REVIEW ARTICLE

Surgical treatment of three and four-part proximal humeral fractures

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Summary Three- and four-part fractures of the proximal humerus are usually treated surgically. Open reduction with internal fixation (ORIF) is the method of choice in younger patients. Anatomic reduction of the tuberosities is crucial to ensure that, in the event of poorly tolerated avascular necrosis of the humeral head, hemiarthroplasty can be performed under optimal conditions. Suboptimal outcomes may occur after ORIF, as less-than-perfect reduction and fixation is poorly tolerated at the shoulder. Preoperative computed tomography must be performed routinely to analyse fragment displacement and comminution, classify the fracture, assess humeral head vitality, and evaluate the mechanical properties of the underlying bone. Fracture reduction relies on principles that are shared by the various available techniques. Reduction of each fragment should be assessed separately. Reduction of the humeral head to the shaft should be performed before reduction of the tuberosities. The fixation technique should ensure stability of the anatomic reduction, with secure fixation of the tuberosities and a minimal risk of material migration into the joint. Here, we provide a detailed discussion of the various techniques, with their advantages and drawbacks, to help surgeons select the method that is most appropriate to each individual patient.

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Introduction

In four-part fractures of the proximal humerus, the humeral head, both tuberosities, and the shaft are separated from one another (Fig. 1), whereas in three-part fractures, one of the tuberosities remains attached to the humeral head [1]. In contrast to proximal humeral fractures that do not involve the tuberosities, three- and four-part fractures are usually treated surgically. Anatomic or reverse shoulder arthroplasty is often indicated in the elderly [2–4] but is a treatment of last resort in younger patients, in whom open reduction and internal fixation (ORIF) is the treatment of choice [2]. This conference focuses solely on ORIF techniques.

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Computed tomography (CT): a key preoperative planning tool

Fracture type and fragment displacement

Codman [1] wrote the first description of proximal humeral fractures based on four parts: the humeral head, the greater tuberosity, the lesser tuberosity, and the shaft (Fig. 1). In 1970, Neer [5] used the four-part concept to develop a classification system for proximal humeral fractures. In the Neer system, displacement of a part is defined as translation by more than 1 cm or angulation by more than 45°. Although additional fracture types have been recognised since the introduction of CT, the Neer system remains widely used because it not only constitutes a descriptive classification scheme, but also explains the displacement of each fragment based on the pulling forces exerted by the rotator cuff muscles. Huten and Duparc [6] suggested the individualisation within Neer four-part fractures of intra-articular fractures that separate the head, shaft, and tuberosities (Fig. 2). They divided these cephalo-tuberosity fractures into four types based on the amount of displacement:

- type 1, little or no displacement;
- type 2, displacement with impaction of the head;
- type 3, non-impacted fracture with the cephalic fragment within the joint capsule;
- type 4, cephalic fragment outside the joint capsule (fracture-dislocation) and located either anteriorly (type 4a) or posteriorly (type 4b).

The risk of avascular necrosis (AVN) of the humeral head increases from type 1 to type 4 [7].

Many other classification systems have been reported [8–10]. We believe these systems are complex and fail to contribute meaningfully to the ORIF strategy. In contrast, a detailed analysis of the preoperative CT images is crucial to predict which corrective procedures will be required during surgery to ensure the optimal reduction and fixation of all the fragments. Two features used in these classification schemes deserve special attention: the direction of humeral head displacement (in varus or valgus) and presence of a medial hinge (continuity of the bone tissue) [9,10] on the one hand, and presence of a secondary fracture line into the humeral head leading to loss of joint congruity [9–12] on the other (Fig. 3).
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Bone quality

Osteoporosis increases the risk of comminution, reduction difficulties, and insecure fixation with disassembly of the construct or material migration through the humeral head [13].

Migration of the internal fixation material into the glenohumeral joint causes cartilage damage that translates into poor clinical outcomes and a need for glenoid resurfacing if arthroplasty is required subsequently. Malunion of the tuberosities due to insecure fixation followed by migration is also associated with functional impairments and jeopardises the results of subsequent arthroplasty.

A careful assessment of bone quality is therefore crucial before performing internal fixation. On standard radiographs, osteoporosis manifests as decreased humeral head density, comminution of the tuberosities, and a low cortico-medullary index of the humeral shaft [14]. Nevertheless, osteopenia, most notably of the tuberosities, and fragment displacement are best assessed by preoperative CT [15].

Impact of the fracture and/or fixation on the blood supply to the humeral head

AVN of the humeral head is a common complication, and an assessment of humeral head vitality [16] is therefore fundamental to determine the best surgical strategy. Furthermore, the blood supply to the humeral head must be preserved during surgery.

The blood supply to the humeral head comes chiefly from the anterior circumflex artery, which emerges about 1 cm under the pectoralis major tendon then courses between the coracobrachialis tendon and the short head of the biceps, reaching the surgical neck of the humerus at the lower edge of the subscapularis tendon. At that point, it gives off an anterolateral branch that provides the feeding arteries to the lesser tuberosity, runs across the deep aspect of the long head of the biceps, and courses along the lateral edge of the bicipital groove. Finally, the anterolateral branch penetrates into the humeral head, where it gives off the arcuate artery, [17] which has a postero-medial trajectory within the epiphysis and supplies the entire humeral head except for a small postero-inferior region. This small region of the epiphysis and adjacent greater tuberosity is vascularised by the posterior circumflex artery, which usually originates from the axillary artery and less often from the deep brachial artery. Despite anatomic studies demonstrating that the posterior circumflex artery never supplies an extensive portion of the humeral head, it has been suggested [10] that partial or complete reperfusion of the humeral head can occur from the posterior circumflex artery, even when the arcuate artery is completely severed.

Duparc et al. [18], then Hertel et al. [9], identified a number of factors associated with a good vascular prognosis:

- above all, a three-part fracture, which carries a far lower risk of AVN than a four-part fracture;
- having more than 50% of the lesser tuberosity still connected to the head;
- an intact medial hinge (Fig. 4);
- a greater than 8-mm medial calcar segment attached to the head (Fig. 5).

In contrast, fragment dislocation and extensive displacement are of adverse prognostic significance.

Finally, it is worth mentioning that surgery increases the risk of AVN. Minimally invasive surgical techniques result in better preservation of the regional vasculature.

Thus, humeral head vitality is a major factor in the choice of the best fixation technique for proximal humeral fractures. However, other criteria should be taken into account also. In younger patients, anatomic reduction of the tuberosities is crucial to ensure that, in the event of poorly tolerated AVN, hemiarthroplasty can be performed under optimal conditions, i.e., with reduced tuberosities.

Principles shared by all internal fixation techniques for three- and four-part fractures

Installation

The patient can be placed in the beach chair position, the supine position with a support under the medial edge of the
scapula, or the lateral decubitus position. The installation must provide space for an image amplifier (towards the head of the patient) and must allow free upper-limb motion in all planes (adduction and retropulsion, in particular, must not be restricted by the operating table or supports). The iliac crest should always be included within the operative field.

Reduction and fixation of the humeral head

The procedure starts with reduction of the humeral head followed by fixation to the shaft. This step is difficult and can benefit from the use of the image amplifier. The displacement can be analysed first based on whether the fractured head is tilted in varus or valgus [4].

Varus angulation

The head is separated from the shaft and pulled in varus by the rotator cuff muscles that are still attached to it (Fig. 6). If only the lesser tuberosity is attached to the head, then the head is usually pulled in medial rotation by the subscapularis tendon.

A second criterion is whether the head is impacted into the shaft.

Impacted fractures. In impacted fractures, overlap exists between the medial part of the head and shaft, and the lateral periosteum is intact (between the lateral edge of the head, the tuberosities, and the shaft). The stability provided by the intact lateral periosteum allows medial hinge reduction via external manoeuvres involving abduction and protraction of the shoulder.

Non-Impacted fractures. In non-impacted fractures, in contrast, the head is completely separated from the shaft and the lateral periosteum is torn. Reduction is considerably more challenging in this situation. The first step consists in aligning the head on the shaft. With the arm in traction and the shoulder protracted, an instrument is introduced at the medial edge of the anatomic neck to reduce the medial hinge. Residual varus of less than 20° can be tolerated [4,11,12,19]. Medial rotation of the head (if present) is corrected by looping a suture around the bone-tendon junction of the subscapularis then pulling it in the medial-to-lateral direction.

Valgus angulation

Fractures with varus angulation of the head are characterised by lateral impaction of the head on the shaft. The fractured tuberosities remain aligned with the head and shaft, and the lateral periosteum connecting the four fragments is intact. In this situation, the medial hinge should be analysed: it may be either intact or disrupted with lateral displacement of the infero-medial edge of the head relative to the medial edge of the shaft (Fig. 7).

Impacted fractures. When the medial hinge is intact, reduction can be achieved by simply introducing an instrument between the tuberosities and pushing the supero-lateral edge of the head upwards. The medial periosteum acts as a hinge that prevents medial translation of the head. Correction of the valgus angulation of the head is considered satisfactory when perfect reduction of the tuberosities with the head and shaft is achieved.

Non-Impacted fractures. Disruption of the medial periosteum (allowing lateral translation of the head) results in instability of the head. The introduction of an instrument at the medial hinge is often required to restore the medial hinge and to prevent medial translation and varus angulation of the head.

Regardless of the fracture type (varus or valgus angulation), most internal fixation techniques involve securing the reduced head to the shaft using temporary pinning.
Reduction and fixation of the lesser tuberosity

The lesser tuberosity is an important landmark for fracture reduction, as comminution is often less marked than at the greater tuberosity. Identification of the bicipital groove enables correction of the epiphyseal-metaphyseal rotation relative to the shaft. Reduction of the lesser tuberosity is readily achieved via the delto-pectoral approach. A traction suture placed at the tendon-tuberosity junction, combined with internal rotation of the shaft, ensures reduction of the fragment. If the fracture line runs through the bicipital groove, fixation should be combined with tenotomy or tenodesis of the long head of biceps (LHB) tendon to prevent subsequent pain due to LHB tendinopathy.

The fracture line that separates the lesser tuberosity is not always located at the junction between the anatomic neck and the head. A secondary line through the head may separate an anterior cephalic fragment attached to the lesser tuberosity (Fig. 3). Restoration of joint surface congruity is crucial in this situation and is achieved under direct visual guidance after opening the rotator interval by an incision that prolongs the peristeal tear, at the level of the fracture line, between the two tuberosities.

Reduction and fixation of the greater tuberosity

Anatomic reduction and stable fixation of the greater tuberosity are of the utmost importance, as they govern long-term shoulder function. Imperfect reduction and/or secondary migration of the greater tuberosity result in loss of motion after internal fixation or after secondary arthroplasty. In addition, high-quality reduction is associated with reperfusion of the humeral head [10].

The greater tuberosity is displaced upwards and, above all, backwards, which makes access difficult via the delto-pectoral approach. One or more traction sutures (depending on fragment size) are positioned at the cuff-tuberosity junction, and the shaft is placed in external rotation [2]. The fragment is then brought forward. The periosteum should be preserved to the extent possible to maximise reduction stability. The fixation material is placed on its lateral aspect (where blood vessels are scarce) [20].

The treatment is more challenging in patients with comminution of the greater tuberosity and/or marked osteoporosis. Comminution is least marked at the bicipital groove, which can serve as a landmark for the reduction. Traction sutures placed at the junction of the cuff and tuberosities (greater and lesser) can be knotted together or to the material in order to improve fixation stability.

A fragment of the humeral head may remain attached to the greater tuberosity, particularly in four-part fractures (transcephalic pattern). The result is loss of joint surface congruity, which must be completely corrected.

Reduction and fixation of the shaft

Displacement of the shaft is often inaccurately assessed. The shaft is displaced in medial rotation by the pectoralis major and rhomboid major muscles. This rotation must be corrected. The bicipital groove is a good landmark for achieving reduction. Post-operatively, immobilisation in neutral rotation has been advocated [2] to neutralise the effect of the internal rotators on the shaft and to minimise traction of the rotator cuff muscles on the greater tuberosity.

Fracture-dislocation

Three- and four-part fracture-dislocations of the proximal humerus may be impacted or non-impacted. In impacted fractures, cautious reduction via external manoeuvres in
the operating room under general anaesthesia and image amplifier guidance can be attempted. There is a risk of disimpaction, an event consistently followed by AVN in four-part fractures. Another option consists in percutaneous pinning of the head before the reduction. The indication for fixation depends on the amount of displacement, as assessed on the films obtained after the reduction. Non-impacted fractures require open reduction as part of ORIF. An anterior approach is used in both anterior and posterior dislocations.

Internal fixation techniques for three- and four-part fractures

Minimally invasive techniques

Advantages of minimally invasive surgery are limited soft-tissue dissection, preservation of the blood supply to the head, and expedited postoperative rehabilitation. However, the reduction is often less than perfect, most notably at the tuberosities, and the fixation lacks stability.

Percutaneous fixation by pinning and the humerus block technique

This minimally invasive technique is used chiefly in three-part fractures, and more rarely in four-part fractures, with valgus impaction and an intact medial hinge that are stable after reduction (as assessed by fluoroscopy while mobilising the arm). Good bone quality is required for this technique (shaft cortex thickness > 3 mm according to the manufacturer). The procedure is performed under image-amplifier guidance.

Reduction. Reduction is achieved by external manoeuvres with traction, adduction, and internal rotation of the arm. To complete the reduction, a bone-graft tamp or spatula is introduced via a small incision then used to correct the humeral head valgus angulation by pushing on the supero-lateral portion of the head [12]. Then, if needed, a hook is introduced into the subacromial space and used to

Figure 8  Open reduction and internal fixation of a four-part fracture using percutaneous pinning.
complete the reduction of the greater tuberosity by pulling the tuberosity forwards and downwards.

Fixation. Two or three 25/10 mm pins are inserted percutaneously through the lateral aspect of the shaft into the humeral head, parallel to one another and angulated by 45° from bottom to top and 30° from front to back, in order to take the humeral head retroversion into account. The pins are inserted into the deltoid V, at a distance from the diaphyseal-metaphyseal fracture line. Excessively proximal insertion can injure the axillary nerve and excessively distal insertion the radial nerve. Threaded pins should be preferred to prevent pin migration [21]. The pins are then cut and buried under the skin. Cannulated screws 4.0 mm in diameter are used to secure the tuberosities and have been suggested for securing the head to the shaft (Fig. 8). The pins are removed after the sixth week.

Humerus block technique. The humerus block technique [22] is a recently introduced percutaneous fixation method. The underlying concept is “dynamic” fixation, which is presumed to decrease the risk of non-union and material migration into the humeral head, two known complications of rigid constructs. Two pins 2.5 mm in diameter that diverge in the sagittal plane are inserted from the lateral aspect of the shaft into the humeral head through a cylinder that is screwed to the shaft. This method ensures that the two pins are inserted along the axes of maximal loading.

Transosseous suturing and stapling

Although bone suturing and stapling resemble invasive techniques in terms of the surgical approach, they are minimally invasive because they preserve the soft tissues surrounding the fractures. A wide approach, preferably the delto-pectoral approach, enables better reduction of the tuberosities, followed by their fixation to each other and to the shaft. The humeral head is not directly involved by the fixation. It is reduced and held between the glenoid cavity medially, the tuberosity-shaft unit created by the reduction and fixation step laterally, and the soft tissues (periosteum, capsule, and rotator cuff). These techniques are therefore chiefly indicated for fractures with valgus impaction and an intact medial hinge.

Once the approach is created, the rotator interval is opened by an incision that prolongs the tear in the perios- teum between the tuberosities. This step exposes the humeral head, which is then reduced by using a bone-graft tamp to push against its supero-lateral edge, thereby allowing approximation of the tuberosities. Non-absorbable sutures are then used to suture the tuberosities to each

Figure 10  Radiographs obtained before surgery (left) and after fracture healing (right) in staple fixation of a four-part cephalo-tuberosity fracture.
other than to the shaft in an X configuration [23] (Fig. 9). Direct screw fixation can be added. The rotator interval is then closed. Shape-memory bone staples can be used instead of (or in addition to) the transosseous sutures. Two staples are used to attach the tuberosities to each other in the horizontal plane then one or two staples to secure the tuberosities to the shaft in the vertical plane (Fig. 10).

Invasive techniques

Nails
Percutaneous nailing is a treatment option in fractures of the proximal humerus with limited displacement. This fixation technique can be likened to a minimally invasive procedure. A short trans-deltoid approach is used. The reduction can be completed using external manoeuvres or percutaneous instruments. The nail is inserted through a short incision along the axis of the supra-spinatus fibres or at the anterior edge of the supra-spinatus tendon, at the rotator interval, after checking the absence of impingement on the LHB tendon. The slightly bent nails that were used initially were associated with pain due to impingement on the rotator cuff. They have been replaced by straight nails, which do not impinge on the cuff, because the nail is flush with the cartilage.

In many cases, however, the amount of displacement of the tuberosities and head requires an invasive approach. The supero-lateral approach is used. The nail is introduced through the fracture site and supports the humeral head after reduction is achieved (Fig. 11). Proximal locking is performed through the fractured tuberosities, ensuring their fixation. When non-locking screws are used, backwards displacement of the screws can compromise the fixation of the tuberosities. On the other hand, locking screws can result in humeral head perforation with joint destruction in the event of screw cut-out, for which osteoporosis and AVN are risk factors. Nails secured by oblique locking screws were developed recently to avoid this complication [2].

Nail fixation of proximal humeral fractures enables medi-alisation of the construct relative to the head and shaft, thereby increasing fixation strength, and allows the use of a

Figure 11 Radiographs obtained before surgery (left) and after surgery (right) in nail fixation of a four-part cephalo-tuberosity fracture.

Figure 12 Intraoperative evaluation after reduction of a four-part fracture and temporary pin fixation.
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limited approach. Nevertheless, even with locking screws, fixation of the greater tuberosity to the shaft — a crucial step in building the construct — offers less strength than a screw-plate applied to the greater tuberosity, particularly in the event of comminution.

Plates
We routinely use the delto-pectoral approach. The superolateral approach carries a high risk of injury to the axillary nerve, which courses across the deep aspect of the acromial head of the deltid muscle 3 to 4 cm from the lateral edge of the acromion [24].

The approach should be prolonged down the arm to the deltoid V. We use a rectilinear approach that extends from the coracoid process down to the middle of the anterior aspect of the arm, at the deltoid V. This incision remains at a distance from the axilla and avoids the formation of tight subcutaneous adhesions. Closure is also rectilinear, which improves the cosmetic appearance compared to an S-shaped incision. The cephalic vein is retracted laterally or medially or even ligated immediately. A 1-cm cut can be made in the anterior part of the deltoid V, 1 cm from its insertion, in the fibrous zone, to improve exposure. The V should be reattached at the end of the procedure. The LHB tendon is then identified at the upper part of the pectoralis major tendon and followed to its cranial extremity. The rotator interval is opened. The coraco-acromial ligament can be partly divided at the lateral edge of the coracoid process. After reduction of the humeral head, two temporary pins are introduced from the shaft towards the head (Fig. 12). If a bone defect is present under the head and tuberosities, a tri-cortical bone graft is harvested from the ipsilateral iliac crest, whittled, and inserted into the shaft to support the reduced humeral head. Morsellised cancellous grafts are implanted under the tuberosities. Two non-absorbable sutures are placed at the insertions of the subscapularis and infraspinatus, respectively, through the terminal tendons. The tuberosities are

Figure 13  Intraoperative evaluation after reduction and internal fixation of a four-part fracture using a non-locking plate.

Figure 14  Radiographs obtained before surgery (left) and after surgery (right) of a four-part fracture managed with cup-and-ball fixation.
reduced and the sutures knotted to stabilise the reduction before implantation of the plate. The supra-spinatus tendon can be secured to the plate using the same method. Adjusting the height of the plate is crucial both to avoid subacromial impingement (plate positioned too proximally, with the upper edge of the plate above the upper edge of the greater tuberosity) and inadequate tuberosity fixation (plate positioned too distally). Transosseous sutures are used to secure the tuberosities to the plate, particularly in comminuted fractures. Finally, the temporary pins are removed.

Plate fixation recently acquired new popularity with the introduction of locked plate technology. Nevertheless, high complication rates were found in many studies. For instance, in a systematic review by Thanasas et al., [25] 12% of patients experienced humeral head perforation with joint destruction due to backward displacement of an osteoporotic or necrotic head. We therefore prefer non-locking plates, which allow the screws to move backwards in the event of backward displacement of the humeral head (Fig. 13).

Cup-and-ball fixation
The cup-and-ball technique consists in intra-osseous fixation to support the humeral head reduction [26]. The device is composed of a plate bearing staples and attached to an intramedullary stem. Application of the cancellous aspect of the humeral head onto the staples secures the head to the shaft. The tuberosities are then sutured (Fig. 14). This invasive technique carries a high risk of AVN. In addition, the tuberosities are secured only by transosseous sutures. This method has the advantage of producing anatomic reduction with no impingement of the material on the neighbouring tissues. In addition, in the event of humeral head necrosis, a prosthetic head can be attached to the intramedullary stem.

Conclusion
All the available ORIF techniques for three- and four-part fractures of the proximal humerus require a careful analysis of the fracture type, fragment displacement, and underlying bone quality. Consequently, preoperative CT is extremely valuable. Numerous ORIF techniques are available. The most common complications are humeral head AVN and malunion of the tuberosities due to faulty reduction or fixation. Humeral head AVN is well tolerated in some patients. Tuberosity malunion, in contrast, is always poorly tolerated and extremely difficult to correct, with the outcomes being largely unpredictable.

Disclosure of interest
The authors have not supplied their declaration of conflict of interest.

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