A**) Preoperative radiograph showing ANF with shoulder dislocation. (**B**) Preoperative computed tomography (CT) scan and 3-dimensional reconstruction, showing displacement of greater tuberosity. (**C**) Preoperative CT scan and 3-dimensional reconstruction, showing part of residual lesser tuberosity. Postoperative radiograph (**D**) and CT scan and 3-dimensional reconstruction (**E**) showing ANF fixed with proximal humeral locking plate and implanted artificial bone. (**F**) Radiograph showing osteosynthesis of ANF at 13 months postoperatively. There was no sign of osteonecrosis.

fractures are usually older than those with femoral neck fractures by approximately 10 years.[28] We deduced that the main reason for the age difference in our study may involve age-related bone metabolism differences between the anatomic neck and surgical neck of the proximal humerus. The underlying potential mechanisms concerning the anatomic features and biomechanics of ANFs in the proximal humerus need to be explored.

Another notable finding in our study was that both the NSA and SD were significantly decreased at 12 months after surgery in patients with ANFs. This finding suggests the presence of greater bone resorption at the fracture site, resulting in a decreased NSA during the bone union process and leading to varus displacement to some extent. A decrease in the NSA and SD is usually accompanied by a loss of screw purchase and penetration of the humeral head. Although the NSA and SD tended to be decreased in patients with SNFs, the difference did not reach statistical significance (Supplementary Table S3). These results suggest that instability in ANFs fixed with PHLPs can easily lead to a decreased NSA and varus malalignment.

Our results also showed that osteonecrosis occurred significantly more often in the ANF group than in the SNF group. A previous report showed that when the humeral head was displaced into varus malalignment, a higher number of complications and worse clinical results occurred, and primary or secondary postoperative varus displacement was noted.[4] However, in our study, no association was found between osteonecrosis of the humeral head and a decrease in the NSA (Supplementary Table S5). Consistent with our results, Hertel et al[12] found that the basic fracture pattern is a good predictor of ischemia for combined types 2, 9, 10, 11, and 12, which indicates that the anatomic neck component has high vascular risk. However, the LEGO model (Lego, Billund, Denmark) by Hertel et al[12] has some limitations, as it was based on Codman's modified concept, which considers the tuberosities as intercalated segments between the head and shaft, rather than as protuberances sitting on the metaphysis.[5] Furthermore, their binary description system (LEGO) did not sharply discern the parts of the humerus, and the metaphysis of the humerus was not included in their diagram, which can be easily distinguished in the anatomy of the proximal humerus. The lesser and greater tuberosities do not occupy the entire 360° of the metaphysis (Fig. 4).

Humeral head osteonecrosis may develop in some patients with ANFs. In this study, the mean CMS peaked at 12 months and then decreased at last follow-up in the ANF group. Some osteonecrosis of the humeral head can occur

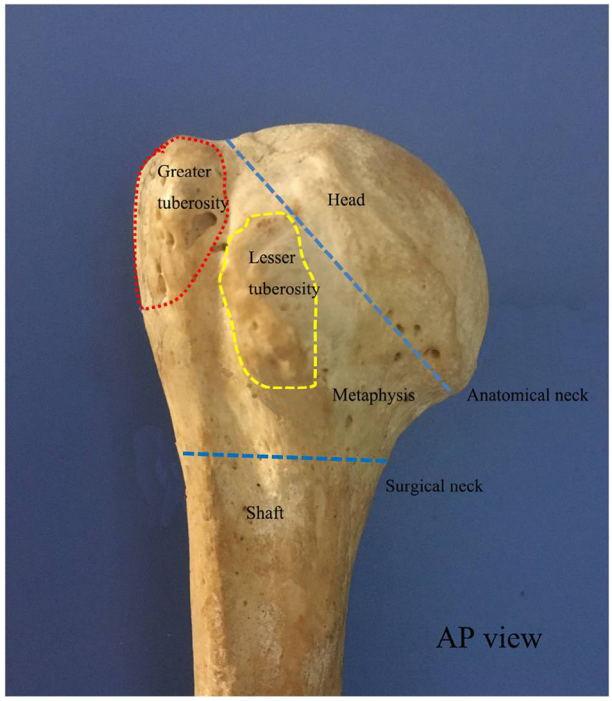

Figure 4 Anteroposterior view (*AP*) of proximal humerus. The proximal humerus can be divided into 5 parts, with the humeral head located proximal to the anatomic neck, the humeral shaft located distal to the surgical neck, the humeral metaphysis located between the anatomic neck and surgical neck metaphysis, and the protuberances of the lesser and greater tuberosities sitting on the metaphysis. The lesser and greater tuberosities did not occupy the entire 360° of the metaphysis. In 4-part anatomic neck fractures, the displaced humeral head, lesser tuberosity, greater tuberosity, and humeral shaft plus part of the humeral metaphysis are separated from one another. Meanwhile, in 4-part surgical neck fractures, the displaced humeral shaft, lesser tuberosity, greater tuberosity, and humeral head plus part of the humeral metaphysis are separated from one another.

even when the internal fixation instruments have been removed and osteosynthesis has occurred during the 1- to 3-year postoperative period. The results of a previous report suggested that osteonecrosis has a negative impact on outcomes.[11] Our results may be indirect evidence to support this viewpoint: In the ANF group, the CMS decreased from 63.3 at the 12-month follow-up to 62.0 at last follow-up but was not significantly different. However, this score was significantly lower than that in the SNF group in the same follow-up period, which may have been due to the development of humeral head osteonecrosis and has led to a decrease in the CMS in the ANF group.

The mechanism of osteonecrosis in humeral head fractures may be similar to that in femoral neck fractures, in which biomechanical factors may be the main cause of femoral head necrosis, rather than the blood supply. After internal fixation of a femoral neck fracture, new trabecular bone grows and remodeling occurs according to the biomechanics of the internal fixation. When the internal fixation is removed after osteosynthesis, microfractures in the new trabecular bone occur, resulting in collapse of the femoral head and osteonecrosis.[16] The same process may occur in the remodeling of ANFs; however, the true mechanism is unknown. Notably, the associated biological, biomechanical, and/or human risk factors must be understood better, because the evolution of osteonecrosis in fractures is not always predictable.[4]

The limitations of this study include its retrospective design, short follow-up period, small cohort sizes, no control group, lack of performance of a power analysis, inherent difficulties in retrieving complete data, surgeon-to-surgeon variability in the surgical technique, and technical variations. Measurements were performed in only 1 plane and cannot accurately reflect the 3-dimensional structure, and attempts to measure the head-shaft angle in the axillary view were proved to be inaccurate.[1] In addition, the injury severity score was not evaluated in every patient. Moreover, radiographic measurements may vary from 1 observer to another, introducing a significant uncontrolled variable.

Conclusion

In this study, patients with ANFs were younger than those with SNFs and the incidence of ANFs was higher than expected. ANFs are complex PHFs resulting in more complicated surgical procedures, with increased operative times, EBL, and rates of bone grafting, as well as higher complication rates. ANF treatment with PHLPs is more prone to a decreased NSA and humeral head osteonecrosis and has poorer clinical outcomes than SNF treatment with PHLPs. Therefore, because of the complexity of ANFs, further high-quality, multicenter, large-scale, randomized controlled trials are required. In addition, further follow-up of the patients in our study may help identify those with late osteonecrosis, as its onset can occur as much as 2 years after surgery.[20] The potential mechanisms of the anatomic features and biomechanics of ANF need to be further explored. Meanwhile, long-term follow-up is necessary to determine the final outcome of ANFs treated with PHLPs.

Disclaimer

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Supplementary data

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