Fractures of the Proximal Humerus Treated by Plate Fixation

Pierre Hoffmeyer

Contents

Introduction 1260

Indications 1260

Surgical Technique 1262
Patient Positioning 1262

Surgical Approaches 1262
Trans-Deltoid Approach 1262
Delto-Pectoral Approach 1263
Standard Plates 1266
Anatomical Plates with Divergent Locked Screws 1266
Blade-Plates 1266

Fractures of the Anatomical Neck (Two Fragments) 1266

Isolated Fractures of the Greater Tuberosity (Two Fragments) 1267

Fractures of the Surgical Neck (Two Fragments) 1267
Valgus Displacement 1267
Varus Displacement 1267

Three and Four Fragment Fractures 1268

Complications 1272

Rehabilitation 1273

References 1273

Abstract

Treatment of displaced fractures of the proximal humerus in the fit and active patient remains a challenge. Accurate imaging is essential first with plain x-rays and with three-dimensional imaging. Knowledge of the vascular anatomy of the humeral head is mandatory to understand the consequences of the fracture pattern. When surgery is contemplated, positioning of the patient must allow a quasi-circumferential approach to the shoulder. The deltopectoral approach is the most popular but lesser invasive transdeltoid approaches are coming into vogue. Plates with locking screws afford great stability and ease of use. However the basics of biomechanics must not be forgotten, namely the presence of a medial buttress. Ignoring the principles will need to failure. Rehabilitation must be tailored to each patient but gentle early motion is encouraged in all cases. Complications of the technique are reviewed.

Keywords

Deltopectoral approach • locking plates • proximal humerus fractures • rehabilitation • surgical technique • transdeltoid approach • delto-pectoral approach • three and four part fractures • two-part fractures

P. Hoffmeyer
University Hospitals of Geneva, Geneva, Switzerland
e-mail: Pierre.Hoffmeyer@hcuge.ch;
pierre.hoffmeyer@efort.org

G. Bentley (ed.), *European Surgical Orthopaedics and Traumatology*,
DOI 10.1007/978-3-642-34746-7_6,

Introduction

Fractures of the proximal humerus present a major clinical problem and the techniques of fixation including nailing, percutaneous pinning, osteosuture and plating have evolved over time [1–22]. Plate fixation for proximal humerus fractures has gained in popularity with the advent of new locking plates that afford greater stability and are easier to apply than standard plates because of the immediate stability they provide [19, 23–35]. Clearly the ultimate prognosis of a fracture of the proximal humerus depends largely on the vascular status of the proximal humerus and the more specifically on the location of the main fracture line [8, 36–38] (Fig. 1). With a high fracture line an interruption of the vascular supply is likely. If the fracture line is lower the chances of necrosis become lower (Fig. 2).

Indications

The indications for plating are determined by the fracture pattern, essentially displaced two- and three-part fractures, as determined by Codman and Neer and refined by other authors using advanced imaging techniques such as 3D CT [2, 39–44]. Displaced head-split fractures not amenable to reduction should be treated with other means such as hemi- or total arthroplasty whether anatomic or inverted. Clearly to determine the indication an accurate diagnosis is necessary and this is only possible with well executed x-rays, if possible of digital quality, that need to be perpendicular to the glenohumeral joint in the frontal anteroposterior plane and in the transverse axial plane (Fig. 3). CT and 3D CT images may also be of assistance in the understanding of complex fractures [39, 45–47].

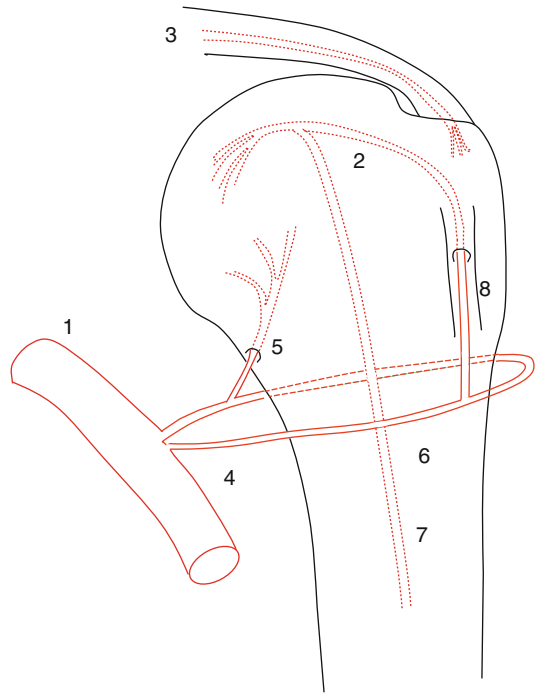

Fig. 1 Vascularisation of the humeral head

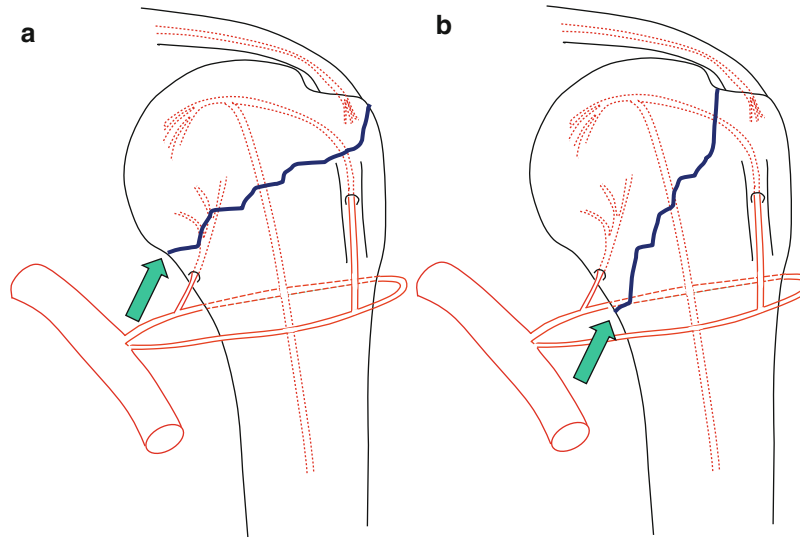

Fig. 2 Fracture line determines the risk of necrosis. (**a**) High fracture line (*arrow*) with high risk of necrosis. (**b**) Low fracture line (*arrow*) with a lesser risk of necrosis

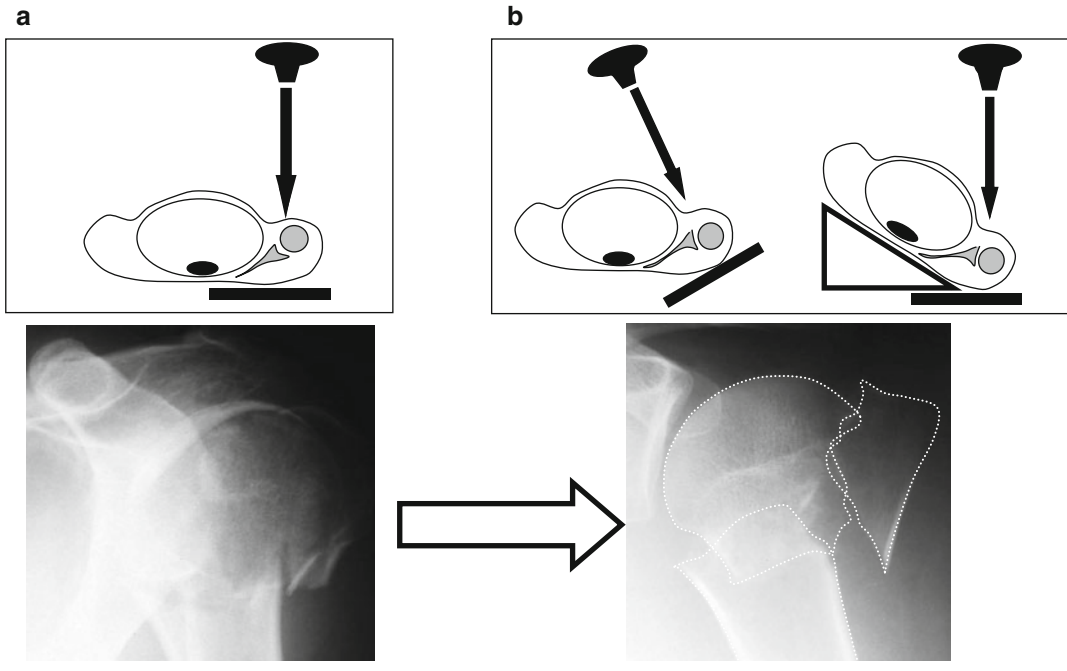

Fig. 3 Accurate radiological assessment is necessary. (**a**) AP perpendicular to the coronal plane is unsatisfactory. (**b**) Strict AP view perpendicular to the scapular plane is necessary for diagnosis

Surgical Technique

Patient Positioning

Under general anaesthesia and in some cases with an additional scalene block, the patient is placed on the operating table in a semi-sitting "beach-chair" position. It is important that the table be slightly up-tilted so that the buttocks rest squarely in the seat of the table avoiding any tendency to downward slippage. The head is held securely in a head rest with a firm bandage providing secure fixation. The cervical spine is in neutral position without inclination, rotation, extension or flexion. Special care should be given to protecting the patient's eyes. It is important to verify the position of the contralateral upper extremity so as to avoid pressure areas [24, 28] (Fig. 4).

The totality of the shoulder region from the superolateral torso and including the whole upper extremity should be left free. Some modular tables will allow removal of an upper corner piece therefore allowing access to all parts of the shoulder. The downside of this possibility is that the scapula tends to sag backwards somewhat. This may be counteracted by slightly rolling the table contralaterally. If this possibility does not exist a bolster may be used to prop-up the scapula. Care is taken to ensure that the shoulder may be thoroughly explored with a C-arm fluoroscope. Modern smaller C-arms are extremely manoeuvrable. Test the images obtained before definitive draping and adjust so as to obtain AP and axial views of the glenohumeral joint [24, 28] (Fig. 5).

Pain management modalities must be discussed with the anaesthetist. In some cases a scalene block may be indicated. In acute cases where nerve damage is possible this is best avoided. Routine single dose intravenous prophylaxis with an appropriate antibiotic administered before the incision, usually 20 min, is recommended [48].

Surgical Approaches

Trans-Deltoid Approach

This approach is appropriate for a displaced tuberosity fracture. Some authors use this approach as their standard for fractures of the proximal humerus [27, 29, 34]. The vertical incision of 5–7 cm starts from the acromion at the junction between the anterior and the middle third of the deltoid. After undermining the subcutaneous tissue the acromion, the acromioclavicular joint, clavicle and deltoid muscle are recognized. The anterior and mid-deltoid portions are then split through an often identifiable tendinous streak using a cold knife or electrocautery. This separation should not exceed 5 cm distal to the acromion and the axillary nerve should be identified either by palpation or visualization. Neer [49] recommended placing a suture at the end of the muscle slit to avoid unnecessary propagation. If absolutely necessary the deltoid may be economically released from the acromion in T fashion. The subacromial bursa is then opened and the surprisingly wide separation of the fracture lines will come into view. Traction sutures inserted through the supra- and infra-spinatus tendons will aid in reduction. Once the fracture is reduced, the plate is slipped along the bone and screws are inserted. The distal screws may be inserted through separate cutaneous incisions underneath the passage of the axillary nerve [27, 29]. The imager intensifier is used to control the fracture reduction. Remember that the vision is limited using this approach and that the utmost care in placing the implant must be exerted. The most frequent complications of this approach are malreduction of the fracture, malposition of the plate and injury to the axillary nerve with denervation of the anterior deltoid as a result (Fig. 6).

Fig. 4 Patient positioning. The patient is in semi-sitting position and the head is in the neutral position fixed in a headrest. The shoulder and upper extremity is free so as to allow image intensifier use. A scalene block may be used to provide post-anesthesia pain control

Delto-Pectoral Approach

The delto-pectoral approach is the favoured approach for proximal humerus fractures. It is a utilitarian and extensile approach both proximally and distally that respects the anatomy of the shoulder [28, 49]. For proximal humeral fractures a straight or oblique 10–15 cm incision is the best choice starting at the junction of the mid- and lateral third of the clavicle, passing over the coracoid and

Fig. 5 In a semi-sitting position, the arm is placed on a Mayo stand in abduction to relax the deltoid. Intra-operatively the image-intensifier allows control of the reduction manoeuvres

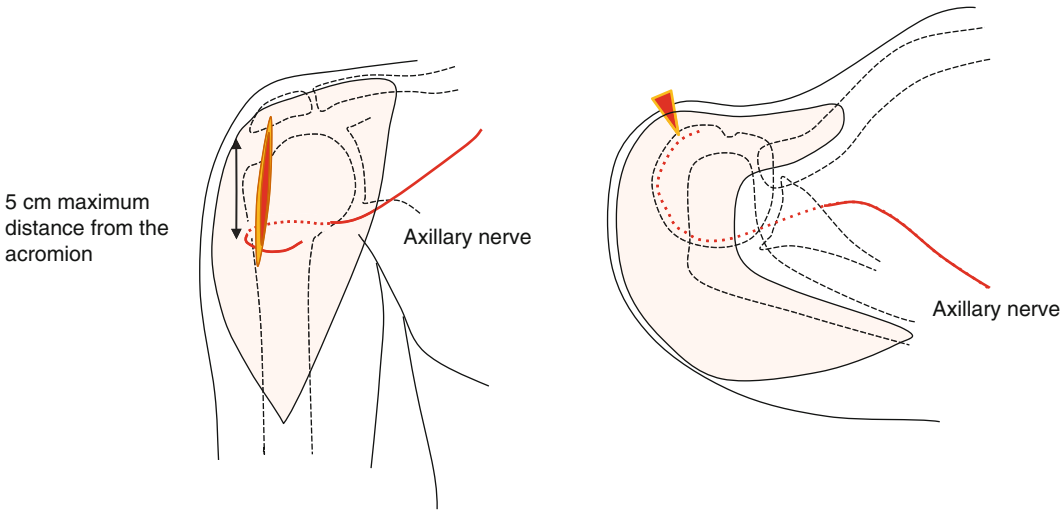

Fig. 6 Trans-deltoid approach. The cutaneous incision is straight going down from the acromion at the junction of the anterior and middle third of the deltoid. Separation of the deltoid fibres should not exceed a point 5 cm. distal to the acromion to protect the axillary nerve

ending distally near the insertion of the deltoid. Subcutaneous tissues are undermined and the delto-pectoral interval must be clearly identified. Haematoma and swelling may render this difficult so that it may be necessary to find the interval high up between the pectoralis and the deltoid proximally at their clavicular insertion. The cephalic vein is preserved and left either laterally along the deltoid or medially. The deltoid fascia is incised to allow palpation of the axillary nerve on the underside of the anterior deltoid by running a finger around the proximal humeral metaphysis [3, 9]. The pectoralis muscle is retracted medially while the deltoid is retracted laterally (Fig. 7). Abduction will facilitate deltoid retraction and exposure. The conjoint tendon is then retracted medially to identify the subscapularis muscle and its tendon. At this time it is wise to find the axillary nerve coursing on the anterior surface of the subscapularis muscle so as to protect it [50].

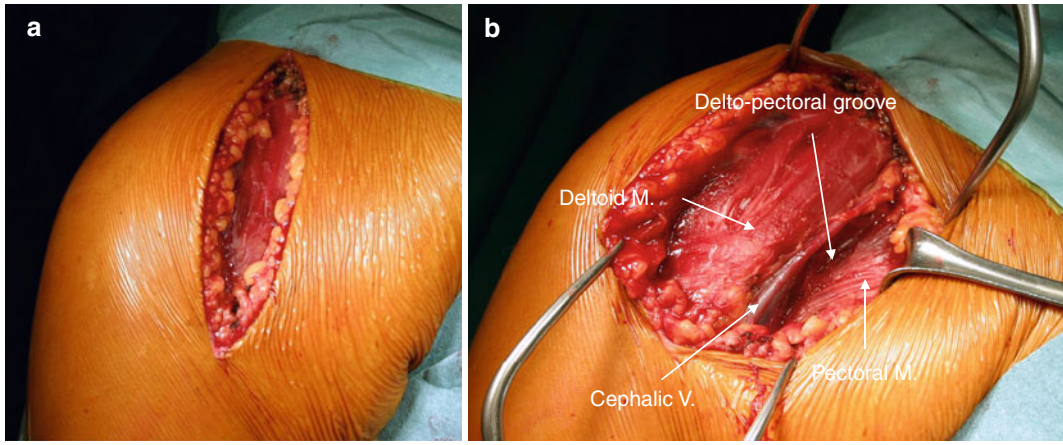

Fig. 7 Delto-pectoral approach: (**a**) The skin incision begins at the junction of the proximal and lateral thirds of the clavicle, passes over the coracoid and stops over the direction of pectoralis major. (**b**) The subcutaneous tissue is undermined in order to visualize the delto-pectoral groove. Proximally the vein can be found where it plunges into the brachial vein in the triangle between deltoid and pectoralis insertion origins

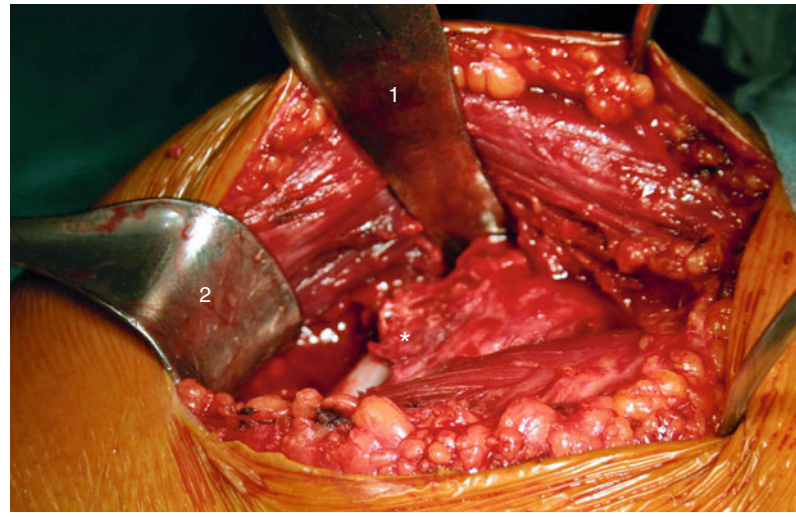

Fig. 8 Exposing the fracture. A blunt curved Hohmann retractor (1) is placed in the subacromial space and a wide Richardson retractor pulls away the deltoid (2) with the arm in abduction, allowing exposure of the fracture site (*)

Beware of the musculocutaneous nerve that penetrates the coracobrachialis at a mean distance of 5 cm from the tip of the coracoid [28, 49]. The tendon of the long biceps is a precious landmark and if damaged should not be sectioned for tenodesis until the fracture is properly reduced and the implants are in place [3]. The trajectory of the tendon must be straight and lie squarely in the groove. This will guide the reduction as the groove can generally be identified in the majority of fractures. Furthermore, the structures medial to the long biceps tendon make up the lesser tuberosity and subscapularis complex while the structures lateral to the long biceps are the greater tuberosity and supra- and infraspinatus [3, 9, 28]. To augment the exposure, the coraco-acromial ligament may be incised and the distal insertion of the deltoid may be released on the humerus. Rarely the anterior deltoid may be released from the clavicle. In this case the incision of the muscle insertion must be on top of the clavicle to leave a tendinous band for reinsertion [3] (Fig. 8).

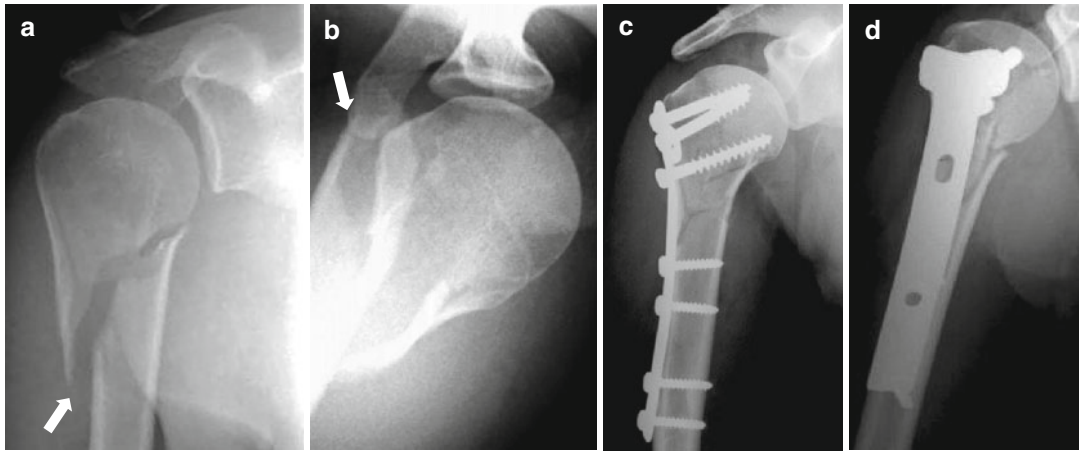

Fig. 9 Two part fracture (**a, b**) with a long spiral (*arrows*). (**c, d**) Fixation with a long T-plate

Standard Plates

There are many different types of plates including standard plates. They all have in common the possibility of inserting multiple screws into the humeral head. Some are T-shaped, others are cloverleaf or racket-shaped [6, 7, 20, 51]. These implants can be used through delto-pectoral or trans-deltoid approaches (Fig. 9). Biomechanically all plates are placed on the lateral cortex to produce a tension band effect. For best function and results a medial buttress and a valgus reduction must be obtained. If no medial buttress is present the implants will fatigue and ultimately fracture [28, 30, 31, 34, 35]. It should also be noted that in the osteoporotic bone multiple screws of a small diameter (3.5 mm) are more efficient than a large diameter screw (6.5 mm) [8, 27, 28, 31].

Anatomical Plates with Divergent Locked Screws

The trend is towards anatomically designed plates with engineered screw holes able to lock angularly stable and diverging screws These locking screw holes impose a direction to the screws although the latest models allow a greater latitude in the choice of angles. This angular stability with diverging screws is an advantage for the stabilization of osteoporotic fractures [19, 23–35].

Blade-Plates

For indications where a high degree of stability is required, 90° angled blade-plates for the proximal humerus provide rigid fixation and allow interfragmentary compression. These implants are useful in certain situations such as non-unions or for fixing osteotomies after a malunion [52].

Fractures of the Anatomical Neck (Two Fragments)

This is a rare lesion often associated with a dislocation or a subluxation of the cephalic fragment. This pattern is most often encountered in high energy trauma in the young. Reduction is performed through a delto-pectoral approach and an arthrotomy through the rotator interval will permit visualization of the displaced fragment. Once anatomical reduction is obtained a plate may be used for fixation, preferably a plate with locked screws to obtain a rigid fixation of this intra-articular fragment. Prognosis is dismal however with a high rate of post-traumatic necrosis of the cephalic fragment [53].

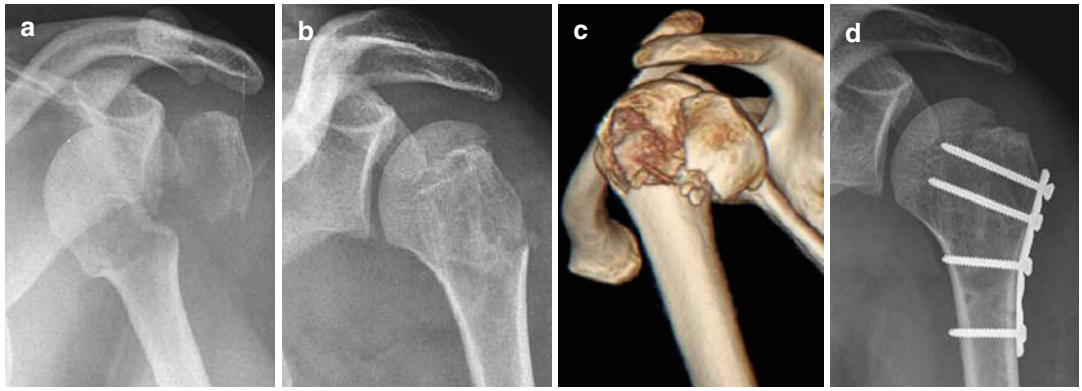

Fig. 10 Plate fixation with a third tubular plate. Glenohumeral dislocation and tuberosity fracture (**a**) After closed reduction a posterior displacement of the greater tuberosity (**b, c**) Reduction and fixation of the greater tuberosity with a third tubular plate (**d**)

Isolated Fractures of the Greater Tuberosity (Two Fragments)

Fractures of the greater tuberosity with posterior and superior displacement are typically associated with antero-inferior dislocations of the shoulder. These fractures are in fact completed Hill-Sachs fracture impactions. Surgical intervention is considered with a displacement of the tuberosities greater than 3 mm in young active patients. Up to 1 cm of displacement may be tolerated in less active elderly patients [49]. A trans-deltoid approach may be used. Once the fracture is reduced, a plate with locking screws may be used to stabilize the fragment. To ensure adequate fixation sutures however are passed through the supraspinatus, infraspinatus and subscapularis tendons and secured to the plate [54] (Fig. 10).

Fractures of the Surgical Neck (Two Fragments)

Fractures of the surgical neck tend to be unstable because of the actions of the rotator cuff muscles, the teres minor and major muscles, the deltoid and the pectoralis [23, 25, 32]. With an angularly displaced fracture (>30°) surgical stabilization is necessary. These fractures may be displaced into valgus or varus and the fixation technique will vary.

Valgus Displacement

If a plate is used, a standard 1/3 or 1/2 tubular plate may be inserted using either a delto-pectoral or a trans-deltoid approach. The plate is placed without any attempt at contouring. A screw inserted distally to the fracture line is gradually tightened thus bringing the plate in close contact with the cortex. In case of a valgus displacement reduction is obtained automatically. Care must be taken that the proximal fragment is well aligned in the sagittal plane and that no excessive flexion or extension remain [8] (Fig. 11).

Varus Displacement

In case of varus displacement it is imperative to reduce the proximal fragment so as to obtain a satisfactory alignment both in the frontal and in the sagittal planes. A Steinmann pin fixed into the humeral head may be useful as a "joystick" to obtain the reduction. Sutures are also passed through the supraspinatus, subscapularis and infraspinatus tendons. These may also be useful in reducing the varus displaced proximal humerus. Once the proximal fragment is well seated on the metaphysis and after ascertaining that the reduction is clinically acceptable, using an image intensifier if necessary, a plate with locking screws is used to secure the fixation.

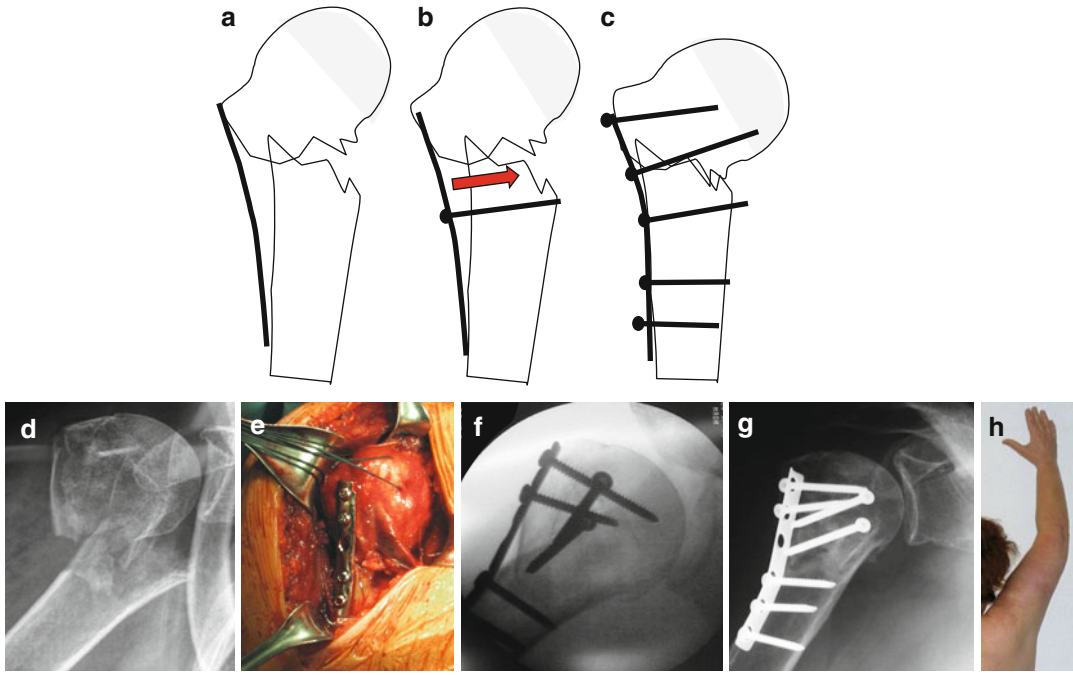

Fig. 11 Three-part fracture in valgus. (**a, b, c**) In this situation the spring properties of a semi- or third tubular plate may be used to reduce a displaced fracture. After a delto-pectoral approach, the plate is applied on the diaphysis and gradual tightening of a screw placed distally to the fracture line will bring about the reduction. It is important not to pre-bend the plate. (**d, e, f**) In this example two extra screws are used to fix a non-displaced lesser tuberosity fragment. (**g, h**) Healed fracture and functional result at 1 year

The cuff tendon sutures are tied to the plate using empty screw holes or specific holes in the plate (Fig. 12) [18, 28].

Three and Four Fragment Fractures

For a displaced three or four fragment fracture in a young active individual osteosynthesis with a rigid fixation and accurate reduction is always the first choice. For elderly less active patients a less rigid fixation using heavy suture material may be sufficient. No matter the fixation technique it is important to restore the anatomical relationships as only this will guarantee the best chances for recovering a functional articulation [4, 28].

These fractures when displaced should be reduced and fixed and the surgical approach may be delto-pectoral or trans-deltoid. The author's preference is the delto-pectoral approach which allows a good visualization of the fracture lines and adequate control of the fracture fragments for the purpose of obtaining a satisfactory reduction. Priority is given to tuberosity placement. If too high it will impinge against the acromion and damage the cuff, whilst if too low there will be undue tension on the rotator cuff tendons. Ideally the greater tuberosity should lie 10 mm under the humeral head [1, 3, 8, 28, 32, 34, 35].

After the standard delto-pectoral approach the fracture fragments must be identified. Stay sutures are placed in the tendons at the tendino-osseous junction of the fractured tuberosities. These sutures placed in the tendons along with a 2.5 mm Steinmann fixed in the cephalic fragment as a joystick will allow manipulation of the fragments. The medial fracture line at the head-metaphysis junction identified with the image intensifier is a landmark that will aid in adequately reducing the cephalic fragment on the metaphysis. A solid medial buttress is essential in

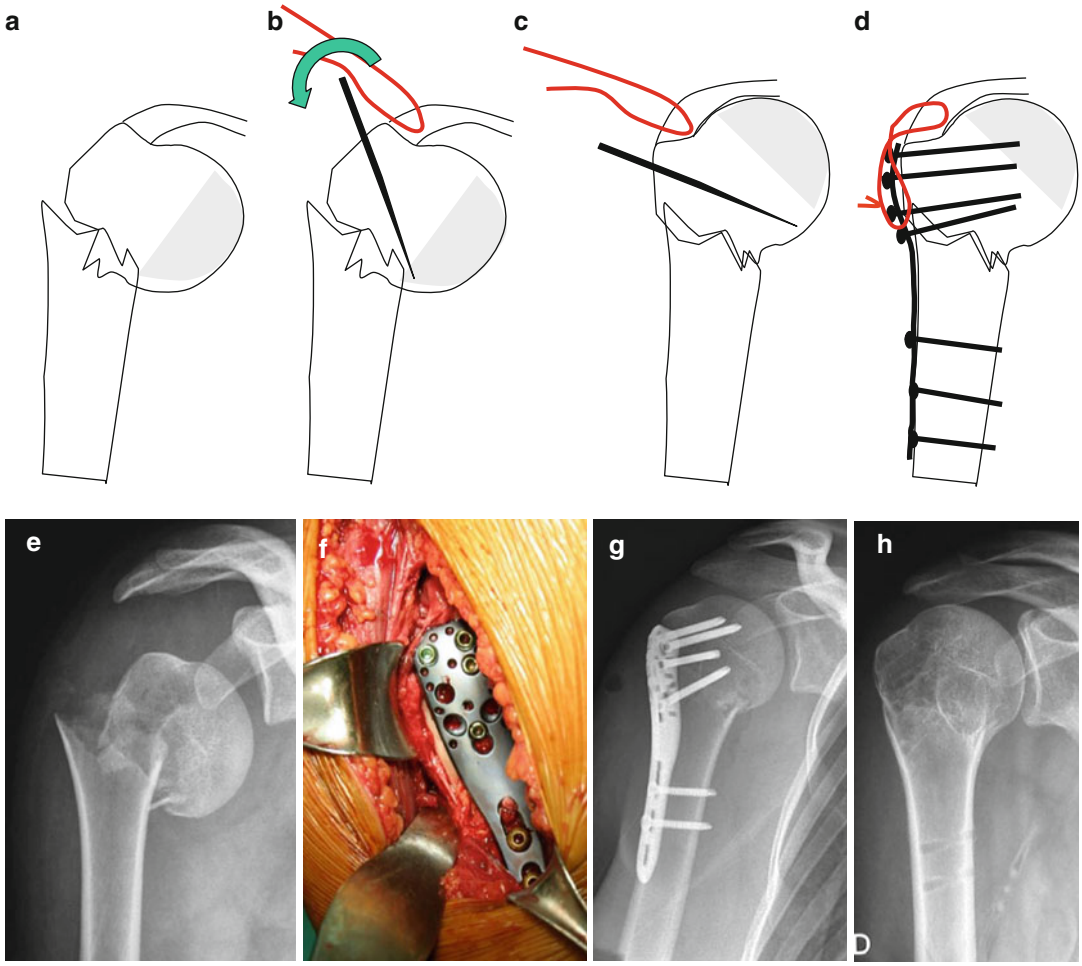

Fig. 12 Two-part fracture in varus. (**a, b, c, d**) After a delto-pectoral approach a Steinmann pin is inserted into the cephalic fragment and used as a joystick, a plate is applied for fixation. (**e, f**) Clinical case: Displaced two-part fracture fixed with a locking plate. Once reduced a locking plate is applied. (**g, h**) Result after fracture healing and hardware removal

ensuring a stable construct. Inspection of the articular surface may necessitate an arthrotomy through the rotator interval if the view afforded by lifting the tuberosity fragment is not sufficient. A pin fixing temporarily the cephalic fragment on the metaphysis is sometimes necessary. Rarely a bone graft is needed which may be inserted between the metaphysis and the cephalic fragment to maintain the head in good position. The tuberosities are then coaxed and manipulated into a reduced position around the cephalic fragment and fixed using the previously-inserted transtendinous sutures. The tuberosity fragment usually has a pointed triangular point which will fit into the metaphyseal mirror triangular fracture line. The position and alignment of the biceps tendon is a good witness as to the quality of the reduction. After the biceps tendon has been ascertained to be in good position, if its integrity is in doubt, a tenodesis may be needed [28, 33].

The transtendinous traction sutures may be then passed through holes in the locking screw-plate. The plate needs to be positioned on the metaphysis avoid the bicipital groove. Care must be taken that the plate is not too high or impingement on the acromion will occur.

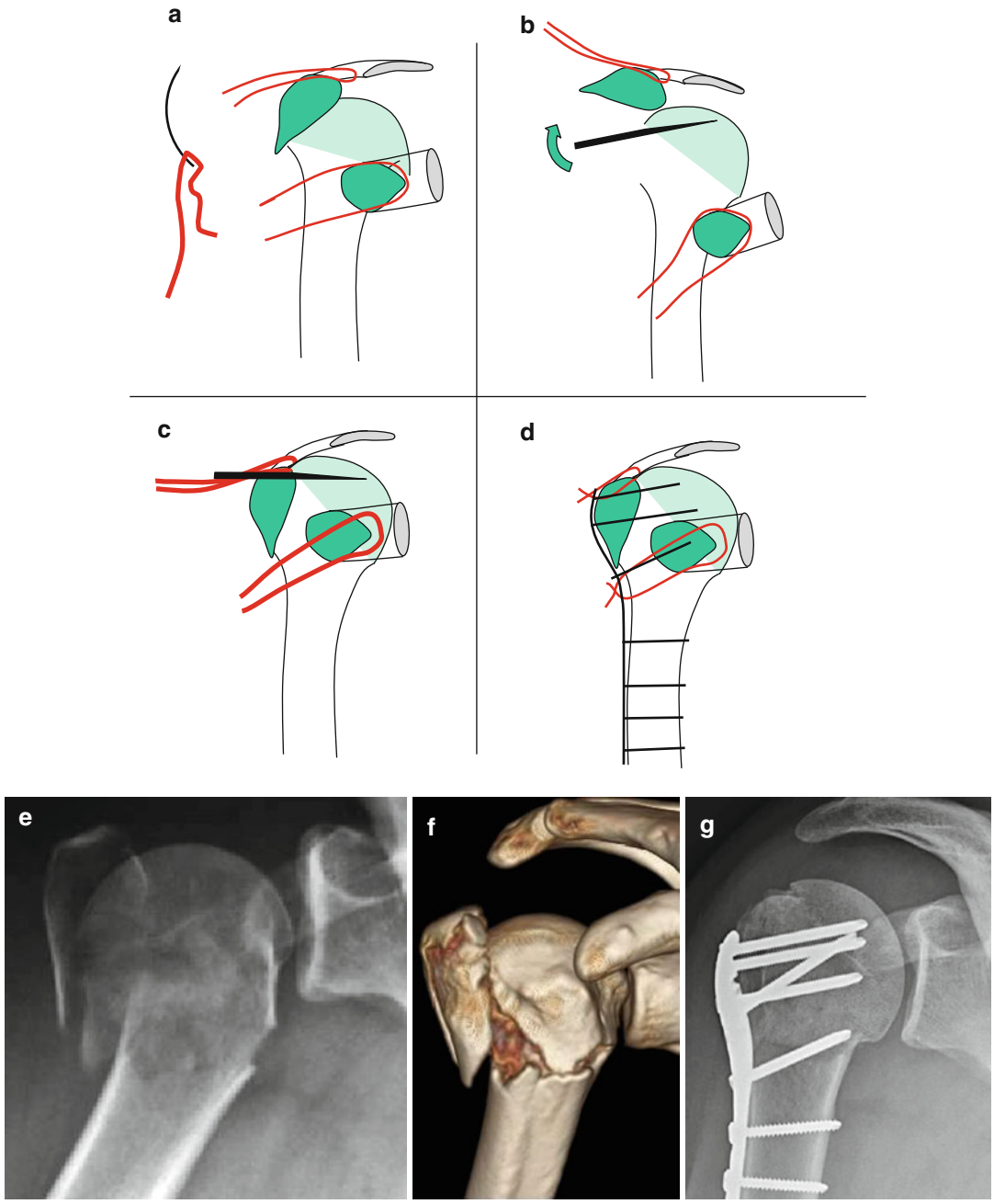

Fig. 13 Three-part fracture. (**a, b, c, d**) Transtendinous sutures are placed followed by reduction of the humeral head using a joystick manoeuvre with a Steinmann pin. Once the reduction achieved the locking plate is applied and sutures are tied onto the plate. (**e, f, g**) Clinical case: Three-part fracture fixed with a locking plate

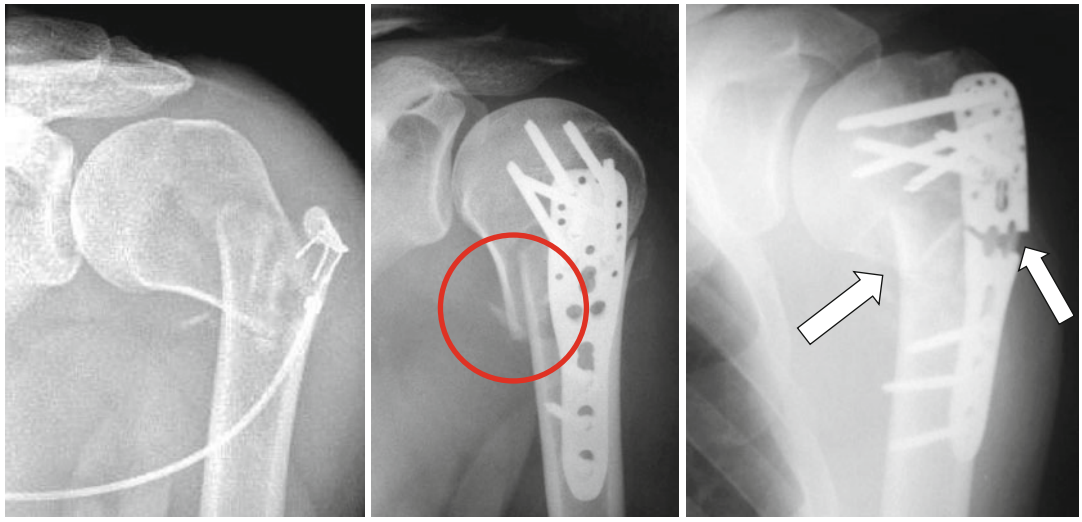

Fig. 14 Lack of a mechanically sound medial buttress (*Circle*) such as in this two- part fracture will lead to fracture collapse into varus and plate breakage

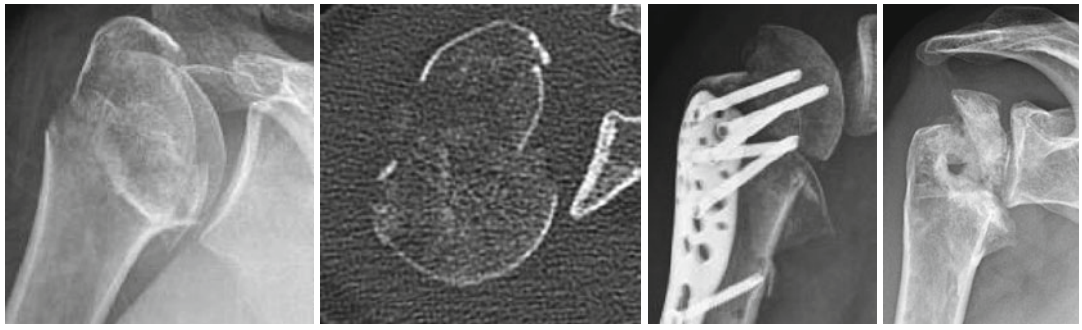

Fig. 15 Complications of plating. A fracture-dislocation with a head split in a 25 years-old woman. Attempt at plating leads to failure with collapse and severe necrosis

The image intensifier will control the reduction and position of the plate. The 3.5 mm screws are then inserted beginning with a screw in the middle of the plate and proceeding to insert the proximal cephalic screws. Length must be carefully gauged to avoid protrusion, more than 35 mm of length is unusual. Once the screw is inserted the transtendinous sutures should be tied on the plate. An image intensifier check will ascertain that the fracture is well reduced, that a good medial buttress has been achieved and that the screws are of the right length. The last screws are inserted into the cephalic fragment and locked into the plate. For Titanium implants always use the torque-limiting device on the screwdriver when indicated by the manufacturer so as to avoid a so-called "cold" welding effect, rendering future hardware removal almost impossible without destroying the screw head. The lesser tuberosity may be fixed with screws outside the plate but as a rule transtendinous sutures tied down to the plate will afford an adequate fixation [28, 33].

Before closure, a last image intensifier check, taking the shoulder through a range of motion will verify that no screws are intra-articular and that the reduction is adequate (Fig. 13).

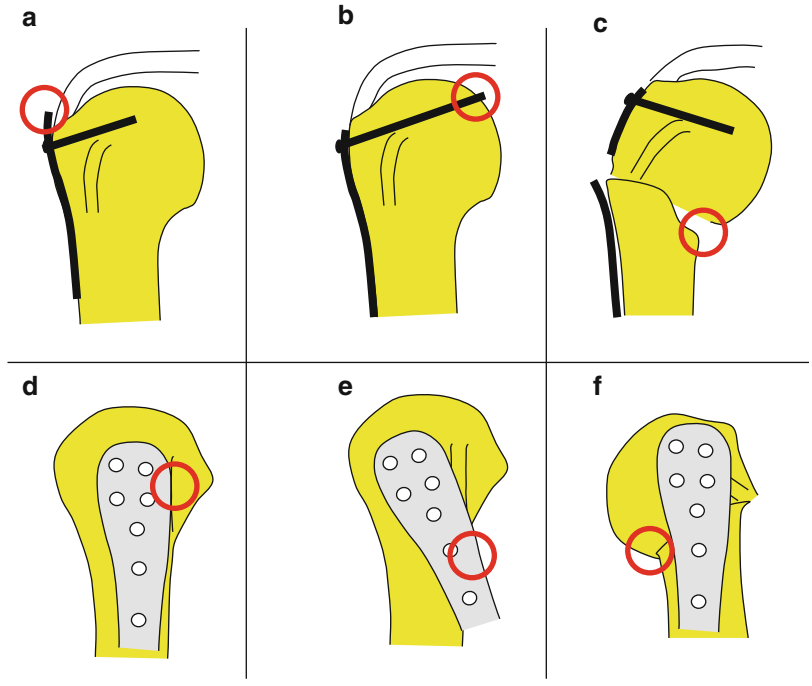

Fig. 16 Common complications (**a**) Plate too high. (**b**) Screws too long. (**c**) Insufficient medial buttress and plate breakage. (**d**) Impingement of biceps. (**e**) Plate not aligned on the diaphysis. (**f**) Malreduction with posterior tilt

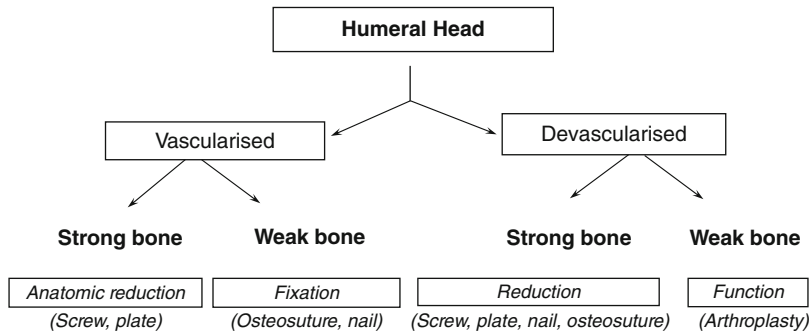

Fig. 17 Algorithm for managing displaced proximal humeral fractures

Complications

Complications are many and the literature is rich in articles and reports detailing the types of complications most frequently encountered [26, 27, 34, 35]. A strong medial buttress must be present if varus displacement and plate breakage are to be avoided (Fig. 14). The indication must be well determined. Certain head-split fracture-dislocations are not amenable to reduction and fixation and even if that were the case necrotic collapse is inevitable (Fig. 15). The main complications related to technique are described in Fig. 15. A plate too high will lead to impingement. Screws that are too long will damage the articular surfaces and lead to pain, as a general rule avoid screws longer than 35 mm in the humeral head. Lack of a strong medial buttress will lead to fracture collapse in varus. The plate should not impinge on the biceps if it is left in place. The plate should be placed on the diaphysis and not obliquely as this is potentially an unstable situation. Frequently a malreduction, where the proximal fragment remains tilted posteriorly, is encountered. This will lead to reduced motion and possibly residual pain (Fig. 16).

As a general rule plates should be used according to the algorithm below. The best indication is a displaced fracture occurring in strong bone with a pattern that preserves the vascularity of the articular cephalic fragment (Fig. 17).

Rehabilitation

As a rule the shoulder should be mobilized as early as possible (Rehabilitation will pass through three phases -I-II-III). During phase I the accent is placed on passive assisted mobilization in some cases under scalene bloc. The shoulder should be mobilized in elevation in the plane of the scapula by the physiotherapist and the patient is encouraged to mobilize himself the injured shoulder using his uninjured arm. The exercises should be performed supine and then later in the sitting position. Exercising in the water in an adapted pool under supervision should be started as soon as possible. In some cases a watertight film may be applied to the operative wound even before suture removal, thus allowing the patient to exercise in water with his wound kept dry. This phase should last for the first 6 weeks post-operatively, the aim being to achieve the best possible range of motion. Phase II starts at 6 weeks and active movements are encouraged along with strengthening exercise. At this time slings and shoulder immobilizers are stopped. The goal is to obtain a full range of motion. Starting at week 10, phase III stats. with strengthening and stretching exercises that are recommended and encouraged. After 3 months, formal physiotherapy is discontinued and the patient is encouraged to use his shoulder as normally as possible [11, 49, 53].

References

1. Bigliani LU. Treatment of two- and three-part fractures of the proximal humerus. AAOS Instr Course Lect. 1989;38:231–44.
2. Codman EA. The Shoulder. Malabar: Krieger; 1984. p. 319.
3. Cofield RH. Comminuted fractures of the proximal humerus. Clin Orthop. 1988;230:49–57.
4. Court-Brown CM, Garg A, McQueen MM. The translated two-part fracture of the proximal humerus. Epidemiology and outcome in the older patient. J Bone Joint Surg Br. 2001;83:799–804.
5. Duparc J, Largier A. Fracture-dislocations of the upper end of the humerus (French). Rev Chir Orthop Reparatrice Appar Mot. 1976;62:91–110.
6. Ehlinger M, Gicquel P, Clavert P, Bonnomet F, Kempf J-F. A new implant for proximal humeral fracture: experimental study of the basket plate (French). Rev Chir Orthop Reparatrice Appar Mot. 2004;90:16–25.
7. Esser RD. Treatment of three- and four-part fractures of the proximal humerus with a modified cloverleaf plate. J Orthop Trauma. 1994;8:15–22.
8. Hertel R. Fractures of the proximal humerus in osteoporotic bone. Osteoporos Int. 2005;16(Suppl 2):S65–72.
9. Hoffmeyer P. The operative management of displaced fractures of the proximal humerus. J Bone Joint Surg Br. 2002;84:469–80.
10. Ko JY, Yamamoto R. Surgical treatment of complex fracture of the proximal humerus. Clin Orthop. 1996;327:225–37.
11. Koval KJ, Gallagher MA, Marsicano JG, Cuomo F, McShinawy A, Zuckerman JD. Functional outcome after minimally displaced fractures of the proximal part of the humerus. J Bone Joint Surg Am. 1997;79:203–7.
12. Mittlmeier TWF, Stedtfeld H-W, Ewert A, Beck M, Frosch B, Gradl G. Stabilization of proximal humeral fractures with an angular and sliding stable antegrade locking nail (Targon PH). J Bone Joint Surg Am. 2003;85:136–46.
13. Mouradian WH. Displaced proximal humeral fractures. Seven years' experience with a modified Zickel supracondylar device. Clin Orthop. 1986;212:209–18.
14. Park MC, Murthi AM, Roth NS, Blaine TA, Levine WN, Bigliani LU. Two-part and three-part fractures of the proximal humerus treated with suture fixation. J Orthop Trauma. 2003;17:319–25.
15. Resch H, Pocacz P, Frölich R, Wambacher M. Percutaneous fixation of three and four-part fractures of the proximal humerus. J Bone Joint Surg Br. 1997;79:295–300.
16. Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. Results of operative treatment. J Bone Joint Surg Am. 2003;85:1647–55.
17. Rowles DJ, McGrory JE. Percutaneous pinning of the proximal part of the humerus. An anatomic study. J Bone Joint Surg Am. 2001;83:1695–9.
18. Schlegel TF, Hawkins RJ. Displaced proximal humeral fractures: evaluation and treatment. J Am Acad Orthop Surg. 1994;12:54–78.
19. Siegel HJ, Lopez-Ben R, Mann JP, Ponce B. Pathological fractures of the proximal humerus treated with a proximal humeral locking plate and bone cement. J Bone Joint Surg Br. 2010;92:707–12.
20. Wanner GA, Wanner-Schmid E, Romero J, Hersche O, von Smekal A, Trentz O, Ertel W. Internal fixation of displaced proximal humeral fractures with two one-third tubular plates. J Trauma. 2003;54:536–44.

21. Wijgman AJ, Roolker W, Patt TW, Raaymakers EL, Marti RK. Open reduction and internal fixation of three and four-part fractures of the proximal part of the humerus. J Bone Joint Surg Am. 2002;84:1919–25.
22. Zyto K, Ahrengart L, Sperber A, Tornkvist H. Treatment of displaced proximal humeral fractures in elderly patients. J Bone Joint Surg Br. 1997;79:412–7.
23. Agudelo J, Schürmann M, Stahel P, Helwig P, Morgan SJ, Zechel W, Bahrs C, Parekh A, Ziran B, Williams A, Smith W. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma. 2007;21:676–81.
24. Badman BL, Mighell M. Fixed-angle locked plating of two-, three-, and four-part proximal humerus fractures. J Am Acad Orthop Surg. 2008;16:294–302.
25. Chudik SC, Weinhold P, Dahners LE. Fixed-angle plate fixation in simulated fractures of the proximal humerus: a biomechanical study of a new device. J Shoulder Elbow Surg. 2003;12:578–88.
26. Clavert P, Adam P, Bevort A, Bonnomet F, Kempf JF. Pitfalls and complications with locking plate for proximal humerus fracture. J Shoulder Elbow Surg. 2010;19:489–94.
27. Helwig P, Bahrs C, Epple B, Oehm J, Eingartner C, Weise K. Does fixed-angle plate osteosynthesis solve the problems of a fractured proximal humerus? A prospective series of 87 patients. Acta Orthop. 2009;80:92–6.
28. Konrad G, Bayer J, Hepp P, Voigt C, Oestern H, Kääb M, Luo C, Plecko M, Wendt K, Köstler W, Südkamp N. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate: surgical technique. J Bone Joint Surg Am. 2010;92:85–95.
29. Laflamme GY, Rouleau DM, Berry GK, Beaumont PH, Reindl R, Harvey EJ. Percutaneous humeral plating of fractures of the proximal humerus: results of a prospective multicenter clinical trial. J Orthop Trauma. 2008;22(3):153–8.
30. Lescheid J, Zdero R, Shah S, Kuzyk PR, Schemitsch EH. The biomechanics of locked plating for repairing proximal humerus fractures with or without medial cortical support. J Trauma. 2010;69:1235–42.
31. Lever JP, Aksenov SA, Zdero R, Ahn H, McKee MD, Schemitsch EH. Biomechanical analysis of plate osteosynthesis systems for proximal humerus fractures. J Orthop Trauma. 2008;22:23–9.
32. Lungershausen W, Bach O, Lorenz CO. Locking plate osteosynthesis for fractures of the proximal humerus. Zentralbl Chir. 2003;128:28–33.
33. Ricchetti ET, DeMola PM, Roman D, Abboud JA. The use of precontoured humeral locking plates in the management of displaced proximal humerus fracture. J Am Acad Orthop Surg. 2009;17:582–90.
34. Sproul RC, Iyengara JJ, Devcica Z, Feeley BT. A systematic review of locking plate fixation of proximal humerus fractures. Injury. 2010. doi:10.1016/j.Injury.2010.11.058.
35. Südkamp N, Bayer J, Hepp P, Voigt C, Oestern H, Kääb M, Luo C, Plecko M, Wendt K, Köstler W, Konrad G. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. Results of a prospective, multicenter, observational study. J Bone Joint Surg Am. 2009;91:1320–8.
36. Gerber C, Hersche O, Berberat C. The clinical relevance of posttraumatic avascular necrosis of the humeral head. J Shoulder Elbow Surg. 1998;7:586–90.
37. Gerber C, Schneeberger AG, Vinh TS. The arterial vascularzation of the humeral head. An anatomical study. J Bone Joint Surg Am. 1990;72:1486–94.
38. Laing PG. The arterial supply of the adult humerus. J Bone Joint Surg Am. 1956;38:1105–16.
39. Jurik AG, Albrechtsen J. The use of computed tomography with two- and three-dimensional reconstructions in the diagnosis of three- and four-part fractures of the proximal humerus. Clin Radiol. 1994;49:800–4.
40. Muller ME, Nazarian S, Koch P. Classification A.O. des fractures. Berlin: Springer; 1987.
41. Neer II CS. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am. 1970;52:1077–89.
42. Neer CS. Four segment classification of proximal humeral fractures: purpose and reliable use. J Shoulder Elbow Surg. 2002;11:389–400.
43. Sidor ML, Zuckerman JD, Lyon T, Koval K, Cuomo F, Schoenberg N. The Neer classification system for proximal humeral fractures. An assessment of interobserver reliability and intraobserver reproducibility. J Bone Joint Surg Am. 1993;75:1745–50.
44. Siebenrock KA, Gerber CH. The reproducibility of classification of dractures of the proximal end of the humerus. J Bone Joint Surg Am. 1992;75:1751–5.
45. Bahrs C, Rolauffs B, Südkamp NP, Schmal H, Eingartner C, Dietz K, Pereira PL, Weise K, Lingenfelter E, Helwig P. Indications for computed tomography (CT-) diagnostics in proximal humeral fractures: a comparative study of plain radiography and computed tomography. BMC Musculoskelet Disord. 2009;2:10–33.
46. Bernstein J, Adler LM, Blank JE, Dalsey RM, Williams GR, Iannotti JP. Evaluation of the Neer system of classification of proximal humeral fractures with computerized tomographic scans and plain radiographs. J Bone Joint Surg Am. 1996;78:1371–5.
47. Edelson G, Kelly I, Vigder F, Reis ND. A three-dimensional classification for fractures of the proximal humerus. J Bone Joint Surg Br. 2004;86:413–25.
48. Culebras X, Van Gessel E, Hoffmeyer P, Gamulin Z. Clonidine combined with a long acting local anesthetic does prolong postoperative analgesia after brachial plexus block but does induce hemodynamic changes. Anesth Analg. 2001;92:199–204.
49. Neer CS. Shoulder reconstruction. Philadelphia: W.B. Saunders; 1990. p. 363–401.

50. Flatow EL, Bigliani LU. Tips of the trade. Locating and protecting the axillary nerve in shoulder surgery. The tug test. Orthop Rev. 1992;21:503–5.
51. Bahrs C, Oehm J, Rolauffs B, Eingartner C, Weise K, Dietz K, Helwig P. T-plate osteosynthesis–an obsolete osteosynthesis procedure for proximal humeral fractures? Middle-term clinical and radiological results (In German). Z Orthop Unfall. 2007;145:186–94.
52. Jupiter JB, Mullaji AB. Blade plate fixation of proximal humeral non-unions. Injury. 1994;25:301–3.
53. Hodgson SA, Mawson SJ, Stanley D. Rehabilitation after two-part fractures of the neck of the humerus. J Bone Joint Surg Br. 2003;85:419–22.
54. Gruson KI, Ruchelsman DE, Tejwani NC. Isolated tuberosity fractures of the proximal humeral: current concepts. Injury. 2008;39(3):284–98.