3 Proximal Humeral Fractures

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3.1 Introduction

Proximal humeral fractures are quite frequent, especially in elderly females with osteopenic bone structure. With precise diagnostics and a consequent classification of the fracture, it is possible to define an individual treatment protocol. In doing so, it is helpful to understand the individual pathomechanisms leading to the fracture pattern that must be addressed. Even today, proximal humeral fractures are treated mostly nonoperatively. Operative treatment is challenging. In order to cover the entire variety of fractures it is necessary to perform all kinds of osteosynthesis, including K-wires, nails, plates, and both anatomic and inverse fracture prostheses.

3.2 Epidemiology

The proximal humerus is one of the most frequently seen fracture locations. These fractures are the third most common in the elderly, after hip and wrist fractures. The incidence in Europe can be estimated between 63/105,000 and 342/100,000 [1–3]. This depends on age and gender and is often associated with osteopenia. Females older than 80 years have the highest incidence, with approx. 1,150/100,000 [2]. Following the calculation of Palvanen, it can be concluded that the incidence will increase up to three times in the next three decades [3].

3.3 Etiology

Proximal humeral fractures can be seen isolated or in combination with other injuries. The high-energy traumas mostly seen in the younger patients should be distinguished from low-energy traumas, which occur mainly in the elderly. High-energy traumas result in both a severe soft-tissue injury and a severe comminution of the proximal humerus, frequently associated with a polytrauma. The latter results from a simple fall from standing height with the arm either in ab- or adduction. The position of the arm determines the displacement of the humeral head fragment. The pull of the rotator cuff not only separates the tuberosities but also the rotation of the humeral head fragment.

3.4 Classification

Common classifications of proximal humeral fractures are:

- Codman classification
- Neer classification
- AO/ASIF classification
- LEGO-Codman classification according to Hertel

To date, there is no single classification system in common use. A classification should be intuitive, comprehensive, and have clinical relevance. It is obvious that the more complex a classification becomes, the lower the inter- and intra-observer reliability [4].

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All four above-mentioned classification systems distinguish between the four main fragments: the humeral head fragment, the lesser tuberosity, the greater tuberosity, and the shaft fragment. Seventy-five years ago, Codman introduced his descriptive classification separating the above-mentioned major fragments when there is a displacement larger than 1 cm or an angulation more than 45°. In contrast, the Neer classification provides a classification concept describing the force of the distracting muscle pull of the rotator cuff acting on the four major fragments. Anterior and posterior dislocation fractures and head splitting fractures are also described. The AO/ASIF classification is well-accepted worldwide. Proximal humeral fractures are described by the number code "11". The following letter codes indicate extraarticular unifocal = a, extraarticular bifocal = b, and intraarticular fractures = c. The LEGO-Codman classification according to Hertel [5] offers a comprehensive system with high clinical relevance. It is characterized with:

- Five basic questions defining the main fracture lines
- Seven additional questions defining accessory criteria in order to describe the fracture, including:
  - Length of the posteromedial metaphyseal extension
  - Displacement of the shaft with respect to the head
  - Displacement of the tuberosities with respect to the head
  - Angular displacement of the head
  - Glenohumeral dislocation
  - Head impression fracture
  - Head-split component

Research provided by Majed demonstrates that the overall interobserver reliability shows slight to moderate agreements. However, the LEGO-Codman classification has the most reliable interobserver scores compared with the others [6].

3.5 Diagnostic Procedures

Diagnosis is based on plain X-rays, with at least two (e.g., true ap and outlet view), if not three plains. The axillary view is sometimes challenging to achieve because abduction is painful. In these cases, the Valpeau view is recommended. Additional CT scans are helpful for gathering additional fracture information. In combination with plain X-rays, several questions have to be answered:

- The exact fracture pattern, including position of the head and tuberosities
- Head-splitting component
- Bone quality
- Comminution
- Signs of humeral head ischemia
- Additional injuries (e.g., glenoid fractures, coracoid fractures, acromion fractures)

Even with the availability of sectional images, one should still rely on plain X-rays inasmuch as they offer the most important information. Ultrasound and MRI are, in general, not necessary. In order to rule out additional injuries, they can be helpful in some specific situations.

A precise neurological and vascular evaluation is mandatory, especially of the axillary nerve and/or brachial plexus if a glenohumeral dislocation is present.

3.6 Risk of Osteonecrosis

Initial radiographs can estimate the risk of osteonecrosis. An anatomic neck fracture, a short posteromedial metaphyseal extension of the humeral head less than 8 mm, and a ruptured medial hinge are powerful predictors. All three items together are able to predict an ischemia of the humeral head with an accuracy of 97 % [7]. However, not every initial ischemia has to develop a humeral head necrosis [8]. According to Gerber, not every posttraumatic avascular necrosis becomes symptomatic and some can be well tolerated over many years without requirement of a humeral head replacement. If needed, this can be done with good results if the tuberosities have healed in an anatomic position [9, 10].

3.7 Treatment

3.7.1 Nonoperative Treatment

3.7.1.1 Indication

Nearly every proximal humeral fracture can potentially be treated conservatively. This is explained by a high rate of complications associated with osteosynthesis of the proximal humerus, independent of the kind of implant, fracture pattern, and bone quality.

The more severe the fractures are, the poorer the results are, even with osteosynthesis or arthroplasty; the latter results in a higher rate of complications.

3.7.1.2 Rehabilitation

The injured shoulder is typically immobilized in a sling for 3 weeks followed by active assisted physiotherapy and pendulum exercises for the following 3 weeks. After the sixth week active physiotherapy is performed.

3.7.1.3 Results

Even today, nonoperative therapy represents the main and most frequently used treatment option. Its incidence of nonunion is low, accounting all types of fractures. According to Court-Brown, nonunions amount to approximately 1.1 % [11]. Risk factors for mal- and nonunions are a comminuted metaphysis and a displacement of the humeral shaft in respect to the humeral head of 33–100 %. In these cases, the incidence of nonunions increases up to 8 % and 10 %, respectively. Less complex fracture types such as 11A2, 11A3, and 11B1 according to AO/ASIF result in a good clinical outcome with mean Constant scores of 64/100, 65/100, and 72/100, respectively [12]. Iyengar published a meta-analysis involving 650 proximal humeral fractures in 12 studies, all treated nonoperatively. There were 317 one-part fractures, 165 two-part fractures, 137 three-part fractures, and 31 four-part fractures involved. The mean follow-up was 45 months. Union was seen in 98 %, and the mean Constant score of all fractures was remarkably high, with 72/100 points. Incidence of complication was calculated at 13 %, mainly seen in varus malunions [13].

Today, there is also level-I evidence available, provided by two prospective randomized trials, that conservative therapy is at least not inferior compared with operative treatment in more complex fractures, for example, displaced three- and four-part fractures [14] and all types of three-part fractures [15]. Constant scores are comparable in both groups without any significant difference (58/100 points for nonoperative therapy; 61/100 points for plating using Philos®). However, the operative groups resulted in a significantly higher rate of complications, requiring second surgery in up to 30 % and consuming much higher costs. Stressing the benefits of nonoperative treatment, Sanders published a matched-paired study involving 36 proximal humeral fractures, with mean patient age of 61 years and a mean follow-up of 1 year [16]. In this study, the nonoperative group resulted in a significantly better range of movement compared with plating and a significantly better postoperative function measured with the ASES score (82.5/100 versus 71.6/100, respectively).

3.7.2 Operative Treatment

3.7.2.1 General Considerations

Operative treatment is supposed to correct fracture displacement and to achieve higher stability in order to gain earlier and/or better shoulder function. Doing so, it is crucial to achieve a proper, in most aspects, anatomically reduction. The key fragment is the humeral head. This fragment has to be managed gently and precisely at the same time. The goal is to place the humeral head in the correct inclination and torsion [17]. This is necessary to restore the proper space for the tuberosities. If the humeral head is not placed at its original position, there is no way to reduce the tuberosities adequately underneath it, resulting in either lower stability of the construct and/or impingement problems [7, 17]. Therefore, any kind of manipulation must be performed gently. The osteopenic humeral head of elderly females and their tuberosities are especially fragile and do not forgive rough maneuvers with forceps or elevators. Indirect procedures using sutures are preferred.

3.7.2.2 Timing

Proximal humeral fractures are rarely urgent situations requiring immediate surgery. If surgery is foreseen, it can usually be performed within 7–10 days after trauma. Immediate surgery is recommended in the following cases:

- Open fractures
- Glenohumeral dislocation
- Ischemic humeral head if osteosynthesis is attempted
- Neurovascular co-injuries

3.7.2.3 Positioning

In the surgical treatment of proximal humeral fractures, two positions are commonly used:

- Beach-chair position
- Supine position

The beach-chair position is usable in almost all cases. It is mainly employed if an anterolateral or lateral approach is chosen. It offers excellent access to the whole shoulder, in contrast to the supine position, and also to the lateral and some posterior parts. The disadvantages are the time-consuming positioning, a potential risk of traction lesions of the brachial plexus, and gravity forcing the humeral shaft in a natural posterior displacement that must be actively counterforced.

The supine position is a less common placement. The shoulder is typically placed laterally on a shoulder support. Benefits of this positioning are the easy and quick preparation time and the ability to place the humerus on supports, helping to avoid a severe posterior displacement of the shaft. Additionally, it is easier to achieve two perpendicular X-ray planes, especially a transaxillary view, without movement of the arm intraoperatively. This is strongly recommended in order to minimize the rate of primary intraarticular implant malpositioning. It is also possible to convert a primary intended osteosynthesis into a fracture arthroplasty without changing into the beach-chair position.

3.7.3 K-Wires

3.7.3.1 Indication

K-wires are widely used in adolescent proximal humeral fractures but not so much in adults. Resch promoted the semirigid concept in the treatment of osteoporotic proximal humeral fractures introducing the "Resch-Block". It is an extra medullary device fixing two K-wires. The main advantage of this technique is the reduction of load at the bone-metal interface and their ability to allow a controlled, guided impaction of the humeral head [18]. This is important because the fractured humeral head has a strong tendency toward impaction. A further benefit of fixed K-wires is their implanted direction, which is in line with the direction of peak forces according to Bergmann [19].

3.7.3.2 Positioning

Supine and beach-chair position are commonly used.

3.7.3.3 Approach

A closed reduction is typically performed. An open reduction via an anterior or anterolateral approach can also be chosen. The possibility of intraoperative X-ray should be checked precisely.

3.7.3.4 Implant-Related Risks

- K-wire perforations of the humeral head in the progress of a controlled sintering are frequently seen. They can result in early implant removal.
- Injury of the axillary nerve, especially while implantation of the lateral K-wires.
- Injury of the biceps tendon during K-wire insertion from the anterior.

3.7.3.5 Postoperative Rehabilitation

The injured shoulder is typically immobilized in a sling for 3 weeks, followed by slow rehabilitation. The subsequent 3 weeks are characterized by an active assisted physiotherapy. Active movements are usually allowed after 6 weeks.

This rehabilitation program is conservative. Stiff shoulders are rarely seen as long as a closed reduction is performed and the subacromial space was not entered.

3.7.3.6 Results

To date, there are only a few papers published reporting on the outcome of K-wire osteosynthesis [18, 20, 21]. In experienced hands, good to very good results can be achieved in three-part fractures with an average Constant score of 91 % (84–100 %) and without any signs of osteonecrosis at the latest follow-up at 24 months. Even in four-part fractures, the average Constant score was 87 % (75–100 %) in patients who did not need further operation [21, 22].

3.7.4 Nails

3.7.4.1 Indications

The main and recommended indications are two-part surgical neck fractures and slightly displaced three- and four-part fractures. Reduction and fixation is limited in multifragmentary three- and four-part fractures. In these cases, their use should be restricted to experienced hands.

3.7.4.2 Positioning

- Beach-chair position

3.7.4.3 Approach

- Anterolateral approach
- Lateral approach

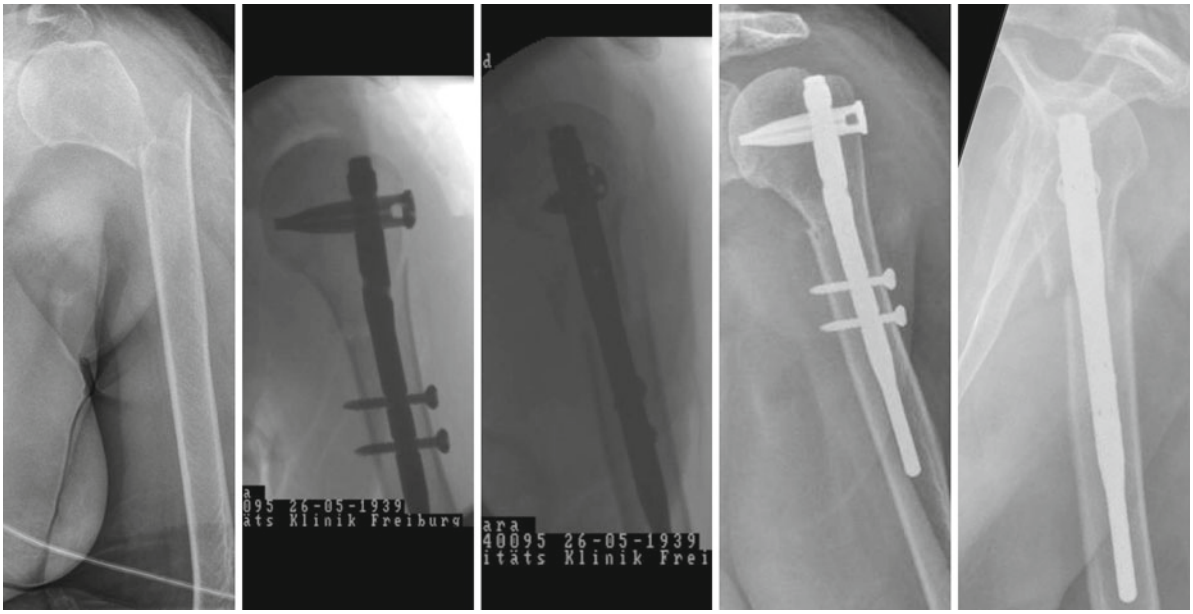

Fig. 3.1 Varus-displaced, surgical neck two-part-fracture of the proximal humerus of a 68-year-old male after a car accident, treated with a proximal humerus nail (Synthes®)

3.7.4.4 Implant-Related Risks

- Malreduction resulting from wrong insertion point of the nail
- Iatrogenic injury of the long head of the biceps tendon
- Intraarticular, primary implant malposition
- Injury of the axillary nerve
- Cuff insufficiency resulting from supraspinatus split and/or insertion in the footprint area

3.7.4.5 Results

In many trials, nails are proven to be superior biomechanically compared with plates. This is especially evident in osteopenic bone quality because the proximal nail is anchored in the best bone stock of the humeral head. It is crucial to access the proper entry point of the nail. Using straight nails, this entry point is projected in the line of the humeral shaft crossing the apex of the humeral head. Particularly in varus-displaced fractures, it is mandatory to reduce the humeral head prior to implantation of the nail. Stay sutures or K-wires used as joysticks are helpful to achieve the proper reduction of the humeral head.

A recent prospective multicenter trial performed by the AO = Arbeitsgemeinschaft für Osteosynthesefragen revealed excellent clinical results using antegrade locking nails. After a follow-up of 1 year, the postoperative absolute Constant score was 75.3/100 points, and the relative Constant score 83.8/100 points. Nonunions were seen in 1 % of all patients. The number of complications and poor clinical outcome measured with the Constant and DASH score was seen more frequently in increasingly complex fracture patterns such as the C-type fractures [23]. These results are confirmed by other authors [24] (Fig. 3.1).

3.7.5 Plates

3.7.5.1 Indications

Plates have a wide spectrum of indications. Even in osteopenic, complex fracture patterns, stable osteosynthesis can be achieved using plates. Today, angular stable locking plates are state-of-the-art. Less complex fractures can be treated by closed reduction and minimally invasive plate osteosynthesis using MIPO techniques. More complex fractures should be addressed by open reduction and lateral plate osteosynthesis. Limitations are poor bone quality, head-splitting fractures, and a medial comminution, especially in varus-displaced fracture types. An additional tension-band suturing is recommended inasmuch as it provides less secondary displacements of the tuberosities.

3.7.5.2 Positioning

- Beach-chair position
- Supine position

3.7.5.3 Approach

- Anterior, deltopectoral approach
- Anterolateral approach
- Lateral approach
- Minimally invasive approach

3.7.5.4 Implant-Related Risks

- Secondary loss of reduction (especially in varus-displaced fractures)
- Primary and secondary intraarticular malposition of screws
- Implant failure
- Injury of the axillary nerve if a lateral or anterolateral approach is chosen
- Iatrogenic injury of the long head of the biceps tendon

3.7.5.5 Results

Successful healing can be achieved with locking plates, even in osteoporotic four-part-fractures (Fig. 3.2). However, it is essential to pay special attention to the following.

- Anatomic reduction
- Proper plate positioning below the greater tuberosity and in line with the shaft axis
- Correct primary screw placement in the humeral head with subchondral bone purchase
- Medial calcar screw support from inferior-lateral to superior-medial in varus-type fractures
- Sutures through the rotator cuff to the plate

A recent prospective multicenter trial conducted by the AO shows an overall good clinical outcome using plates in 346 patients. The individual Constant score reaches values between 85 % and 87 % after 1 year follow-up [22, 25]. Nonunion is seen only in up to 5.8 %. It is remarkable that there was a high unsuspected rate of complications, up to 45 %. According to the systematic review of 791 patients treated with a locking plate, Thanasas confirmed a high incidence of complications. Osteonecrosis occurred in 7.9 %, screw cut-out in 11.6 %, and reoperations in 13.7 % [26]. Analysis of these complications shows that most result from surgical mistakes and are therefore avoidable. This is true for a wrong placement of the plate, especially a too high position resulting in an impingement, and for the primary intraarticular perforation of the screws. To decrease these mistakes, it is recommended to use a supine position, placing the shoulder on small shoulder supports to allow a precise intraoperative X-ray control in two perpendicular views without moving the arm.

Nevertheless, a meta-analysis published by Lanting in 2008 that included 66 studies and 2,155 fractures demonstrated that angularly stable plates seem to be favorable to nails in three- and four-part fractures [24].

Varus displaced humeral head four-part fractures, especially in combination with a medial comminution, are challenging, even today. In these cases, it is advisable to reduce the proximal humerus anatomically and to restore the calcar as precisely as possible. It is proven that a remaining varus angulation of 120° is a strong predictor of a secondary varus collapse with consequent secondary screw cut-out [27]. In addition, it is generally accepted to support the medial column with ascending calcar screws and/or a slight impaction of the humeral head. In cases of a medial comminution, implantation of an intramedullary fibular graft is shown to be beneficial. Augmentation with bone substitutes is disappointing because they do not integrate and are not able to prevent a secondary varus collapse.

Krappinger and colleagues determined several prognostic factors predicting a failure of plate osteosynthesis. These were for patients aged 63 years and older, with poor bone density of less than 95 mg/ccm, a nonanatomical reduction of the proximal humerus, and a lack of restoration of the medial calcar. The risk of failure highly increases in the presence of two or more risk factors [28]. Similar predictors of failure were detected by Südkamp and colleagues in a path analysis of factors for functional outcome at 1 year in 463 proximal humeral fractures [29].

3.7.6 Fracture Arthroplasty

3.7.6.1 Indications

Indications for fracture arthroplasty are mainly given if a stable osteosynthesis is not achievable because of either bad, osteoporotic bone quality and/or comminution of the proximal humerus. The poor bone quality can be estimated by measurements on preoperative CT scans [30] and/or based on the thickness of the metaphyseal cortex

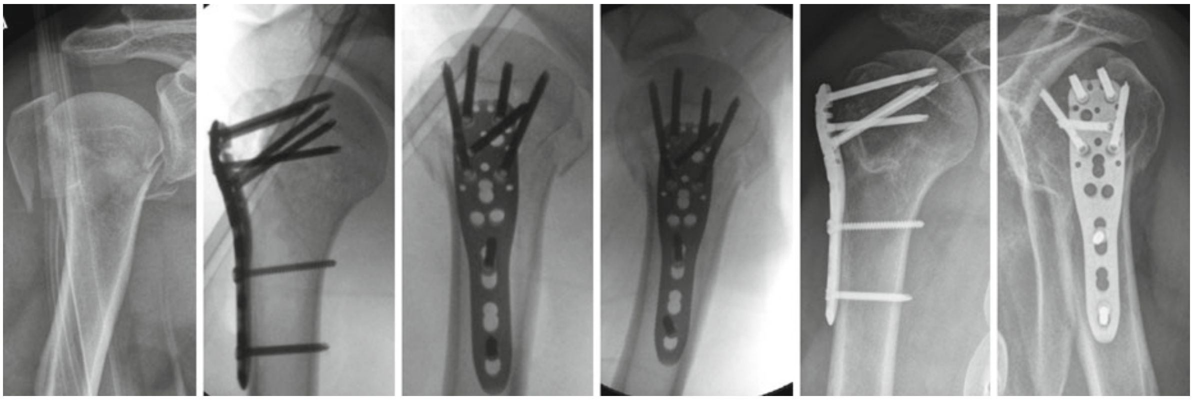

Fig. 3.2 Valgus-displaced humeral head four-part fracture of a 72-year-old male treated with Philos®-plate. (**a**) Preoperative fracture situation, (**b**) the intraoperative result, (**c**) the result 2 days postop, and (**d**) the result at 1 year postop

on plain X-rays. If both the medial and lateral cortex are less than 4 mm in length, severe osteoporosis is obvious [31]. Head-splitting fractures and impression-fractures involving more than 40 % of the humeral head surface are also considered to be treated with a fracture arthroplasty. However, in young patients, an osteosynthesis should be attempted because a secondary fracture arthroplasty in these fracture sequelae achieves better results. Humeral head ischemia should also be considered with care because only the humeral head ischemia seems to be predictable according to the predictors of Hertel [7] but not its consecutive development of an avascular necrosis [32]. This is also underlined by the fact that not every avascular necrosis of the humeral head becomes symptomatic.

In cases of a preexisting cuff-tear arthropathy or massive rotator cuff tear, a reverse shoulder arthroplasty is indicated. It is also suggested by some authors to use reverse shoulder arthroplasty generally in patients aged 75 and above. This recommendation derived from the bad outcome of many anatomic fracture arthroplasties accompanied by a secondary cuff insufficiency because of displaced and/or resorbed tuberosities.

3.7.6.2 Positioning

- Beach-chair position
- If a supine position was chosen when previously attempting an osteosynthesis, it is also possible to convert into a fracture arthroplasty using the supine position

3.7.6.3 Approach

- Anterior, deltopectoral approach (standard)

3.7.6.4 Specific Risks

- Secondary loss of reduction and/or resorption of the tuberosities
- Incorrect implantation of the prosthesis (e.g., retrotorsion, height)
- Incorrect dimension of the prosthesis (e.g., overstuffing)
- Nerve lesion (axillary nerve)
- Infection

3.7.6.5 Results

It is possible to achieve good clinical results, in terms of pain relieve and function, using an anatomical fracture arthroplasty. Hertel shows a main Constant score of 70/100 points [32] (Fig. 3.3). Other authors report less positive results, including a main Constant score of 41/100–64/100 points [33]. It is well known that the outcome strongly depends on the anatomic ingrowth of the tuberosities. Especially in the elderly, a secondary displacement and/or resorption of the tuberosities is frequently seen [34–36]. To decrease this risk, it is crucial to implant the prosthesis in an anatomic position avoiding any overstuffing and to reduce the tuberosities properly. It is also recommended to use autologous bone grafting, retrieving cancellous bone out of the humeral head and using tubercables instead of sutures in order to increase primary fixation. In order to prevent a negative winging effect of the tuberosities, a medial embracing fixation technique should be used.

The reverse fracture arthroplasty seems to be independent of the ingrowth of the tuberosities because the effective moment of the deltoid muscle is increased. In fact, it is still crucial to achieve an ingrowth of the

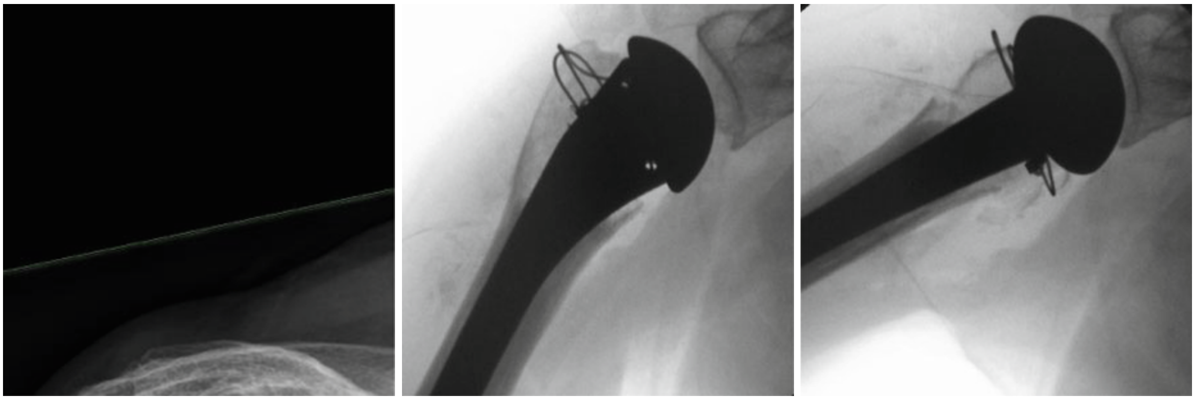

Fig. 3.3 Severely displaced humeral-head four-part fracture of an 86-year-old female resulting from a domestic fall, treated with an anatomic fracture prosthesis (Epoca®)

tuberosities in order to achieve sufficient internal and external motions that are necessary for all daily activities. Until now, it was not possible to state the superiority of reverse fracture arthroplasty in comparison to anatomic fracture arthroplasty measured with the Constant score. Using reverse fracture arthroplasty, a mean Constant score between 53/100 points and 68/100 points can be achieved [37, 38]. Gallinet compared both systems in a matched-pair study in 2009 [39]. Reversed prostheses showed better results in terms of abduction, forward flexion, and Constant score (53/100 points versus 39/100 points, respectively). However, rotation was better with anatomic prostheses. The DASH score was equal in both groups. Typical complications differed significantly. The main complication was an abnormal tuberosity fixation in 17.6 % in the anatomic arthroplasty group and inferior glenoid notching in 93.7 % in the reverse arthroplasty group. According to the study published by Favard, one should use the reverse fracture arthroplasty with care, especially in patients aged less than 75 years [40–42]. Although Favard described a survival rate of reverse prostheses of 89 % after 10 years, taking removal or conversion to a hemi-arthroplasty as an endpoint, it is noteworthy that 72 % of all patients showed a Constant score of 30/100 points or less 10 years postoperatively [43]. This may be explained by a secondary weakness of the deltoid muscle and/or a polyethylene disease.

Literature

1. Court-Brown C, Caesar B (2006) Epidemiology of adult fractures: a review. Injury 37(8):691–697
2. Péntek M, Horváth C, Boncz I, Falusi Z, Tóth E, Sebestyén A et al (2008) Epidemiology of osteoporosis related fractures in Hungary from the nationwide health insurance database, 1999–2003. Osteoporos Int 19(2):243–249
3. Palvanen M, Kannus P, Niemi S, Parkkari J (2006) Update in the epidemiology of proximal humeral fractures. Clin Orthop Relat Res 442(1):87–92
4. Bahrs C, Schmal H, Lingenfelter E, Rolauffs B, Weise K, Dietz K et al (2008) Inter- and intraobserver reliability of the MTM-classification for proximal humeral fractures: a prospective study. BMC Musculoskelet Disord 9:21
5. Hertel R, Hempfing A, Stiehler M, Leunig M (2004) Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg 13(4):427–433
6. Majed A, Macleod I, Bull AMJ, Zyto K, Resch H, Hertel R et al (2011) Proximal humeral fracture classification systems revisited. J Shoulder Elbow Surg 20(7):1125–1132
7. Hertel R (2005) Fractures of the proximal humerus in osteoporotic bone. Osteoporos Int 16(Suppl 2):S65–S72
8. Bastian J, Hertel R (2008) Initial post-fracture humeral head ischemia does not predict development of necrosis. J Shoulder Elbow Surg 17(1):2–8
9. Boileau P, Trojani C, Walch G, Krishnan S, Romeo A, Sinnerton R (2001) Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. J Shoulder Elbow Surg 10(4):299–308
10. Boileau P, Chuinard C, Le Huec J-C, Walch G, Trojani C (2006) Proximal humerus fracture sequelae: impact of a new radiographic classification on arthroplasty. Clin Orthop Relat Res 442:121–130
11. Court-Brown CM, McQueen MM (2008) Nonunions of the proximal humerus: their prevalence and functional outcome. J Trauma 64(6):1517–1521
12. Court-Brown CM, McQueen M (2009) Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. J Bone Joint Surg Am 91(11):2771; author reply 2771–2772
13. Iyengar JJ, Devcic Z, Sproul RC, Feeley BT (2011) Nonoperative treatment of proximal humerus fractures: a systematic review. J Orthop Trauma 25(10):612–617
14. Fjalestad T, Hole MØ, Jørgensen JJ, Strømsøe K, Kristiansen IS (2010) Health and cost consequences of surgical versus conservative treatment for a comminuted proximal humeral fracture in elderly patients. Injury 41(6):599–605

15. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark J (2011) Internal fixation versus nonoperative treatment of displaced 3-part proximal humeral fractures in elderly patients: a randomized controlled trial. J Shoulder Elbow Surg 20(5):747–755
16. Sanders RJ, Thissen LG, Teepen JC, van Kampen A, Jaarsma RL (2011) Locking plate versus nonsurgical treatment for proximal humeral fractures: better midterm outcome with nonsurgical treatment. J Shoulder Elbow Surg 20(7):1118–1124
17. Jakob R, Miniaci A, Anson P, Jaberg H, Osterwalder A, Ganz R (1991) Four-part valgus impacted fractures of the proximal humerus. J Bone Joint Surg Br 73(2):295–298
18. Resch H (2011) Proximal humeral fractures: current controversies. J Shoulder Elbow Surg 20(5):827–832
19. Bergmann G, Graichen F, Rohlmann A, Westerhoff P, Bender A, Gabel U et al (2007) Loads acting on orthopaedic implants: measurements and practical applications. Orthopade 36(3): 195–204
20. Ogawa K, Kobayashi S, Ikegami H (2011) Retrograde intramedullary multiple pinning through the deltoid "V" for valgus-impacted four-part fractures of the proximal humerus. J Trauma 71(1):238–244
21. Resch H, Povacz P, Frohlich R, Wambacher M (1997) Percutaneous fixation of three- and four-part fractures of the proximal humerus. J Bone Joint Surg Br 79(2):295–300
22. Brunner F, Sommer C, Bahrs C, Heuwinkel R, Hafner C, Rillmann P et al (2009) Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. J Orthop Trauma 23(3):163–172
23. Blum J, Hansen M, Rommens PM (2009) Angle-stable intramedullary nailing of proximal humerus fractures with the PHN (proximal humeral nail). Oper Orthop Traumatol 21(3):296–311
24. Lanting B, Macdermid J, Drosdowech D, Faber K (2008) Proximal humeral fractures: a systematic review of treatment modalities. J Shoulder Elbow Surg 17(1):42–54
25. Sudkamp N, Bayer J, Hepp P, Voigt C, Oestern H, Kaab M et al (2009) 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 91(6):1320–1328
26. Thanasas C, Kontakis G, Angoules A, Limb D, Giannoudis P (2009) Treatment of proximal humerus fractures with locking plates: a systematic review. J Shoulder Elbow Surg 18(6):837–844
27. Fjalestad T, Stromsoe K, Blucher J, Tennoe B (2005) Fractures in the proximal humerus: functional outcome and evaluation of 70 patients treated in hospital. Arch Orthop Trauma Surg 125(5):310–316
28. Krappinger D, Bizzotto N, Riedmann S, Kammerlander C, Hengg C, Kralinger FS (2011) Predicting failure after surgical fixation of proximal humerus fractures. Injury 42(11):1283–1288
29. Sudkamp NP, Audige L, Lambert S, Hertel R, Konrad G (2011) Path analysis of factors for functional outcome at one year in 463 proximal humeral fractures. J Shoulder Elbow Surg 20(8):1207–1216
30. Krappinger D, Roth T, Gschwentner M, Suckert A, Blauth M, Hengg C et al (2012) Preoperative assessment of the cancellous bone mineral density of the proximal humerus using CT data. Skeletal Radiol 41(3):299–304
31. Tingart M, Apreleva M, von Stechow D, Zurakowski D, Warner J (2003) The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. J Bone Joint Surg Br 85(4):611–617
32. Bastian J, Hertel R (2009) Osteosynthesis and hemiarthroplasty of fractures of the proximal humerus: outcomes in a consecutive case series. J Shoulder Elbow Surg 18(2):216–219
33. Dietrich M, Meier C, Lattmann T, Zingg U, Gruninger P, Platz A (2008) Complex fracture of the proximal humerus in the elderly. Locking plate osteosynthesis vs hemiarthroplasty. Chirurg 79(3):231–240
34. Fialka C, Stampfl P, Arbes S, Reuter P, Oberleitner G, Vécsei V (2008) Primary hemiarthroplasty in four-part fractures of the proximal humerus: randomized trial of two different implant systems. J Shoulder Elbow Surg 17(2):210–215
35. Kralinger F, Schwaiger R, Wambacher M, Farrell E, Menth-Chiari W, Lajtai G et al (2004) Outcome after primary hemiarthroplasty for fracture of the head of the humerus. A retrospective multicentre study of 167 patients. J Bone Joint Surg Br 86(2):217–219
36. Amirfeyz R, Sarangi P (2008) Shoulder hemiarthroplasty for fracture with a conservative rehabilitation regime. Arch Orthop Trauma Surg 128(9):985–988
37. Cazeneuve JF, Cristofari D-J (2010) The reverse shoulder prosthesis in the treatment of fractures of the proximal humerus in the elderly. J Bone Joint Surg Br 92(4): 535–539
38. Klein M, Juschka M, Hinkenjann B, Scherger B, Ostermann PA (2008) Treatment of comminuted fractures of the proximal humerus in elderly patients with the Delta III reverse shoulder prosthesis. J Orthop Trauma 22(10):698–704
39. Gallinet D, Clappaz P, Garbuio P, Tropet Y, Obert L (2009) Three or four parts complex proximal humerus fractures: hemiarthroplasty versus reverse prosthesis: a comparative study of 40 cases. Orthop Traumatol Surg Res 95(1): 48–55
40. Werner C, Steinmann P, Gilbart M, Gerber C (2005) Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. J Bone Joint Surg Am 87(7): 1476–1486
41. Rockwood C (2007) The reverse total shoulder prosthesis. The new kid on the block. J Bone Joint Surg Am 89(2):233–235
42. Boileau P, Watkinson D, Hatzidakis A, Hovorka I (2006) Neer Award 2005: the Grammont reverse shoulder prosthesis: results in cuff tear arthritis, fracture sequelae, and revision arthroplasty. J Shoulder Elbow Surg 15(5): 527–540
43. Favard L, Levigne C, Nerot C, Gerber C, Wilde L, Mole D (2011) Reverse prostheses in arthropathies with cuff tear: are survivorship and function maintained over time? Clin Orthop Relat Res 469(9):2469–2475