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Complex Proximal Humerus Fractures Treated With Locked Plating Utilizing an Extended Deltoid Split Approach With a Shoulder Strap Incision

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Objectives: The goal of the study is to analyze the outcome and complications after locked plating of proximal humerus fractures with the extended deltoid split approach though a shoulder strap incision.

Design: Prospective.

Setting: Tertiary care referral center.

Patients: Fifty-two adult patients with a displaced 3 or 4 part proximal humerus fracture or fracture dislocation.

Interventions: Open reduction and locked plate osteosynthesis through an extended deltoid split approach using a strap incision.

Outcome Measurements: Electrophysiological assessment of axillary nerve function at 6 weeks and at 3, 6, and 12 months postoperatively in those patients in whom an abnormality was detected postoperatively. Functional outcome measurement using normalized Constant scores at 6 and 12 months. Other measures include radiological assessment and complications.

Results: Traction injury to the anterior part of the axillary nerve was electrically evident but not clinically apparent in 4 patients. The normalized Constant score continued to show significant improvement 1 year post surgery, 67.3 ± 11.3 at 6 months and 80.2 ± 7.7 at 1 year ($P = 0.001$)). Union was obtained in all patients. Varus/valgus/tuberosity malreductions were seen in 8 patients. Loss of reduction was seen in 2 patients. Two patients had radiological evidence of avascular necrosis at 1-year follow-up.

Conclusions: Locked plating of proximal humerus fractures through an extended deltoid split approach using a shoulder strap incision provides satisfactory outcomes. Axillary nerve injury is the only limitation of the approach and can be minimized with careful identification and protection of the nerve throughout the procedure.

Key Words: extended deltoid split, shoulder strap, transdeltoid approach, proximal humerus fractures

(*J Orthop Trauma* 2012;0:1–4)

Accepted for publication April 10, 2012.

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The authors declare no support or conflict of interest.

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INTRODUCTION

The deltopectoral approach remains the gold standard for operative management of proximal humerus fractures,[1] but concerns have been raised with the limited exposure of the posterolateral aspect of the proximal humerus through the approach. Accurate reduction of the greater tuberosity fragments, plate placement posterior to the bicipital groove and subsequent insertion of fixed angle screws can be difficult with the deltopectoral approach.[2,3] Improved exposure of the posterolateral aspect may require excessive retraction of the muscles and in obese patients detachment of the anterior deltoid from the clavicle and release of the insertion of pectoralis major.[4,5]

The transdeltoid approaches have been used sparingly for the fear of axillary nerve injury. Robinson et al[6] described good results with the transdeltoid approach through a shoulder strap incision. The strap incision with a distal based skin flap offers excellent exposure of the posterolateral shoulder and can be used for locked plating of proximal humerus fractures. The incision is cosmetic and heals well compared with the straight lateral incision as it is situated along the relaxed skin tension lines of the shoulder girdle.[7] With this background, we performed a prospective study at our institution to evaluate the clinical, radiologic, and functional outcomes after internal fixation of complex fractures of the proximal humerus using the shoulder strap approach.

MATERIALS AND METHODS

The study was conducted from September 2008 to December 2009. Patients admitted with a displaced 3-part or 4-part proximal humerus fracture or a fracture dislocation. Open fractures, patients with open physes, patients with altered mental status, neurological disease, bilateral, or pathological fractures were excluded. Patients with preoperative clinical evidence of axillary nerve dysfunction and associated brachial plexus injury were also excluded. Anteroposterior (AP), axillary x-rays of the injured shoulder, and a 3D computerized tomography (CT) scan were taken to assess fracture displacement and plan surgical treatment. Fractures were classified according to Neer system. Locked plating was performed in all patients through an extended deltoid split using a shoulder strap incision. Two surgeons (A.S.G., N.C. T.) performed the surgeries. The institutional review board approved the study, and informed written consent was obtained from patients before the surgery.

Surgical Technique

Surgery was performed under general anesthesia in a beach chair position. The image intensifier was positioned from the opposite side to enable AP and modified axial views.[8] The shoulder strap incision was made with the apex centered on the acromion (Fig. 1). A distally based skin flap was created leaving behind the fascia overlying the deltoid. The anterior raphe between the anterior and middle portions of the deltoid was identified and split bluntly. The anterior branch of the axillary nerve was located at a variable distance of 4–6 cm distal to the acromion as it traversed from posterior to anterior along the undersurface of the deltoid in close proximity to the bone. The nerve was identified by blunt dissection from proximal to distal direction along the anterior raphe. A finger passed distally in a lateral direction through the proximal window helped in identification of the nerve without extensive dissection. The nerve once identified was then protected using an umbilical tape. A distal window was created only after the identification of the axillary nerve to facilitate insertion of distal screws. A more proximal exposure if needed was obtained with detachment of the deltoid from the acromion.

Fracture reduction was then performed according to standard methods. A 3.5-mm proximal humeral locking plate with angle stable screws was used for fixation. The plate was inserted carefully under the axillary nerve and care was taken to make sure it was positioned posterior to the bicipital groove and at least 5 mm below the tip of the greater tuberosity to prevent impingement. AP, modified axial, and AP views with the shoulder in internal and external rotation were taken to rule out intra-articular screw placement before wound closure.

Doubtful screw positions in the postoperative radiographs were further assessed by CT to rule out intra-articular penetration. Gravity assisted pendulum exercises and passive range of motion were started from the first postoperative day. Active assisted ROM exercises were initiated at suture removal, and active exercises were started at the end of the third week. A graduated strengthening program was started at 6 weeks extending up to 4 months. Follow-up visits were conducted at 3, 6, 9, 12 weeks and at 6 and 12 months.

Outcome Analysis

The study was primarily aimed to assess the incidence of axillary nerve injury with the approach and functional outcome (Constant score) with emphasis on restoration of shoulder flexion, abduction, and strength. Other outcomes studied included the quality of fracture reduction achieved through the approach, flap healing, incidence of avascular necrosis, and complications.

An independent radiologist blinded to the study outcome performed all postoperative radiological assessments and 2-blinded orthopedic trainees performed the follow-up clinical and functional outcome assessment. Fracture reductions were classified as anatomic or nonanatomic. Nonanatomic reductions were further classified as varus (neck shaft angle $<120°$) and valgus malalignments (neck shaft angle $> 150°$). Tuberosity malreduction was documented if displacement was more than 5 mm in any direction. Secondary displacements were documented if there was $>5°$ change in the head-shaft angle. Avascular necrosis was documented by the presence of sclerotic areas in the humeral head with or without collapse on follow-up x-rays.

Axillary nerve function was assessed by clinical and neurophysiological testing. Clinical assessment included sensory and motor examination of the anterior deltoid muscle. Neurophysiological outcome was assessed using nerve conduction velocity and electromyography studies, performed at 6 weeks. The contralateral anterior deltoid was tested to serve as the control. Patients demonstrating abnormal findings in neurophysiological testing at 6 weeks were scheduled for repeat tests at 3, 6, and 12 months.

The Constant score was obtained at 6 and 12 months. Forward flexion and abduction were measured with a goniometer, and strength was assessed using a spring balance (Ikata, India) and was recorded in kilograms. Readings were taken for both shoulders in the scapular plane at 90 degrees and were converted into pounds (lbs). The Constant score[9]

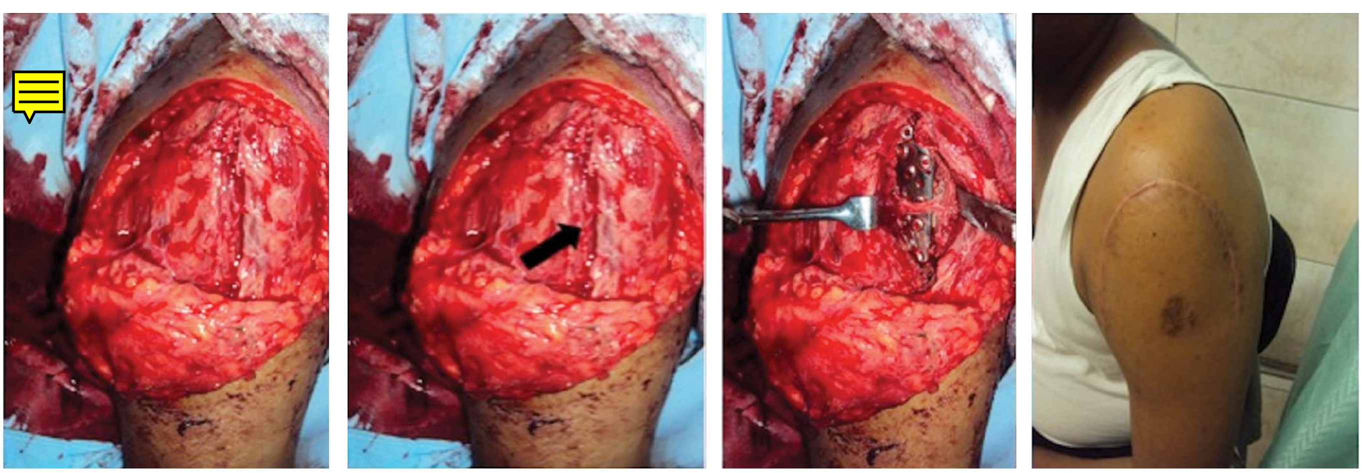

FIGURE 1. Raising of the distally based flap, identification of the anterior deltoid raphe (black arrow), positioning of the plate beneath the axillary nerve, and the appearance of the surgical scar.

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was adjusted for age and gender as described by Katolik et al,[10] and a normalized Constant score was generated.

Statistics

Standard descriptive statistics were used to describe all baseline and follow-up parameters. The variables tested were continuous and were represented as means, standard deviation, and ranges. Series of paired *t*-tests were used to assess statistical difference between follow-ups. The level of significance was set at $P < 0.05$. To adjust the Constant score with respect to age and gender, a normalized Constant score was generated using the formula; (raw score/normal score) × 100.

RESULTS

Eighty-seven patients (88 fractures) were admitted during the study period. Sixty-one satisfied the inclusion criteria. Nine patients refused to participate in the study, and 2 were lost to follow-up leaving a final cohort of 50 patients. The mean age was 53 years (range: 27–71 years), and there were 26 males and 24 females. The mean delay in surgery was 3 days (0–16 days). Of the 50 fractures, there were 23 (3) part greater tuberosity fractures, 9 (3) part lesser tuberosity fractures, 6 classic (4) part fractures, 8 valgus impacted (4) part fractures, and 4 (3) part anterior fracture dislocations. The mode of violence was domestic low-velocity injury in 30 patients and high-velocity injury (road traffic accidents or fall from height) in 20 patients.

Forty-two (84%) of the 50 fractures were classified as anatomically reduced in the immediate postoperative x-rays. Four fractures were fixed in varus, and 2 fractures were fixed with valgus malalignment. Tuberosity malreduction was found in 2 fractures; greater tuberosity—1 and lesser tuberosity—1. Secondary displacement was identified in 5 fractures. Three of these fractures had displacement of <10°. Two patients with initial varus fixation had complete loss of reduction. Both these patients did not take part in further evaluation and were considered early failures. Union was achieved in all patients available for follow-up at a mean of 10 weeks (8–14 weeks). The greater tuberosity was reduced to a level below the humeral head articular surface in all but 1 patient. The proximal tip of the plate was at a mean of 6 mm (4 mm–9 mm) below the tip of the humeral head.

All surgical wounds healed primarily, and there was no evidence of flap necrosis. A superficial infection was seen in 4 patients, and treated with extended parenteral antibiotics. There were no incidences of deep infection. One patient on anticoagulant therapy had prolonged wound drainage beyond day 5 which resolved without intervention.

Although there was no clinical evidence of axillary nerve dysfunction before and after surgery, neurophysiological tests revealed an increased distal latency and loss of waveforms in 4 patients at 6 weeks suggesting injury to the anterior part of the axillary nerve. No abnormal waveforms were reported from other nerve territories thereby ruling out the possibility of a preoperative brachial plexus injury. Testing at 3 months showed normal latency in 3 of the 4 patients and low amplitude waveforms in all 4 patients, suggesting recovery and the possibility of neuropraxia due to traction injury. The distal latency in the fourth patient had normalized at 6 months but low amplitude waveforms in the anterior deltoid remained in 3 of the 4 patients at 6 months and 1 year. Two of the 4 patients had a dislocated head fragment on presentation. Despite the findings of neurophysiologic tests, there was no significant motor weakness in these patients as evident from ROM and strength tests.

Two cases (4%) of avascular necrosis were seen at 1-year follow-up, 1 patient with a classic (4) part fracture had avascular changes at 6 months but was symptomatic. He had continued worsening of function with radiological evidence of head collapse at 1 year. Another patient with a similar fracture presented with sclerotic changes of the humeral head at 1 year but had good clinical function.

The mean abduction and forward flexion at 1 year (131 ± 15.9°, 112 ± 19.8°) was significantly better compared with (112° ± 14.1°, 99° ± 14.5°) at 6 months ($P = 0.038$ for abduction and $P = 0.04$ for forward flexion). The mean shoulder strength was 5.6 ± 3.6 lbs at 6 months, which improved significantly to 9.8 ± 4.7 lbs at 1 year ($P = 0.17$). The difference in strength was significantly different favoring the normal shoulder (14.6 ± 4.9 lbs) both at 6 months and 1 year ($P < 0.01$). The mean normalized Constant score was 67.3 ± 11.3 at 6 months and 80.2 ± 7.7 at 1 year. Stratification of the 1-year Constant scores in relation to fracture pattern revealed better scores for (3) part and (4) part valgus impacted fractures compared to classic (4) part fractures and fracture—dislocations.

One patient required repeat surgery to revise a screw 2 days after CT evaluation confirmed intra articular placement. Five (10%) patients were diagnosed with symptomatic impingement, and 3 of them underwent interval acromioplasty during follow-up.

DISCUSSION

The deltopectoral approach is considered the gold standard for anterior access to the shoulder but when stabilizing proximal humeral fractures with a laterally placed proximal locking plate this approach can be technically difficult. The exposure of the greater tuberosity where the anatomical locking plates are to be seated is limited through the deltopectoral approach.[11] Reduction and stable fixation of the greater tuberosity fragment may be difficult in cases of extreme comminution or displacement.

Gallo et al[12] described the use of 2 incisions to overcome the above difficulties with the deltopectoral approach. They achieved reduction of the anterior fracture fragments through the deltopectoral incision and used a small lateral incision to facilitate placement of fixed angle screws. Laflamme et al[13] described a minimally invasive transdeltoid approach and a similar technique has been reported by us[14] as successful in a select group of fractures. Robinson et al[6,15] have extensively described their successful results with the shoulder strap incision in both fracture fixation and arthroplasty.

The strap approach offers good exposure of the posterolateral shoulder with minimal retraction. The anterior raphe is a relatively avascular zone[16,17] and bleeding is often minimal. Fracture reduction through the approach is relatively straightforward except in anterior fracture dislocations. The reduction of the dislocated head fragment can cause a traction injury to the axillary nerve, which remains tight in spite of the elaborate exposure. We have observed that the use of mountable drilling guide and insertion of inferomedial calcar screws, which are critical for providing medial support,[18] may sometimes be difficult with the approach due to the unyielding position of the axillary nerve.

The chance of axillary nerve injury is the chief limitation of the approach as with all transdeltoid approaches. Traction neuropraxia to the anterior branch of axillary nerve can occur; 8% in the current study, but permanent deficits are uncommon. However, temporary dysfunction of the axillary nerve after proximal humerus fractures has been previously reported.[19] Because no electrophysiological testing was carried out preoperatively, such a possibility cannot be ruled out. Khan et al[20] reported a lower incidence of traction injuries using neurophysiological tests in their study. The reason may be that they performed the tests at 6 months by which time most of the traction neuropraxias would have recovered.

The rates of osteonecrosis occurring with the deltopectoral approach vary from 8% to 40% in the reported studies.[21] Gerber et al[22] reported avascular necrosis of the humeral head in 11 of the 31 patients (35.4%) who underwent open reduction through the deltopectoral approach. In a cadaveric study, Gardner et al[23,24] reported that the anterior circumflex vessel courses directly in line with the deltopectoral approach. They confirmed that surgical approach through the anterior deltoid raphe preserves both the anterior and posterior vascular supply to the humeral head. The incidence of avascular necrosis in the current study was 4% (2 patients), which is similar to the reported incidence of AVN with the transdeltoid approach. The presence of a classic (4) part fracture in both patients can be attributed as the chief cause of AVN rather than the surgical approach, but control based long-term follow up studies are required to confirm this hypothesis.

The strengths of the study include prospective data collection and analysis. Follow-up electrophysiological studies, radiological and functional outcome analyses were performed by independent personnel blinded to the study outcome. The chief limitations of the study are a short follow-up period especially with regard to the assessment of osteonecrosis and the lack of controls. In summary, the shoulder strap incision offers good exposure of the proximal humerus and can be recommended as a useful alternate approach to the conventional deltopectoral approach in complex fractures of the proximal humerus. Anterior fracture dislocations may represent a difficult indication and the approach is not recommended, as atraumatic retrieval of the humeral head without traction on the axillary nerve can be relatively difficult as shown in our study population. Traction injuries to the anterior portion of the axillary nerve can occur as shown by electrophysiological testing but are rarely clinically evident. The incidence can be lessened with careful retraction and minimal dissection around the nerve.

REFERENCES

1. Wijgman AJ, Roolker W, Patt TW, et al. Open reduction and internal fixation of three and four-part fractures of the proximal part of the humerus. *J Bone Joint Surg Am*. 2002;84:1919–1925.
2. Naranja RJ, Iannotti JP. Displaced three- and four-part proximal humerus fractures: evaluation and management. *J Am Acad Orthop Surg*. 2000;8:373–382.
3. Rees J, Hicks J, Ribbans W. Assessment and management of three- and four-part proximal humeral fractures. *Clin Orthop*. 1998;353:18–29.
4. Hawkins RJ, Kiefer GN. Internal fixation techniques for proximal humeral fractures. *Clin Orthop*. 1987;223:77–85.
5. Schlegel TF, Hawkins RJ. Displaced proximal humeral fractures: evaluation and management. *J Am Acad Orthop Surg*. 1994;2:54–66.
6. Robinson CM, Khan L, Akhtar A, et al. The extended deltoid-splitting approach to theproximal humerus. *Curr Orthop Pract*. 2008;19:308–313. AU6
7. Borges AF. Relaxed skin tension lines. *Dermatol Clin*. 1989;7:169–177.
8. Wallace WA, Hellier M. Improving radiographs of the injured shoulder. *Radiography*. 1983;49:229–233.
9. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res*. 1987;214:160–164.
10. Katolik L, Romeo A, Cole B, et al. Normalization of the constant score. *J Shoulder Elbow Surg*. 2005;3:279–285.
11. Iannotti JP, Ramsey ML, Williams GR, et al. Nonprosthetic management of proximal humeral fractures. *J Bone Joint Surg Am*. 2003;85:1578–1593.
12. Gallo RA, Zeiders GJ, Altman GT. Two-incision technique for treatment of complex proximal humerus fractures. *J Orthop Trauma*. 2005;19:734–740.
13. Laflamme G Y, Rouleau DM, Berry GK, et al. Percutaneous humeral plating of fractures of the proximal humerus: results of a prospective multi- center clinical trial. *J Orthop Trauma*. 2008;22:153–158.
14. Ashok Gavaskar S, Muthukumar S, Naveen Chowdary T. Biological osteosynthesis of complex proximal humerus fractures; surgical technique and results from a prospective single center trial. *Arch Orthop Trauma Surg*. 2010;130:667–672.
15. Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. *J Bone Joint Surg Am*. 2004;86:143–155.
16. Hue E, Gagey O, Mestdagh H, et al. The blood supply of the deltoid muscle; application to the deltoid flap technique. *Surg Radiol Anat*. 1998;20:161–165.
17. Munnoch DA, Herbert KJ, Morris AM, et al. The deltoid muscle flap: anatomical studies and case reports. *Br J Plast Surg*. 1996;49:310–314.
18. Gardner MJ, Weil Y, Barker JU, et al. The Importance of medial support in locked plating of proximal humerus fractures. *J Orthop Trauma*. 2007;21:185–191.
19. Visser CP, Coene LN, Brand R, et al. Nerve lesions in proximal humeral fractures. *J Shoulder Elbow Surg*. 2001;10:421–427.
20. Khan LA, Robinson CM, Will E, et al. Assessment of axillary nerve function and functional outcome after fixation of complex proximal humeral fractures using the extended deltoid-splitting approach. *Injury*. 2009;40:181–185.
21. Gerber C, Schneeberger AG, Vinh TS. The arterial vascularization of the humeral head: an anatomical study. *J Bone Joint Surg Am*. 1990;72:1486–1494.
22. Gerber C, Werner CM, Vienne P. Internal fixation of complex fractures of the proximal humerus. *J Bone Joint Surg Br*. 2004;86:848–855.
23. Gardner MJ, Voos JE, Wanich T, et al. Vascular implications of minimally invasive plating of proximal humerus fractures. *J Orthop Trauma*. 2006;20:602–607.
24. Gardner MJ, Griffith MH, Dines JS, et al. A minimally invasive approach for plate fixation of the proximal humerus. *Bull Hosp Joint Dis*. 2004;62:18–23.

