Review Article

Obere Extremität 2019 · 14:93–102
https://doi.org/10.1007/s11678-019-0520-6
Received: 22 December 2018
Accepted: 3 April 2019
Published online: 2 May 2019

Markus Scheibel[1,2] · Paulina Peters[2] · Fabrizio Moro[1] · Philipp Moroder[2]
[1] Schulthess Clinic, Zurich, Switzerland
[2] Center for Musculoskeletal Surgery, Charité-Universitaetsmedizin Berlin, Berlin, Germany

Head-split fractures of the proximal humerus

Introduction

Proximal humerus fractures account for approximately 6% of all fractures [1]. Several different types of proximal humerus fracture patterns with varying treatment options exist. A particular fracture pattern is the so-called head-split fracture, which is rarely encountered but represents a serious treatment challenge because of the involvement and occasionally the comminution of the articular surface [24]. The term "head-split" is often associated with consecutive avascular necrosis (AVN), even though this condition can only be considered a poor-to-moderate predictor of humeral head ischemia [11]. In general, a clear definition and a classification of head-split fractures are lacking in the current literature, which makes the already scarce number of outcome reports even more difficult to interpret.

» Proximal humerus fractures account for about 6% of all fractures

The goal of this article is to provide a review of the available knowledge regarding the pathomorphology, diagnosis, and treatment of head-split fractures.

Epidemiology and mechanism of injury

Patients presenting with head-split fractures generally can be divided into two groups. One group includes younger and predominantly male patients involved in high-energy trauma (i. e., bicycle, motorcycle-, or car accident; epileptic seizure) with typically good bone quality and good potential for revascularization [4]. The other group includes older mainly female patients involved in low-energy trauma (i. e., a simple fall) and typically poor bone quality with limited regenerative potential [9].

Pathomorphology and classification

Head-split fractures occur when the articular surface area of the humeral head cleaves into two or more parts as it impacts against the narrow "anvil" of the glenoid [25]. Despite the suggested mechanism of the humeral head surface being split by impaction against the glenoid, it is also possible that there is contact with the acromion or other structures of the scapula including the coracoid process.

Generally, a consensus on the definition of head-split fractures does not exist and the interobserver agreement in the diagnosis of a head-split fracture is poor even in the presence of a computed tomography (CT) scan with three-dimensional (3D) reconstruction [24]. Some authors suggest that a head-split fracture is present if at least 20% of the articular surface is involved [27]. However, area estimations of the humeral articular surface are unreliable and accurate measurement is difficult with conventional software [17].

There are a vast number of different classifications for proximal humerus fractures. The most frequently used is the Neer classification published in 1970 [21]. Neer classified head-split fractures along with "impression" fractures in the group of "articular surface defects" as: "special fracture-dislocations, because parts of the articular surface are displaced outside of the joint" [21].

» There are numerous classifications for proximal humerus fractures

The AO classification describes head-split fracture as 11C2-3, which includes a "transcephalic fracture line" [19]: "This (line) runs obliquely, somewhat parasagittal. A significant portion of the head remains attached to the greater tuberosity" [13].

Hertel et al. created a classification based on Codman's original drawings [11]. In this fracture description system, five fracture planes are combined, which render 12 proximal humerus fracture patterns, including two types of head-split fractures that differ regarding perfusion of the head fragments. The authors have also analyzed the predictors of humeral head ischemia after intracapsular fractures of the proximal humerus. The most relevant predictors of ischemia were the length of the dorsomedial metaphyseal extension, the integrity of the medial periostal hinge, as well as the basic fracture pattern according to the binary description system [11].

In contrast to traditional beliefs, head-split fractures alone are not synonymous with head ischemia or even AVN. Gavaskar et al. believe that the risk factors for AVN include a complex fracture pattern, the presence of anterior dislocation, the associated soft tissue injury, and the choice of the surgical approach (deltopectoral approach, used in the study for all anterior frac-

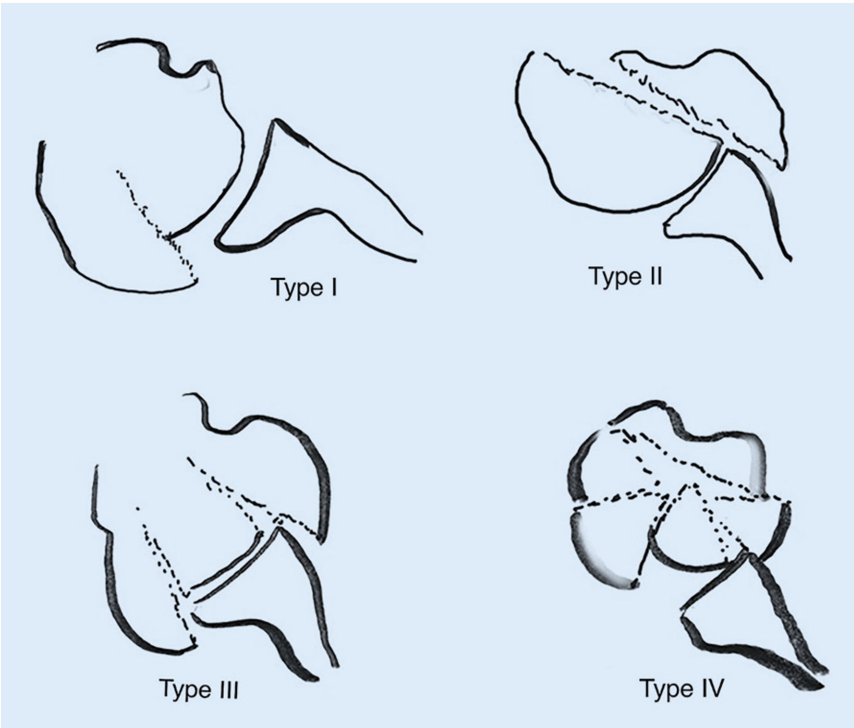

Fig. 1 ▲ Schematic drawing of four distinct patterns of head-split fractures

Fig. 2 ▲ Head-split fracture type I with the fracture line within the posterior half of the humeral head with the larger head fragment located anteriorly

Fig. 3 ▲ Head-split fracture type II with the fracture line within the anterior half of the humeral head with the larger head fragment located posteriorly

ture–dislocations, has been shown to be associated with a higher incidence of AVN; [7]). Similarly, Ogawa et al. reported that the split-head fragment in a posterior fracture–dislocation remained in good contact with an intact inferomedial attachment in 90% of the cases, and henceforth that the risk of AVN is low with head-splitting fractures associated with a posterior dislocation [22].

Another proximal humerus fracture description based on Codman was published in 2009 by Mora Guix et al. [16]. The authors locate head-split fractures in the "humeral head and cephaloglenoid group," characterized by "articular surface fractures involvement" and describe them as follows: "The articular surface is fragmented into a number of separated pieces and at least 20% of the articular surface is affected."

All of the aforementioned classifications are based on plain radiographs. Edelson et al. proposed a classification based on 3D CT reconstructions, which achieved higher interobserver reliability than classification systems based on X-rays or 2D CT imaging [6]. The authors categorized head-split fractures as pertaining to "the shield-fracture pattern" and described them as follows: "Most of the head is detached and driven backwards by the thrust of the glenoid. But, in this type, a part of the cartilaginous head is left attached to the shield fracture."

As a synopsis of all the currently available knowledge, and based on our own clinical observations, we propose the following classification system of four distinct head-split fracture patterns (◘ **Fig. 1**).

- Type I: Head-split fracture with the fracture line within the posterior half of the humeral head with the larger head fragment located anteriorly (◘ **Fig. 2**)
- Type II: Head-split fracture with the fracture line within the anterior half of the humeral head with the larger head fragment located posteriorly (◘ **Fig. 3**)
- Type III: Head-split fracture with a loose or free-floating central fragment (◘ **Fig. 4**)
- Type IV: Comminuted head-split fracture (◘ **Fig. 5**)

Clinical examination

A careful clinical history including comorbidities, time and cause of injury, as well as previous shoulder function, complaints, or interventions is an important component of the assessment. Inspection can reveal extensive ecchymosis and swelling. Obvious deformity with visible changes of the shoulder contour due to a shift of the humeral head in the anterior or posterior direction is suggestive of glenohumeral dislocation. The physical examination typically reveals tenderness of the upper arm and pain upon movement of the arm. A diligent neurovascular examination is crucial, with particular attention paid to axillary nerve function. Slow capillary refill, weak one-sided distal pulses, as well as paresthesias, numbness, and weakness are all warning signs of neurovascular injury. Although rare, acute neurovascular compromise may indicate the need for acute surgical intervention [20].

Imaging

Generally, standard radiographic imaging should include a true anteroposterior (a/p) view and a Y view. The Y view helps to further determine the position of the humeral head in relation to the glenoid and shows posterior or postero-superior displacement of the greater tuberosity. If possible, an axillary view is also recommended. An axillary view not only can identify a dislocation but is also helpful in determining involvement of the articular surface. However, the patient may be unable to tolerate the pain associated with the abduction of the arm that is necessary to obtain the axillary view. The Velpeau view may represent an adequate alternative in these cases.

Head-split fractures can often be identified by a double contour of the articular surface. Upon close examination, in 87.5% of cases the so-called pelican sign can be identified on a/p radiographs and sometimes also on axillary views [9]. The first arc represents the superior aspect of the greater tuberosity and the second arc a part of the articular surface that remained attached to the greater tuberosity resulting in a type I head-split fracture (**Fig. 6**). If the pelican sign is detected on axillary views, a type II head-split fracture is diagnosed. The first arc represents the lesser tuberosity and the second arc a part of the articular surface that remained attached to the lesser tuberosity (**Fig. 7**).

Another line of increased bone density similar but lateral to the subchondral bone called the "trough line" as described by Cisternino et al. visible on a/p radiographs is suggestive of a large reverse Hill–Sachs lesion, which is frequently encountered after posterior shoulder dislocations and is associated with nondisplaced or displaced head-split fractures in approximately 24% of cases [5, 18]. Overlapping of the articular surfaces of the humeral head and the glenoid on a true a/p view indicates glenohumeral dislocation.

> » Nondisplaced head-split fractures may be treated conservatively

Computed tomography reconstruction should be obtained in all complex proximal humerus fractures in order to enable precise analysis of the fracture pattern [24]. Computed tomography, and especially 3D CT imaging, allows for better evaluation of the head–shaft relationship, tuberosity displacement, degree of comminution, and glenoid articular surface involvement and therefore facilitates the choice of treatment as well as surgical planning. The number of fragments in the setting of severe comminution is underestimated by standard radiography in more than 60% of cases [10]. Chesser et al. reported that head-split fractures in particular can be difficult to recognize, and, when left untreated, poor outcomes can be expected [4]. Greiwe et al. reported that only 37.5% of the head-split fractures were identified on preoperative radiographs and 50% on

Abstract · Zusammenfassung

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M. Scheibel · P. Peters · F. Moro · P. Moroder

Head-split fractures of the proximal humerus

Abstract

Head-split fractures account for less than 5% of proximal humerus fractures and occur when the humeral head cleaves as it impacts against the narrow "anvil" of the glenoid into two or more large fragments, generally associated with fractures of the tuberosities or surgical neck. The articular surface is fragmented into disconnected pieces, frequently these fractures often very challenging and demanding in terms of initial diagnosis and treatment options. They often need surgical intervention because of their articular fracture pattern and their high risk of malunion with the development of premature glenohumeral arthritis. Moreover, head-split fractures are often misdiagnosed on initial plain radiographs, which can delay and complicate appropriate treatment. The purpose of this article is to provide an overview of the diagnosis, classification, and treatment of head-split fractures.

Keywords

Humeral head · Shoulder fractures · Avascular necrosis · Misdiagnosis · Imaging

Head-Split-Frakturen des proximalen Humerus

Zusammenfassung

Trümmerfrakturen des Oberarmkopfs (Head-Split-Frakturen) machen weniger als 5 % der proximalen Humerusfrakturen aus und treten auf, wenn der Humeruskopf sich beim Zusammenprall mit dem wie ein „Amboss" wirkenden Glenoid in 2 oder mehr große Fragmente spaltet, was allgemein mit Frakturen der Tubercula oder des chirurgischen Halses einhergeht. Die Gelenkfläche wird in unverbundene Stücke zerteilt, oft sind diese Frakturen eine große Herausforderung und schwierig in Bezug auf die anfängliche Diagnose und die Therapieoptionen. Diese Art der Gelenkfraktur erfordert häufig einen operativen Eingriff wegen des hohen Risikos einer Pseudarthrose und Entwicklung einer vorzeitigen Arthrose des Schultergelenks. Außerdem werden Head-Split-Frakturen oft auf den anfänglich erstellten einfachen Röntgenaufnahmen fehldiagnostiziert, was die entsprechende Therapie verzögern und erschweren kann. Ziel des vorliegenden Beitrags ist es, einen Überblick über Diagnose, Klassifikation und Behandlung von Head-Split-Frakturen zu bieten.

Schlüsselwörter

Humeruskopf · Schulterfrakturen · Avaskuläre Nekrose · Fehldiagnose · Bildgebung

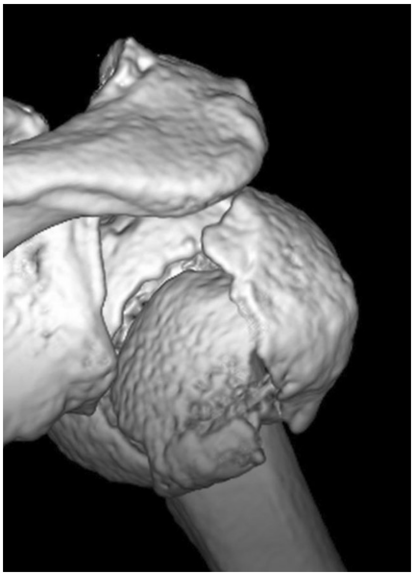

Fig. 4 ▲ Head-split fracture type III with a loose or free-floating central fragment

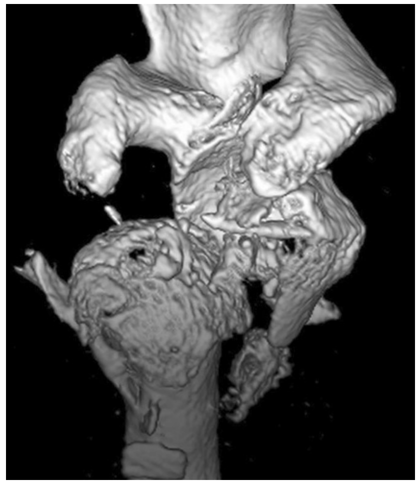

Fig. 5 ▲ Head-split fracture type IV with comminution of the humeral head

Fig. 6 ▲ Anteroposterior radiograph of a type I head-split fracture showing the pelican sign at the greater tuberosity

Fig. 7 ▲ Axillary radiograph of a type II head-split fracture showing the pelican sign at the lesser tuberosity

CT [9]. Magnetic resonance imaging (MRI) is rarely indicated in the setting of an acute injury. Only if a pathologic fracture due to primary or metastatic tumor is suspected might MRI be useful for staging of the disease.

Treatment options

Preoperative classification and analysis of the pathomorphology as well as the likely compromise of vascular blood supply of proximal humeral fractures is mandatory for successful treatment.

Nonoperative treatment

Nondisplaced and minimally displaced head-split fractures may be treated conservatively including neutral brace or sling immobilization for 3–4 weeks with passive motion of the shoulder, followed by active-assisted range-of-motion exercises progressing to resisted strengthening at 3 months (**Figs. 8 and 9**). However, there is no consensus on the threshold that distinguishes minimally displaced from displaced fractures in particular with regard to the intra-articular step formation. Displaced head-split fractures are usually not suitable for conservative treatment; however, in some cases, age and severe comorbidities impede surgery. In these cases, malunion or nonunion of the fragments can lead to severe movement restriction; however, many of these low-demand patients are satisfied with the residual function and benefit from generally low pain levels [23].

Operative treatment

Joint-preserving management

Closed reduction and percutaneous osteosynthesis should not be recommended, since anatomical reduction and stable reconstruction are difficult to achieve. An option for joint-preserving treatment of head-split fractures is open reduction and internal fixation (ORIF) using a locking plate and additional a/p screw fixation to stabilize the head-split fracture (**Figs. 9, 10, 11, 12, 13 and 14**).

An anatomical reduction can be achieved through a stepwise approach. First, the head-split component is reduced via image-intensifier control. If a satisfactory reduction cannot be achieved, the rotator interval is opened and the fracture line is palpated in order to facilitate the maneuver of reduction. If reduction is still unsatisfactory, the subscapularis tendon is partially or completely released to allow access to the articular surface. K-wires are used to retain the reduction. Finally screws (i. e., a/p screw) are applied and the plate is attached for definitive fixation.

Gavaskar et al. report that ORIF using a locking plate achieves satisfactory results in simple head-splitting fractures [7]. Out of 15 patients under the age of 55 years, bony union was achieved in 13. At a mean follow-up of 34 months (25–47 months), no osteonecrosis or nonunion was seen in simple fractures (five patients). In complex fractures (10 patients), head osteonecrosis was

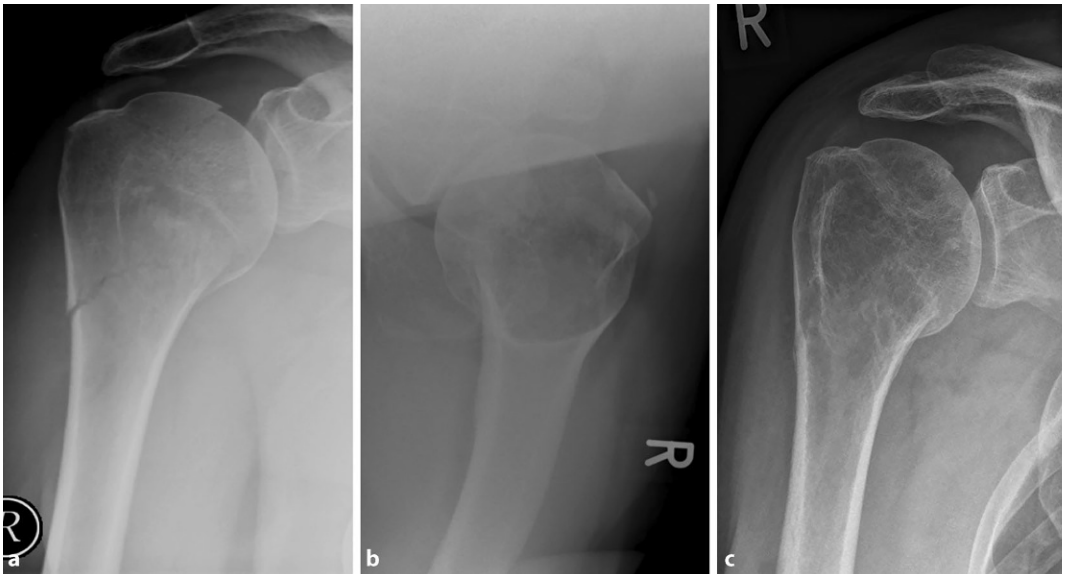

Fig. 8 ◂ Minimally displaced type I head split fracture (**a**, **b**) and excellent radiological outcome (**c**)

Fig. 9 ▴ Clinical outcome 3 years after conservative treatment

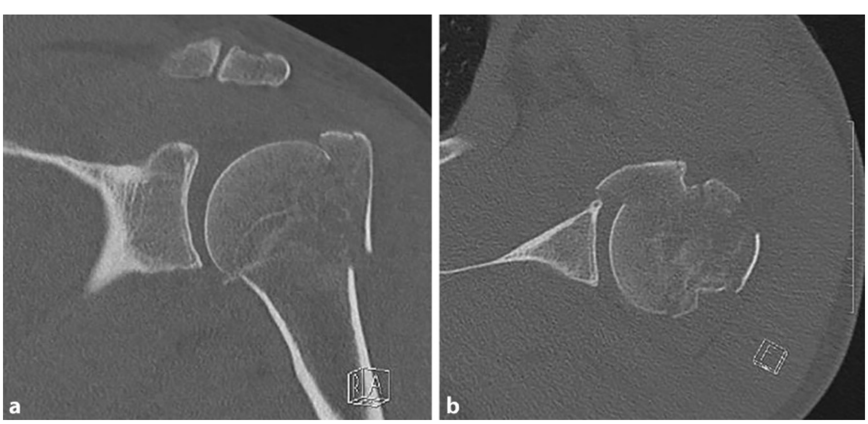

Fig. 10 ▴ Displaced type II head-split fracture

seen in four patients, nonunion in two patients, and posttraumatic osteoarthritis in one patient. Functional outcome scores showed significantly better results in simple fractures [7]. Chesser et al. describe good results with internal fixation (one or two cancellous screws) in simple head-splitting fractures in three of the eight patients who were young (19–41 years), and opted for hemiarthroplasty in patients older than 55 years [4].

While improvement of surgical techniques and fixation devices may allow for adequate fragment reduction and retention, ischemia leading to AVN of single or multiple fragments of the humeral head remains a concern in the treatment of head-split fractures or complex proximal humerus fractures in general

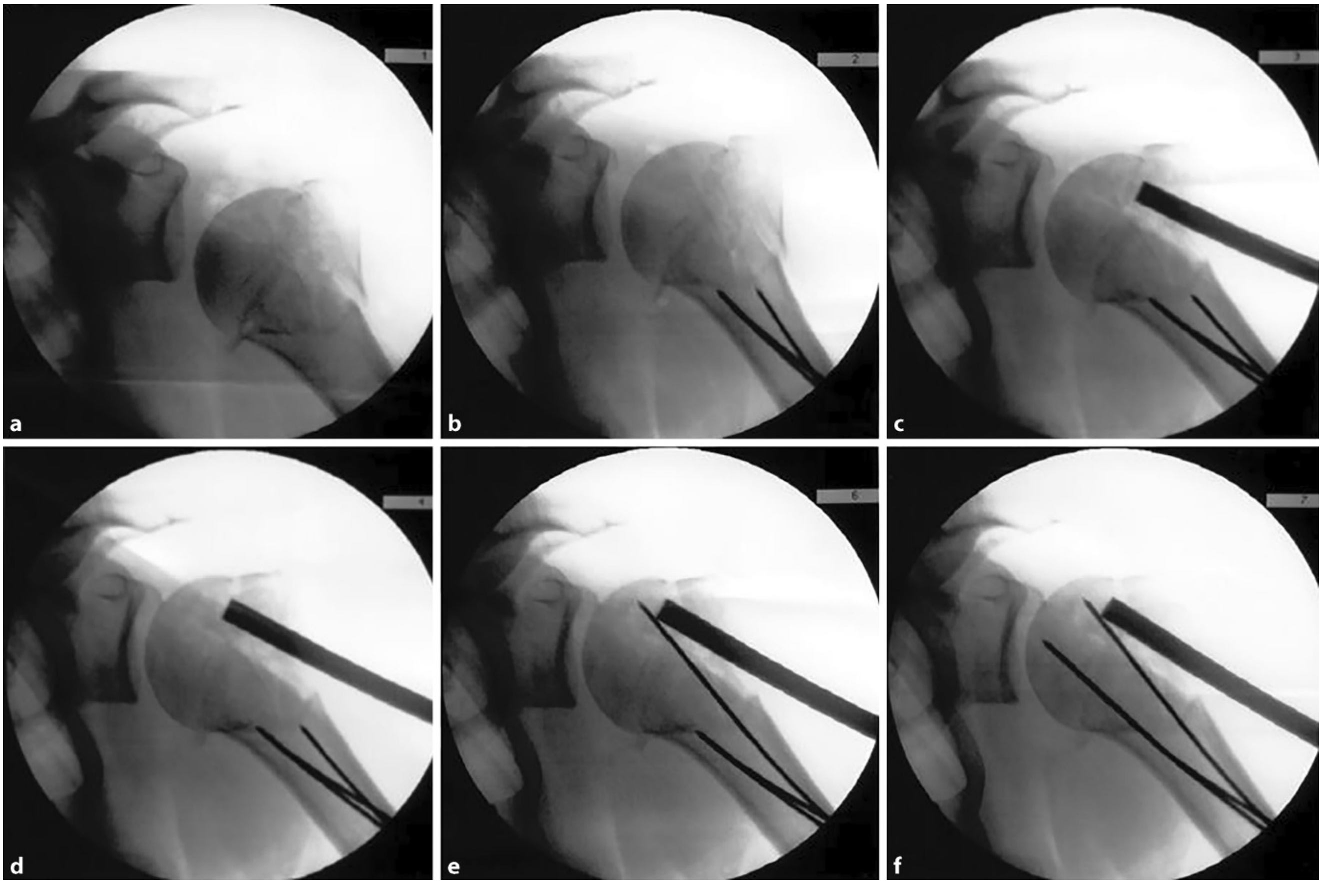

Fig. 11 ▲ Displaced type II head-split fracture

[11]. Robinson et al. investigated patients with complex proximal humerus fracture–dislocations and divided them into two groups based on the integrity of soft tissue attachment and arterial backbleeding of the head fragment. After open reduction and plate osteosynthesis, only two of 23 patients in the group with supposedly preserved vascular supply developed radiological evidence of osteonecrosis of the humeral head, compared with four of seven patients with complete soft tissue detachment and supposed compromise of vascular blood supply [26].

Owing to the difficulty of exactly determining the extent of damage to the vascular blood supply of the head fragments and the existing chance of revascularization, joint-preserving treatment is recommended in young patients regardless of the complexity of the proximal humerus fractures including head-split fractures as long as acceptable reduction and sufficient stabilization of the fragments can be achieved [3].

Hemiarthroplasty

Primary arthroplasty must be considered in patients where a stable reduction is not feasible because of severe comminution, considering the goal to avoid poor outcome and the necessity of multiple revision surgeries after a failed osteosynthesis [14]. The decision to perform a primary shoulder arthroplasty should always be made on an individual basis and include patient-specific factors such as age, general health status, functional demand, as well as preexisting shoulder pathologies, including symptomatic glenohumeral osteoarthritis, or cuff arthropathy (**Fig. 15**).

Primary replacement of the humeral head in the form of a hemiarthroplasty has been advocated for head-split fractures [15]. Antuña et al. reviewed 57 patients (44 women and 13 men, mean age 66 years) and evaluated the long-term outcome (minimum 5-year follow-up) of patients who underwent hemiarthroplasty for the treatment of a proximal humerus fracture. Seven patients had a three-part fracture, 32 had a four-part fracture, four had a three-part fracture dislocation, nine had a four-part fracture and dislocation, and five had a head-splitting fracture. They report an average forward flexion of 146° ± 34° for patients with head-split fractures, which is better than for the other types of fractures (average of forward flexion 100°) but they do not offer an explanation [2]. Greiwe et al. compared the outcomes of hemiarthroplasty for head-split fractures ($n = 8$, mean age 64 years) with those with standard three- or four-part fractures of the proximal humerus ($n = 22$, mean age 68 years), and concluded that head-split fractures demonstrate improved range of motion with an average active forward flexion of 138°, complication rate of 12.5%, and revision rate of 0% at an average 3.6 years of follow-up compared

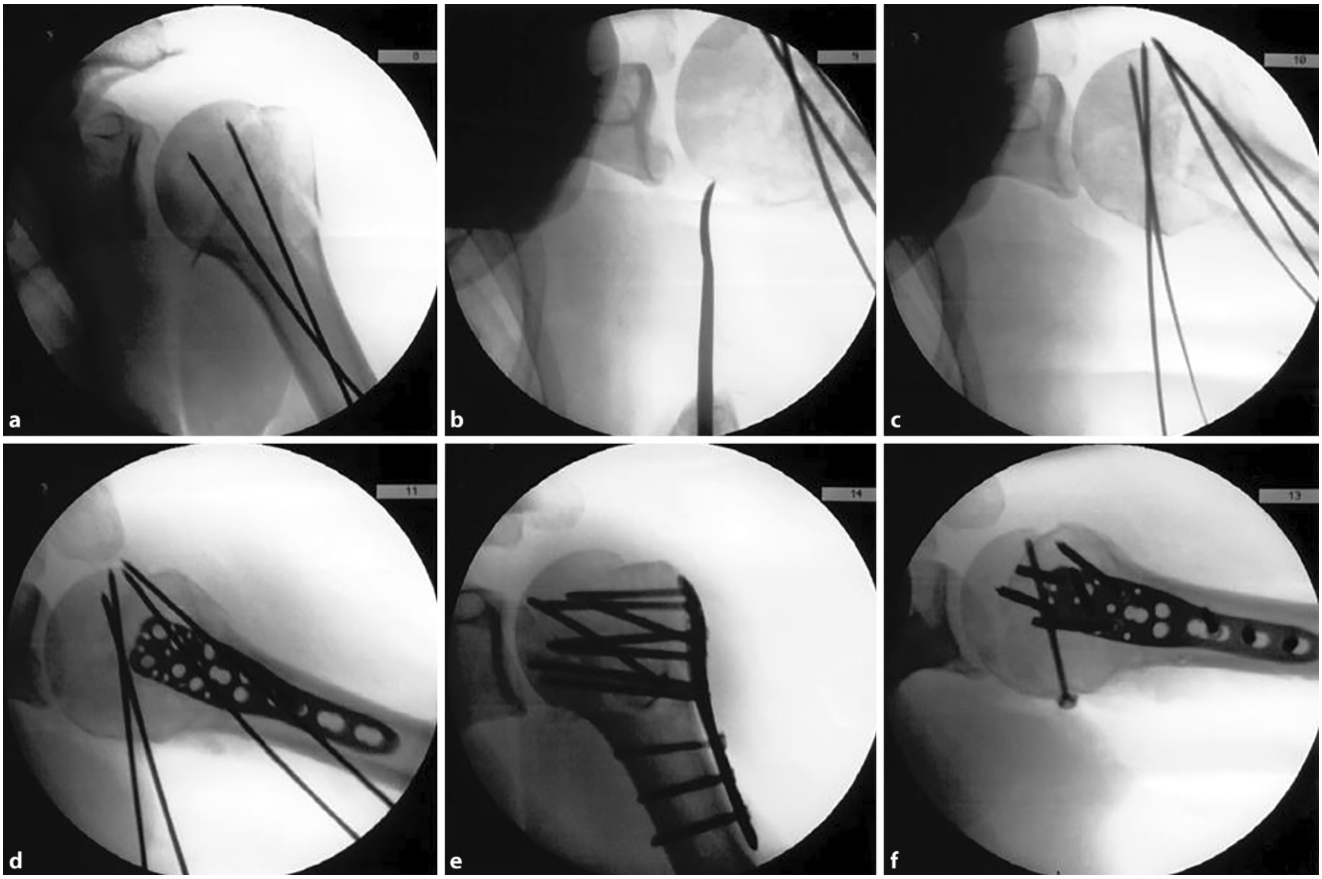

Fig. 12 ▲ Excellent radiological outcome 2 years after open reduction and internal fixation

Fig. 13 ▲ Clinical outcome 2 years after open reduction and internal fixation

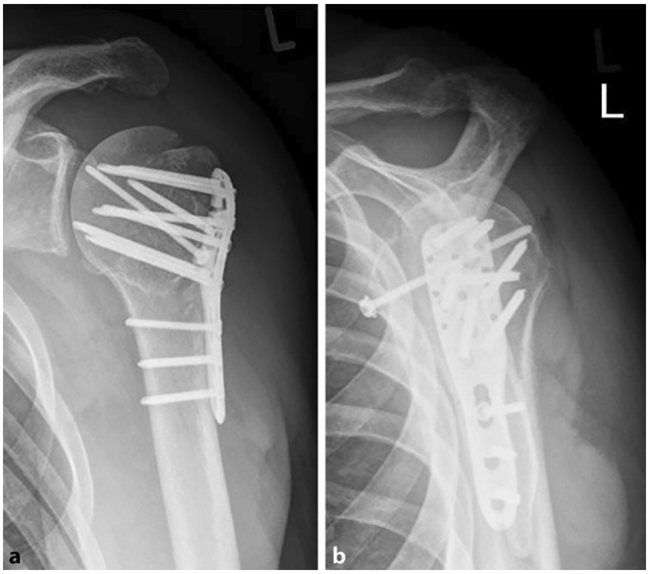

Fig. 14 ◀ Radiological outcome 2 years after open reduction and internal fixation

with standard fractures with an average active forward flexion of 106°, complication rate of 36%, and a revision rate of 14%. Despite these differences, patient satisfaction and American Shoulder and Elbow Surgeons and Simple Shoulder Test scores were not significantly different. The authors explain this unexpected discrepancy by the typically larger size and therefore better bone stock and healing potential of the tuberosities in the case of head-split fractures. They also mention that head-split factures may be technically easier to replace and allow for a more accurate determination of the stem height [9].

Hemiarthroplasty should be preserved for elderly patients owing to the fact that results regarding function are often unpredictable and therefore associated with unsatisfactory results beside the eminent risk for young patients of loosening over time [28].

Reverse total shoulder arthroplasty

Reverse total shoulder arthroplasty is reserved for patients with highly comminuted tuberosities, a preexisting deficient or irreparable rotator cuff, or glenohumeral arthritis, as well as for elderly patients (◘ Fig. 16). With reverse shoulder arthroplasty, functional outcomes depend less on tuberosity healing and rotator cuff integrity, and patients have been observed to recover more quickly, with less requirement of careful protection and rehabilitation, than hemiarthroplasty patients [8]. Functional results are more predictable; however, there are no studies referring to the use of reverse arthroplasty in head-split fractures as a primary treatment.

Complications

Both, conservatively and surgically treated, head-split fractures can result in severe complications including malunion, nonunion, and AVN. Jost et al. reported that ten of 11 head-split fractures treated with locking plate osteosynthesis showed malunion at follow-up, highlighting the general difficulty of achieving adequate reduction and stable retention of these fractures [12].

Gavaskar et al. state that most of their complications were seen in complex fracture patterns including a nonunion rate of 20% and an AVN rate of 40%. They also reported one case of glenohumeral arthritis, one case of primary intra-articular screw placement, two cases of secondary articular screw penetration after AVN and secondary collapse, and one patient with symptomatic impingement. Nonetheless, they recommended osteosynthesis in young patients, focusing on anatomic head and tuberosity reduction as well as bony union in order to provide a good bone stock for potentially necessary arthroplasty in the future [7].

A missed diagnosis of head-split fractures can lead to severe complications. Chesser et al. described three cases of missed diagnoses where the patients developed bony ankylosis and stiffness [4]. However, just one of them was unsatisfied because of the pain, requiring a secondary surgical treatment. Spross et al. treated seven patients with head-split fractures with hemiarthroplasty and one with a locking plate, who developed a partial AVN but with no need for a revision surgery [29].

Practical conclusion

- **Because of the rarity of head-split fractures, there is limited evidence in the literature regarding the best choice of treatment.**
- **Delineating the exact fracture pattern with sophisticated imaging will influence the individual patient-specific procedure approach. Standardized imaging should be part of the diagnostic process including radiographs and additional three-dimensional computed tomography.**
- **A new classification of head-split fractures helps to better understand the pathomorphology.**
- **Despite a substantial complication rate, joint preservation should be attempted in patients younger than 50 years while older patients should be treated with prosthetic replacement owing to the significant damage to the articular surface and potential loss of vascularity.**
- **Hemiarthroplasty for head-split fractures provides better functional results compared with classic three- and four-part fractures.**
- **Reverse shoulder arthroplasty is favorable in cases with highly comminuted tuberosities, a deficient or irreparable rotator cuff, glenohumeral arthritis, and risk of tuberosity nonunion as well as for elderly patients.**
- **Patients younger than 60 years who are healthy and active may be treated with osteosynthesis as well. Conversely, patients with comorbidities and lower demands may benefit more from arthroplasty.**

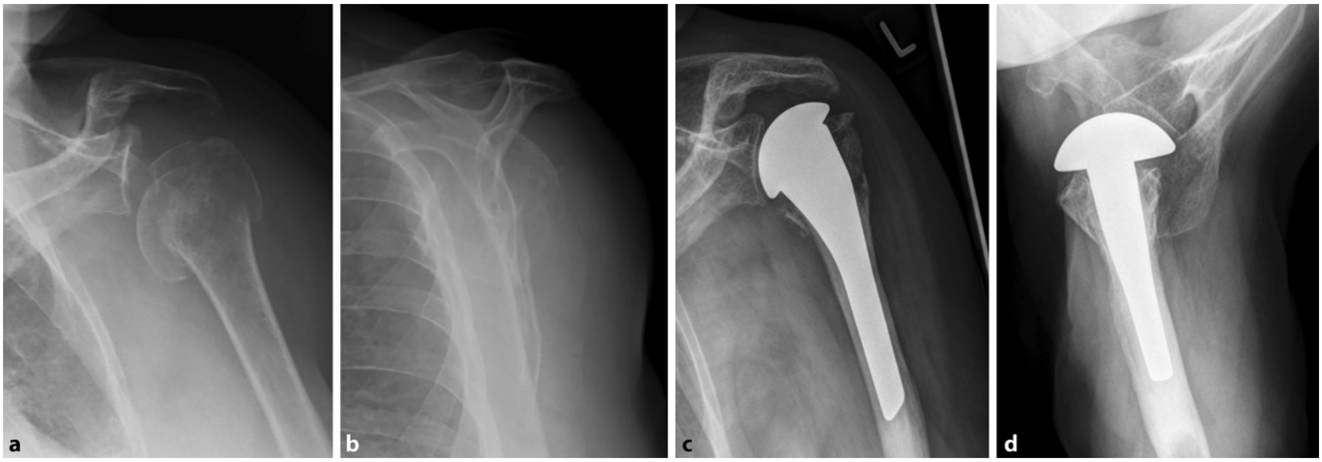

Fig. 15 ▲ Displaced type II head-split fracture treated with anatomical hemiarthroplasty

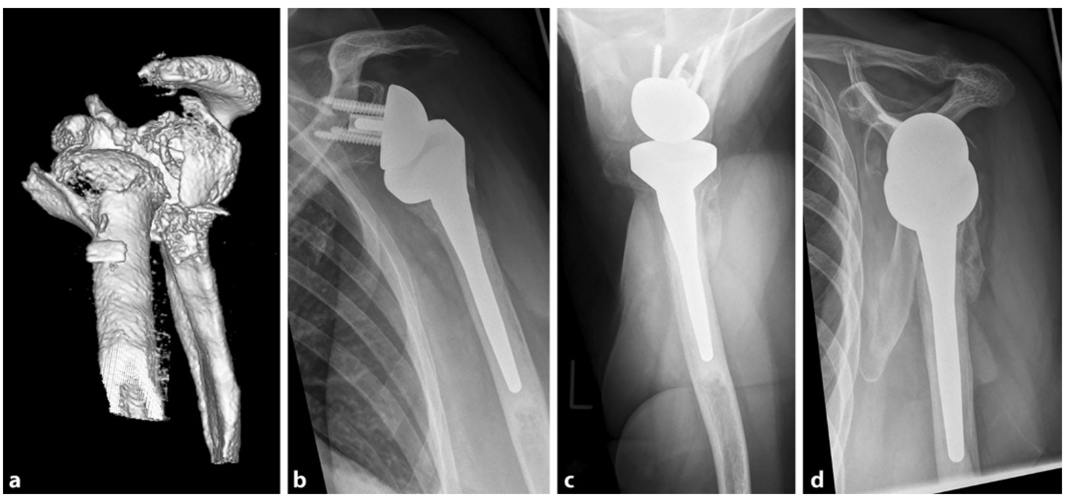

Fig. 16 ◀ Severely comminuted head-split fracture treated with reverse shoulder arthroplasty

Corresponding address

Prof. Dr. med. Markus Scheibel
Center for Musculoskeletal Surgery, Charité-Universitaetsmedizin Berlin
Augustenburgerplatz 1, 13353 Berlin, Germany
markus.scheibel@charite.de

Acknowledgements. The authors would like to thank Dr. Levon Doursounian for the illustration.

Compliance with ethical guidelines

Conflict of interest M. Scheibel is a consultant for Wright Medical. P. Peters, F. Moro, and P. Moroder declare that they have no competing interests

For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

References

1. Aaron D, Shatsky J, Paredes JC et al (2013) Proximal humeral fractures: internal fixation. Instr Course Lect 62:143–154
2. Antuna SA, Sperling JW, Cofield RH (2008) Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up. J Shoulder Elbow Surg 17:202–209
3. Bastian JD, Hertel R (2008) Initial post-fracture humeral head ischemia does not predict development of necrosis. J Shoulder Elbow Surg 17:2–8
4. Chesser TJ, Langdon IJ, Ogilvie C et al (2001) Fractures involving splitting of the humeral head. J Bone Joint Surg Br 83:423–426
5. Cisternino SJ, Rogers LF, Stufflebam BC et al (1978) The trough line: a radiographic sign of posterior shoulder dislocation. AJR Am J Roentgenol 130:951–954
6. Edelson G, Kelly I, Vigder F et al (2004) A three-dimensional classification for fractures of the proximal humerus. J Bone Joint Surg Br 86:413–425
7. Gavaskar AS, Tummala NC (2015) Locked plate osteosynthesis of humeral head-splitting fractures in young adults. J Shoulder Elbow Surg 24:908–914
8. Gerber C, Pennington SD, Nyffeler RW (2009) Reverse total shoulder arthroplasty. J Am Acad Orthop Surg 17:284–295
9. Greiwe RM, Vargas-Ariza R, Bigliani LU et al (2013) Hemiarthroplasty for head-split fractures of the proximal humerus. Orthopedics 36:e905–e911
10. Haapamaki VV, Kiuru MJ, Koskinen SK (2004) Multidetector CT in shoulder fractures. Emerg Radiol 11:89–94
11. Hertel R, Hempfing A, Stiehler M et al (2004) Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg 13:427–433
12. Jost B, Spross C, Grehn H et al (2013) Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome. J Shoulder Elbow Surg 22:542–549
13. Kellam J, Audigè L (2007) Fracture classification. In: AO Principles of fracture management. Thieme, Stuttgart

14. Khmelnitskaya E, Lamont LE, Taylor SA et al (2012) Evaluation and management of proximal humerus fractures. Adv Orthop 2012:861598
15. Kralinger F, Schwaiger R, Wambacher M 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 86:217–219
16. Guix MJM, Pedros JS, Serrano AC (2009) Updated classification system for proximal humeral fractures. Clin Med Res 7:32–44
17. Moroder P, Tauber M, Hoffelner T et al (2013) Reliability of a new standardized measurement technique for reverse Hill-Sachs lesions in posterior shoulder dislocations. Arthroscopy 29:478–484
18. Moroder P, Tauber M, Scheibel M et al (2016) Defect characteristics of reverse Hill-Sachs lesions. Am J Sports Med 44:708–714
19. Mueller MN, Nazarian S, Koch P, Schatzker J (1990) The comprehensive classification of fractures of long bones. Springer, Berlin
20. Naranja RJ Jr., Iannotti JP (2000) Displaced three- and four-part proximal humerus fractures: evaluation and management. J Am Acad Orthop Surg 8:373–382
21. Neer CS 2nd (1970) Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am 52:1077–1089
22. Ogawa K, Yoshida A, Inokuchi W (1999) Posterior shoulder dislocation associated with fracture of the humeral anatomic neck: treatment guidelines and long-term outcome. J Trauma 46:318–323
23. Rasmussen S, Hvass I, Dalsgaard J et al (1992) Displaced proximal humeral fractures: results of conservative treatment. Injury 23:41–43
24. Resch H, Tauber M, Neviaser RJ et al (2016) Classification of proximal humeral fractures based on a pathomorphologic analysis. J Shoulder Elbow Surg 25:455–462
25. Robinson (2010) Rockwood and Green's Fractures in Adults. Lippincott, Williams & Wilkins, Philadelphia
26. Robinson CM, Khan LA, Akhtar MA (2006) Treatment of anterior fracture-dislocations of the proximal humerus by open reduction and internal fixation. J Bone Joint Surg Br 88:502–508
27. Shrader MW, Sanchez-Sotelo J, Sperling JW et al (2005) Understanding proximal humerus fractures: image analysis, classification, and treatment. J Shoulder Elbow Surg 14:497–505
28. Sperling JW, Cofield RH, Rowland CM (1998) Neer hemiarthroplasty and Neer total shoulder arthroplasty in patients fifty years old or less. Long-term results. J Bone Joint Surg Am 80:464–473
29. Spross C, Platz A, Erschbamer M et al (2012) Surgical treatment of Neer Group VI proximal humeral fractures: retrospective comparison of PHILOS(R) and hemiarthroplasty. Clin Orthop Relat Res 470:2035–2042