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6.2.1 Humerus, proximal

1 Assessment of fractures

1.1 Imaging and classification

Evaluation and preoperative planning for proximal humerus fractures requires a series of three x-rays taken at right angles to each other (trauma series) (Fig 6.2.1-1):
- true glenoid AP;
- transcapular lateral;
- axillary view.

An axillary view requires abduction of the shoulder (Fig 6.2.1-1e–f), which is painful and difficult with an acute fracture. A less painful alternative is the “bumped up” transscapular view (Fig 6.2.1-1c–d) [1]. Additional views in external and internal rotation of the humerus can improve the understanding and measurement of the displacement of the greater tuberosity (Fig 6.2.1-1g–h) [2]. CT scans can prove useful in multifragmentary fractures or to quantify displacement of the tuberosities (Fig 6.2.1-2). Only with adequate imaging of the fracture can one proceed to accurate classification (Fig 6.2.1-3), surgical treatment, and prognosis.

1.2 Indications for surgery

Indications for surgical intervention are governed by general and associated local injuries, the type and stability of the fracture, the quality of the bone (osteoporosis), and the patient’s age and general medical condition.
Specific fractures

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**Fig 6.2.1-1a–h (cont)** Trauma-series x-rays.

**e–f** Axillary view. The patient is supine with the x-ray plate placed above the shoulder. Abduction of about 30° is needed, which can be painful in an acute setting.

**g–h** Alternative axillary view. A less painful alternative for acute fractures. The patient remains in a comfortable sling and is placed at the edge of the table, a cassette is placed above the shoulder, and the beam is aimed upward from below the table, cranial, through the axilla.

**Fig 6.2.1-2** Computed tomography (CT) scan demonstrating an axial section of the humeral head that allows one to evaluate the extent and localization of the injury.

**Fig 6.2.1-3** Müller AO Classification. Because of the unique anatomy of the proximal humerus, the classification is modified for this special area.

Type A = Extraarticular, unifocal (surgical neck).
Type B = Extraarticular, bifocal.
Type C = Articular (anatomical neck).
Stability and displacement are often interdependent. In many cases the fracture fragments are held together by muscles, tendons (including the rotator cuff), and periosteum. Treatment of these fractures—especially in elderly patients—has traditionally been nonoperative with a predictable outcome and a good to excellent functional score in 88% of cases.

Nonoperative treatment is preferred for elderly patients, patients with significant comorbidities, and for minimally displaced fractures.

However, nonoperative treatment of some fractures has resulted in a poor outcome. Reduction and operative fixation may be indicated in approximately 20% of cases. This group comprises younger patients, or active older patients, with fractures in which at least one of the following occurs:
- Tuberosities are displaced more than 5 mm.
- Shaft fragment(s) are displaced more than 20 mm.
- Head fragment angulation is greater than 45°.

The expectations of patients are important in decision making: Young individuals want to regain preinjury levels of function; active elderly patients may wish to resume their sporting activities, while others only hope to resume daily living activities.

2 Surgical anatomy

It is crucial to differentiate between fractures of the anatomical and surgical neck (Fig 6.2.1-3) because the blood supply to the main head fragment is usually disrupted after anatomical neck fractures, avascular necrosis (AVN) is likely to occur. In contrast, surgical neck fractures are relatively unproblematic as the blood supply to the head is usually preserved. The lateral ascending branch of the anterior circumflex humeral artery (Fig 6.2.1-4) runs a few millimeters posterior, lateral, and parallel to the biceps brachii tendon and bicipital groove.

The lateral ascending branch of the anterior circumflex humeral artery carries the most important blood supply of the humeral head and damage may lead to avascular necrosis.

Its location is important for classification and prognosis, vascularity-sparing dissection, and implant placement. The medial aspect of the capsule has the second most important blood supply. A large, intact, medial spike on the head fragment is an advantageous prognostic sign.

The tendon of the long head of the biceps brachii muscle plays an important role in localizing the lateral humeral ascending artery and in orienting the greater and lesser tuberosities. In fractures that cannot be reduced via closed reduction, the tendon may be trapped between bone fragments. The acromion, coracoacromial ligament, and coracoid process form an arch under which the humeral head rotates. Humeral head movement is constrained by this arch, while the muscles of the rotator cuff guide movement under the arch.

Anatomical reduction of the tuberosities during internal fixation and prosthetic replacement surgery will best restore strength and range of motion, and prevent complications such as impingement.
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3 Surgical treatment

3.1 General strategy

The best results are obtained if the fragments are well reduced and maintained until healing has occurred [4, 9, 10] preferably using the least invasive approach: nonoperative treatment, closed or minimally invasive surgery, formal ORIF or arthroplasty.

The selection of a suitable treatment depends upon the type of fracture, quality of the bone, deforming forces, the surgeon’s skills (experience, preference), the patient’s compliance, and the patient’s expectations. Hoffmeyer [2] proposed an algorithm which takes into account head fragment vascularity and bone quality (Fig 6.2.1-5). This approach takes into account the risk of avascular necrosis and limitations of conventional plate and screw fixation in poor bone.

The three types of fragments (tuberosity, shaft, and articular) are exposed to different deforming forces. The fixation must counter these forces. The tuberosities undergo tension from muscle pull, the shaft undergoes bending and torsional moments, and the articular fragment undergoes compression. Many reduction and fixation techniques have been proposed that allow sufficient stability to initiate early rehabilitation.
### 6.2.1 Humerus, proximal

Fig 6.2.1-5 Proposed algorithm for the surgical treatment of displaced proximal humerus fractures (a modification of Hoffmeyer [2]).

<table>
<thead>
<tr>
<th>Humeral head</th>
<th>Adequate blood supply</th>
<th>Poor blood supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone quality</td>
<td></td>
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<tr>
<td>Good</td>
<td>Osteopenia Osteoporosis</td>
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<td>Osteopenia</td>
<td>Osteosynthesis</td>
<td>Arthroplasty</td>
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<tr>
<td>Osteoporosis</td>
<td>Osteosuture</td>
<td>(Arthroplasty)</td>
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<table>
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<tr>
<th>Procedure of choice</th>
<th>Osteosynthesis</th>
<th>Osteosuture</th>
<th>Osteosynthesis (Arthroplasty)</th>
<th>Arthroplasty</th>
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<td>Bone quality</td>
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<td>Bone quality</td>
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<td>Osteopenia Osteoporosis</td>
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<td>Arthroplasty</td>
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</table>
Specific fractures

6.2 Humerus

Locking plates, providing angular stability, combined with suture holes for soft-tissue fixation, have resulted in renewed interest in plate and screw fixation. Arthroplasty is generally kept as a salvage option when adequate ORIF is not possible.

3.2 Closed reduction

The patient is placed supine on a table or in a beach chair position with the affected arm supported on an armrest (Fig 6.2.1-6). The image intensifier is positioned at the top of the table (patient’s head), and AP and axillary views are confirmed. Before draping, however, closed manipulation is attempted under the image intensifier. If alignment is achieved and the reduction is stable, the arm is immobilized in a sling.

Limited (percutaneous) technique: If closed reduction is not achieved or is unstable, the arm is draped free on the operating table, allowing for limb mobility and access to the axillary artery, if necessary. The surgeon may then attempt the same closed reduction and percutaneous fixation with K-wires if reduction can be achieved.

If closed reduction fails, a limited-access reduction is attempted employing joysticks (small Schanz screws or K-wires), or hooks placed through stab incisions. The fragments are then manipulated, and if adequate reduction can be achieved, the surgeon may proceed with minimally invasive osteosynthesis. A variety of implants have been proposed for definitive fixation (terminally threaded K-wires (with humerus block), small-diameter Schanz screws, cannulated screws). They will all work if the deforming forces on the fixed fragment can be adequately countered. Attention should be given to adjacent neurovascular structures that must be avoided [11].

3.3 Approaches

If percutaneous reduction cannot be achieved, open reduction will be necessary in order to obtain good alignment and fixation, allowing early rehabilitation.

3.3.1 Deltopectoral approach

The incision starts at the coracoid process and extends to the humerus at the level of the deltoid tuberosity (Fig 6.2.1-7). The cephalic vein is identified proximally and usually retracted laterally while exposing the deltopectoral plane. The pectoralis fascia is incised lateral to the tendon of the short head of the biceps brachii muscle, maintaining the coracoacromial ligament proximally and incising the upper border of the pectoralis major muscle insertion by 1–2 cm. The fracture fragments are identified and the hematoma is evacuated. The long head of the biceps brachii muscle is identified under the pectoralis major muscle and serves as a reference for the lesser

Fig 6.2.1-6 Beach chair position. The right shoulder is resting on a radiolucent part of the operating table; the entire shoulder is checked first with the image intensifier before draping.
6.2.1  Humerus, proximal

**Fig 6.2.1-7a–b  Deltopectoral approach.**

*a*  Skin incision from the coracoid to the deltoid tuberosity.

1  Coracoid process.
2  Axillary nerve.
3  Acromion.
4  Lateral end of clavicle.
5  Axillary artery.
6  Brachial plexus.

*b*  The deltopectoral groove is opened.

7  Deltoid muscle.
8  Cephalic vein.
Muscle and vein are retracted to the lateral side exposing the humeral head.
9  Pectoralis major muscle.
10  Anterior circumflex humeral artery.
11  Long head of biceps brachii tendon.
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Specific fractures
6.2 Humerus

Potential trauma to the axillary nerve. Reduction is achieved through the fracture, preserving vascularity. If a plate is used, it should lie laterally to the lateral ridge of the bicipital groove to preserve the lateral ascending branch of the anterior circumflex humeral artery (Fig 6.2.1-4).

3.3.2 Transdeltoid lateral approach
This approach is used for isolated fractures of the tuberosities or injuries of the rotator cuff (Fig 6.2.1-8). The incision extends distally from the anterolateral corner of the acromion to no further than 5 cm (marked by a “safety-suture” to protect the axillary nerve) along the raphe separating the anterior and middle portion of the deltoid. Dissection is carried through this raphe to the subdeltoid bursa. Proximal extension sharply separates the anterior deltoid from the most anterior portion of the trapezius muscle at the lateral clavicle and acromion. These thick soft-tissue flaps are reattached at closure. Internal and external rotation allows inspection, reduction, and fixation of the tuberosities or rotator cuff.

3.4 Instruments and implants for osteosynthesis
The goals of osteosynthesis are anatomical reattachment of the tuberosities as well as attaching the humeral shaft to the humeral head/tuberosities to allow early movement and rehabilitation. There are many implants or fixation options for the proximal humerus. A careful preoperative study of individual fragments and their deforming forces will allow the surgeon to plan definitive fixation. Having the following devices available has proven useful: K-wires, cannulated screws, heavy braided resorbable sutures, and 1 mm wire. In osteoporotic bone, the impaction of bone fragments will minimize devascularization, limit implant prominence, and avoid poor screw purchase. An “osteosuture” with large-caliber resorbable sutures or nonresorbable surgical tape [2, 12], tension band wiring [13], or the minimal use of screws provides relative stability, which is sufficient to allow early rehabilitation.

Fig 6.2.1-8 Transdeltoid lateral approach.
Incision from the anterolateral corner of the acromion extending distally no further than 5 cm.
1 Acromioclavicular joint.
2 Axillary nerve.

(anterior and medial) and greater (lateral) tuberosities and their associated rotator cuff muscles. By abducting the arm, the subdeltoid space is exposed to allow proximal access. Distal extension of the fracture and the use of longer plates may require detachment of the anterior half of the distal deltoid muscle insertion. A retractor is carefully placed behind the proximal fragment which is delivered into the wound, mindful of potential trauma to the axillary nerve. Reduction is achieved through the fracture, preserving vascularity. If a plate is used, it should lie laterally to the lateral ridge of the bicipital groove to preserve the lateral ascending branch of the anterior circumflex humeral artery (Fig 6.2.1-4).
Plate and screw fixation
4.5 mm implants such as the T-plate are not recommended because of extensive dissection, intraarticular hardware penetration, and subacromial impingement [14]. Good results have been obtained with smaller 3.5 and 2.7 mm implants [15], eg, the modified small-fragment clover leaf plate (Fig 6.2.1-9), when good purchase in the bone can be achieved. There is renewed interest in plate osteosynthesis for treating proximal humeral fractures due to advances in locking plate technology (chapter 3.3.4). This design aims at improving purchase and pull-out strength in osteoporotic bone by using convergent and divergent locked screws (Video 6.2.1-1). It can bridge multifragmentary fractures of the surgical neck, and the rotator cuff can be attached to the plate through suture holes. It is very effective (Fig 6.2.1-18).

A proximal humerus right-angle blade plate is available. The blade is inserted over a K-wire and the plate allows placement of screws into the head or the medial cortex. This plate is especially useful in delayed union and nonunions when the articulated tension device is used to provide compression. It is sometimes used in acute fracture care for compression or bridge plating. Because of the biomechanics, fractures of the tuberosities and attached rotator cuff are often fixed with a tension band wire.

Intramedullary nailing
The main indication for intramedullary nails is a multifragmentary fracture of the surgical neck and metaphysis where the tuberosities and humeral head remain a single fragment (11-A3.3). The second important indication is complete or impending pathological fractures.

- Intramedullary nails cannot be used to stabilize tuberosity fragments.
Antegrade or retrograde nails (single and multiple) have been used successfully (Fig 6.2.1-10). The main complication of antegrade nails is pain in the shoulder and rotator cuff dysfunction.

**Adjuncts to fixation**

Autogenous bone graft is used for atrophic nonunions or to gain more stability by filling a void following reduction of an impacted fragment. If the anchorage of the screws is not reliable, methylmethacrylate [16] or calcium phosphate bone cement may be filled into the drill holes or the fracture gap to improve fixation [15, 17].

**3.5 Prosthetic replacement**

Stable osteosynthesis allowing early rehabilitation remains the preferred technique.

- The surgeon should be prepared to carry out a prosthetic replacement in complex articular fractures or patients with severe osteoporosis where poor implant purchase is expected.

This is also advisable in elderly patients with little or no soft-tissue attachment to the main articular fragment. Under these conditions, results are better with primary hemiarthroplasty, as compared to secondary replacement [6]. Success factors which relate to timing, technique, and implant position have been identified [18].

Factors that negatively affect the outcome in hemiarthroplasty:
- preoperative delay > 13 days;
- tuberosity problems: loss of fixation, resorption, mal-union;
- malpositioned prosthesis [19].

Fig 6.2.1-10a–c
- a Surgical neck fracture with multiple fragments (11-A3.3).
- b Illustrative case: Active elderly patient, fall while skiing. Preoperative AP internal and external rotation views.
- c Indirect reduction and stabilization using multiple retrograde flexible titanium elastic nails inserted through the lateral epicondyle (alternately posteriorly above the olecranon fossa). These achieve adequate minimal rigidity to allow rehabilitation and maintain alignment. Protrusion of intramedullary nails is possible in osteopenic bone.
A malpositioned prosthesis is judged by:
- height: humeral head to greater tuberosity distance:
  - lengthening (overstuffing): > 10–14 mm [19];
  - shortening: greater tuberosity < 10 mm below or 5 mm above prosthesis;
- offset: humeral head to lateral cortex at greater tuberosity: lateralization < 23 mm [19];
- version: < 10° or > 40° of retroversion.

**Arthroplasty technique**
Following the decision not to carry out an ORIF, the tuberosities must be identified and secured with heavy sutures. The articular fragment is retrieved and its cancellous bone is preserved for grafting. The proximal subarticular medial cortex of the shaft (calcaneus equivalent) is preserved, reduced, and temporarily fixed to the adjacent shaft as a length reference. A trial implant is placed in the medullary canal to establish proper length and retroversion. Length determination can be assisted by the following: intact medial cortex; tension of the long head of the biceps brachii, the rotator cuff, and the deltoid muscles; anatomical reduction of the tuberosities (top of greater tuberosity lying 5–10 mm distal to the implant head’s highest point). Typically, 30–40° of retroversion should be established from the epicondylar coronal plane, which is palpated.

In general, a cemented implant is recommended. The medullary canal should be reamed and large-diameter resorbable sutures placed at the tendon-bone junction of each tuberosity fragment, or through 2 mm drill holes. Similar holes and sutures are placed in the shaft 1 cm distal to the surgical neck fracture. The medullary canal is prepared by placing a cement restrictor. An implant should be cemented with a 2 mm mantle to ensure immediate rotational stability and to maintain desired height and version. Any cement which prevents bone contact of fragments proximally should be removed, and the tuberosity fragments must be accurately reduced and tentatively fixed to the shaft and to each other using the previous suture, drill holes, and holes in the implant (Fig 6.2.1-11). The

![Hemiarthroplasty](image)

**Fig 6.2.1-11a–b**  Hemiarthroplasty.

a  Tuberosity fixation technique during hemiarthroplasty. The sutures are secured not only to the implant but also to the shaft and between the tuberosities.

b  Cemented prosthetic hemiarthroplasty where the lesser tuberosity has been used to guide prosthetic length. Tuberosities are fixed 5–10 mm below the level of the prosthetic head.
Specific fractures

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Shoulder is rotated internally and externally and the arm elevated to confirm the absence of movement between the fragments and the shaft, and to confirm adequate range of motion; modular head implants will allow fine tuning. Additionally, bone-to-bone contact is ensured by placing the previously preserved humeral head cancellous bone under the tuberosities and definitively suturing them. The subscapularis-supraspinatus muscular space is then closed.

Displacement of tuberosity fragments is best seen on AP x-rays of the shoulder in internal and external humeral rotation. The axillary view may allow better visualization of lesser tuberosity fragments.

The pull of the rotator cuff may further displace tuberosity fragments, causing impingement and weakness abduction of greater and internal rotation.

Greater tuberosity fracture fragments may be amenable to percutaneous reduction and fixation, or require a transdeltoid lateral approach. Lesser tuberosity fractures are best treated through a deltopectoral approach. Tuberosity reduction is held temporarily with K-wires, and then fixed with a cannulated screw (Fig 6.2.1-13a–b) or a tension band (Fig 6.2.1-13c). Large-diameter resorbable sutures perforate the cuff at its bony insertion by means of a curved needle. A figure-of-eight loop secures it around a screw head or through a 2.0 mm drill hole in the cortex of the proximal shaft. Large resorbable sutures have successfully maintained reduction, avoiding the fatigue failure encountered with K-wires and the persistent foreign body effect of nonresorbable sutures.

If there is an associated glenohumeral dislocation (11-A1.3), careful closed reduction should be attempted first. Fragment reduction is then confirmed and quantified and the fracture is treated as described above.

4.1 Type A fractures (extraarticular unifocal)

(Fig 6.2.1-12)

Fig 6.2.1-12  Müller AO Classification.

4.1.1 A1 fractures

Unifocal fractures of the greater or lesser tuberosity should be treated by sling immobilization in the following cases:

- younger patients with displacement < 6 mm;
- patients > 60 years with displacement < 10 mm.

If there is an associated glenohumeral dislocation (11-A1.3), careful closed reduction should be attempted first. Fragment reduction is then confirmed and quantified and the fracture is treated as described above.

4.1.2 A2 fractures

Surgical neck or subcapital fractures without major displacement (11-A2.1: less than 10 mm and angulation below 45°) will normally be treated by sling immobilization until the pain is gone. This is followed by an early rehabilitation program. Early rehabilitation (within 14 days after surgery) results in a better outcome [3]. This consists of passive motion and pendulum exercises until the fracture heals clinically, when full active motion starts. Strengthening starts after clinical and x-ray
6.2.1 Humerus, proximal

Evidence of union. If the fracture is impacted with an acceptable amount of varus or valgus alignment (11-A2.2 and 11-A2.3) earlier active range of motion exercises are allowed in relation to the patient’s age. Varus alignment and subacromial impingement will be tolerated less in a younger patient.

4.1.3 A3 fractures

Most comminuted/displaced surgical neck fractures are treated nonoperatively in the elderly, with operations reserved for younger, or older active patients. A large nonrandomized observational study [20] showed that 11-A3.2 two-part fractures in the elderly who received nonoperative treatment resulted in a predictable and “acceptable” outcome. Reduced function and nonunion were associated with increasing age and shaft fragment translation. There was no statistically significant difference in outcome (Neer score) between operative and nonoperative cases with displacement > 66%, but a larger percentage of patients who were operated on returned to common daily living activities.

Elderly active patients and younger patients do not tolerate unstable fracture (11-A3.1: varus, 11-A3.3: comminuted metaphysis) patterns well, and surgery is often indicated. In such cases, closed reduction is attempted in the operating room. If this can be achieved, simple percutaneous K-wire fixation [10] or cannulated screws are used. Extensive metaphyseal comminution can make these options impractical. In such cases, a percutaneously applied locking plate [21], an antegrade intramedullary nail, a single retrograde intramedullary nail, or multiple retrograde flexible nails (Fig 6.2.1-10) can be inserted.

Fig 6.2.1-13a–c
a Displaced greater tuberosity fracture 11-(A1.2).
b Reduction and provisional K-wire fixation. A cannulated lag screw is used to compress the fracture.
c Tension band with wire or strong resorbable suture passed around the tendon-bone interface. Distal fixation is through a drill hole (shown) or around a screw head.
If a deltopectoral approach is required and screw purchase is adequate, a conventional implant or a locking plate can be used (Fig 6.2.1-14).

Failed closed reduction is usually due to interposition of the long head of the biceps brachii muscle, button-holing through a split muscle, or interposed fragments. Under these conditions a deltopectoral approach is performed, the situation is corrected and fixation is applied.

**Fig 6.2.1-14a–c**

a Surgical neck fracture with anterior and medial translation and interposition of the biceps brachii tendon (11-A3.2).

b Locking plate (PHILOS) fixation, AP view.

c Lateral view after anatomical reduction of the main fragments.
6.2.1 Humerus, proximal

4.2 Type B fractures (extraarticular bifocal) (Fig 6.2.1-15)

4.2.1 B1 fractures

These bifocal fractures usually occur in fit elderly individuals and show little or no displacement [22]. Displaced tuberosity fractures must be reduced and fixed as described for A1 fractures. The impacted metaphyseal fracture is usually stable, in an acceptable position, and treated nonoperatively. With this treatment, 80% of fractures are expected to have good or excellent functional results [22].

4.2.2 B2 fractures

These are unstable at the surgical neck and if they are combined with a rotary displacement of the head fragment (B2.2), reduction will be required due to the muscle pull on the intact tuberosity (Fig 6.2.1-16a). These will often require a

Fig 6.2.1-16a–c Bifocal 11-B2.2 fracture.

a  Rotation of the head fragment caused by the subscapularis muscle with complete avulsion of the greater tuberosity.

b  Closed reduction by longitudinal traction, external rotation of the head fragment by means of a hook, and stabilization of the greater tuberosity fragment with a K-wire.

c  Percutaneous K-wire and cannulated screw fixation using 4 mm cannulated cancellous bone screws. The tension band wire secures the rotator cuff.
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percutaneous reduction as described in chapter 6.2.1:3.2 (Fig 6.2.1-16b) or an open procedure. If there is limited fragmentation of the surgical neck, stabilization by means of cannulated cancellous bone screws is possible (Fig 6.2.1-16c) [23]. Some surgeons use a closed/percutaneous reduction and K-wire fixation technique described by Boehler [24]. This technique is demanding; it requires an adequate closed reduction and good visualization in two orthogonal planes.

Open reduction requires a deltopectoral approach. The tuberosities/head fragments are reduced and fixed first. Definitive fixation with lag screws allows easier reduction of this head/tuberosity fragment to the shaft. Temporary fixation of the shaft with anteriorly placed K-wires facilitates plate placement. Depending on screw purchase a standard clover leaf plate or a locking plate may be used. Tension band sutures around the tuberosity fragments are anchored to screw heads or in plate holes. When using plates, the surgeon must be careful not to damage the residual blood supply to the head, particularly in multifragmentary fractures (11-B2.3). Hemiarthroplasty in these three-part fractures remains a salvage procedure when stable fixation cannot be achieved.

4.2.3 B3 fractures

Closed reduction is rarely possible in bifocal fracture dislocations. A percutaneous approach may carefully be attempted. However, in most cases, open reduction of the dislocated head fragment is necessary, employing the techniques described for 11-B2 fractures and reserving hemiarthroplasty as a salvage procedure. Good results, even in posterior fracture dislocation with avulsion of both tuberosities (11-B3.3), can be achieved with ORIF. Humeral head impaction fractures (Hill-Sachs lesion) caused by impaction upon the glenoid during dislocation may be treated by elevation and bone grafting to restore anatomy and to prevent recurrent displacement.

4.3 Type C fractures (articular) (Fig 6.2.1-17)

4.3.1 C1 fractures

This type of fracture of the anatomical neck has less than 45° angulation of the head fragment and less than 1 cm displacement of the tuberosity fragment. Any anatomical neck fracture is at risk of avascular necrosis. In a stable variant of this fracture, the head is impacted more than 45° into the valgus so that its articular surface points upwards (“ice cream cone type”). This specific fracture pattern may be treated nonoperatively in some elderly patients using an approach similar to 11-B1.1 fractures (chapter 6.2.1:4.2.1).

With the common 11-C1 fracture, in younger or active older patients, a vascularity-sparing approach is recommended. Closed reduction and percutaneous fixation as described in B fractures (Fig 6.2.1-16) is preferred, if possible. However, slightly displaced four-part fractures treated by open reduction and careful dissection and implant choices which confer stability and preserve vascularity have shown surprisingly good results [10], especially with the use of locking plates through a limited transdeltoid approach [21]. Prosthetic replacement should be avoided in these fractures.
6.2.1 Humerus, proximal

Fig 6.2.1-18a–f  Case of a 69-year-old female, who fell on level ground.

a–b  AP and lateral view. Displaced intraarticular fracture with valgus malalignment (11-C2).
c–d  Postoperative x-rays, AP and lateral view.
e–f  15-month follow-up.

(With permission by Frankie Leung.)
### 4.3.2 C2 fractures
These fractures are the “real” four-part fractures with more than 45° of angulation of the head fragment and more than 1 cm displacement of at least one tuberosity fragment.

Using percutaneous reduction and screw fixation, some authors [10] achieved near-anatomical reduction and very good end results in a high percentage of patients with three-part and less displaced four-part fractures.

When open reduction is chosen, the deltopectoral approach is used. With the intention of reducing the risk of avascular necrosis, many authors prefer osteosynthesis with smaller implants using lag screws and tension bands, or sutures, or two plates 2.4. This approach is sound, reserving plate fixation for cases where smaller implants cannot achieve enough stability and contact between the fragments (Fig 6.2.1-18) [10, 23]. However, other authors have reported poor results with the minimal-implant technique [15]. They advocate a vascularity-sparing plate and screw fixation technique with additional purchase achieved by using calcium phosphate bone cement, with good results. This raises the issue of achieving stability and repairing the damage to the bone caused by the reduction of impacted cancellous bone. These voids may be filled with bone substitutes or autogenous cancellous bone chips. Hemiarthroplasty is reserved for cases where stable ORIF cannot be achieved.

### 4.3.3 C3 fractures
For anatomical neck fracture dislocations and in split-head fractures, many surgeons recommend primary hemiarthroplasty [6], if they cannot reconstruct the head fracture. Hemiarthroplasty is also recommended in the elderly if there are no soft-tissue attachments to the humeral head. There is no clear comparative evidence to conclusively support either recommendation.

A deltopectoral approach is used for open reduction. The head fragment(s) is (are) reduced first. In a split fracture these fragments are reduced and fixed with lag screws. Reduction is confirmed by open view or x-ray. The reduction then proceeds as in 11-C2 fractures.

The main problems are loss of fixation and avascular necrosis. Loss of fixation is difficult to predict. The stability of fracture fixation is tested during surgery by putting the shoulder through a range of motion. If the fixation is not stable enough to allow this, rehabilitation will be limited and a poor result is inevitable. When accurate reduction or stable fixation cannot be achieved, immediate conversion to hemiarthroplasty is probably the best option. Hemiarthroplasty gives good pain relief but function is poor. This, together with the longevity of these implants and the prospect of revision, favors maximal attempts to repair (ORIF) rather than replace the fractured humerus when feasible.

Avascular necrosis is frequent in three-part and four-part fractures. Function is diminished but is acceptable in the majority of patients who develop avascular necrosis [4, 25].

### 5 Postoperative treatment
Rehabilitation is essential to maximize function following a proximal humerus fracture, regardless of whether it is treated operatively (by fixation or arthroplasty) or nonoperatively. Implant constructions should be sufficiently stable to allow passive motion during surgery and rehabilitation immediately after surgery. The same rehabilitation protocol (Tab 6.2.1-1) is used for nonoperative and operative treatment and must start 10–14 days after surgery.
### 6.2.1 Humerus, proximal

<table>
<thead>
<tr>
<th>Phase</th>
<th>Duration (weeks)</th>
<th>Rehabilitation</th>
</tr>
</thead>
</table>
| 1     | 0–3             | Pendulum exercises  
          | Gentle active-assisted motion  
          | Avoid external rotation for 6 weeks |
| 2     | 3–9             | Orthopedic sling for 2–3 weeks  
          | If there is clinical evidence of healing and fragments move as a unit, and no displacement is visible on the x-ray, then:  
          | Active-assisted motion forward and side arm elevation  
          | Partial functional use week 3–6  
          | Week 6: Add active, nonassisted motion  
          | Week 6: Add isometric strength |
| 3     | > 9             | If there is bone healing but joint stiffness, then:  
          | Add manual therapy passive motion by physiotherapist  
          | Add isotonic strength, concentric and eccentric |

Tab 6.2.1-1 Shoulder rehabilitation protocol.

### 6 Pitfalls and complications

#### 6.1 Stiffness

This is the most common complication following shoulder injury. A small number of patients will regain full range of motion, but in most abduction and external rotation is limited, resembling a “frozen shoulder”. These problems can be minimized by early physiotherapy as outlined in chapter 6.2.1:5. Closed mobilization of a stiff shoulder under general anesthesia may be indicated in a few cases but the danger of implant loosening or fracture should be kept in mind. Arthroscopy and even open release and manipulation may be considered under certain circumstances, especially in younger individuals [26].

#### 6.2 Positioning of implants

Implant malpositioning and displacement of fragments or implants can occur, especially in osteoporotic bone. Muscular activity and passive external forces, working on a long lever arm, are often underestimated. Screw length and position, and stability of fixation should be checked by image intensifier before the wound is closed [21, 27]. If fixation is found to be inadequate, a larger sized screw or bone cement around the screw should be used or consideration given to an arthroplasty.

#### 6.3 Malunion and nonunion

If the above mentioned protocol is heeded, malunions and nonunions occur only rarely. If they are symptomatic with significant pain and loss of function, open correction and internal fixation will benefit reliable patients whose bone and soft tissues are of suitable quality (chapter 5.2). In the specific case of proximal humeral nonunions, open reduction and in-
ternal fixation of the tuberosities and/or the surgical neck to the shaft with a tension band (wire or plate) provide best results [28].

6.4 Avascular necrosis

AVN of the humeral head is relatively frequent with the overall rate approaching 35% (reported range: 6–75%) [4, 25].

The most important predisposing factors are:
- length of the dorsomedial metaphyseal extension;
- integrity of the medial hinge;
- fracture type [8].

Despite the high occurrence of AVN it is frequently asymptomatic with 77% of patients still showing good to excellent functional results [4]. This rate compares favorably with the 80% of cases with “acceptable” results in the primary arthroplasty literature [29].

The functional outcome of avascular necrosis is significantly affected by malunion: malunited cases with avascular necrosis display worse function [9] and cases with avascular necrosis requiring an arthroplasty a worse result if there is associated nonunion or malunion. The most favorable choice would then be open reduction and internal fixation if a stable, anatomical construction can be achieved. The best treatment for avascular necrosis is prevention using vascularity-sparing techniques. Should avascular necrosis become painful and require treatment, an arthroplasty will provide predictable pain relief if no concurrent malunion surgery is required [9]. The selection of cases for primary arthroplasty remains difficult as there is little scientific evidence to guide the surgeon. Future developments in implants and technique need to be evaluated in prospective randomized trials to provide a sound scientific basis for treatment protocols.

6.5 Nerve lesions

The axillary nerve is the most frequently injured peripheral nerve at the time of injury and during open or percutaneous surgery [11]. During open reduction, soft-tissue retraction using retractors or hooks is a danger. The adjacent brachial plexus is at risk in fracture dislocations.

- Retractors must never be placed into the axilla and limb positions that stretch the brachial plexus must be avoided.

6.6 Infection

Percutaneously inserted K-wires are usually buried under the skin at the time of insertion. They may cause irritation when swelling recedes and infection with or without skin perforation. If K-wires are outside the skin after surgery, infection can spread along their tracks.

If deep infection occurs with any form of operative treatment, it should be treated aggressively. It will be necessary to wash out and debride soft tissues and infected bone. The infecting organism must be identified and treated with appropriate antibiotics. If the fracture fixation remains stable, there is a good chance for the fracture to heal and the infection to disappear. In rare cases, the whole head fragment will be infected and necrotic. It should be removed and a spacer made of antibiotic cement can be inserted. This leaves the possibility that prosthetic replacement may be considered after the infection has settled.
6.2.1 Humerus, proximal

7 Bibliography


8 Acknowledgment

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