

# Indirect Reduction Technique in Proximal Humeral Fractures Stabilized by Locking Plates

Yong Girl Rhee, Nam Su Cho, Sang Won Cha, Seong Cheol Moon, Sang Phil Hwang

Shoulder and Elbow Clinic, Department of Orthopaedic Surgery, College of Medicine, Kyung Hee University, Seoul, Korea

**Background:** Indirect reduction technique offers a valid option in the treatment of proximal humerus fracture. The purpose of this study is to evaluate the functional outcome and the complication rate after indirect reduction and internal fixation of unstable proximal humeral fractures with use of a locking plate.

**Methods:** Twenty four patients with acute proximal humerus fracture were managed with indirect reduction and internal fixation with a locking plate. The mean follow-up period was 15.5 months.

**Results:** The anatomical reduction of the medial cortex buttress was seen in 16 patients (66%) of the Group A and the non-anatomical reduction was seen in 8 patients (33%) of the Group B. Mean union time was  $3.2 \pm 1.9$  months; it was  $2.2 \pm 0.6$  months in the Group A and  $5.3 \pm 2.2$  months in the Group B ( $p < 0.05$ ). In our series, there were 6 cases of complications and these include 2 cases of varus malunion, 2 cases of shoulder stiffness, 1 case of heterotrophic ossification, 2 cases of screw perforation and 1 case of impingement.

**Conclusions:** We conclude from our studies that indirect reduction and internal fixation using locking plate for acute proximal humerus fracture can give good results with bony union and predictable good overall functional outcome. If the medial cortex buttress is well maintained, a better anatomical reduction would be achieved, the union would be prompted, the pain would be further reduced and the range of the motion would be recovered more promptly.

(Clin Shoulder Elb 2014;17(1):2-9)

**Key Words:** Shoulder; Proximal humerus fracture; Locking plate; Indirect reduction

## Introduction

Proximal humeral fractures constitute up to 5% of all fractures seen in some centers.<sup>1,2)</sup> High energy traumatic fractures are seen in the active young while minor traumatic fractures are commonly seen in the elderly due to osteoporosis and various contributing age related factors.<sup>3,4)</sup> While undisplaced or minimally displaced fractures are generally conservatively managed,<sup>5,6)</sup> unstable, displaced fractures often require some surgical intervention.<sup>7)</sup> Unreduced or poorly reduced fractures with varus angulation of the neck-shaft angle can be a cause of avascular necrosis of the head of humerus.<sup>8-10)</sup> Nevertheless, the indications for selecting a specific treatment from the wide variety of available procedures like wires, sutures, intra-medullary nails

and other fixation techniques<sup>3)</sup> have all been used to maintain the fracture reduction. However, the ability of these fixations alone to restore anatomical relationships, maintain stability and prevent avascular necrosis to the humeral head remains controversial.

Open reduction and internal fixation with plates gained popularity with the advent of angular stable plates or locking plates<sup>3,11-14)</sup> as they have yielded superior results than the conventional plates with rapid good bony union and therefore improved function.<sup>15)</sup> Factors influencing healing and bony union can be largely grouped into presentation factors (fracture type, comminution, vascular insults and other concomitant injuries), patient factors<sup>9,16)</sup> (age, sex, nutrition, medication, general health) and surgeon factors<sup>12,17,18)</sup> (operative techniques, implants, im-

**Received** December 2, 2013. **Revised** March 3, 2014. **Accepted** March 17, 2014.

**Correspondence to:** Yong Girl Rhee

Department of Orthopaedic Surgery, College of Medicine, Kyung Hee University, 23 Kyungheedaero, Dongdaemun-gu, Seoul 130-872, Korea

**Tel:** +82-2-958-8370, **Fax:** +82-2-964-3865, **E-mail:** [shoulderrhee@hanmail.net](mailto:shoulderrhee@hanmail.net)

**Financial support:** None. **Conflict of interests:** None.

mobilization). Out of all these factors, presentation factors cannot be controlled while patient factors can be controlled to only a certain extent by optimization and patient education. This leaves us with the surgeon factors which are entirely in the hands of the surgeon and therefore it is important that we adhere to good surgical guidelines like that which has been laid out by the AO foundation.<sup>1)</sup> The principles enforces anatomical reduction and fixation of the fracture by using a stable rigid fixation or splintage while preserving the blood supply to the soft tissue and bone by careful and gentle handling techniques and lastly by starting mobilization early.

The minimally invasive technique with a locking plate allows good purchase in osteoporotic bone and comminuted fractures with minimal interferences to the fracture site vascularity. Stable fracture fixation with good vascularity will result in early healing which will encourages early mobilization and thereby improving outcome.

The aim of this study is to assess fracture healing, functional outcome and complications of proximal humeral fractures, treated by indirect reduction with a locking plate fixation.

## Methods

### Inclusion and Exclusion Criteria

Patients with proximal humerus fracture which has been treated with a locking plate fixation by using indirect reduction technique were retrospectively reviewed at a minimum of one year postoperatively.

The management of proximal humerus fractures were made entirely with the following criteria. Fractures were conservatively treated if they were undisplaced or minimally displaced but relatively stable. Surgical reduction was indicated for all open fractures, unstable fractures and fractures with severe comminution. Direct reductions were performed on fractures which were difficult to reduce, severely displaced fractures, fractures with failed indirect reduction or neglected fractures which were more than 1 week. However, for this study, patients who were treated conservatively and with open direct reduction were excluded.

Cases that were indirectly reduced had a two to four part fractures of Neer's classification and were reducible without directly touching the fragments. Severely comminuted fractures and fractures which could not be reduced indirectly were converted to direct reductions as necessary.

### Patient Selection

Between October 2005 and January 2012, 87 patients treated for proximal humerus fracture were enrolled. Eight patients were lost to follow-up, 15 patients were treated conservatively while 64 patients were plated surgically. However, 40 of these patients were treated by direct reduction technique or screw fixation and were thereby excluded from this study leaving an-

other 24 patients for the present study.

The mean age at the time of operation was  $62.8 \pm 15.1$  years (range, 24 to 85 years). The mean follow-up period was 15.5 months (range, 12.1 to 27.2 months). Eight patients (33%) were male and 16 patients (66%) were female. The mean time interval from injury to operation was  $5.5 \pm 1.2$  days.

Fractures were classified using the following method: number of displaced fracture parts, Neer's classification and the AO-classification. Nine patients (37.4%) had 2 parts fracture of Neer's classification, while 10 patients (41.6%) had 3 parts fracture and 5 patients (20.8%) had 4 parts fracture (Table 1).

All selected patients were operated within 1 week of the fractures. None of them were delayed more than a week. These operative timings were dependant on the time needed to optimize these patients and the availability of operating time.

### Preoperative and Postoperative Evaluation

Routine roentgenograms with anteroposterior (AP) and axillary views were taken followed by a computed tomography (CT) scan preoperatively.

Clinical follow-up is done bi-weekly for the first 3 months. If healing is uncomplicated, a monthly follow up is done. All patients were evaluated with plain x-rays on a regular basis till union postoperatively. Plain x-rays at the 4 month postoperatively was used to check for signs of union in our study by looking for the loss of the fracture line lucency and callus formation.

Postoperative clinical evaluations were performed regularly on an outpatient basis (at 4 weeks, 6 weeks, 3 months, 6 months, and 12 months postoperatively and at the last follow-up) and the results of the last follow-up were analyzed. Postoperative subjective pain score was measured using the visual analog scale (VAS). Postoperative shoulder range of motion (ROM), forward flexion, external rotation at the side, internal rotation to the back, and abduction were assessed. Quantitative muscle strength measurements of the rotator cuff were assessed with

Table 1. Patients Demographics

Variables	Indirect reduction
No. of patients	24
Sex, male/female	8/16
Dominant/nondominant	17/7
Mean age, y (range)	63.2 (39–83)
Mean follow-up, mo	15.5 ± 6.1
Time interval from injury to operation, day	5.5 ± 1.2
Fracture type (Neer's classification)	
2 part	9 (37.4%)
3 part	10 (41.6%)
4 part	5 (20.8%)

use of a portable, handheld Nottingham Mecmesin Myometer (Mecmesin Co, Nottingham, UK). Elevation strength was tested with the patient in the seated position with the arm flexed to 90° in the scapular plane. External and internal rotation was tested with the shoulder in a neutral position and the elbow in 90° of flexion. The Constant score<sup>19)</sup> and the Shoulder Rating Scale of the University of California at Los Angeles (UCLA)<sup>20)</sup> were used for clinical assessment.

### Operative Techniques

All operations were performed by the senior author with the patient in a beach chair position with the back of the bed flexed about 30°. Ipsilateral arm is free to move in a sterile condition and kept rested on a removable tray table with an adjustable height. Prior to draping the portable C-arm (image intensifier) is adjusted and optimally positioned to take radiographic images.

The deltopectoral approach is used with incision starting just inferior to the coracoid process and extends towards the proximal area of insertion of the deltoid. Deltopectoral interval is established with digital dissection of the subdeltoid fascial plane. The deltoid is retracted laterally along with the cephalic vein while the pectoral muscles retracted medially providing exposure to the anterolateral part of the proximal humerus. Additional exposure can be gained with partial release of the anterior deltoid insertion, along with abduction of the arm during the procedure. The head of the humerus is first reconstructed if required with a few sutures or cerclage wires or both as described by Hertel et al.<sup>21)</sup> as he described it akin to reconstructing a broken eggshell. Larger fragments like tuberosities can be held reduced with pointed reduction clamps and then fixed by Kirschner wires (K-wires). If the medial calcar is fractured, it is important to ensure that the medial calcar is also held reduced

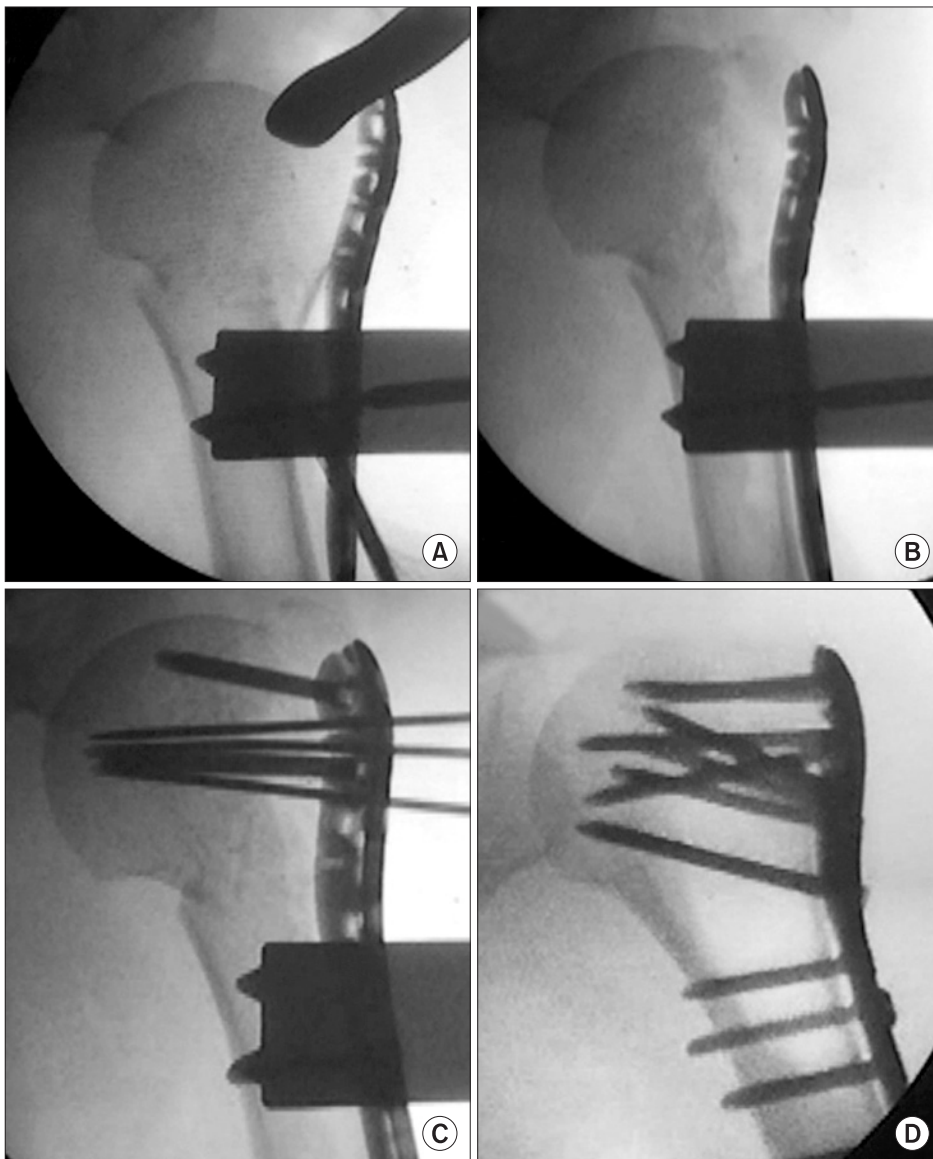


Fig. 1. (A) Locking plate is placed and the non-locking hole just distal to the fracture is drilled perpendicular to the bone fragment. (B) As the screw is tightened, the valgus deformity will reduce itself. (C) Locking and non-locking screw should be placed proximally to catch the head of the humerus. (D) The intraoperative x-ray show good alignment.

as much as possible as this can be a cause to varus displacement post operatively during healing.

The fracture site is not touched in order to preserve existing fragile soft tissue attachments of all its fragments. The fracture is then reduced “indirectly” by using ligamentotaxis, manipulation of the upper arm and the buttressing effect of the plate (PHILOS; Synthes, Oberdorf, Switzerland). The desired length of the plate is first chosen after taking into consideration of the extent of the fracture; usually with length reaching to approximately 3–4 holes distal to the fracture is sufficient. The space for the plate is created via blunt insertion of the plate along the distal fragment of the fracture along the humeral shaft and close to the bone. The proximal humerus is usually already exposed and fracture clearly visualized from this approach. Traction and manipulation restores length and alignment. The plate is then introduced to its desired position in which the ideal position is that the upper tip of the plate should just be about 5 mm inferior to the greater tuberosity.

In a residual valgus deformity of the humeral head, the plate is slightly higher than the tip of the greater tuberosity. With the thumb on the proximal fragment stabilizing the plate and its position the non-locking hole just distal to the fracture is drilled perpendicular to the bone fragment. As the screw is tightened, the valgus deformity will be slowly reduced itself as the shaft which is usually displaced medially also lateralizes to a reduced state. This has to be carefully done and the alignment constantly checked with a C-arm (Fig. 1).

Once the screw is tightened, the angulation is usually reduced to an acceptable position. A few K-wires can be temporarily inserted into the proximal part of the plate to maintain a hold on the proximal humerus if desired. These loosely inserted wires can help maintain plate position to the head while allowing correction.

For varus residual angulation, a similar technique is em-

ployed. However, this time the plate should be sitting better on the proximal. Again a finger with the help of some K-wires if required can hold the plate to the humeral head lightly in position.

After completely screwing in the first screw, the plate is usually already buttressing the bone with its anatomically contoured curves and the fracture should be reduced. The following screws inserted are locking screws in an alternate side manner to the fracture site. The second screw should be placed proximally to catch the head of the humerus while the third can be placed distal to the fracture site. The fourth screw is placed carefully placed at the surgical neck and it should catch the medial calcar of the fracture as it is an important stabilizer to resist postoperative varus angulation (Fig. 2). Once this is done, the rest of the screws can be inserted alternating between fracture sides with the help of the C-arm imaging. Care should be taken to ensure none of the screws are in the joint. This can be thoroughly checked with the C-arm in fluoroscopic mode or by x-rays.

Additionally, cuff tenodesis is done by anchoring the torn cuffs to holes on the plate with the help of sutures. This will help maximize function of the shoulder after healing.

Comminuted fractures can be held reduced with the help of bone clamps, K-wires and sutures to maintain reduction. All post-reduction cases are checked with the C-arm after operation before closure to ensure good reduction, good plate placement and no protruding screws in the joint.

In cases of poor bone quality, it would also be useful to perform a fixation using the cement during the insertion of a screw.

### Postoperative Rehabilitation

All patients were provided with a shoulder sling with from the operation theatre. Intravenous analgesia is given with additional oral pills in the wards. Passive motion is started from postoperative day 1 with pendulum exercises. Assisted arm (passive) flexion with the help of the contralateral hand is then done. Active



Fig. 2. (A) Four-part fracture of proximal humerus: valgus displacement of the humeral head, displaced fracture of the greater tuberosity. (B) Fracture fixation using a locking plate by indirect reduction.



motion is only allowed after 6 weeks postoperatively.

### Statistical Analysis

Independent *t*-test was used to compare UCLA, Constant score, VAS score and radiological results between anatomical reduction group and non-anatomical reduction group. Significance was set at as  $\alpha$  level of 0.05 with 95% confidence intervals. The Statistical Package for the Social Sciences (SPSS) software package (version 17.0; SPSS, Inc, an IBM Company, Chicago, Illinois) was used for all statistical analyses.

## Results

The anatomical reduction of the medial cortex buttress was seen in 16 patients (66%) of the Group A and the non-anatomical reduction was seen in eight patients (33%) of the Group B (Table 2).

### Clinical Results

At a final follow-up, the mean VAS score was reduced to  $1.9 \pm 1.4$ . The mean range of motion of the shoulder joint was 150.8 during the forward flexion, 59.3 during the external rotation and T11.0 during the internal rotation to back. Besides, the mean muscle strength was 6.9 kg during the forward flexion, 5.7 kg during the external rotation and 5.3 kg during the internal rotation. In addition, at a final follow-up, the mean UCLA scores were  $31.9 \pm 3.0$  and constant scores were  $74.5 \pm 11.9$ . At a final follow-up, the mean VAS score was  $0.9 \pm 1.3$  in the Group A and  $2.1 \pm 1.0$  in the Group B. The mean range of motion was 160.8 during forward flexion in the Group A and 145.8 in the Group B. This difference reached a statistical significance ( $p <$

Table 2. Comparison of Clinical Outcomes according to Subgroups

Variables	Overall	Group A	Group B	<i>p</i> -value
Pain (VAS)	$1.9 \pm 1.4$	$0.9 \pm 1.3$	$2.1 \pm 1.0$	$< 0.05$
ROM (degree)				
FF	150.8	160.8	145.8	$< 0.05$
ER	59.3	60.3	58.3	0.25
IR	T11.0	T11.2	T10.8	0.35
Muscle strength (kg)				
FF	6.9	7.0	6.8	0.14
ER	5.7	5.9	5.7	0.07
IR	5.3	5.3	5.3	0.35
UCLA score	$31.9 \pm 3.0$	$32.0 \pm 2.8$	$29.5 \pm 4.2$	$< 0.05$
Constant score	$74.5 \pm 11.9$	$77.5 \pm 12.9$	$69.5 \pm 10.1$	$< 0.05$

VAS: visual analogue scale, ROM: range of motion, FF: forward flexion, ER: external rotation, IR: internal rotation, UCLA: the University of California at Los Angeles.

0.05). At a final follow-up, the mean UCLA and Constant scores were  $32.0 \pm 2.8$  and  $77.5 \pm 12.9$  in the Group A and  $29.5 \pm 4.2$  and  $69.5 \pm 10.1$  in the Group B in the corresponding order. These differences also reached a statistical significance ( $p < 0.05$ ) (Table 2).

### Radiologic Results

The mean union time was  $3.2 \pm 1.9$  months. Six months postoperatively, a total of four patients achieved a union. But one patient achieved a union nine months postoperatively. The mean bone union time was  $2.2 \pm 0.6$  months in the Group A and  $5.3 \pm 2.2$  months in the Group B. This difference reached a statistical significance ( $p < 0.05$ ). Postoperatively, the mean neck shaft angle was  $128.3 \pm 11.9$ ; it was  $133.0 \pm 8.5$  in the Group A and  $117.3 \pm 11.8$  in the Group B. This difference reached a statistical significance ( $p < 0.05$ ) (Table 3).

### Complications

In our series, there were six cases of complications and these include non-implant related complications (two cases of varus malunion, two cases of shoulder stiffness and one case of heterotrophic ossification) and implant-related ones (two cases of

Table 3. Comparison of Radiologic Outcomes according to Subgroups

Reduction in medial buttress	Overall	Group A	Group B	<i>p</i> -value
No. of patients	24	16 (66.6%)	8 (33.3%)	
Union time, mo	$3.2 \pm 1.9$	$2.2 \pm 0.6$	$5.3 \pm 2.2$	$< 0.05$
Neck shaft angle, degree	$128.3 \pm 11.9$	$133.0 \pm 8.5$	$117.3 \pm 11.8$	$< 0.05$

Table 4. Complications

	No. of patients*
Incidence of complications	6 (25%)
Non-implant related	
Varus malunion	2
Nonunion	0
Infection	0
Shoulder stiffness	2
Heterotrophic ossification	1
Osteonecrosis	0
Neurovascular injury	0
Implant related	
Screw perforation	2
Impingement	1
Implant failure	0

\*Several complications per patient were possible.

screw perforation and one case of impingement) (Table 4). In one case of varus malunion, there was a concurrent presence of screw perforation and heterotrophic ossification. However, there were no such complications as osteonecrosis, infection and neurovascular injury.

Technical errors, such as placing the plate too high on the tuberosity with subsequent impingement and reducing the fracture into a varus position, resulted in an unsatisfactory functional outcome. In the current study, there was one case of subacromial impingement; the corresponding patient complained of persistent pain due to a high position of the plate. Nine months postoperatively, the pain was reduced following the plate removal. The patient presented with a motor deficit accompanied by the decreased muscle strength. Moreover, there were two cases of postoperative stiffness. In one case, the motor deficit due to the transient occurrence of adhesive capsulitis was recovered following the conservative treatment. In the other case, there was a persistent presence of the motor deficit. This might be because the rehabilitation could not be appropriately done following the surgery because of old age and concurrent diseases. On radiography, a bone union was achieved within four months. But there were no other notable findings.

## Discussion

Proximal humeral fractures can be treated conservatively or surgically depending on its fracture pattern and stability. The goal of treatment of proximal humerus fracture is to achieve an anatomic reduction with stable fixation, to retain the vascularity of the surrounding tissues and to enable early mobilization. For displaced and unstable fractures, various techniques of close and open reduction and fixation are used.<sup>22-24</sup> In severe and comminuted fracture which can give rise to avascular necrosis of the humeral head, a shoulder replacement is highly recommended.<sup>22</sup> Conversely a fracture with minimal displacement and stable fragments can be conservatively treated. However, often there are cases which lie in between these categories having minimal fragments can be relatively unstable especially if the surgical neck is involved.

Plating of proximal humeral fractures using an indirect reduction technique offers the advantages of obtaining an adequate reduction with minimal vascularity disturbances, stable fixation and therefore enabling early mobilization. The extra-advantage of using a locking plate is for its good purchasing power with its angular stable design with low profile positioning as it is anatomically contoured and minimal periosteal vascular insults.<sup>25</sup> Hessmann et al.<sup>26</sup> used the indirect reduction technique in 98 patients with unstable proximal humeral fracture. According to the reference, results of UCLA-rating system and Constant score were good to excellent in 76% and 69% of fractures, respectively. In addition, according to these authors, there were three cases

of complete humeral head necrosis due to an avascular necrosis. Furthermore, they also noted that there was one case of non-union and 12 cases of varus malunion. Konrad et al.<sup>27</sup> reported the surgical technique for patients with a locking plate fixation of unstable displaced proximal humeral fracture, and the methods of the fixation based on the reduction and fixation of the rotator cuff using a screw fixation of the first hole distal to fracture. We attempted to fix the proximal humerus fracture with the primary use of an indirect technique. But if there was an unreduced poorly displacement or more than 1 week elapsed following the onset of fracture, we performed a fixation of the locking plate using a direct reduction.

The internal fixation using a direct reduction and a plate has long been selected as the treatment modality for patients with proximal humerus fracture. Generally, it is known that osteonecrosis of the humeral head following proximal humeral fractures could be caused by the fracture itself giving rise to compromise of the vascular supply to the humeral head.<sup>28</sup> Sturzenegger et al.<sup>29</sup> reported that an avascular necrosis occurred after plate fixation of multifragmented proximal humerus fractures at an incidence 34%. Thanasis et al.<sup>30</sup> reported the incidence of avascular necrosis, 7.9%. Some authors have attributed higher incidences of avascular necrosis to the Neer's type IV or worse fracture pattern and to severe varus angulation deformity.<sup>31</sup> In view of these, Gerber et al.<sup>32</sup> suggested that a proximal humerus fracture should be reduced anatomically if a joint preserving treatment is required. Hardeman et al.<sup>31</sup> who did a study on 368 surgically treated proximal humeral fractures found anatomical reduction correlated with better results and concluded that articular fractures had better results when treated with a plate with all the physiological factors weighted. In the current study, there were no cases of osteonecrosis. This might be not only because the periosteal circulation could be preserved with the minimization of the soft tissue dissection using an indirect reduction but also because an anatomic reduction could be well maintained through a stable fixation.

Perforation of head screws seems to be the most frequent implant-specific complication, with rate of up to 67%.<sup>33</sup> In the current study, there were two cases of screw perforation. In one case, due to a persistent presence of the pain, the removal of plate and screw was performed following the bone union. Twelve months postoperatively, however, the corresponding patient presented with a glenohumeral joint arthritis accompanied by the varus malunion.

In our technique of indirect reduction, the first screw (non-locking) is placed just distal to the fracture line to reduce the varus or valgus deformity. The maintenance of a reduced state especially from postoperative varus angulation and malunion is minimized with the placement of a screw or two to the calcar of the humerus preventing the collapse of the head shaft angle. Technical errors such as poor positioning of the plate (too

proximal or distal), screw penetration of the glenohumeral joint and poor screw placement must be avoided to achieve a good outcome. The optimum position of the plate is with its proximal end just about 5 mm distal to the proximal tip of the greater tuberosity.

The importance of the medial buttress has previously been noted by Gardner et al.<sup>17)</sup> Egol et al.<sup>34)</sup> also reported that early complications in the proximal humerus were related to restoration of the medial buttress. The restoration of the medial buttress is a key factor for obtaining the successful clinical outcomes. If there is a lack of the contact to the medial cortex, this would cause the progression of varus deformity as well as reduction loss. According to the current study, in all the cases in which more than six months elapsed until a bone union was achieved, there was treatment failure in the anatomical reduction of medial buttress. Also in two cases of varus malunion, the treatment failure occurred as results of the non-anatomical reduction of medial buttress. Moreover, in eight cases (33.3%) in which the non-anatomical reduction of medial buttress was achieved, the neck shaft angle was significantly decreased at a final follow-up as compared with the anatomical reduction group. In addition, there were also significant differences in the clinical outcomes between the two groups. Also in cases in which the non-anatomic reduction of medial buttress was achieved, however, the neck shaft angle was maintained if the fixation of inferomedial screw was sufficiently done. This was also accompanied by a lack of the progression of varus angulation. Therefore, the rigid screw fixation and anatomic reduction would be essential for obtaining satisfactory radiologic and clinical outcomes for the medial buttress during an indirect reduction of the proximal humerus fracture. If there are any chances that it is impossible to achieve a complete anatomical reduction of the medial buttress, postoperative complications could be prevented through a rigid fixation using an inferomedial screw.

The drawbacks of this study are similar with any other retrospective literatures. The use of Neer's classification is easy and simple to use but lacks more description qualities when compared with the AO classification. Thus many cases may fall outside its categories. The low numbers of cases with a relatively short term follow-up may not show cases with delayed complication of avascular necrosis. We were also unable to quantify the severity of the fracture with their vascular impairments as these are very subjective albeit using the many classifications on this subject which is merely addressing the numbers of fragments with displacement.

We conclude from our studies that indirect reduction and internal fixation using locking plate for acute proximal humerus fracture can give good results with bony union and predictable good overall functional outcome. If the medial cortex buttress was well maintained, it was possible to achieve an anatomical reduction. In addition, the mean union time was shortened with

the decreased pain. This was accompanied by the recovery of the range of motion. Furthermore, there were significant differences in the postoperative UCLA scores and Constant scores between the two groups.

## References

1. Bigliani LU, McCluskey GM 3rd. Prosthetic replacement in acute fractures of the proximal humerus. *Semin Arthroplasty*. 1990;1(2):129-37.
2. Lind T, Krøner K, Jensen J. The epidemiology of fractures of the proximal humerus. *Arch Orthop Trauma Surg*. 1989;108(5):285-7.
3. Robinson CM, Page RS, Hill RM, Sanders DL, Court-Brown CM, Wakefield AE. Primary hemiarthroplasty for treatment of proximal humeral fractures. *J Bone Joint Surg Am*. 2003;85-A(7):1215-23.
4. Palvanen M, Kannus P, Niemi S, Parkkari J. Update in the epidemiology of proximal humeral fractures. *Clin Orthop Relat Res*. 2006;442:87-92.
5. Fjalestad T, Strømsøe K, Blücher J, Tennøe B. Fractures in the proximal humerus: functional outcome and evaluation of 70 patients treated in hospital. *Arch Orthop Trauma Surg*. 2005;125(5):310-6.
6. Hanson B, Neidenbach P, de Boer P, Stengel D. Functional outcomes after nonoperative management of fractures of the proximal humerus. *J Shoulder Elbow Surg*. 2009;18(4):612-21.
7. Hessmann MH, Korner J, Hofmann A, Sternstein W, Rommens PM. Angle-fixed plate fixation or double-plate osteosynthesis in fractures of the proximal humerus: a biomechanical study. *Biomed Tech*. 2008;53(3):130-7.
8. Robinson CM, Amin AK, Godley KC, Murray IR, White TO. Modern perspectives of open reduction and plate fixation of proximal humerus fractures. *J Orthop Trauma*. 2011;25(10):618-29.
9. Aggarwal S, Bali K, Dhillon MS, Kumar V, Mootha AK. Displaced proximal humeral fractures: an Indian experience with locking plates. *J Orthop Surg Res*. 2010;5:60.
10. Robinson CM, Wylie JR, Ray AG, et al. Proximal humeral fractures with a severe varus deformity treated by fixation with a locking plate. *J Bone Joint Surg Br*. 2010;92(5):672-8.
11. Schumer RA, Muckley KL, Markert RJ, et al. Biomechanical comparison of a proximal humeral locking plate using two methods of head fixation. *J Shoulder Elbow Surg*. 2010;19(4):495-501.
12. Haidukewych GJ. Innovations in locking plate technology. *J Am Acad Orthop Surg*. 2004;12(4):205-12.
13. Papadopoulos P, Karataglis D, Stavridis SI, Petsatodis G, Christodoulou A. Mid-term results of internal fixation of proximal humeral fractures with the Philos plate. *Injury*.

- 2009;40(12):1292-6.
14. Foruria AM, Carrascal MT, Revilla C, Munuera L, Sanchez-Sotelo J. Proximal humerus fracture rotational stability after fixation using a locking plate or a fixed-angle locked nail: the role of implant stiffness. *Clin Biomech.* 2010;25(4):307-11.
  15. Walsh S, Reindl R, Harvey E, Berry G, Beckman L, Steffen T. Biomechanical comparison of a unique locking plate versus a standard plate for internal fixation of proximal humerus fractures in a cadaveric model. *Clin Biomech.* 2006;21(10):1027-31.
  16. Olsson C, Nordqvist A, Petersson CJ. Increased fragility in patients with fracture of the proximal humerus: a case control study. *Bone.* 2004;34(6):1072-7.
  17. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. *J Orthop Trauma.* 2007;21(3):185-91.
  18. Tingart MJ, Apreleva M, von Stechow D, Zurakowski D, Warner JJ. The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. *J Bone Joint Surg Br.* 2003;85(4):611-7.
  19. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res.* 1987;(214):160-4.
  20. Ellman H, Hunker G, Bayer M. Repair of the rotator cuff. End-result study of factors influencing reconstruction. *J Bone Joint Surg Am.* 1986;68(8):1136-44.
  21. Hertel R. Fractures of the proximal humerus in osteoporotic bone. *Osteoporos Int.* 2005;16 Suppl 2:S65-72.
  22. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. *J Shoulder Elbow Surg.* 2004;13(4):427-33.
  23. Bastian JD, Hertel R. Initial post-fracture humeral head ischemia does not predict development of necrosis. *J Shoulder Elbow Surg.* 2008;17(1):2-8.
  24. Solberg BD, Moon CN, Franco DP, Paiement GD. Surgical treatment of three and four-part proximal humeral fractures. *J Bone Joint Surg Am.* 2009;91(7):1689-97.
  25. Handschin AE, Cardell M, Contaldo C, Trentz O, Wanner GA. Functional results of angular-stable plate fixation in displaced proximal humeral fractures. *Injury.* 2008;39(3):306-13.
  26. Hessmann M, Baumgaertel F, Gehling H, Klingelhoefter I, Gotzen L. Plate fixation of proximal humeral fractures with indirect reduction: surgical technique and results utilizing three shoulder scores. *Injury.* 1999;30(7):453-62.
  27. Konrad G, Bayer J, Hepp P, et al. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. Surgical technique. *J Bone Joint Surg Am.* 2010;92 Suppl 1 Pt 1:85-95.
  28. Kuner EH. Fractures of the proximal humerus. Classification and treatment principles. *Z Unfallchir Versicherungsmed.* 1992;85(3):156-62.
  29. Sturzenegger M, Fornaro E, Jakob RP. Results of surgical treatment of multifragmented fractures of the humeral head. *Arch Orthop Trauma Surg.* 1982;100(4):249-59.
  30. Thanasis C, Kontakis G, Angoules A, Limb D, Giannoudis P. Treatment of proximal humerus fractures with locking plates: a systematic review. *J Shoulder Elbow Surg.* 2009;18(6):837-44.
  31. Hardeman F, Bollars P, Donnelly M, Bellemans J, Nijs S. Predictive factors for functional outcome and failure in angular stable osteosynthesis of the proximal humerus. *Injury.* 2012;43(2):153-8.
  32. Gerber C, Werner CM, Vienne P. Internal fixation of complex fractures of the proximal humerus. *J Bone Joint Surg Br.* 2004;86(6):848-55.
  33. Spross C, Platz A, Erschbamer M, Lattmann T, Dietrich M. Surgical treatment of Neer Group VI proximal humeral fractures: retrospective comparison of PHILOS® and hemiarthroplasty. *Clin Orthop Relat Res.* 2012;470(7):2035-42.
  34. Egol KA, Ong CC, Walsh M, Jazrawi LM, Tejwani NC, Zuckerman JD. Early complications in proximal humerus fractures (OTA Types 11) treated with locked plates. *J Orthop Trauma.* 2008;22(3):159-64.