5 Proximal Humeral Fractures

C. Spross and B. Jost

Introduction

There is no doubt that the number of proximal humeral fractures is high although will undoubtedly increase with an expanding elderly population. As such management of these fractures will become an increasing burden, not only on patients and clinicians but society generally. As such it is important that we develop good and clear evidence for treatment of the various fracture patterns and patient sub-groups. At the beginning of the twentieth century, conservative treatment was the mainstay as there were no viable alternatives. With the foundation of the AO (Association for the Study of Internal Fixation) in 1958 new treatment options were sought and devices for open reduction and internal fixation (ORIF) developed. In 1970 Charles Neer presented his results of hemiprosthetic replacements [1]. Subsequently, more fractures were treated operatively and with the development of anatomically pre-shaped angular stable implants at the beginning of the twenty first century, Open Reduction and Internal Fixation (ORIF) became the mainstay for the surgical treatment of proximal humeral fractures. The success of this, however, does not just depend on the implants themselves but also appropriate patient selection and surgical expertise. More recently there have been some reports of high complication and revision rates [2–7]. As such a number of authors have recommended a return to conservative treatment in many of these cases [8]. At one end of the spectrum in an elderly unfit patient with an undisplaced fracture, few would dispute the role of conservative treatment. Whilst at the other end with a comminuted fracture dislocation there is obviously a role for operative intervention. In between, however, there is a number of complex and perhaps only partially displaced fractures the management of which currently remains controversial. In this group the advantage of ORIF over conservative treatment would be weighed against the potential for significant complications.

More recently new and emerging technologies particularly Reverse Total Shoulder Arthroplasty (RTSA) has become a valuable option for treating severe fracture dislocation of the proximal humerus particularly in elderly patients [9, 10]. While reports of improved function with low revision rates are promising, long term follow up studies have yet to be reported. At this time, however, this implant does appear to be providing a satisfactory outcome for patients over 70.

Having considered the above it is our opinion that the aim of any fracture treatment should be to bring patients back as near as possible to their pre-injury function and quality of life. We do not believe there is one solution for all

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patients and that the whole range of treatment options should be considered for each individual. In this chapter we discuss the most recent literature on the treatment of proximal humerus fractures and will try to elucidate what is known and what is still controversial. Furthermore, we would like to share our first experiences and results with an evidence based treatment algorithm, accounting for patient-specific factors with the aim of finding the right treatment for each patient [11].

Aetiology

Epidemiology

Proximal humeral fractures account for nearly 6% of all fractures [12]. Although they can occur in any age group, over 80% of patients afflicted are older than 50 years and over 70% are female with the most common cause being a low-energy fall [13, 14]. The high percentage of postmenopausal women reflects the important role of osteoporosis with regard to these fractures [15].

Mechanism of Injury

The exact mechanism of injury leading to a proximal humeral fracture is often difficult to ascertain. The type of fracture depends on the position of the arm in relation to the torso at the moment of impact, when the humeral head is pushed against the glenoid or the acromion. For example, straight lateral impact from a fall or direct trauma to the adducted upper arm can result in a typical surgical neck fracture or a head split fracture as described in Neer's group VI [16]. Having the arm in a more abducted position results in more valgus impaction. Posterior fracture dislocation can result from direct trauma to the adducted and internally rotated extremity [17], whereas external rotation and abduction can lead to anterior dislocation with avulsion fracture of the greater tuberosity, especially in older patients [18, 19].

Presentations/Investigations/Treatment Options

Clinical Examination

The first examination of the patient in the emergency department should include a full history particularly regarding to the mechanism of injury as to whether it was a high velocity injury or a low impact domestic fall. Whereas patients sustaining high velocity trauma are prone to associated injuries of the thoracic wall, cervical spine or other extremities as well as neurovascular damage [20], patients with severe osteoporosis or only secondary's a fracture may occur after minimal or indeed no trauma. It is also important to ascertain the patients pre-injury functional status eg dependence, activity level as well as any comorbidities. In our opinion this information is very important for later decision-making.

On physical examination, soft tissue swelling, ecchymosis and deformity may be present. The examiner should also look for concomitant injuries including the neurovascular status of the injured limb. Sensorimotor functions should be assessed and documented before further treatment. Special attention should be paid to the examination of axillary nerve function, which is the most commonly affected nerve in fractures or fracture-dislocations of the proximal humerus. By examining only the sensory function of the axillary nerve a lesion cannot be reliably excluded [21, 22]. Even in the presence of acute pain the motor function can be clinically assessed by feeling for isometric contraction of the deltoid muscle. This is done by putting one hand on the patient's elbow and the other one on the deltoid muscle. The patient is then told to attempt abduction of the elbow against the examiner's hand who can feel contractions of the deltoid muscle with the other hand. Any perceived contraction, even a weak one, of the deltoid, means that the axillary nerve is functioning.

Radiographic Examinations

Radiographic examination of suspected proximal humeral fractures or fracture-dislocations traditionally consists of a trauma series [anteroposterior (AP), scapular lateral and axillary view]. However, the axillary view can be painful for the patient and a recent study showed that it had no influence on further therapeutic decisions [23]. Furthermore, the classification of proximal humerus fractures based on radiographs is notoriously difficult and unreliable [24, 25]. As a consequence we obtain an AP and lateral view first and if we need further information, we have a low threshold for a CT scan with 3D reconstructions undoubtedly gives more accurate information with regard to fracture pattern and certainly allow better planning if surgery is contemplated [26, 27].

Bone Quality

After the first examination and the radiographic diagnosis, it is crucial to obtain more information for decision-making. Low bone mineral density (BMD) has been shown to be a risk factor for complications in the treatment of proximal humeral fractures [28–30].

The DEXA method is still the gold standard to diagnose osteoporosis but there are no defined threshold values for the proximal humerus yet and the examination is often not available at the time of fracture. The quantitative CT (pQCT) is an alternative method, but its availability is also limited and the analysis rather complicated [27]. Thus, several radiographic tools have been suggested to ascertain bone density [31–34]. We defined and validated the deltoid tuberosity index (DTI), which is a simple method to measure local bone quality directly proximal to the deltoid tuberosity on the AP fracture X-ray (Fig. 5.1). This structure is usually not affected by the fracture and well outlined on the AP radiograph due to the internally rotated relieving posture of the arm. The outer cortical diameter is divided by the inner endosteal diameter and does not need to be corrected for the magnification error. In a first study, we found a strong correlation between the DTI and the BMD of the humeral head (measured with pQCT). Furthermore, we were able to define a cut-off value (DTI < 1.4) for low BMD of the proximal humerus. Finally, we validated this index for its use on proximal humerus fractures and found that the DTI has a high intra- and interobserver reliability [35]. In a recent study, we were able to confirm the clinical relevance of this threshold value and its influence on complications after ORIF of proximal humerus fractures [30].

Fig. 5.1 The deltoid tuberositiy index (DTI) is measured directly proximal to the deltoid tuberosity (asterisks). At the level, where the outer cortical borders become parallel, the outer cortical diameter (**a**) is divided by the inner endosteal diameter (**b**)

Fracture Classification

In the past, a variety of classifications have been used to describe proximal humeral fractures and fracture-dislocations. Consequently, it has been difficult to compare the results of the early but also of current literature. Despite ample experience with these fractures, their treatment based on classifications remains controversial.

Codman/Neer Classification

Codman [36] noted that most proximal humeral fractures occur along the lines of the physeal scars at the proximal end of the humerus and described four possible fracture fragments: greater tuberosity, lesser tuberosity, anatomical head and shaft. Based on these four fragments, Neer [16] proposed the four-segment classification system. A segment (greater, lesser tuberosity, anatomical, surgical neck) is defined as a 'part' if its displacement is more than 1 cm or >45°. If none of the fragments meets these criteria, the fracture is called a 1-part fracture, even if all segments are fractured [37].

The AO/ASIF Classification System

The AO/ASIF (Arbeitsgemeinschaft für Osteosynthesefragen/Association for the Study of Internal Fixation) proposed a new classification, which was an expansion on and modification of the Neer classification [38]. Basically, the AO/ASIF system differentiates three types of fractures: extra articular unifocal (11-A), extra articular bifocal (11-B) and intra articular (11-C). Each of these groups is divided into further subgroups depending on impaction and dislocation.

Hertel's Classification and Predictors of Humeral Head Ischemia

Based on the original drawings of Codman, Hertel and colleagues [39, 40] proposed a "LEGO" classification system with 12 basic fracture patterns (+2 additional head split patterns). Furthermore, they found that a dorsomedial metaphyseal head extension of less than 8 mm, a more than 2 mm displaced medial hinge and fractures with isolated articular segments were good predictors for intraoperative head ischemia. However, these findings did not correlate with postoperative AVN in later follow-up studies [41, 42].

Authors' Opinion: Fracture Classification

The reproducibility of the Neer and the AO/ASIF classifications is difficult and has thus been subject to many studies with advantages for the Neer classification, especially with the help of 3D CT reconstructions [24, 26, 43–46]. However, more and more prospective randomised studies on conservative versus operative fracture treatment in elderly patients with three- or four-part fractures showed no functional benefits of surgery [8, 47–50]. Therefore, the discussion of fracture classification is becoming increasingly secondary, at least for elderly patients. However, in high energy injuries or head splitting fractures, particularly in younger patients where surgery is clearly indicated, interpretation of the fracture pattern remains eminently important for preoperative planning [42]. Therefore, in our institution CT scans are used for better imaging of fractures with subtle but potentially relevant displacement and for fractures where surgery is being considered. Based on that, we use the Neer classification and pay special attention to the displacement of the tuberosities in relation to the head and to certain fracture types and configurations, such as varus or valgus impaction of the head fragment [39, 51–60].

> **Clinical Pearl**
> Neer classification of fractures is still in widespread use. Special attention, however, should be paid to displacement of the tuberosity as any varus or valgus impactionof the humeral head.

Treatment Options

The literature regarding the treatment of fracture of the proximal humerus is indeed enormous. Most of the papers, however, are essentially cohort studies and could be used to justify literally every treatment strategy. When it comes to higher level evidence, however (Level 1 and 2 studies) the number shrinks to only a few prospective studies and even fewer prospective randomised studies. As such the evidence-based recommendations for the management of these fractures remains limited [61, 62]. A recent multicentre prospective randomised clinical trial (the PROFHER trial) performed in the UK involving over 30 centres [8]. Randomised patients older than 16 years with a proximal humerus fracture with sufficient displacement (for the treating surgeon to consider surgery) to either conservative or operative treatment. The authors concluded that there is no statistically significant benefit of surgery versus conservative treatment after 2 years. Not surprisingly this study has been criticised by way of its selection bias, inappropriate scoring and the involvement of too many surgeons and too many surgical techniques [63, 64]. There is no doubt, however, this study has stimulated discussion and has paved the way for further studies perhaps looking at individual sub-groups.

Personalising treatment for an individual patient however remains a challenge, particularly in the face of changing interventions. In the following sections, the authors present examples of published literature on individual interventions; and supplement this with the authors' preferred treatment algorithm.

Conservative Treatment

In the Elderly Patient

Since Neer [16] suggested conservative treatment for one-part fractures, they have been the subject of only a few studies of which most reported good functional results in the majority of patients treated [65–67]. Maybe it is due to the high complication rates after ORIF [2, 4, 7, 68, 69] or the restricted functional results after hemiarthroplasty [70–72] that also more extensively displaced fractures are being treated conservatively again. Several studies have been looking for patient and fracture characteristics amenable to conservative treatment. Court-Brown [73] found 80% of good or excellent results after conservative treatment of valgus impacted fractures (Fig. 5.2). The degree of displacement had a negative, and increasing age a positive influence on the final functional outcome after 1 year. The authors recommended conservative treatment for valgus impacted three-part fractures in elderly patients.

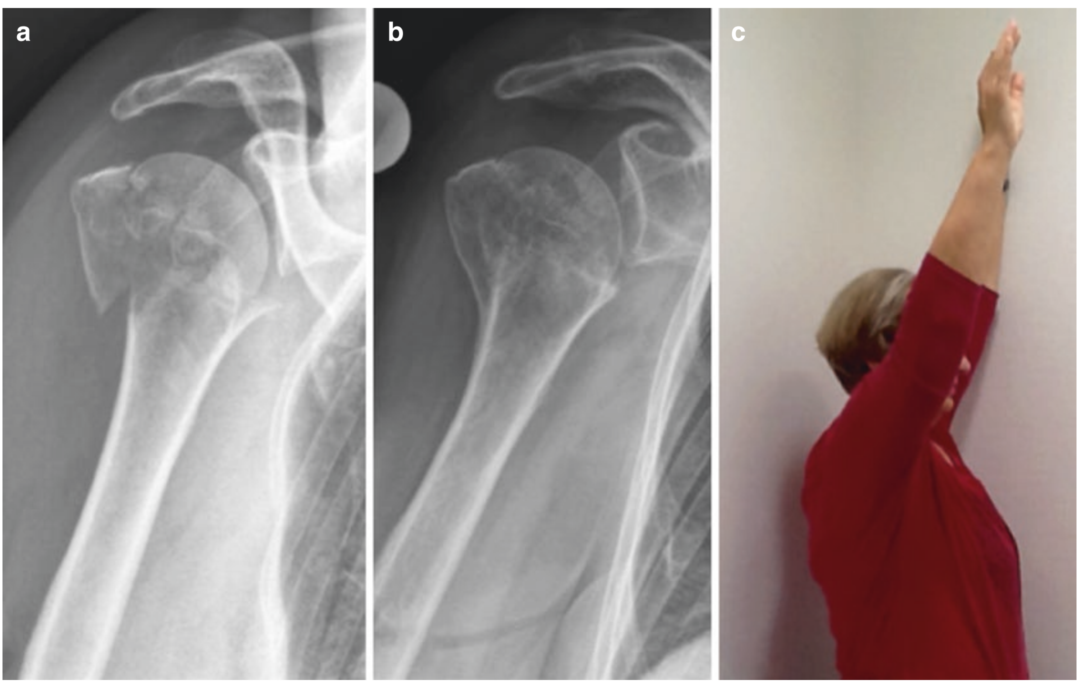

Fig. 5.2 (**a**) AP radiograph of a valgus impacted 2-part fracture of a 69 y.o. female. (**b**) AP radiographic follow-up after 1 year. (**c**) Clinical result (forward flexion) after 1 year

Scandinavian studies were then the first to prospectively randomise conservative versus surgical treatment for all three- and four-part fractures in the elderly (>60 years) [47, 48, 50]. None of these studies found a significant functional benefit of any operative treatment but they might have been underpowered to find such a difference. However, the authors concluded that the tendency of better functional results or quality of life after a surgical procedure has to be balanced against the higher risk of revision rates. They found that the overall acceptable outcome and limited need for surgical intervention might justify conservative treatment of elderly, low-demand patients with three- or four-part fractures.

Also the most recent Cochrane analysis found no difference between conservative and operative treatment in elderly patients with displaced proximal humerus fractures involving the surgical neck. However literature is not sufficient for strong treatment recommendations [62].

In Younger Patients

Now the question arises whether young(er) and active patients, who need maximal shoulder function to go back to work or sports as soon as possible, may tolerate less fracture displacement and malunion than elderly patients. Literature is scarce on this specific question, however a small number of studies had focused on conservative treatment and age groups. Koval et al. [66] found that conservative treatment in younger patients with one-part fractures showed a mainly successful outcome.

Hanson et al. also paid special attention to the conservative treatment of younger patients who are still working. They concluded that conservative treatment is safe and effective in AO 11-A and -B fractures (mainly one- and two-part surgical neck fractures).

This is in accordance to Court-Brown et al. [74] who looked at conservatively treated patients with varus impacted surgical neck fractures. All fractures healed and 79% showed good or excellent functional results independently from the final varus angle and age.

Therefore, it seems that even for young and active patients, conservative treatment of one-part fractures and some two-part fractures may be justified with acceptably satisfying results.

Conservative Treatment Protocol

Lefevre-Colau et al. [75] showed that physiotherapy with early mobilisation is safe for the conservative treatment of patients with stable impacted proximal humeral fractures. Patients in the early mobilisation group wore a sling for 4–6 weeks and started physiotherapy after 3 days with pendulum and passive ROM exercises. After 6 weeks, they started with active ROM exercises.

In case of unstable fractures, the arm can be immobilised in a sling for 2 weeks. Then physiotherapy may be started with pendulum exercises and passive elevation/abduction up to 90°. After 4–6 weeks, patients can be allowed a free active ROM [47, 48, 50].

Surgical Treatment

Despite the abundance of literature on surgical treatment of proximal humerus fractures, there is still no standard of care, and the main question of which patient and fracture is suitable for which surgical treatment remains unanswered. Surgeon's preference, patient's individuality, the high variety of fracture configurations, the difficulty in classification and the high number of different implants are the main reasons for these disagreements. Also, prospective studies comparing different treatment options for specific fracture types are relatively rare and the management and especially the surgical technique are mainly based on the surgeon's experience and preferences. However, with the large choice of different implants, there may not be a gold standard and it may be reasonable that each surgeon chooses the implant, which works best in their hands for the cases that need surgery. In the following, the most common implants for proximal humerus fractures are described including their range of indications according to the most recent literature.

Conventional (Non-locking) Plate

Before the appearance of anatomically preshaped, angular stable plates for the proximal humerus, one third tubular plates or T-plates were used for open reduction and internal fixation of all types of fractures of the proximal humerus [76–79]. Nowadays, some surgeons still use them mainly for more stable valgus impacted fractures.

However, newer and specifically preshaped plates have widely replaced the conventional ones.

Locking Plate

In biomechanical studies angular stable locking plates have shown some advantage compared to conventional plates [80]. These implants are currently the ones most widely used for proximal humeral fractures. Reports in the literature vary in terms of complications and revision rates but it seems that along with their broad use their indications have been expanded to all types of fractures. This might explain why reports about complication rates up to 49% can be found [2, 4–6, 69]. As a shoulder referral centre, we have seen several devastating situations after locking plate ORIF of proximal humerus fractures with often limited options for revision surgery [7]. Thus, it has been our priority to find predictors for complications and to consequently lower the complication rate after such operations. Further analysis of complications showed the following fracture characteristics to be at risk for later failure: a markedly displaced anatomical neck fragment, fracture-dislocations and head-splits [2, 3, 69]. Predictors for failure or impaired outcome were found to be: low BMD, increasing age, non-anatomical reduction of the medial hinge and smoking [2, 28–30, 81].

Percutaneous Fixation

The general advantage of closed reduction and fixation is minimal impairment of the vascular supply to the fragments. This technique has been modified from sole pin fixation to a "humerus block" fixation with pins and screws [82] or to a hybrid external fixation [83]. The indications for this technique are mainly based on the surgeon's experience with it. Good indications are described to be: surgical neck fractures with avulsion of the greater tuberosity and displaced articular segment fractures with valgus impaction or little medial displacement. Severely displaced articular segment fractures and fracture-dislocations [82] as well as comminution of the surgical neck, the medial calcar or the greater tuberosity are relative contraindications for this technique, as primary stability is much more difficult to achieve and maintain [28].

Intramedullary Nail

Some surgeons prefer the use of antegrade locked nails for the treatment of proximal humerus fractures, either minimally invasive [84] or through an open approach [85]. The results seem to be comparable to locking plate ORIF [84, 86]. However, a recent systematic review revealed that the indications for nailing may be limited to two-part surgical neck and three-part fractures as the complication rate of four-part fractures was found to be up to 63% [87].

The Da Vinci System

An interesting new device has been introduced by Russo et al. [88, 89]. The so-called "Da Vinci System" is a triangularly shaped, hollow cage, which can be put into the bone void after the reduction of the head fragment. This intraosseous device gives further support and stability to the head fragment and prevents secondary dislocation. This cage may be combined with screws, plates and screws or pins and according to the results of the inventor, even three- and four-part fractures may be treated successfully [89].

Hemiarthroplasty

Before reversed total shoulder arthroplasty (RTSA) was introduced, hemiarthroplasty was the mainstay of treatment for fractures that could not be reconstructed. Originally, Neer proposed primary hemiarthroplasty for four-part fractures, four-part fracture-dislocations and fractures with more than 50% of cartilage-covered articular defect [1]. The clinical results have consistently been reported as unpredictable mainly because of malunion of the tuberosities [90]. However, hemiarthroplasty may result in good functionality if the fragments heal in place and anatomical relations can be restored [70, 71, 91–94].

Reverse Total Shoulder Arthroplasty (RTSA)

Primary RTSA is becoming an increasingly popular option for the treatment of proximal humerus fractures, especially in the elderly patient. Compared to primary hemiarthroplasty, it has been shown that clinical results are better and more predictable with an even lower revision rate [95–99]. Looking at these results, one might be tempted to use this treatment option also in younger patients if the fracture is not reconstructable. However, long-term results on primary RTSA for fractures are only available from small case series [100, 101]. Considering the invasiveness of this implant and possible problems like infection or long-term deterioration of the deltoid muscle as well as glenoid loosening [102], stronger long-term data should first be available to guide its use. Therefore, primary RTSA should mainly be considered for patients over 70 years of age [103] with fractures that cannot be treated conservatively, either due to high functional demands or persistent pain.

One current dilemma is that, on one hand we have the RTSA promoted as an intervention with more predictable results but mainly reserved for elderly patients and on the other hand, a hemiprosthesis which results in less predictable results, recommended for younger patients with non-reconstructable fractures and higher functional demands. A possible solution may be to lower the age cut-off for RTSA with all its concomitant risks. In any case, more scientific efforts are needed to find better solutions for young patients to spare the glenoid, a structure not usually affected by the initial injury [104].

Authors' Preferred Treatment Algorithm

In our opinion, a 16-year-old patient with a three-part fracture needs different treatment than a 90-year-old patient with the same fracture who lives in a high level of care nursing home. If both had a displaced fractured neck of femur and were unable to walk, everybody would agree that both needed surgery. However, for proximal humerus fractures, the crucial question seems to be: "how much shoulder function does a patient need to reach his/her maximum quality of life after treatment?" Young patients have high expectations and need maximal shoulder function for their work and their lives at home, whereas some elderly patients may only desire to be free of pain and are content with limited shoulder function as long as they don't need surgery. In our opinion, treatment should be adapted to the patient's needs and expectations first and second to the biological conditions and then to the fracture pattern itself. As it is difficult to draw a clear line at a certain age, bone quality is helpful to assess at least the biological age of the patient's proximal humerus. Therefore, we developed and published a first suggestion of an evidence based treatment algorithm, which includes conservative and operative treatment for patients of different ages and with different demands [11]. In this section, we present and discuss the evidence the algorithm is based on, as well as our preliminary clinical results with the use of an adjusted version (Figs. 5.3 and 5.4).

The Young and Active Patient

These patients usually have good bone quality and need to return to work as soon as possible. Thus, the aim is to regain maximal shoulder function and our treatment pathway is depicted in Fig. 5.3. The range of non-surgical treatment in these patients is limited to one-part fractures except for isolated fractures of the tuberosities. We use CT scans to assess the exact degree of displacement and prefer operative treatment in the case of more than 5 mm of superior displacement of the greater or more than 5 mm of medial displacement of the lesser tuberosity [52, 53]. Small avulsions are usually treated arthroscopically with a double row or a suture bridge technique. For large fractures of the greater tuberosity we use a lateral one-third tubular buttress plate.

Two-, three- or four-part fractures as well as fracture-dislocations and head-split fractures are usually treated with ORIF in young patients.

We prefer the deltopectoral approach and use an angular stable implant. In case of unstable and severely displaced three- or four-part fractures ORIF is attempted whenever possible. However, if the head fragment shows no borehole bleeding and no stable reduction is possible, we change to primary hemiarthroplasty with modularity, which allows a later conversion to a RTSA without the need of changing the stem.

The Elderly Patient

We generally differentiate between elderly patients with high or low demands. Patients who exercise regularly (e.g.: walking, swimming, ski-

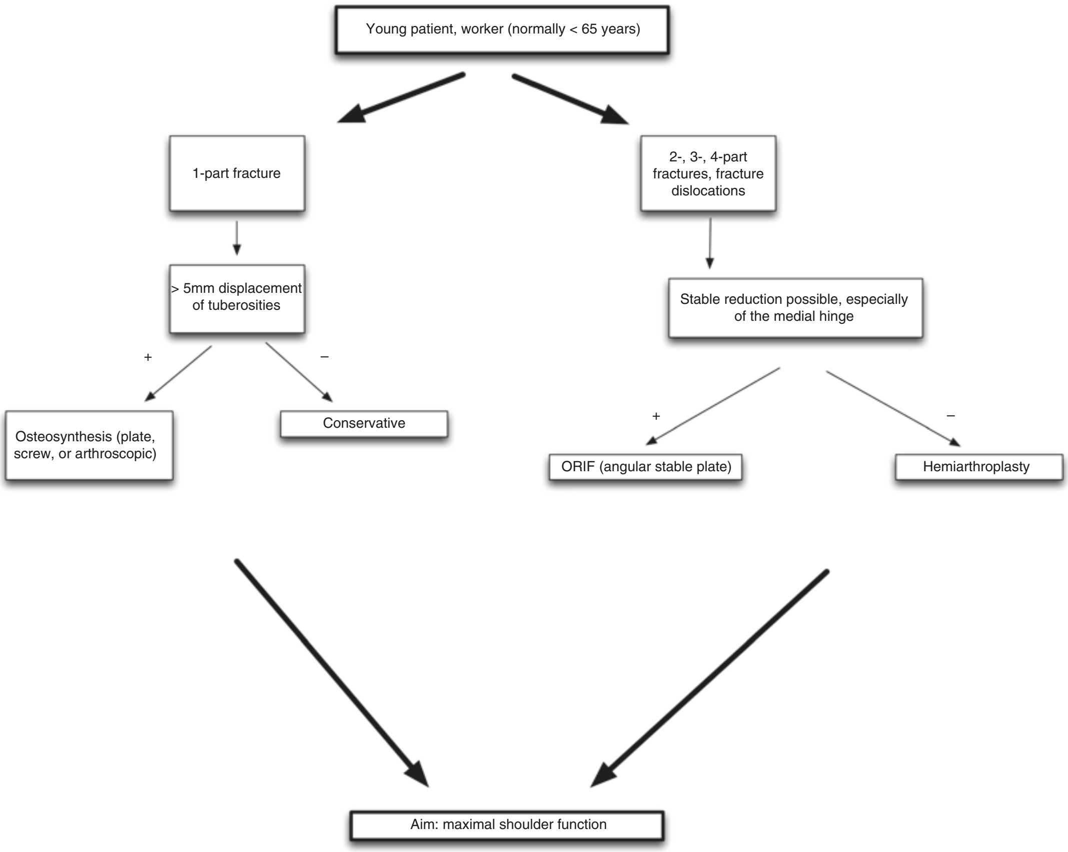

Fig. 5.3 Authors' preferred treatment strategy for younger and active patients with the aim of maximal shoulder function after treatment. (ORIF open reduction and internal fixation)

ing, golf, tennis) and live independently are classified as high-demand requiring maximal shoulder function. On the other hand, patients who can hardly fend for themselves and need regular help for daily living are classified as low-demand and do not require full shoulder function. We treat these patients conservatively whenever possible [47, 48, 50]. Only persistent pain would be an indication for surgery, which would then be a hemiprothesis.

Elderly patients with high needs are further assessed for osteoporosis using the Deltoid tuberosity index (DTI) (Fig. 5.1). If the bone quality is good (DTI > 1.4), we treat them in the same manner as young patients (Fig. 5.3) with the exception of using primary RTSA rather than hemiarthroplasty in patients older than 70 years. The algorithm for treatment of patients with osteoporosis is shown in Fig. 5.4. The indication for non-operative treatment is broader and includes all one-part fractures, even 1 cm displacement of the tuberosities. Also varus or valgus impacted two-part surgical neck and valgus impacted three-part fractures are treated conservatively (Fig. 5.2) [74, 105]. Valgus impacted four-part fractures with less than 1 cm displacement of the tuberosities in relation to the head fragment (centre of rotation) are not treated surgically either. Thus, in this population with limited bone quality our indications for angular stable ORIF are narrowed down to severely displaced fractures, which can be fixed in a stable manner, in patients <70 years (Fig. 5.5). Otherwise, we prefer prosthetic replacement for

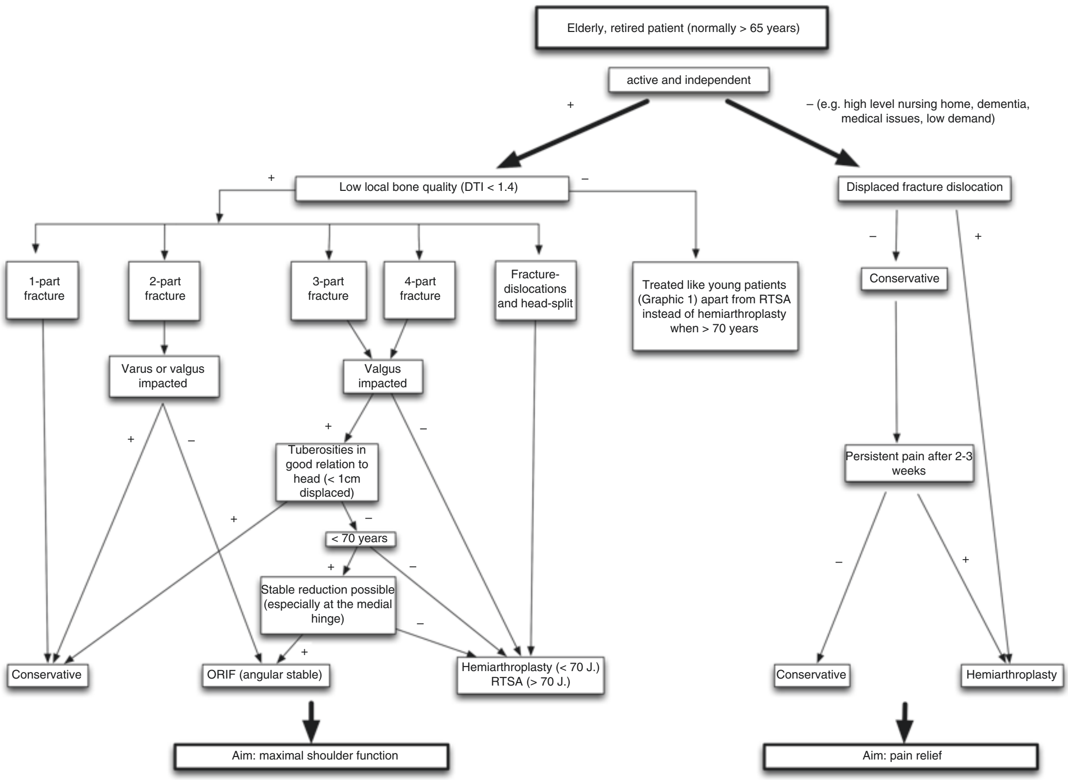

Fig. 5.4 Authors' preferred treatment strategy for elderly patients (>65 years) with either aim of maximal shoulder function or pain relief after treatment. (ORIF open reduction and internal fixation, RTSA reverse total shoulder arthroplasty)

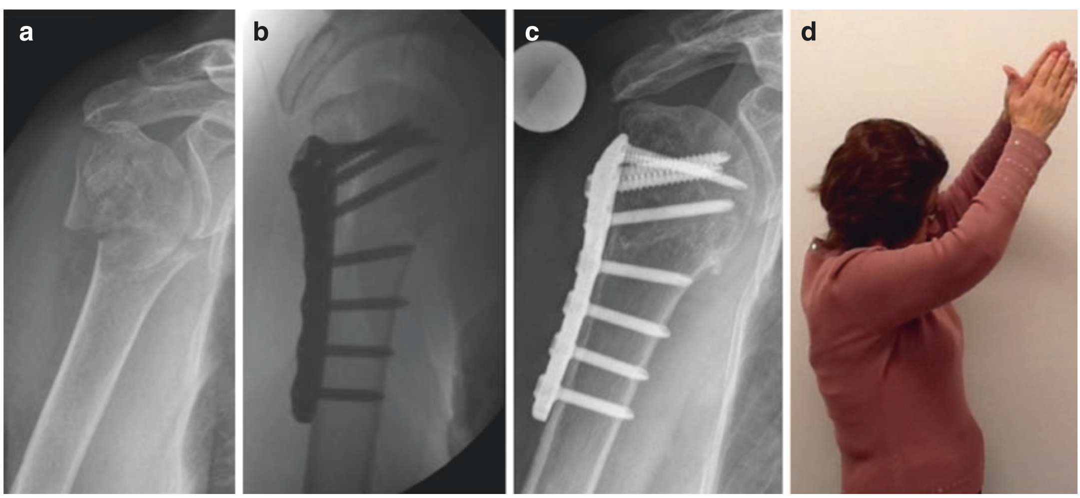

Fig. 5.5 (**a**) AP radiograph of a not impacted 2-part surgical neck fracture of a 65 y.o. female with limited bone quality (DTI < 1.4). The indication to ORIF was made according to the algorithm. (**b**) direct postoperative radiograph after angular stable ORIF. (**c**) AP radiographic follow-up after 1 year. (**d**) Clinical result (forward flexion) after 1 year

severely displaced three- and four-part fractures and fracture-dislocations (RTSA when patients are older than 70 years).

Clinical Pearl
There is significant debate and disagreement between the roles of conservative and operative intervention for proximal humeral fractures. Many factors have to be considered including the nature of the injury, the status or age of the patient, the bone quality and finally patient expectations.

Surgical Technique/Rehabilitation

Authors' Preferred Technique for Locking Plate ORIF

Positioning Techniques and Surgical Approach

The patient is positioned in a beach chair position, the arm draped free and positioned in a hydraulic device (e.g. Spider Limb Positioner; Smith & Nephew, London, U.K.). The image intensifier is placed over the shoulder from the top end of the table and covered with sterile drapes for free manipulation and independent use by the surgeon [106]. For open shoulder surgery we mainly use the deltopectoral approach, which has an internervous plane with minimal risk of nerve injury, can be safely extended distally and used for further revisions in the future. An approximately 8 cm long incision is made from the tip of the coracoid aiming to the middle of the upper arm. After identifying the cephalic vein, it is retracted laterally and the deltopectoral interval is sharply opened down to the conjoining tendon, which is retracted medially with a Langenbeck retractor. An 8 mm Hohman retractor is then placed on the top of the coracoid and the aperture is opened distally up to the insertion of the deltoid muscle. A blunt Eva retractor is placed laterally around the humerus directly proximal to the deltoid insertion. The plane between the deltoid and the rotator cuff is dissected in order to put a Browne Deltoid Retractor (Arthrex, Naples, Florida) around the proximal humerus. During this manoeuvre, special attention must be paid not to further displace the greater tuberosity fragment. As a next step, the tendon of the long head of the biceps is identified. If it is unstable and/or damaged, either the rotator interval or the cuff tear resulting from the fracture is extended slightly lateral to the bicipital groove towards the coracoid for tenotomy or tenodesis. We use heavy non-absorbable stay sutures (No 2 FiberWire; Arthrex, Naples, Florida), at least one for each tendon (subscapularis, supraspinatus, infraspinatus, teres minor). These stay sutures are kept during the surgery for better control of the reduction and later fixation to the plate as a tension band construct (even for two-part surgical neck fractures with intact tuberosities).

Reduction and Fixation Techniques

Generally, dissection and soft tissue damage should be kept minimal during the operation. The joint may be seen through the above-mentioned opening of the interval. The rest of the reduction depends on the type of fracture.

In case of valgus impacted fractures, the plate may be preliminarily fixed to the shaft with a conventional screw for indirect reduction using ligamentotaxis. The tuberosities can be pulled towards their anatomical position while the head is disimpacted and laterally lifted into normal angulation through the fracture gap between the tuberosities. Once the tuberosities can be brought together laterally, the plate can be slowly pressed against them by tightening the conventional screw. This results in an indirect reduction of the humeral head fragment with stable fixation of the fracture parts. If necessary, the space created behind the humeral head can be filled with bone substitute before this manoeuvre [78, 107], but we rarely use this option. Finally, further head and shaft screws may be applied and the tuberosities fixed to the plate using the stay sutures.

For unstable surgical neck fractures, we preposition two intramedullary K-wires (2 mm) (Fig. 5.6). To avoid later conflict with the plate, they are introduced percutaneously about 5 cm distal to the approach. The reduction may then be achieved with indirect manipulation of the arm (flexion and ab- or adduction) using the hydraulic positioner and the K-wires protruded to fix the head preliminary (Fig. 5.6b). In case of an unstable reduction at the calcar, we aim for impaction of the head on the shaft to prevent later varus collapse and secondary screw cut outs (Fig. 5.6c, d).

For severely displaced 3- and 4-part fractures, we try to proceed in the same way. Firstly, prepare the intramedullary K-wires, then we reduce the head fragment into a valgus position with as minimal soft tissue dissection as possible. Then the steps are the same as for the above-mentioned valgus fracture (Fig. 5.7).

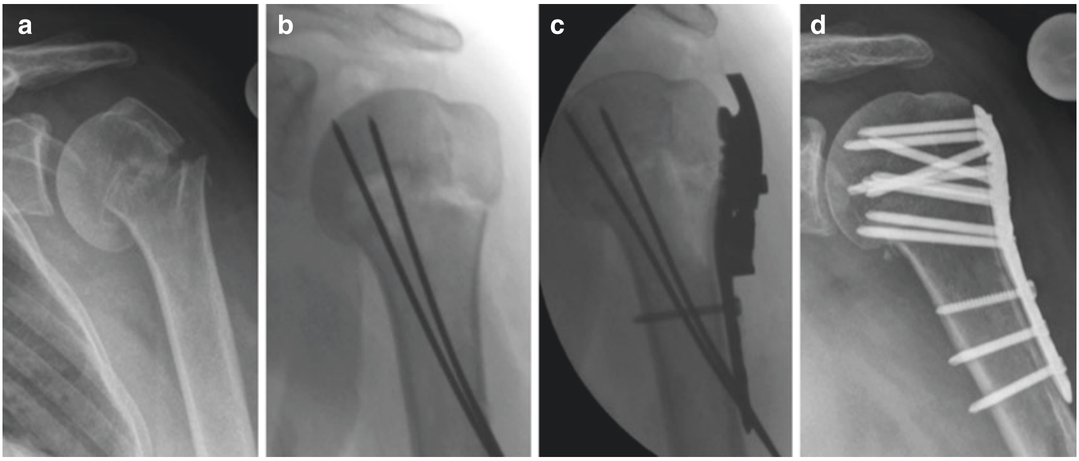

Fig. 5.6 (**a**) Radiograph of a varus displaced 2-part surgical neck fracture of a 35 y.o. female. (**b**) Reduction of the head fragment and preliminary fixation to the shaft with two previously introduced intramedullary K-wires (2 mm). (**c**) Final reduction by tightening the conventional screw of the plate first. (**d**) AP radiographic follow-up after 3 months

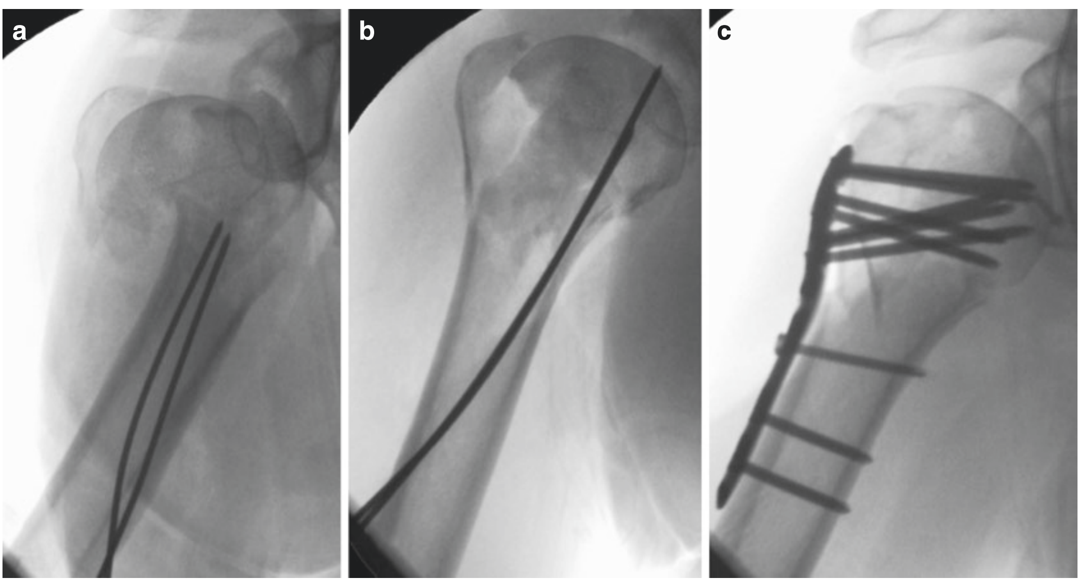

Fig. 5.7 (**a**) Intraoperative radiograph of a 4-part fracture of a 45 y.o. male. The head fragment has been put into a valgus position after the placement of two intramedullary K-wires. (**b**) From the valgus position, the head has been reduced to the shaft and preliminarily fixed with the K-wires. (**c**) Definitive fixation with plate and screws after the reduction of the tuberosities

The Minimal Invasive Plate Osteosynthesis (MIPO) Technique for Locking Plates

A minimally invasive technique has also been described for the use of locking plates [108–110]. The axillary nerve should be marked approximately 5–6 cm distal to the edge of the acromion. After the deltoid-split approach, sutures are placed in the rotator cuff tendons and preliminarily fixed to the plate. The plate is inserted underneath the deltoid muscle, always in contact to cortical bone, with a Langenbeck retractor securing the axillary nerve. Under fluoroscopic control, a stab incision is made for the most distal hole. Also, plate-specific aiming devices are available and useful for this technique. The plate is fixed to the head proximally with K-wires. The most distal hole of the plate must be placed in the middle of the shaft and can therefore be temporarily secured by drilling and leaving the bur in situ. A conventional screw is placed in the hole distal to the surgical neck fracture and tightened to the shaft. This results in indirect repositioning of the head in case of valgus displacement. At the end, the proximal locking screws and the already drilled distal locking shaft screw are inserted and the prepared rotator cuff sutures are fixed to the plate [108].

Percutaneous Fixation Techniques

Resch et al. described their detailed reduction technique [82, 111]. For reduction an elevator or a pointed hood retractor can be inserted through a small incision, the fragments can be fixed internally with 2–2.5 mm threaded K-wires. Depending on the displacement of the fragments they may be reduced with separate manoeuvres. First, axial traction to the adducted and internally rotated arm is needed to reduce the surgical neck fracture. The reduction is then secured with two or three K-wires drilled from inferior to superior, starting at the deltoid tuberosity. Then, the arm can be carefully returned to neutral position. In a second step, the greater tuberosity can be grasped with the help of a pointed hook retractor, which is inserted through the subacromial space. The greater tuberosity fragment is pulled in anterior and lateral direction until it reaches its anatomical position. It can be fixed with K-wires and its correct reduction is checked with internal and external rotation of the arm under fluoroscopy. Also, cannulated screws can be inserted over the K-wires for definitive fixation of the greater tuberosity. The pins can either be buried under the skin or left to protrude through the skin. They may be removed after 4–6 weeks under local anaesthesia.

Authors' Preferred Technique for Hemiarthroplasty

As a first step, all rotator cuff tendons are secured with at least one stay suture to secure the tuberosities. The articular segment is retrieved and saved as a potential bone graft.

The glenoid is examined for evidence of cartilage defects.

Together with preoperative CT planning, the medial calcar area is used as a bony landmark for proper positioning of the implant's humeral component. If the calcar is fractured as well, the insertion of pectoralis major may be used as a consistent reference to measure the height of the prosthesis with a specific measuring device. We aim for 20° of retroversion of the shaft to recreate anatomical conditions and perform a tenotomy (or tenodesis) of the long biceps tendon, as this has been shown to be beneficial for the functional outcome [112].

Before cementing the humeral implant, the shaft is prepared for the refixation of the tuberosities. Holes are drilled in the shaft so vertically oriented sutures can be used to repair each tuberosity. A preliminary reduction is then performed so that the tuberosities can be held together with a towel clip while determining proper head height.

We use a cemented implant in most of the cases as the fractured metaphysis may not allow enough press fit for the round shaft. We pay a lot of attention to the fixation of the tuberosities (No 2 FiberWire; Arthrex, Naples, Florida). We fix them to the humerus shaft and to the prosthetic stem with four sutures which go through the medial part of the prosthesis. Two of them are put around both tuberosities, the other two around each tuberosity separately. Then two further vertical sutures are used to fix each tuberosity to the stem through the pre-drilled shaft holes. Finally the stay suture of the greater is fixed to the stay sutures of the lesser tuberosity.

Authors' Preferred Technique for Reverse Total Shoulder Arthroplasty

We use a CT scan to assess the glenoid bone quality (e.g. cysts) and version, which should be corrected to 0° during surgery, but this is rarely necessary in fracture cases. The tuberosities are grasped with sutures as described above and retracted to remove the head fragment. The most anterior part of the supraspinatus tendon and the long biceps tendon are cut for better exposure of the glenoid. In our opinion it is important that the tuberosities are reduced and fixed to the shaft and prosthesis to restore at least some external and internal rotation [9, 10, 113]. Fixation of the greater tuberosity is of higher priority compared to fixation of the lesser tuberosity.

The anteroinferior capsule is only partially removed for good access to the glenoid; the labrum is completely removed circumferentially; the triceps is slightly released to identify the lateral border of the scapula. After reaming off the cartilage and correcting the glenoid version to 0° (if necessary), the baseplate should be orientated flush to its inferior border and centred in the anterior-posterior direction with a slight inclination of maximally 10°. After fixation of the baseplate and the insertion of the glenosphere, the shaft is prepared aiming to achieve 20° of retroversion. The correct height of the prosthesis is crucial; if the calcar is intact it can be used as reference together with preoperative CT planning. If the calcar is fractured, the correct height can be planned with additional full length X-rays of both upper arms [114]. A preliminary reduction can be made to test the laxity and stability of the joint before the definitive stem is inserted (cemented or uncemented) to the planned height. The sutures for fixation of the tuberosities are prepared the same way as described for hemiarthroplasty (see description above). After a careful trial reduction, soft tissue tension and distraction of the components is assessed and can be corrected with the use of different inlays. The goal is to achieve stability in all directions with no gapping when pulling on the arm. Finally, the tuberosities are fixed back to the stem and the humerus shaft as described above (Fig. 5.8).

Postoperative Rehabilitation

Independently from the type of technique for osteosynthesis, postoperative treatment mainly depends on the stability achieved. Stable reductions and fixations may be passively mobilised immediately after surgery and a sling used for 6 weeks. Active ROM exercises are usually started after 6 weeks and muscle strengthening exercises after 3 months. However, the relatively high rate of reduction failures even with the use of rigid angular stable implants has called early mobilisation after this procedure into question [115].

In our opinion, follow up care of three- or four-part ORIF, primary hemiarthroplasty or RTSA is limited by the healing of the tuberosities to the stem and to each other. As a stiff shoulder or prosthesis is still better to treat than displaced tuberosities, we use a more restrictive mobilisation algorithm. Patients wear a sling for 6 weeks and pendulum exercises are started 2 weeks postoperatively. Passive and active assisted mobilisation with the arm in neutral rotation is allowed up to an elevation and flexion of 90° in the fifth and sixth postoperative weeks. After the first clinical and radiographic control at 6 weeks, free active and passive ROM are permitted. Muscle strengthening is usually started after 3 months.

Fig. 5.8 (**a**) AP radiograph of a proximal humerus fracture of a 78 y.o. female. (**b**) 3D CT-reconstruction of the fracture shows severe displacement and involvement of the tuberosities. The indication for primary RTSA was made according to the algorithm. (**c**) Directly postoperative after implantation of a RTSA. (**d**) AP radiographic follow-up after 1 year. (**e**) Clinical result (forward flexion) after 1 year

Results

Outcome After Open and Minimally Invasive Osteosynthesis

The fragile blood supply and the often limited bone quality of the humeral head may be the two main reasons for failure after any kind of osteosynthesis. However, if a stable construct can be achieved with any kind of fixation, it appears that the fracture will heal without limiting sequelae resulting in good function. As it seems, any kind of technique has its pros and cons and is dependent on the surgeon's experience with it.

Conventional ORIF

Wanner et al. [76] reported their results after the use of double-plates in mainly three- and four-part fractures. The mean Constant score was 61 points (75% of the contralateral side) at a mean follow-up of 17 months. The functional results were rated to be good or excellent in 63% of patients. The authors concluded that the use of double-plates achieved good stability that allowed early mobilisation.

Bastian and Hertel [41] reported their results with mainly three- and four-part fractures, they found a mean Constant score of 77 points and a mean SSV of 92% after a mean follow-up of

5 years. They concluded that conventional osteosynthesis is worth considering in displaced fractures when adequate and stable reduction can be achieved intraoperatively.

Angular Stable ORIF

Südkamp et al. [6] first reported on a relatively large collective retrospectively. All types of fractures were included. After a mean follow-up of 12 months, the mean Constant score was 70 points (85% of the contralateral side) and 34% of complications were found, of which most were due to incorrect surgery. They concluded that angular stable ORIF provides good functional results as long as used with correct surgical technique.

Sproul et al. [5] did a systematic review. They found a complication rate of 33%. The mean Constant score was 74 points and the reoperation rate 16%. They concluded that the complication and reoperation rate is high with the use of these implants.

Acklin and colleagues [109] conducted a prospective study on patients treated with the MIPO technique. The mean Constant score at the latest follow-up was 75 points and the complication rate 19%, of which 4% of axillary nerve lesions were observed without clinical consequences. They concluded that the MIPO technique resulted in a relatively low complication rate with good functional results.

Percutaneous Fixation Techniques

Resch et al. [82, 111] found good reduction and healing results for almost all treated fracture types in their initial study with Constant scores around 90% compared to the uninjured side.

Also Brunner et al. [116] found mainly good functional results after the use of "humerus block". The overall mean Constant score was 73 points, 88% compared to the uninjured side. However, the 40% rate of unplanned surgery with either change or removal of the implant was relatively high.

Outcome After Hemiarthroplasty

The results after hemiprosthesis are very inconsistent and it still seems difficult to achieve a predictable and reliable clinical outcome. The main reason for this is the unsolved problem of the tuberosities. If they heal in anatomical position, the clinical result is usually good, but if they don't, the outcome will usually be a pain free shoulder without function. As long as there is no better solution to improve the healing of the tuberosities, hemiarthroplasty will mainly remain a good treatment for pain with low revision rates.

Boileau and colleagues [70] retrospectively reviewed their patients after a mean of 27 months after hemiarthroplasty and found Constant scores of 56 points with 58% of satisfied or very satisfied subjective results and a mean forward flexion of 101°. Final malposition of the tuberosities correlated with unsatisfactory results.

Fucentese et al. [93] reported their series with the use of a large metaphyseal volume prosthesis and found a mean Constant score of 59 points after at least 2 years of follow-up. However, White et al. [90] were not able to reproduce these results with the same prosthesis and found only a mean Constant score of 34 points after at least 2 years. They reported resorption of the tuberosities in more than 50% of their patients.

Park et al. [94] published their retrospective series of a low volume metaphysis prosthesis with bone block autograft. After a mean follow-up of 54 months, they found mainly good clinical results with a mean forward flexion of 125° and only two patients where the tuberosities did not heal.

Outcome After Reverse Total Shoulder Arthroplasty

Throughout recent literature, it seems that very consistent clinical results may be achieved with the use of RTSA for proximal humerus fractures. The tuberosities should be fixed, at least the greater tuberosity, to restore some external rotation. The complication and revision rate is still low. However, the longest follow-ups are small case series with a mean of 5–8 years.

Cazeneuve et al. [100] have so far the longest follow-up period with a mean of 86 months. They resected the tuberosities in nearly 2/3 of the patients. In their analysis, they found a mean Constant score of 60 points, with better results in terms of internal and external rotation in patients with fixed tuberosities.

Russo et al. [101] reported their results with a mean of 5 years of experience. They paid special attention to attaching the tuberosities with the help of a bone graft retrieved from the head. They found mean Constant scores of 73 points.

Grubhofer et al. [10] published their results after a mean of 35 months. In their retrospective case series, they found a mean Constant score of 62 points (86% compared to the uninjured side) and a mean subjective shoulder value of 83% with significantly better function in patients with healed tuberosities.

Chun et al. [9] did a recent study on their outcome after RTSA for proximal humerus fractures. Their mean follow-up was 36 months and they analysed their patients with special focus on the healing of the tuberosities. The Constant score was not different between patients with and without healing of the tuberosities (68 and 64 points). However, in terms of external rotation, patients with healed tuberosities had significantly better results.

Authors' Opinion: Preliminary Results of the Treatment Algorithm

In 2014, we started to treat our patients with proximal humerus fractures according to an evidence-based treatment algorithm and followed them prospectively (Figs. 5.3 and 5.4). In the emergency department, patients are first evaluated in terms of their needs and dependency and the pre-injury quality of life is assessed with the EQ-5D score. Clinical and radiographic examinations take place at first presentation, after 3 months, after 1 and 2 years. With this study, it is our aim to assess the clinical feasibility of such an algorithm in a teaching hospital like ours (level-1 trauma centre in Switzerland) and to follow all the patients closely with special focus on their quality of life 1 and 2 years after the injury. This prospective non-randomised study is still on going but we are able to present preliminary 1-year results of the first 60 patients included.

The mean age of the patients was 69 years (SD: 17.4) with 75% females and 25% males included. A total of 84% of the patients have been treated according to the algorithm, whereas unclear fracture criteria and intraoperative decisions were the main reason for deviation from the algorithm. In total, 36 patients (60%) have been treated conservatively, 14 (23%) with locking plate ORIF and 10 (17%) with hemiarthroplasty (n = 2) or RTSA (n = 8). Whereas the collective is too small to perform subgroup analyses of each treatment option, we are able to draw a first conclusion on the overall results and it looks promising so far. On one hand, the spectrum of treatment seems to be well balanced with nearly equal distribution of ORIF and arthroplasty and conservative treatment as the mainstay. On the other hand, the mean objective and subjective functional results are satisfying for each group (Table 5.1). Especially good quality of life 1 year after trauma supports our theory of tailored indications for the treatment of proximal humerus fractures (Table 5.2).

Overall, 7 patients (12%) had further surgery. Five of them were from the ORIF group including one conversion to RTSA due to secondary fracture displacement; the plate was removed four times due to patient's wish, stiffness and/or impingement. One infection occurred in a patient treated

Table 5.1 Preliminary clinical 1-year results

Mean	CS (pts)	Percentage of uninjured side (%)	SSV (%)
Conservative (n = 36)	76	95	87
ORIF (n = 14)	62	76	73
Prosthesis (n = 10)	70	87	83

CS constant score, *SSV* subjective shoulder value

Table 5.2 Preliminary 1-year quality of life

Mean	EQ-5D (1 = max.)		
	Pre Fx	3mt	1y
Conservative (n = 36)	0.9	0.8	0.9
ORIF (n = 14)	0.87	0.75	0.85
Prosthesis (n = 10)	0.9	0.75	0.9

with hemiarthroplasty that needed revision and finally implantation of RTSA. Of the conservatively treated patients, only one secondary ORIF was needed due to further fracture displacement.

Complications

Complications After Nonoperative Treatment

In our experience with a specifically selected collective of patients for conservative treatment (Figs. 5.3 and 5.4), we found mainly satisfying objective and subjective results 1 year later (Fig. 5.2). Impingement or limited ROM may be a sequelae of the not anatomically healed fracture. However, most of the patients don't wish further treatment, as they are not significantly bothered by these symptoms. In the above-mentioned collective, only 1 patient with conservative treatment needed secondary surgery due to severe early displacement of the fracture.

Looking at the literature, conservatively treated one-part fractures may result in limited ROM, especially internal and external rotation [67]. Markedly limited shoulder function, mainly due to stiffness, occurred in up to 10% of the patients [66]. However, nonunion and avascular necrosis (AVN) are very rare and have not been described for such fractures [66, 67]. Conservatively treated two- and three-part fractures can result in impingement, nonunion, and also AVN has been described. But the rate of these complications depends on the primary stability of the fracture type [58, 74, 105].

Complications After Open and Minimally Invasive Osteosynthesis

Looking at our preliminary results of specifically chosen patients for locking plate ORIF (Figs. 5.3 and 5.4), we still see a relatively high complication rate with need for secondary surgery. About one-third of our patients required at least a second operation to remove the plate either due to patient's wish or some kind of impingement or stiffness. Furthermore, we performed one secondary RTSA for a patient with early failure after ORIF. However, as bone quality is a high selection criterion in our treatment algorithm, we have not seen any secondary head screw cut out so far, which used to be the most common complication of these implants. As a consequence of these results, we changed our implant to a less prominent one. Further analysis of our results will show whether the selection criteria for ORIF, especially in elderly patients with limited bone quality, should be even stricter to not put them at risk for a second operation.

Complications After Conventional ORIF

The most frequently reported complication after open reduction with conventional plate fixation is partial or total AVN with a large range from 0% to 50%, [42, 76, 78, 79] occurring less often in valgus impacted fractures [78]. Total head collapse was reported in about 15% of patients treated [42, 79]. Further complications which led to revisions were: impingement, loss of reduction, loosening of screws and failure of the implant. The revision rate is reported to be between 0% and 40%, whereas most revisions included removal of screws or the implant [42, 76, 78, 79]. The rate of conversion to arthroplasty was about 1–5% [76, 79].

Complications After Angular Stable ORIF

Generally, the complication rate after angular stable implants varies between 10% and 49% with revision rates up to 25% [2, 4–6, 109, 117]. The rigid fixation of multiple head screws in the plate led to new, implant-specific complications such as screw cut outs into the joint involving the glenoid as a further devastating complication [7]. Thus, it is crucial to check the screws first intraoperatively to preclude primary screw cut outs [6, 7, 117]. We published a series of intraoperative fluoroscopic projections including AP views in internal, neutral and 30° external rotation as well as an axial view with 30° abduction to detect primary screw cut outs [118].

In larger series or systematic reviews, the rate of partial or total avascular necrosis (AVN) is reported to be between 4% and 54%, depending on type of fracture (highest for fracture-dislocations and head-splits) [2, 3, 5, 6, 117, 119]. The rate of secondary varus displacement is reported to be up to 25% [4, 5]. The occurrence of secondary screw cut out, after AVN or secondary varus displacement, is consistently reported to be between 6% and 11% and thus the most common complication of these implants needing revision surgery [2, 5, 6, 109, 117]. A further complication, which is primarily related to the MIPO technique, is axillary nerve injury. This reported to be between 0% and 4% [109, 110].

Complications After Percutaneous Fixation Techniques

Low BMD and comminuted medial hinge are relative contraindications for this technique because of increased risk of reduction failure or pin migration [28].

If the pins are left outside the skin, pin track infection can require early removal of the pins and additional treatment with systemic antibiotics. The rate of this complication is reported to be 8% [120]. Pin migration however, is a frequent complication related to this technique. It was mainly found in patients with osteoporotic bone [28, 82, 83, 111]. To solve this problem, angular stability of the pins with either a "humerus block" [82] or a hybrid external fixation [83] has been invented. However, even with this more rigid fixation technique the pin cut out rate has been reported to be up to 22%. The 40% rate of unplanned surgery including early change or implant removal was also afound to be relatively high [116]. The rate of partial or total AVN has been reported to occur in 4–21% of patients treated [82, 83, 120].

Complications After Hemiarthroplasty

In our above-mentioned collective, we implanted only two hemiprostheses in younger patients with not reconstructable fractures. One of these patients contracted an infection and later required revision to RTSA. This number is too small to draw conclusions on complication and revision rates, but it shows that we hardly use this implant any longer. In younger patients with good bone quality, we encourage osteosynthesis and in the elderly, we prefer primary RTSA.

Generally, the main reason for limited function after hemiarthroplasty is malpositioning or secondary displacement of the greater tuberosity, which is reported to occur in up to 50% of the patients treated [70, 71, 90]. Increasing age, osteoporosis and female gender are risk factors for this type of complication [70, 71, 121]. Also proximal migration of the prosthesis with decrease of the acromio humeral distance is a relatively frequently observed complication with an incidence of up to 30%, correlated to impaired shoulder function [70, 72, 122]. Radiographic signs of heterotopic ossification are reported in up to 25% of the patients treated but its clinical relevance is debatable [70, 72]. The dislocation and infection rate of primary hemiarthroplasty is about 1% [70, 122, 123]. The general revision rate is low and the overall rate of prosthetic survival was found to be 97% at 1 year, 95% at 5 years and 94% at 10 years [99, 121].

Complications After Reversed Total Shoulder Arthroplasty

In our experience, primary RTSA leads to more predictable and satisfying results. So far, none of our patients with primary RTSA needed any kind of revision surgery. But we need to keep in mind, that, generally, the threshold to revise RTSA may be much higher than to revise hemiarthroplasty.

As no strong long-term data on RTSA for fracture treatment is available, we have to look up these results for RTSA in general. Bacle and Walch recently published their experience with a mean follow-up of 150 months. They report a general decrease in function between midterm and long-term follow-up. An explanation for this finding may be the general ageing of the patients as well as deterioration of deltoid function. In their series, the complication rate was 29% and revision rate 12%. In the first 2 years of follow-up, the main reasons for revision were dislocation and infection, whereas implant loosening was the main reason for revision in the long-term. However, the 10-year over-all survival of the prosthesis was 93%.

A recent review on RTSA after fracture treatment included 256 patients with a mean follow-up of around 2 years. The most common complication was found to be scapular notching (38%) which might be rather a radiographic problem than a real complication followed by malunion, nonunion or resorption of the tuberosities in 21%. The revision rate was 3% mainly due to instability or infection [124].

In terms of limited function, it seems that mal-, nonunion or resection of the tuberosities is at least associated with decreased external rotation [9, 10].

Conclusions

Despite the relatively high incidence of fractures of the proximal humerus and an abundance of literature there is still not enough good evidence to give clear treatment recommendations. There is moderately good evidence in elderly patients that surgical management does not necessarily result in better clinical function when compared to conservative treatment [62]. These studies, however, do not take into account the individual needs of patients. For younger patients, at least most one-part fractures may be treated conservatively with early mobilisation. However, there is still controversy as to how much displacement of the greater tuberosity may be accepted to achieve maximal shoulder function in these patients. What is also important to remember is that the results of rigid fixation in good quality bone may not necessarily apply for older patients with severe osteoporosis [28, 30] and as such any extrapolation should be viewed with caution.

Primary hemiarthroplasty has been shown to result in good pain relief with a relatively low rate of revision surgery. However, the consistently high failure rate of the tuberosities to heal makes the functional outcome unpredictable [90, 94]. As a consequence reverse total shoulder arthroplasty is now becoming the mainstay of arthroplasty management of difficult fractures particularly in elderly patients. With this implant the functional results appear more satisfying and predictable and again has a low revision rate [95, 99]. However, there is currently not yet enough long-term evidence for its widespread use in fracture treatment and as such it is still restricted to patients over 70 years of age. Going forward, however, it may well be that this cut-off age for primary RTSA may be lowered as further long-term data becomes available.

Finally with the help of our evidence-based treatment algorithm, we are trying to find the best solution for each patient using the currently available treatment methods. The highest priority is given to the patients needs, then to their biological condition (local bone quality) and finally to the fracture pattern. We believe this algorithm is a helpful tool for decision making, for which we have achieved good overall clinical results with high satisfaction and low revision rates. However, we do accept that there will be deviations from these guidelines and exceptions need to be made with even more tailored solutions. We will further continue to analyse, improve and adjust our algorithm to meet these patients needs.

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