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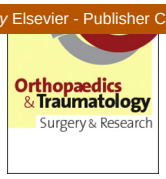

Original article

Radiological evaluation of reduction loss in unstable proximal humeral fractures treated with locking plates

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ABSTRACT

Purpose: The aim of this study was to radiologically evaluate the risk of reduction loss after locking plate fixation of proximal humerus fractures.
Methods: From September 2007 to April 2009, 71 patients (28 males, 43 females) with unstable proximal humeral fracture were treated with open reduction and internal fixation by locking plate. The mean follow-up time was 31.2 months (range: 26–47). The head-shaft angulation (HSA) and the humeral head height (HHH) in true anteroposterior (AP) were recorded and compared over time. All complications were noted. Shoulder function was measured by the Constant score.
Results: Patients with ΔHSA >10° (t = 2.740, $P = 0.008$) and ΔHHH >5 mm ($t = 2.55$, $P = 0.019$) were more likely to have impaired shoulder function. Varus collapse occurred most frequently in patients with initial reduction of HSA <125° (χ^2=19.17, P<0.001, Fisher's exact test F<0.001). Patients with >5 mm HHH decrease were strongly associated with loss of reduction ($\chi^2 = 24.23$, P<0.001, F<0.001).
Conclusions: Dynamic change of HSA >10° and HHH >5 mm were radiological factors that indicated poor shoulder function. Intra-operative HSA >125° should be achieved to avoid reduction loss following locking plate fixation of proximal humerus fracture.
Level of evidence: level IV.

1. Introduction

Fracture of the proximal humerus accounts for about 5% of all clinically-treated fractures [1], and occurs most frequently in elderly female patients [2]. The increasing incidence of proximal humeral fractures in the general population has been accompanied by a significantly increased rate in surgical plate fixation treatment of such fractures [3]. Locking plates were developed to produce more reliable fixation, and their advantages have been demonstrated in many multicenter clinical research trials. However, a major complication of locking plate-treated proximal humeral fractures is reduction loss and varus malunion [4–8]. The results of varus malunion caused by reduction loss are functional limitations, and even complete fixation failure. Previous studies have suggested that fractures healed with a humeral head-shaft angle less than 120° are at a higher risk of shoulder function impairment [5,8–10].

As a dynamic process, reduction loss can be clinically observed throughout the process of bone repair, until it is eventually healed. By comparatively evaluating the radiographic data obtained immediately after surgery and in follow-up, we were able to identify risk factors that predict postoperative varus malunion. Our purpose was to identify radiological changes that occur during the process of reduction loss, which may be prognositc factors for the development of varus malunion and functional outcome of proximal humeral fractures.

2. Patients and methods

Between September 2007 and April 2009, 79 proximal humerus fractures were surgically treated in our department. Patients with complete follow-up data were included in our study. The population was composed of 28 males and 43 females with a mean age of 60.1 years (range: 27–87). According to their medical records, all patients were hospitalized within 48 hours after injury and none showed evidence of a pathological fracture. Preoperative plain radiographs in the anteroposterior and axillary view were taken for all the patients upon admission. Those with comminuted fractures underwent three-dimensional (3D) computed tomography

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(CT) reconstruction. Based on the Orthopaedic Trauma Association (OTA) classification system, the fractures in this set were: type 11-A2 (n = 4, 6%), type 11-A3 (n = 8, 11%), type 11-B1 (n = 26, 37%), type 11-B2 (n = 20, 28%), type 11-B3 (n = 8, 11%), type 11-C1 (n = 3, 4%), and type 11-C2 (n = 2, 3%). Dislocation was present in eight patients (11%).

The causes of injury included simple fall (61 cases), fall from a great height (4 cases), motor vehicle accident (5 cases), and fall from a horse (1 case). Some patients suffered concomitant injuries to the ipsilateral ribs (1 case, sixth and seventh rib fractures), bilateral multiple ribs and hemopneumothorax (1 case), ipsilateral patellar fracture (1 case), contralateral distal radius fracture (1 case), and thoracic-lumbar compressive fractures (two cases, without nerve symptom). One case was classified as a Gustilo type I open fracture. The average length of time from injury to plate fixation surgical intervention was 3.3 days. Most fractures (59 cases) were fixed using the AO PHILOS system (PHILOS; Proximal Humerus Interlocking System,Synthes; Oberdorf, Switzerland). For the remaining cases, the AO LPHP system (15 cases; Oberdorff) or Periarticular Locking Plate system (5 cases; Zimmer Warsaw IND USA) was used.

3. Surgical technique

Patients under general anesthesia were placed in a beach chair position. The proximal humerus was exposed using a deltopectoral approach. The displaced fragments were reduced and temporarily fixed with Kirschner wires. C-arm X-ray was taken to ensure satisfactory positioning, and the fracture was fixed with a locking plate. Drainage was routinely performed. Postoperative X-ray was taken in all cases for reference purposes.

The postoperative rehabilitation regimen was designed on an individual basis, according to the type of fracture and general condition of the patient. Passive range of motion, including pendulum exercise, flexion, and external rotation, was initiated at two days after surgery. Internal rotation was gradually introduced, including adduction and abduction exercises. For all patients, at the end of 12 weeks after surgery, strength training and enhanced range of motion exercises were encouraged.

4. Postoperative follow-up

The follow-up clinical evaluation included assessment of affected shoulder function (measured by the Constant-Murley score), pain, and range of motion. A set of X-rays was obtained for all patients at 2-days, 3- and 6-months, and 1-year post-surgery, including views in the true anteroposterior (with the arm in a neutral position), lateral, and axillary. The HSA was measured at the intersection of the tangent line of the articular surface with a line parallel to the long axis of the humeral shaft, as previously described [4]. The humeral head height (HHH) was measured on the anteroposterior radiographic image by calculating the vertical distance between the tangent line of the highest point of the humeral head and the greater tuberosity (Fig. 1). The measurement taken immediately after plate fixation was recorded as initial HSA or HHH, for subsequent use in comparative analysis with the measurements taken upon fracture healing. All evaluations of clinical features and radiographic images were carried out by a single group of specialized surgeons. According to the criteria defined by Lee [11] and Owsley [12], loss of reduction was defined as a decrease in the HSA of >10°.

Statistical analysis was performed with the PASW statistical software, version 18.0 (SPSS Inc., IBM, Chicago, IL, USA). All numeric data were summarized as mean ± standard deviation ($x \pm$ SD). Numerical data were compared with the Student's t-test and categorical data were compared with the Chi-square (χ^2) test and Fisher's exact test. The Pearson's correlation test was used to measure the correlation between two groups of consecutive data. A significant difference was defined as P<0.05.

5. Results

The mean follow-up time was 31.2 months (range: 26–47). The final analysis included 71 patients with complete data. At the one-year follow-up (1-yr after surgery), bony union had been achieved in all patients.

Change in the HSA >10° indicated loss of reduction, and was observed in 14 patients (19.7%). Among these patients, 12 had HHH decrease of more than 5 mm. Following the recommendation of Greiner et al., [13] an HSA of <120° was considered indicative of varus malunion, and was found in nine of our patients (12.6%). Complications included humeral head osteonecrosis (4 cases, 5.6%), plate impingement (2 cases, 2.9%), adhesive capsulitis (3 cases, 4.2%), screw cut-out (2 cases, 2.9%), and displaced greater tuberosity (1 case, 1.4%). There were no cases of rotator cuff injury, infection, or implant failure.

In this cohort, the mean Constant score in the loss of reduction group (ΔHSA >10°) was 64.1 ± 9.7, and 76.7 ± 10.1 in the alignment normal group. The difference between the two groups was

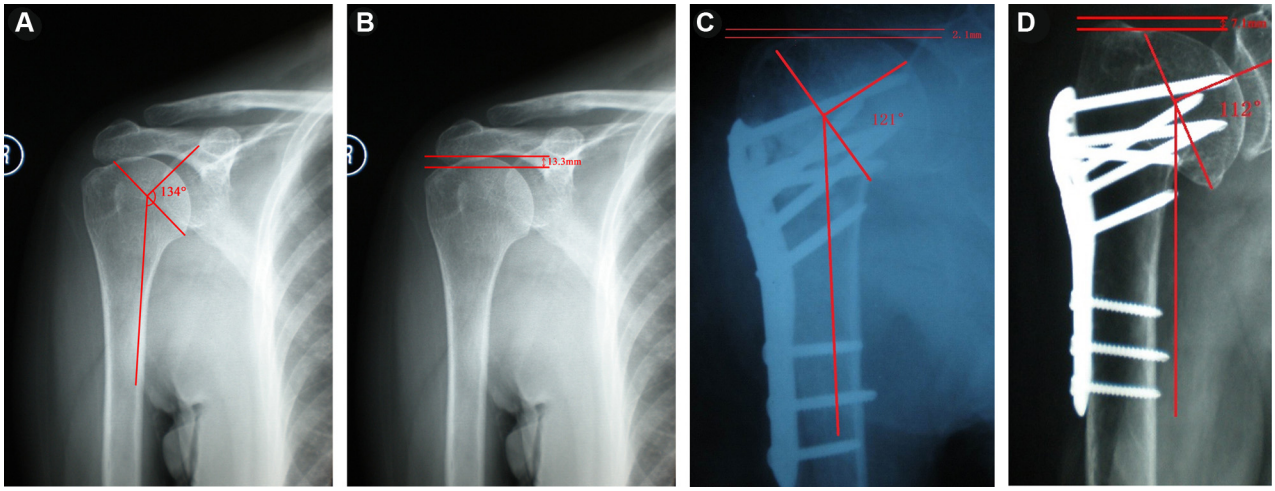
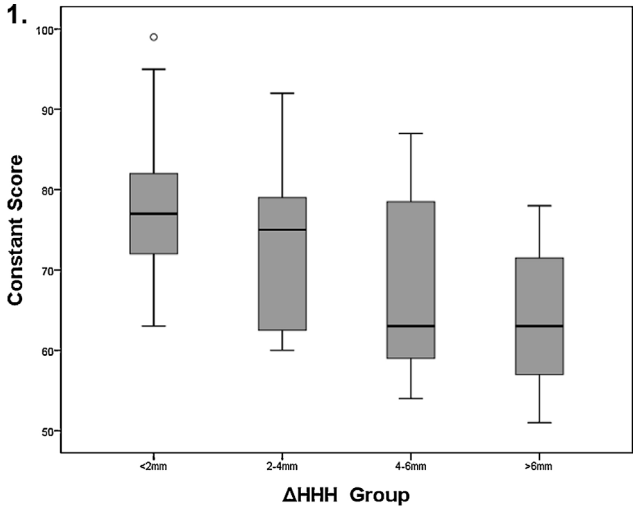


Fig. 1. Measurement of head-shaft angle and humeral head height. A–B show the methods used for HHH and HSA measurements. C shows the initial postoperative X-ray of a representative patient, with HSA 121° and HHH 2.1 mm (humeral head above great tuberosity). D shows the same patient's most recent follow-up X-ray with HSA 112° and HHH 7.1 mm (humeral head below great tuberosity). Compared with the initial postoperative X-ray, the patient experienced reduction loss and varus malunion.



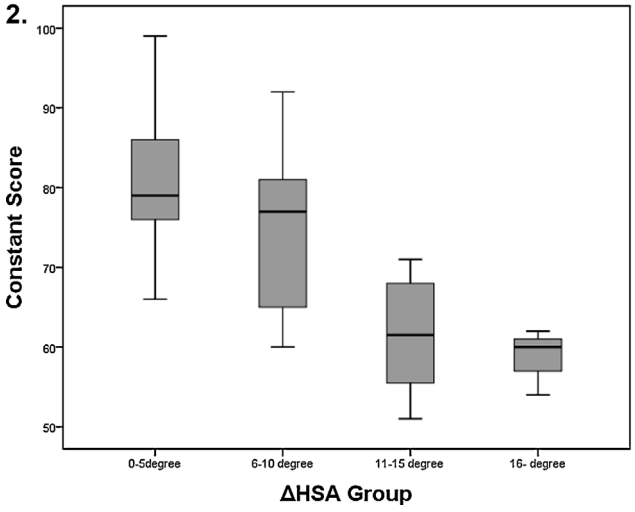


Fig. 2. Boxplot view of Constant score in the ΔHSA groups and ΔHHH groups.

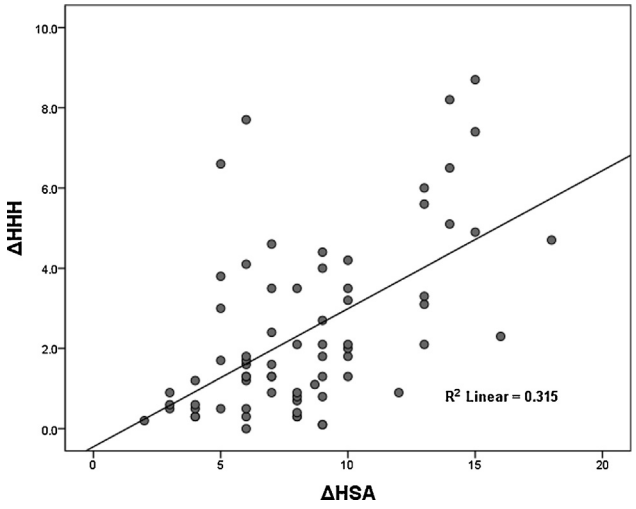


Fig. 3. Plot of changes and correlations of ΔHSA and ΔHHH.

significant ($t = -2.740$, $P = 0.008$). We also found that patients with a decrease of HHH >5 mm had poorer function than those with a smaller ΔHHH (66.7 ± 13.4 *vs.* 75.7 ± 12.6; $t = 2.55$, $P = 0.019$). These findings are detailed in Fig. 2.

6. Radiography

The mean HSA decrease angle in the loss of reduction group was 12.6±3.1° (range: 11–18). In the alignment normal group, the mean HSA taken immediately after surgery was 134.0 ± 7.5° (range: 131–147), and after fracture healing, the mean HSA was 130.3 ± 8.1° (range: 128–147). The change in HSA was not statistically significant ($t = 1.58$, $P = 0.87$). The mean HHH decrease in the loss of reduction group was 5.0 ± 2.5 mm (range: 4.1–13.3). In the alignment normal group, the mean HHH decrease was 1.7 ± 1.4 mm (range: 0.4–2.3), which was not statistically different after healing ($t = -1.35$, $P = 0.26$). The ΔHHH between the two groups was, however, statistically significant ($t = 3.889$, $P = 0.001$).

Most patients (47/51) without loss of reduction had an initial (measured immediately postoperative) HSA >125°. Varus collapse occurred most frequently (11/20) in the patients who had an initial HSA <125° ($\chi^2 = 19.17$, $P<0.001$, Fisher's exact test F<0.001). Thus, initial HSA less than 120° was strongly associated with loss of reduction, and may represent a prognostic indicator. Ten of the total patients had >5 mm decrease of HHH, and eight of those (80%) experienced loss of reduction. In contrast, the loss of reduction rate in patients with <5 mm decrease in HHH was only 11.4% (7/61) ($\chi^2 = 24.23$, $P<0.001$, Fisher's exact test F<0.001). These data suggest that a progressive decrease of HHH is associated with loss of reduction. Moreover, ΔHHH (change of HHH) and ΔHSA (change of HSA) were positively associated with one another ($r = 0.561$, $P = 0.000$, 95% CI: 0.431–0.709) (Fig. 3).

7. Discussion

The main advantage of locking plates for treating proximal humerus fracture is their ability to achieve better fixation stability. However, the associated postoperative complications remain a major concern. Agudelo et al. conducted a multicenter retrospective analysis of 153 patients with proximal humerus fractures that had been fixed with locking plates [5]. They concluded that loss of fixation (including implant failure and varus collapse with or without intra-articular screw penetration) occurred primarily in the presence of initial varus malreduction. More importantly, however, the authors noted that an initial HSA of <120° produced a three-fold higher risk of fixation failure than HSA >120° (30.4% *vs.* 11.0%). At the early stage of fracture healing, varus displacement of the humeral head shifts the stress load to the implant, which predisposes the implant to early failure and further varus displacement [7,8]. At the later stage, without effective support or normal alignment [14,15], the humeral head can suffer from reduction loss until it heals in the varus position. A recent meta-analysis of 12 studies of angular stable locking plates and patient outcome demonstrated that loss reduction leading to varus malunion was the most common complication reported (16.3% of cases) [16]. Previous studies [5,6,10,16,17], along with our own clinical experience, have suggested that if fixation does not fail, a majority of patients with loss of reduction experience fracture healing despite development of noticeable varus collapse.

Furthermore, varus malunion without loss of fixation was demonstrated by several other studies to negatively impact the functional outcomes of the shoulder [4,9,10]. A recent study revealed that varus deformity changes the pretension of the rotator cuff, leading to decreased supraspinatus efficiency, and ultimately requiring significantly higher forces to achieve normal arm elevation [18]. Thus, we propose that loss of reduction, defined as varus malunion with an HSA decrease of >10°, is a clinically-relevant outcome measure. Although the normal values of HSA and HHH

have varied among published studies [19–21], and the average HSA of different populations may be slightly different, according to our research, radiological change with HSA <120° is a functional predictor. Furthermore, ΔHHH may also indicate poor shoulder function. When we conducted a Pearson correlation test on ΔHHH and ΔHSA, we found these measurements were statistically correlated with each other ($r = 0.561$). This is in accordance with previous findings from an Asian population radiographic study (described above), in which a high correlation between HHH and HSA was reported [21]. Regarding proximal humerus fractures fixed by locking plates, we believe progressive decrease of HSA leads to loss of reduction, followed by reduced HHH and, finally, humeral head collapse and insufficient shoulder function, as is frequently seen in clinics.

In our study, an initial HSA of <125° was found to predispose patients to further varus displacement and loss of reduction. Fractures with excessive varus malreduction are known to be generally associated with early fixation failure or screw penetration, necessitating revision surgeries. Therefore, to avoid postoperative complications, such as functional impairment of shoulder caused by varus malunion, an initial HSA of >125° should be achieved intraoperatively. In cases of initial varus malreduction >10°, or lack of a medial column support, the angular stable locking plates are known to be insufficient to provide necessary support for the proximal fragment [22]. Under these circumstances, placement of a superiorly directed oblique locked screw in the inferomedial region of the proximal fragment may be helpful to achieve better maintenance of reduction [14].

Our data and previously published results have underscored the predictive value of HSA for outcome of proximal humerus facture fixed by locking plates [18]. However, the measurement of HSA is not without difficulty and bias. Internal and external rotations of the glenohumeral joint are known to complicate the measurement; for example, the HSA is larger for an internally rotated glenohumeral joint, and smaller for an externally rotated joint. Interestingly, in this study, we found that both ΔHHH and HSA were independent risk factors for loss of reduction and functional outcome. HHH, used as an additional prognostic factor, will provide an optional evaluation of loss of reduction following locking plate fixation. Moreover, slight varus of HSA alone is well-recognized as insufficient to predict function outcomes of the shoulder [7,23]. However, displacement (>5 mm) of the greater tuberosity relative to the humeral head, caused by reduction loss, is believed to impair the supraspinatus efficiency, thereby increasing the strength required for abduction. Therefore, HHH may be more clinically-relevant for prediction of loss of reduction.

The occurrence of reduction loss and varus malunion was influenced by several factors, such as lack of a medial column support and calcar screw support. The functional outcome of proximal humeral fractures was also affected by age, bone quality, existing rotator cuff myopathy, and fracture pattern. Our results indicate that radiological measurements may predict the possibility of varus malunion and functional outcome of the shoulder; in particular, ΔHSA >10°and ΔHHH >5 mm indicate poor functional outcome. Finally, initial HSA <125° may be a risk predictor of varus malunion.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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