Proximal humeral fractures: The role of calcium sulphate augmentation and extended deltid splitting approach in internal fixation using locking plates

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A B S T R A C T

The aim of our study is to analyse the results of our surgical technique for the treatment of proximal humeral fractures and fracture dislocations using locking plates in conjunction with calcium sulphate bone-substitute augmentation and tuberosity repair using high-strength sutures. We used the extended deltid-splitting approach for fracture patterns involving displacement of both lesser and greater tuberosities and for fracture-dislocations. Optimal surgical management of proximal humeral fractures remains controversial. Locking plates have become a popular method of fixation. However, failure of fixation may occur if they are used as the sole method of fixation in comminuted fractures, especially in osteopenic bone.

Methods: We retrospectively analysed 22 proximal humeral fractures in 21 patients; 10 were male and 11 female with an average age of 64.6 years (range 37–77). Average follow-up was 24 months. Eleven of these fractures were exposed by the extended deltid-splitting approach. Fractures were classified according to Neer and Hertel systems. Preoperative radiographs and computed tomography (CT) scans in three- and four-part fractures were done to assess the displacement and medial calcar length for predicting the humeral head vascularity. According to the Neer classification, there were five two-part, six three-part, five four-part fractures and six fracture-dislocations (two anterior and four posterior). Results were assessed clinically with disabilities of the arm, shoulder and hand (DASH) scores, modified Constant and Murley scores and serial postoperative radiographs.

Results: The mean DASH score was 16.18 and the modified Constant and Murley score was 64.04 at the last follow-up. Eighteen out of twenty-two cases achieved good clinical outcome. All the fractures united without evidence of infection, failure of fixation, malunion, tuberosity failure, avascular necrosis or adverse reaction to calcium sulphate bone substitute. There was no evidence of axillary nerve injury. Four patients had a longer recovery period due to stiffness, associated wrist fracture and elbow dislocation. The CaSO₄ bone substitute was replaced by normal appearing trabecular bone texture at an average of 6 months in all patients.

Conclusion: In our experience, we have found the use of locking plates, calcium sulphate bone substitute and tuberosity repair with high-strength sutures to be a safe and reliable method of internal fixation for complex proximal humeral fractures and fracture-dislocations. Furthermore, we have also found the use of the extended deltid-splitting approach to be safe and to provide excellent exposure facilitating accurate reduction for fixation of the fracture patterns involving displacement of both lesser and greater tuberosities and for fracture-dislocations.

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Fractures of the proximal humerus are relatively common injuries, accounting for approximately 4–5% of all fractures.1 There is a steady increase in the incidence of this type of fracture in the osteoporotic population.2 Optimal surgical management of these fractures remains controversial, with many advocating prosthetic replacement in elderly osteoporotic patients.3,4

Recent advances in implants and operative techniques seem to have improved the outcome after open reduction and internal fixation of proximal humeral fractures compared with prosthetic replacement.5–7 However, despite the use of locking plates, significant rates of complications have been reported including loss of fixation, humeral head perforation and impingement.8,9

The aim of our study is to analyse the results of our surgical technique for the treatment of proximal humeral fractures and
fracture dislocations using locking plates in conjunction with calcium sulphate bone-substitute augmentation and tuberosity repair using high-strength sutures. We used the extended deltoid-splitting approach as an alternative to the deltopectoral approach for fracture patterns involving displacement of both lesser and greater tuberosities and for fracture-dislocations.

Biomechanical and in vivo studies showed better stability and outcome following internal fixation of comminuted proximal humerus fractures when augmented with a calcium-phosphate (Ca₃(PO₄)₂) bone substitute (Norion SRS, Skeletal Repair System; Norion, CA, USA)⁵,¹⁰ in our series we used a calcium-sulphate (CaSO₄) injectable bone substitute instead (Stimulan, Biocomposites, Staffordshire, UK)¹¹.

Materials and methods

We retrospectively analysed proximal humeral fractures and fracture dislocations treated operatively at our hospital between July 2007 and November 2009. We excluded undisplaced or minimally displaced fractures (<5 mm), patients with low mental test scores (treated non-operatively) and cases where tuberosity repair or bone-substitute augmentation was not required. This yielded 22 proximal humeral fractures/fracture dislocations in 21 patients. All these fractures were treated with open reduction and internal fixation using locking plates in conjunction with CaSO₄ bone-substitute augmentation and tuberosity repair using high-strength sutures. The extended deltoid-splitting approach was used to expose fractures involving displacement of both tuberosities and fracture-dislocations in 11 fractures. During the study period, only two cases were treated with hemiarthroplasty as they had high risk of humeral head ischaemia as predicted by Hertel’s criteria.¹²

The average age of patients was 61.6 years (range 45–77 years) and 15 were over the age of 60 years (Graph 1). There were 10 male and 11 female patients. Nine patients had fractures on the right side.

Fractures were assessed according to Neer’s classification based on radiographs.¹³ There were five 2-part, six 3-part, five 4-part fractures and six fracture-dislocations (two undisplaced and four posterior). Eighteen patients had computed tomography (CT) scans and fractures were further classified according to the author’s LEGO-Codman classification.¹² There were four Type I, one Type II, seven Type VII, one Type VIII, one Type IX, five Type XI and three Type XII fractures.

In accordance with Hertel’s criteria, the lengths of the intact medial calcar and the medial hinge were used to predict the risk of ischaemia of the humeral head.¹² Only one patient had combined disruption of both the medial hinge and the medial calcar (<8 mm in length). All the others had either an intact medial hinge (5/22) or a calcar length >8 mm (20/22).

The specified operative technique as described below was followed by all the senior authors performing the surgical procedures (B two cases, C nine cases and D 10 cases). The study did not receive any funding from external sources and it was done in accordance with the rules of the audit and research department at our hospital.

Surgical technique

The deltopectoral approach was used in the Neer two-part and three-part fractures. The Mackenzie shoulder approach¹⁴ was evolved further by author D into extended deltoid-splitting approach. This approach was used in four-part fractures and fracture-dislocations to facilitate exposure and reduction of the tuberosity fragments. The deltopectoral approach is well described in the orthopaedic literature and is not discussed further. We describe below the technique that we follow for the extended deltoid-splitting approach.

Position and fluoroscopic access

The patient is placed in the deckchair position. The surface marking of the acromion and lateral clavicle is drawn with a skin marker (Fig. 1(a)). Adequate fluoroscopy access is ensured prior to draping.

Incision

The skin incision starts just posterior to the acromioclavicular joint and is followed to the anterolateral corner of the acromion and then extended to a distance of 10–12 cm from the lateral edge of the acromion in line with the interval between the anterior and middle bellies of the deltoid muscle. The subcutaneous tissue is divided in line with the skin incision down to the deltrotrapezial fascia.

Proximal deltoid split

After identifying the interval between the anterior and middle bellies, the proximal deltoid is initially split for a distance of less than 5 cm from the edge of the acromion (Fig. 1(b)). The axillary nerve generally runs 6 cm distal to the anterior acromion.¹⁵ Osteoperiosteal flaps are raised to release the proximal deltoid from its origin, thus exposing the anterolateral third of the acromion.

Identification of the axillary nerve

The next crucial step is to define the deep surface of the deltoid muscle and mobilise it away from the fractured tuberosities and proximal shaft of the humerus. This is best achieved by palpating the deep surface of the acromion posteriorly using the index finger and then sweeping the finger in a posteroinferior direction, thus bluntly lifting away the posterior and middle bellies of the deltoid from the proximal humerus (Fig. 1(c)). Often during this manoeuvre, the axillary nerve can be palpated running transversely across the deep surface of the deltoid at the tip of one’s finger inferiorly. A similar manoeuvre is used to mobilise the anterior deltoid from the lesser tuberosity.

Distal deltoid split

The deltoid is then split superficially to a distance of 10 cm from the lateral edge of the acromion. Note that the axillary nerve lies on the deep surface of the deltoid and is closely related to the lateral cortex of the proximal humeral shaft.¹⁶ The deltoid split is carefully
deepened down to the humeral shaft at the distal end of the incision, thus creating a second window of dissection (Fig. 1(d)). This creates two deltoid-splitting windows, one proximally and one distally around the transversely running axillary nerve and accompanying vessels.

**Isolation of the nerve**

The next step is to pass a rubber sling from the distal to the proximal window deep to the axillary nerve using a curved artery forceps. This sling is then used to gently retract the nerve away from the proximal humerus during plate application and insertion of the distal screws. The plate must be placed deep into the axillary nerve sling to avoid injuring the nerve.

**Securing the tuberosity fragments**

The tuberosity fragments are identified and controlled by passing multiple high-strength sutures (Fibrewire No. 2, Arthrex, Naples, FL, USA). Some of the sutures are passed circumferentially from the greater to the lesser tuberosities and others as reverse mattress sutures. We prefer to pass three to four circumferential sutures between the tuberosities and three to four reverse mattress sutures to further control the rotator cuff muscles. Note that the bicipital groove is part of the lesser tuberosity fragment in a classic four-part fracture unlike the original illustrations by Neer. After reduction of the head and shaft fragments, the displaced tuberosity fragments are temporarily reduced by loosely tying one of the circumferential sutures prior to injection of CaSO₄.

**Fig. 1.** (A) Bony landmarks and skin incision marked. (B) Deltoid split <5 cm distally from acromion. (C) Mobilisation of anterior deltoid of lesser tuberosity. (D) Creation of inferior window and sling around axillary nerve.

**Fig. 2.** Shield type fracture. (E) Interval between tuberosities split to expose head/shaft fragments. (F) Tuberosity distraction to expose underlying fracture. (G) Schematic representation of rotator cuff suture configuration.
Shield-type fractures

Identification and reduction of the fragments could be difficult in shield-type fractures as the intact soft tissue across the tuberosities hides the tuberosity and anatomical head fracture lines. We recommend that the primary fracture line between the tuberosities (which usually lies 5–10 mm posterior to the bicipital groove) is first identified with palpation using a blunt instrument and then split sharply with dissecting scissors (Fig. 2(e)). To achieve full visualisation of the head fragment, this incision may need to be extended proximally to a distance of 1–2 cm into the supraspinatus tendon in line with its fibres, especially if dealing with a case of posterior fracture-dislocation (Fig. 2(f)). Separating the tuberosities then facilitates exposure of the head fragment. Next, multiple high-strength polyethylene sutures are passed as described in the previous section (Fig. 2(g)).

Reduction, fixation and CaSO₄ bone-substitute augmentation

After checking the preliminary reduction with an image intensifier, a proximal humeral locking plate is applied and held using a few distal screws, to act as a buttress before injecting CaSO₄.

Once the head and neck fragments are anatomically reduced, a metaphyseal void becomes evident. At this point, the CaSO₄ (Stimulan, Biocomposites, UK) is prepared and injected under fluoroscopy to ensure adequate filling of the void and to prevent extrusion into the surrounding soft tissues or joint (Fig. 3(h)–(j)).

The remaining locking screws are placed into the proximal humerus after injecting CaSO₄. On an average, we have placed five screws proximally into the head and three distally into the shaft. The proximal screws were kept 2–4 mm short of the subchondral bone to minimise the risk of joint penetration.

Rotator cuff repair

The rotator cuff and tuberosities are meticulously repaired to the plate through the suture holes on the plate using high-strength sutures, which have been previously placed into the tuberosities and the rotator cuff.

Wound closure

Closure of the deltid proximally is achieved using transosseous non-absorbable sutures to the acromion. The distal deltid split is closed with absorbable sutures.

Postoperative phase

Postoperatively, the arm is placed in a sling and early passive shoulder stretching and pendulum exercises are started followed by active mobilisation after 6 weeks.

Results

Functional outcomes were assessed with DASH scores and modified Constant and Murley scores by excluding power measurements, reducing the maximum total score to 75. The average follow-up of patients was 24 months. All patients were assessed for axillary nerve sensation and anterior deltoid contraction, during the follow-up.

The mean DASH score was 16.18 and the mean modified Constant and Murley score was 64.04 (Graphs 2 and 3). All fractures united with no evidence of infection, failure of fixation, malunion, tuberosity failure, avascular necrosis or adverse reaction to CaSO₄. There was no evidence of axillary nerve injury. Eighteen out of twenty-two patients achieved good clinical outcome. Four patients had prolonged recovery due to stiffness and associated injuries (ipsilateral wrist fracture/elbow dislocation).
In all patients, the CaSO₄ bone substitute was replaced by normal-appearing trabecular bone at an average of 6 months. The results of a valgus impacted fracture (Fig. 4) and a bilateral posterior fracture-dislocation (Fig. 5) from our study are illustrated.

Discussion
The optimal treatment of displaced three- or four-part proximal humerus fractures or fracture-dislocations remains controversial. Open reduction and internal fixation with standard non-locking implants has been generally disappointing due to a high rate of malunion or loss of fixation, especially in osteopenic bone or comminuted fractures.⁷,⁸

We aimed to analyse the results of our technique, which mainly comprises a CaSO₄ substitute and the extended deltoid splitting approach. We have found it to be effective with good-to-excellent results. Hemiarthroplasty was initially considered a good option for treating these fractures, but high rates of complications and poor functional outcome due to a variety of reasons such as tuberosity mal-reduction or migration as well as postoperative instability, pain or stiffness have also tempered the attitudes towards this method of treatment.²²–²⁴

Another reason for the change in practice away from treating these fractures with hemiarthroplasty is our better understanding of the vascular supply to the humeral head following complex fractures. According to the study by Hertel, the best indicators of vascularity of the humeral head in these injuries are the length of the intact medial calcar (optimum vascularity if >8 mm) and the displacement of the medial hinge (optimum vascularity if <2 mm).¹³ In our series, all the patients except one had either an intact medial hinge or calcar length >8 mm. We have not observed any cases of avascular necrosis in our series so far, supporting the fact that internal fixation could be carried out safely in appropriately selected four-part fractures or fracture-dislocations.

Over the last decade a great deal of interest has been shown in the use of locking plates to deal with these complex fracture patterns, resulting in a bewildering choice of implant designs by numerous manufacturing companies. However, failure of fixation remains common if they are used as the sole method of fixation, especially in osteopenic bone or in comminuted fractures with large metaphyseal bone loss.⁸,⁹,²⁴

Complications such as humeral head perforation by the proximal locking screws are particularly common with this technique of internal fixation due to secondary impaction and loss of fixation in the proximal fragment. This is not surprising when the biomechanics of the proximal humerus are taken into account. The proximal humerus is subjected to significant forces during normal physiological activities. This could be as much as...
600 N of compressive force on the humeral head or 300 N of distractive force on the tuberosities, as noted in rotator cuff studies.\(^{25}\)

Recent clinical and biomechanical studies have shown that one of the best ways to resist the compressive forces on the humeral head in comminuted or osteopenic fractures is to fill the metaphyseal void with injectable bone substitutes such as the CaPO\(_4\) bone substitute.\(^{5,10,26–28}\) In our series, we substituted CaPO\(_4\) with CaSO\(_4\) (Stimulan, Biocomposites, UK) as we found it easier to prepare and handle as well as being cost-effective. As it is less crystalline in nature, it is absorbed faster with comparable initial strength to the CaPO\(_4\) bone substitute.\(^{28,30}\) In particular, we have observed rapid replacement of CaSO\(_4\) with viable-looking bone without any loss of fixation or evidence of adverse reactions. We believe that this bone substitute helped to support the initial reduction and continued to maintain the normal proximal humeral anatomy during the early healing phase.

Accurate reduction and secure fixation of tuberosity fragments is paramount for optimal rotator cuff function in proximal humerus fractures. As the experience from rotator cuff surgery suggests, the best way to neutralise the distractive forces generated by the rotator cuff muscles on the tuberosities would be to use suture repair techniques with multiple high-strength sutures. In this context, the main role of the locking plate on the lateral surface of proximal humerus would be to act as a secure platform to tie these sutures. To reduce the chance of suture breakage from fretting on the metallic surfaces or jagged bone, polyethylene-based sutures are preferred to other non-absorbable sutures.\(^{17}\)
To further enhance the accuracy of the tuberosity reduction and fixation in displaced four-part fractures and fracture-dislocations, we advocate the use of the extended deltoid-splitting approach. Although we have not observed any cases of iatrogenic axillary nerve injury in our series, we emphasise the importance of careful nerve isolation and protection throughout the procedure. In our operative technique, we have highlighted a number of key steps to minimise the chances of this devastating complication. Having isolated and protected the nerve with the cuff of the deltoid between the two windows and the sling, safe access for fixation is provided through the proximal and the distal windows.

Our study is the largest reported series of using CaSO₄ bone substitute in proximal humeral fracture fixation. We performed a 2-year follow-up of all our patients with outcome measured by well-recognised scoring systems. The study comprised same operative technique performed by the three senior authors highlighting the reproducibility of our technique. We understand the limitations of our retrospective study with a limited number of patients. It leads us to the future scope of randomised controlled trials comparing CaSO₄ bone substitute with other substitutes.

In our experience we have found the use of locking plates, injectable CaSO₄ bone-substitute augmentation and tuberosity repair with high-strength sutures as well as the extended deltoid-splitting approach to be a safe and reliable method of internal fixation for complex proximal humeral fractures or fracture dislocations. Based on our experience with this form of fixation for complex fractures of the proximal humerus, we recommend this technique that comprises:

1. A deltoid-splitting approach for more direct access and better fracture visualisation in displaced four-part fractures and fracture-dislocations.
2. Internal fixation with locking plates and multi-planar screws staying short of sub-chondral bone by 2–4 mm.
3. Injectable CaSO₄ to fill metaphyseal bone void to prevent secondary fracture collapse.
4. Accurate reduction and secure fixation of the tuberosity fragments with high-strength polyethylene sutures tied to the plate to restore rotator cuff function paving the way for early rehabilitation.

Conflict of interest statement

None.

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