Lynn A. Crosby
Robert J. Neviaser
Editors

Proximal Humerus Fractures

Evaluation and Management

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Editors
Lynn A. Crosby, MD
Professor and Director of Shoulder Surgery
Department of Orthopaedic Surgery
Medical College of Georgia
Georgia Regents University
Augusta, GA, USA

Robert J. Neviaser, MD
Professor and Chairman
Department of Orthopaedic Surgery
George Washington University
Washington, DC, USA

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I would like to dedicate this book to all the residents over the last 25 years that I have had the pleasure of adding to their understanding and treatment of proximal humerus fractures. Some have gone on to careers in shoulder surgery and a few have been contributors to this book. Also to my wife Sheila who has gracefully put up with me for the last 37 years and allowed me to do what I have been passionate about; the treatment of shoulder-related conditions.
—Lynn A. Crosby, MD

To those residents, whom I have had the honor of training, who have chosen to become shoulder surgeons, hopefully in some small part through my influence. They carry on the legacy of this program and my family.
—Robert J. Neviaser, MD

Preface

The treatment for fractures of the proximal humerus varies according to the amount of displacement, bone quality, age, activity level, and general medical condition of the patient. There does not exist one treatment that can be utilized for all proximal humerus fractures. This review of the classification, nonoperative treatment, percutaneous pinning, open reduction internal fixation and different arthroplasty options gives the reader examples of when different approaches are needed for the most desirable outcomes. The chapter on complications allows the reader to learn from commonly seen problems that surgeons encounter in treating this very common injury of the shoulder girdle. There has been a greater understanding of which techniques work best for certain types of fracture patterns, but, more importantly, taking into consideration the age of the patient at the time of the injury has seemed to change treatment choices the most over the last 5–10 years. More long-term outcomes studies are needed to continue to clarify which treatments are appropriate in which situations. We have come a long way in the treatment of proximal humerus fractures but it still takes sound judgment when making the recommendations for surgical treatment.

As the editors, we would like to thank the authors for their dedication in preparing this book. The priceless contribution of their time is greatly appreciated.

Augusta, GA — Lynn A. Crosby
Washington, DC — Robert J. Neviaser

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List of Contributors

Toby Anderton, MD Department of Orthopedic Surgery Georgia Regents Medical Center, Augusta, GA, USA

Alexander Auffarth, MD Traumatology and Sports Injuries Paracelsus Medical University Salzburg, Salzburg, Austria

Julie Y. Bishop, MD Department of Orthopaedics, Wexner Medical Center The Ohio State University, Columbus, OH, USA

Pascal Boileau, MD Department of Orthopaedic Surgery and Sports Traumatology L'Archet 2 Hospital, Nice, France

Lynn A. Crosby, MD Department of Orthopaedic Surgery, Medical College of Georgia Georgia Regent's University, Augusta, GA, USA

Thomas d'Ollonne, MD Department of Orthopaedic Surgery and Sports Traumatology L'Archet 2 Hospital, Nice, France

Armodios M. Hatzidakis, MD Western Orthopaedics PC, Denver, CO, USA

John A. Hinson, MD Department of Orthopaedic Surgery Georgia Regents University, Augusta, GA, USA

Robert G. Lewis, MD St. Francis Orthopaedic Institute Shoulder Center, St. Francis Orthopaedic Institute St. Francis Hospital, Columbus, GA, USA

Philipp Moroder, MD Traumatology and Sports Injuries Paracelsus Medical University, Salzburg, Austria

Mark E. Morrey, MD Department of Orthopedics Mayo Clinic, Rochester, MN, USA

Andrew S. Neviaser, MD Department of Orthopaedic Surgery George Washington University, Washington, DC, USA

Robert J. Neviaser, MD Department of Orthopaedic Surgery George Washington University, Washington, DC, USA

Parthiv Patel, DO St. Francis Orthopaedic Institute Shoulder Center St. Francis Hospital, Columbus, GA, USA

Dale Nicholas Reed, MD Department of Orthopedics Associates in Orthopedics and Sports Medicine, Dalton, GA, USA

Herbert Resch, MD Traumatology and Sports Injuries Paracelsus Medical University, Salzburg, Austria

Domenic Scalamogna, MD St. Francis Orthopaedic Institute Shoulder Center St. Francis Hospital, Columbus, GA, USA

Todd Twiss, MD Department of Orthopaedic Surgery Freeman Health System, Joplin, MO, USA

1 Anatomy and Classification of Proximal Humerus Fractures

John A. Hinson

Introduction

Proximal humerus fractures are a common injury accounting for approximately 5 % of all fractures [1, 2]. They occur with increasing frequency in elderly patients with a majority occurring in patients over 60; there is a 3:1 female-to-male preponderance in this age group [3]. Eighty-five percent of these injuries are minimally displaced and amenable to nonoperative treatment. The true challenges for the shoulder surgeon lie in the 15 % of significantly displaced fractures that require accurate diagnosis and treatment. Accurate diagnosis and classification of the fracture are the first steps in the successful treatment of these injuries.

A classification system for proximal humerus fractures should be comprehensive enough to account for all fracture types, but concise enough to allow for ease of use and ease of communication between users. It should be reproducible by any one user or between users describing the same fracture. The system should help dictate treatment for any defined fracture pattern. The complex nature of the anatomy and the complex nature of some fracture patterns make it challenging to make an ideal classification system for these injuries. This is further complicated by the fact that it is difficult to consistently produce good radiographic images of the proximal humerus. Although there have been a number of classification systems proposed through the years, the Neer classification system has become the most widely used system today. A thorough understanding of the anatomy, the pathomechanics of proximal humerus fractures, and the imaging of proximal humerus fractures will improve the surgeon's ability to accurately classify these fractures.

J.A. Hinson (✉)
Department of Orthopaedic Surgery, Georgia Regents University, 937 15th Street, Augusta, GA 30912, USA
e-mail: jhinson@gru.edu

Anatomy

Humerus

The proximal humerus includes the articular surface, greater tuberosity, lesser tuberosity, and the humeral shaft. The shaft joins the proximal segment at the surgical neck, just inferior to the metaphyseal flare and the tuberosities. The anatomic neck is located between the tuberosities and the articular surface and serves as the site of attachment of the articular capsule (Fig. 1.1). The bicipital groove is located between the greater and lesser tuberosities. The long head of the biceps passes through the groove prior to entering the glenohumeral joint. The bicipital groove rotates internally as it goes distally [4]. The surgical neck is the most common site of surgical neck fractures, but anatomic neck fractures are uncommon. Greater tuberosity fractures are much more common than lesser tuberosity fractures. Fractures that involve the

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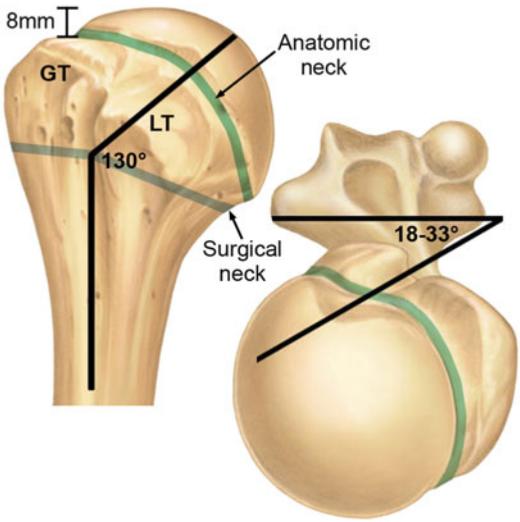

Fig. 1.1 The average humeral neck angle is 130°. The superior aspect of the articular surface is 8 mm above the greater tuberosity. Average retroversion values are 18–33°

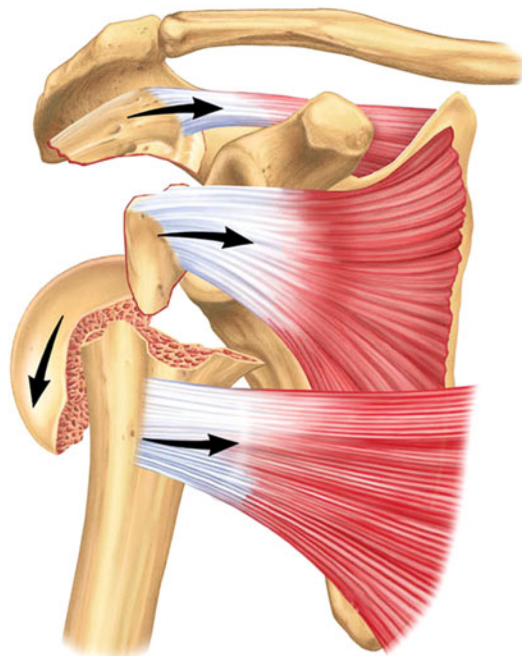

Fig. 1.2 Displacement of fracture fragments is determined by the pull of the attached muscles

articular surface include head-splitting fractures and impaction fractures.

The proximal humeral articular surface is a segment of a sphere that measures from 37 to 57 mm in diameter [5]. The average neck angle is 130°. The humeral head average offset from the shaft is 3 mm posterior and 7 mm medial. The most superior portion of the humeral head is typically 8 mm above the height of the greater tuberosity [2]. Humeral retroversion has been found to vary widely with reported average values ranging from 18° to 33° [5–9]. Retroversion has been found to average 4° more in the dominant shoulder [7]. Wide ranges in retroversion values have led to the use of bony landmarks, such as the bicipital groove, in proximal humerus reconstruction. Strong bone can be found in the subchondral area of the head; however, the cancellous bone of the proximal humerus does lose density with aging [10–12].

Musculature

The pectoralis major has a broad insertion along the lateral lip of the bicipital groove. It acts as a major deforming force in proximal humerus fractures as it causes the humeral shaft to be displaced anteriorly and medially. The supraspinatus, infraspinatus, and teres minor attach to their respective facets on the greater tuberosity. The supraspinatus can cause superior displacement while the infraspinatus can cause posterior displacement of greater tuberosity fragment. The tuberosity can be a single fragment or multiple with the cuff tendons attached to independent fragments. The lesser tuberosity is the site of attachment of the subscapularis; lesser tuberosity fragments can be displaced medially by the pull of the subscapularis tendon (Fig. 1.2).

In three-part proximal humerus fractures with either a greater or lesser tuberosity fracture the displacement of the head fragment will be dictated by the rotator cuff insertion to the intact tuberosity. If the greater tuberosity is fractured but the lesser tuberosity is intact, then the head fragment will rotate internally from the attachment of the subscapularis. In three-part lesser tuberosity fractures the humeral head segment rotates externally from the pull of the infraspinatus on the intact greater tuberosity.

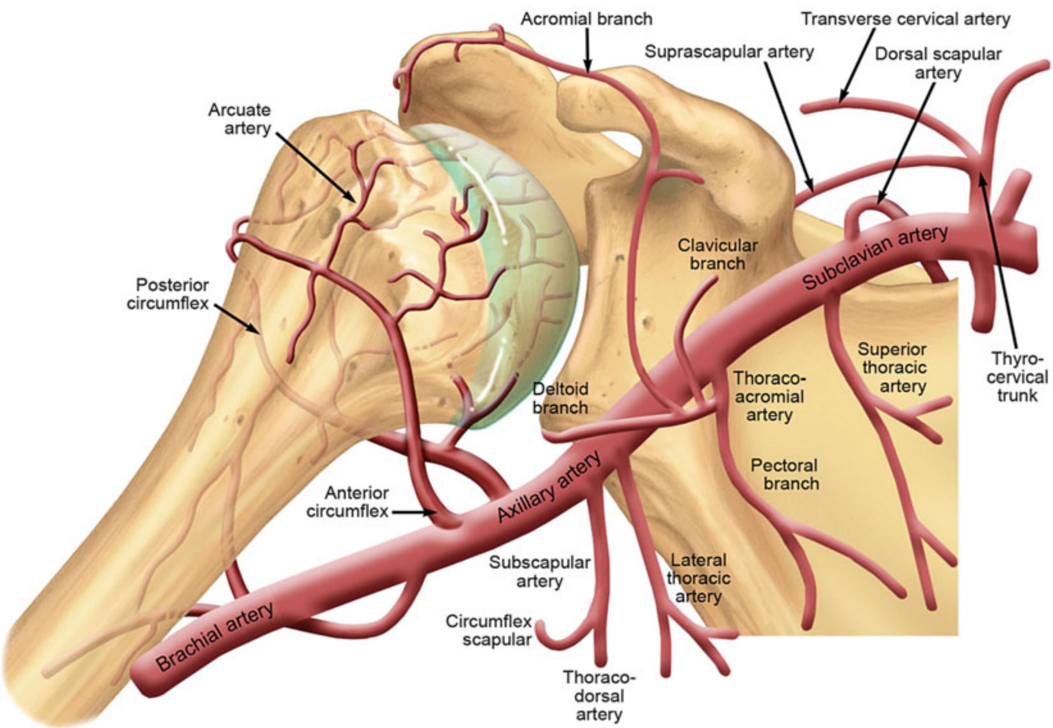

Fig. 1.3 Vascular supply of the proximal humerus

Vascular

Outcomes after proximal humerus fractures are affected by the fracture pattern and its relationship to the vascular anatomy. Understanding the local vascular anatomy is important to understanding this relationship. The perfusion of the proximal humerus is derived from terminal branches of the axillary artery, the anterior and posterior humeral circumflex arteries. Due to the location of these vessels in close proximity to the fracture, they can be injured in significantly displaced fractures and fracture-dislocations.

The anterior humeral circumflex artery arises from the axillary artery and courses along the inferior border of the subscapularis. The artery gives off an anterolateral ascending branch that courses along the lateral aspect of the bicipital groove before entering the humeral head and becoming the arcuate artery. The main portion of the anterior humeral circumflex vessel continues posterolaterally to anastamose with the posterior humeral circumflex vessel. There are numerous extraosseous anastomoses with the anterolateral branch and ligation of the anterior humeral circumflex proximal to these can be compensated by this collateral circulation. The posterior humeral circumflex artery arises from the axillary artery and travels with the axillary nerve through the quadrilateral space before it goes on to its anastomosis with the anterior humeral circumflex artery. Posteromedially it gives off branches that enter the humeral head (Fig. 1.3).

Based on the work of Laing and Gerber et al. [13, 14] it has been believed that the anterolateral branch of the anterior humeral circumflex artery is the main source of perfusion of the humeral head with the posterior vessels only perfusing a small portion of the head. Later work by Brooks et al. [15] agreed that the head was predominantly perfused by the anterolateral branch. However, they found that even after ligation of this vessel as it enters the head, the head could be well perfused by intra-osseous anastomoses with the posteromedial vessels, metaphyseal vessels, and branches from the greater and lesser tuberosities. In a study [16] performed on patients with proximal humerus fractures the anterior humeral circumflex vessel was found to be disrupted in 80 % of cases. The posterior vessel was found to be normal in 85 % of cases. While rates of avascular necrosis after three-part and four-part fractures have been reported in the literature to range from 0 to 34 % [17–28], these findings would suggest a much higher rate of avascular necrosis should be seen if the anterolateral branch is the main source of perfusion for the head. A recent study [29] used MRI imaging to do a quantitative analysis of the perfusion of the humeral head. Their work identified that 64 % of the humeral head blood supply was derived from the posterior humeral circumflex artery and the anterior vessel only accounted for 36 % of the perfusion. The authors questioned the methodology of the earlier literature and felt their improved methods allowed them to better assess the perfusion of the humeral head.

Nerves

The shoulder is innervated by the brachial plexus (C5-T1 nerve roots) with small contributions from the C3 and C4 nerve roots. The nerve roots give rise to the upper (C5–6), middle (C7), and lower (C7-T1) trunks. The trunks are the source for the lateral, posterior, and medial cords of the plexus which are named according to their relationship to the axillary artery. The axillary nerve and subscapular nerves arise from the posterior cord; they innervate the deltoid and teres minor as well as the subscapularis, respectively. The suprascapular nerve arises from the upper trunk and innervates both the supraspinatus and the infraspinatus. Articular innervation is primarily from branches of the axillary, suprascapular, and lateral anterior thoracic nerves [30].

In a study of 143 consecutive patients with low energy proximal humerus fractures nerve injuries were documented by EMG in 67 % of patients [31]. The axillary nerve was the most commonly injured nerve. After arising from the posterior cord it passes through the quadrilateral space, wraps around the humerus, and then runs on the deep surface of the deltoid. It gives off three motor branches that innervate the teres minor and the deltoid. The lateral brachial cutaneous nerve arises from the axillary and penetrates through the deltoid to innervate the overlying skin. Anatomic studies have shown the nerve to pass an average of 1.7 cm from the surgical neck of the proximal humerus [32].

The suprascapular nerve is the second most commonly injured nerve in proximal humerus injuries. The nerve arises from the upper trunk and then passes through the scapular notch before innervating the supraspinatus. It then passes around the base of the scapular spine and through the spinoglenoid notch to innervate the infraspinatus. It is susceptible to traction injury at its origin from the upper trunk and as it passes through the scapular notch [31, 33].

The musculocutaneous nerve originates from the lateral cord with input from the C5–C7 nerve roots. It passes through the conjoined tendon at an average distance of 5.6 cm from the coracoid process, but can be found as close as 3.1 cm [34]. After innervating the flexor compartment of the arm it terminates in the lateral antebrachial cutaneous nerve. Injury to this nerve is uncommon but can occur with blunt trauma, traction injuries, or iatrogenic injuries during surgery.

Pathomechanics of Proximal Humerus Fracture

The most common mechanism of injury for a proximal humerus fracture is a fall on an outstretched arm in an elderly patient with osteoporotic bone [1]. The fracture can be caused by a direct blow to the upper arm or occur when the humeral head strikes the glenoid or the acromion [35]. Less frequently, fractures are seen in younger patients after high-energy injuries such as motor vehicle accidents or falls from a height. A rare potential mechanism is violent muscle contraction caused by electric shock or seizure [36].

Isolated greater tuberosity fractures are a common injury making up approximately 20 % of proximal humerus fractures and 5 % of fractures treated with surgery [37]. Tuberosity fractures can be due to multiple mechanisms [38]. These include a direct blow in a fall onto the shoulder or a shearing mechanism as the tuberosity strikes the glenoid rim or acromion. The fracture can also be caused by avulsion from the pull of the rotator cuff tendons. Greater tuberosity fractures are commonly seen in anterior dislocations as the tuberosity is fractured as it contacts the glenoid rim. Isolated lesser tuberosity fractures are much less common accounting for approximately 2 % of proximal humerus fractures [37].

Diagnosis

History and Exam

The most common patient with a proximal humerus fracture is an elderly patient who has sustained a ground level fall. Younger patients sustain this fracture after higher energy injuries. Regardless of mechanism the entire extremity should be assessed for any evidence of other injury. In patients with higher energy injuries care should be taken to observe for evidence of rib fractures, scapula fractures, head or spine injuries, and intra-abdominal or intra-thoracic injuries.

The history should include the age and hand dominance of the patient. The mechanism and velocity of injury should be recorded. Occupation and the patient's premorbid level of function should be noted. The patient should be assessed for the ability to participate in a structured rehabilitation program. A thorough medical history should be obtained including the presence of any significant comorbid conditions and any history of malignancy. Any previous shoulder surgeries to the affected shoulder should be noted. The review of systems should include loss of consciousness, any paresthesias, and any elbow, wrist, or hand pain of the affected extremity.

Ecchymosis and swelling of the shoulder are common physical exam findings. These will appear in the first 24–48 h after injury and can be present for many days. Ecchymosis and swelling can extend to affect the entire extremity down to the level of the hand, as well as affect the chest wall and the breast. The condition of the skin should be examined. Crepitus can sometimes be felt as the shoulder is palpated and range of motion is attempted. The examiner can attempt to assess fracture stability by palpating the humeral head while gently rotating the humeral shaft. In stable fractures the head and shaft will move as a single unit. Patients will often have significant pain and hold the arm in an internally rotated position. The patient will guard against significant active or passive range of motion. A complete neurovascular evaluation including an evaluation of the axillary nerve, brachial plexus, and vascular status should be performed. The surgeon should be concerned for a possible axillary artery injury in a four-part fracture dislocation with axillary dislocation of the humeral head. A palpable radial pulse does not completely rule out the possibility of vascular injury and an angiogram should be obtained.

Imaging

X-Rays

Radiographic evaluation is typically sufficient for assessment and classification of a proximal humerus fracture. Carefully positioned radiographs can give detailed information about fracture pattern and displacement. The surgeon should be prepared to position the patient if necessary to obtain the needed views. Radiographic evaluation will usually include an AP scapular view (true AP), axillary lateral view, and a scapular Y view.

The AP scapular view or true AP view requires understanding of shoulder anatomy to properly obtain the film. The scapula is not positioned in the coronal plane on the chest wall; it sits approximately 30°–40° angled anterior from the coronal plane. To obtain the AP view the

Fig. 1.4 Scapular AP radiograph technique

Fig. 1.5 Scapular Y radiograph technique

unaffected shoulder is angled approximately 40° toward the beam to allow the affected side to lie flat against the X-ray plate (Fig. 1.4). AP views taken with the arm in external rotation (greater tuberosity) and internal rotation (lesser tuberosity) can be useful in evaluation of tuberosity fractures.

The scapular Y view can be obtained with the arm maintained in a sling. The patient is positioned with the anterior aspect of the shoulder against the X-ray plate. The unaffected shoulder is rotated towards the beam approximately 40° (Fig. 1.5).

The axillary lateral view is vital for assessing the position of the greater tuberosity, the glenoid articular surface, and the relationship of the humeral head to the glenoid. The X-ray is obtained by placing the cassette on the superior aspect of the shoulder. The arm is held in a position abducted away from the body. The X-ray beam is then directed cephalad from a position inferior to the shoulder with the beam aimed at the axilla of the patient (Fig. 1.6). The Velpeau axillary lateral is an alternative for the patient that cannot tolerate abducting the arm for the axillary lateral. This view is taken with the arm

Fig. 1.6 Axillary lateral radiograph technique

in a sling. The cassette is placed on a flat surface. The patient then leans back over the cassette as the X-ray beam is aimed from superior to inferior at the cassette (Fig. 1.7).

CT

Computed tomography (CT) images can be a useful tool in evaluation and classification of proximal humerus fractures. The detailed bony detail of images can be used to evaluate tuberosity displacement, humeral head splitting and impaction components, degree of comminution, and any involvement of the glenoid articular surface (Fig. 1.8). The advent of three dimensional reconstruction views has been a useful advance to allow the surgeon to further assess fractures (Fig. 1.9). While traditional two-dimensional CT has not been shown to improve the reliability of classification, the use of three-dimensional imaging has been shown to improve both intra- and inter-observer reliability of both the AO/ASIF and the Neer classification system [39].

MRI

Magnetic resonance imaging (MRI) plays a limited role in the assessment of acute proximal humerus fractures. While playing a limited role in assessment of acute fractures MRI can be useful in diagnosing non-displaced greater tuberosity fractures (Fig. 1.10).

Classification

History

As early as the late nineteenth century efforts were made to classify proximal humerus fractures. Kocher described proximal humerus fractures based on location of the fracture [35, 40]. Fractures were divided into supratubercular, pertubercular, infratubercular, and subtubercular. In 1934 Codman described proximal humerus fractures as occurring along the lines of the epiphyseal scars. He noted four possible fracture fragments: the articular surface, the humeral shaft, the greater tuberosity, and the lesser tuberosity (Fig. 1.11). Codman stressed the importance of vascular considerations to fractures of the articular segment of the proximal humerus [1, 35, 41].

Later classification systems attempted to classify fractures based on mechanism of injury [42, 43]. The Watson-Jones classification system was published in 1940 and described fractures that occurred by impacted abduction, impacted adduction, and minimally displaced

Fig. 1.7 Velpeau lateral radiograph technique

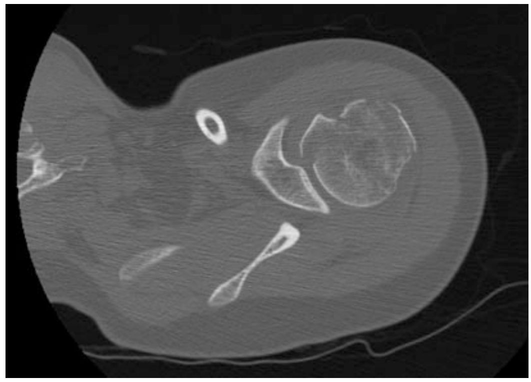

Fig. 1.8 This axial CT image demonstrates a head-split component as well as comminution of the tuberosity fragments

Fig. 1.9 Three dimensional CT imaging can further enhance the surgeon's ability to characterize fractures. The comminuted tuberosity fragments with extension into the articular surface are visualized in this CT image

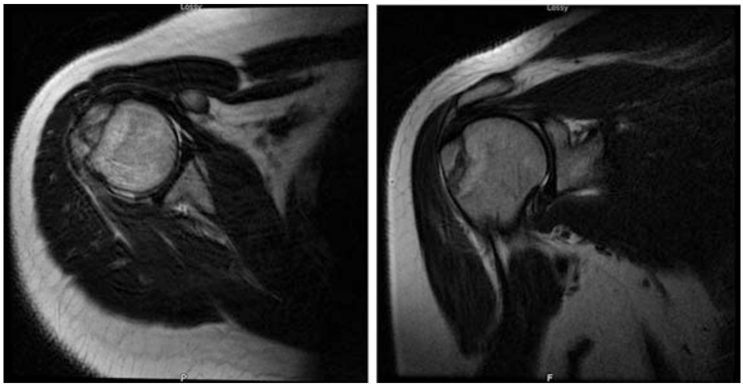

Fig. 1.10 MRI images clearly show this minimally displaced greater tuberosity fracture

Fig. 1.11 Codman's fragments: articular surface, greater tuberosity, lesser tuberosity, and humeral shaft

"contusion-crack" fractures. Dehne's classification system, published in 1945, also classified fractures based on the mechanism of injury. He felt that forced abduction created a "three-fragment" fracture with head, greater tuberosity, and shaft fragments. Forced extension created a "two-fragment" fracture with the humeral head separated from the shaft at the surgical neck. Impaction of the head into the glenoid created "head-splitting" fractures. Dehne did not include lesser tuberosity fractures in his classification but did recognize the presence of more complex fractures and fracture-dislocations. The utility of classification of these injuries by mechanism is limited. As recognized by Neer [44] abduction and adduction injuries could be mistaken for each other due to differing rotation of the arm during radiography (Fig. 1.12). These systems do not assess the details of fracture anatomy and management is not dictated by these systems due to fact that there is no correlation between mechanism and outcomes [45].

In 1950 De Anquin and De Anquin proposed a classification that divided the proximal humerus into three fracture zones and fragments. In their work they noted a difference between impacted and non-impacted four-part fractures [35, 46]. Like Codman, they stressed the importance of vascular considerations on fractures that involved the articular segment [1, 46]. Depalma recognized the roll that displacement had on vascular status when he differentiated between

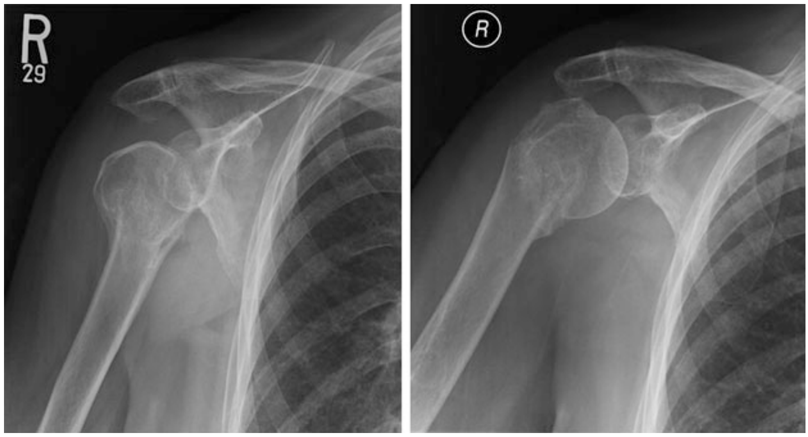

Fig. 1.12 Classification by mechanism can be a source of confusion. The *left* radiograph shows a valgus positioned adduction fracture. The *right* film shows a varus positioned abduction fracture. The films are actually internal and external views, respectively, of the same malunited fracture

fracture dislocations when there was a complete loss of contact between the humeral head and the glenoid surface and those with a rotational deformity but the head remained within the capsule [47].

Neer utilized Codman's idea of four possible fracture fragments when he developed his classification system [44]. Published in 1970, his system was based on an observation study of 300 displaced proximal humerus fractures (Fig. 1.13). He focused on the patterns of displacement rather than the location of fracture lines. His retrospective study attempted to correlate the classification with outcomes. He attempted to identify which fracture types were best treated with open reduction and to identify which fracture types had a high risk of avascular necrosis and were best treated with prosthesis [28].

Developed in the 1980s the AO/ASIF classification system was an attempt to make a classification system that was inclusive of all fracture types [17, 48]. The system includes 27 subgroups distinguished by articular surface involvement, location, and degree of comminution and dislocation (Fig. 1.14). There is an emphasis placed on the integrity of the vascular supply to the humeral head. There is a distinction made between valgus-impacted four-part fractures and the classic four-part fracture described by Neer [17]. The valgus-impacted fracture has an intact medial soft tissue hinge and a much lower observed rate of avascular necrosis. The cumbersome nature of this system has led to minimal utilization of it on a regular basis. However, when compared to the Neer classification system, it has shown similar inter- and intraobserver reliability [49]. There are no long-term studies evaluating treatment based on the AO classification system.

In 2013 a new comprehensive classification system of proximal humerus fractures, the HGLS system, was introduced [50]. The system is based on the work of Hertel et al. [51] who devised a binary system to classify proximal humerus fractures as part of an attempt to predict what fractures were at risk for development of avascular necrosis. A 12 question questionnaire was used to help define the avascular necrosis risk for a fracture. Based on the location of five possible fracture lines there were 12 basic fracture types identified (Fig. 1.15). The authors used LEGO blocks to help pictorially represent the 12 fracture types and each type of fracture was assigned a number. In contrast to the Neer system, a fracture fragment was considered to be present if a cortical disruption could be identified on any radiographic view. In their paper they identified length of metaphyseal hinge <8 mm, disruption of medial hinge, and fracture pattern as good predictors of humeral head ischemia. The authors of the HGLS system felt that while this binary system was a good classification scheme, its numbering system was confusing and led to errors in correctly categorizing fractures and decreased reliability. They introduced an alphabet-based "pictogram"

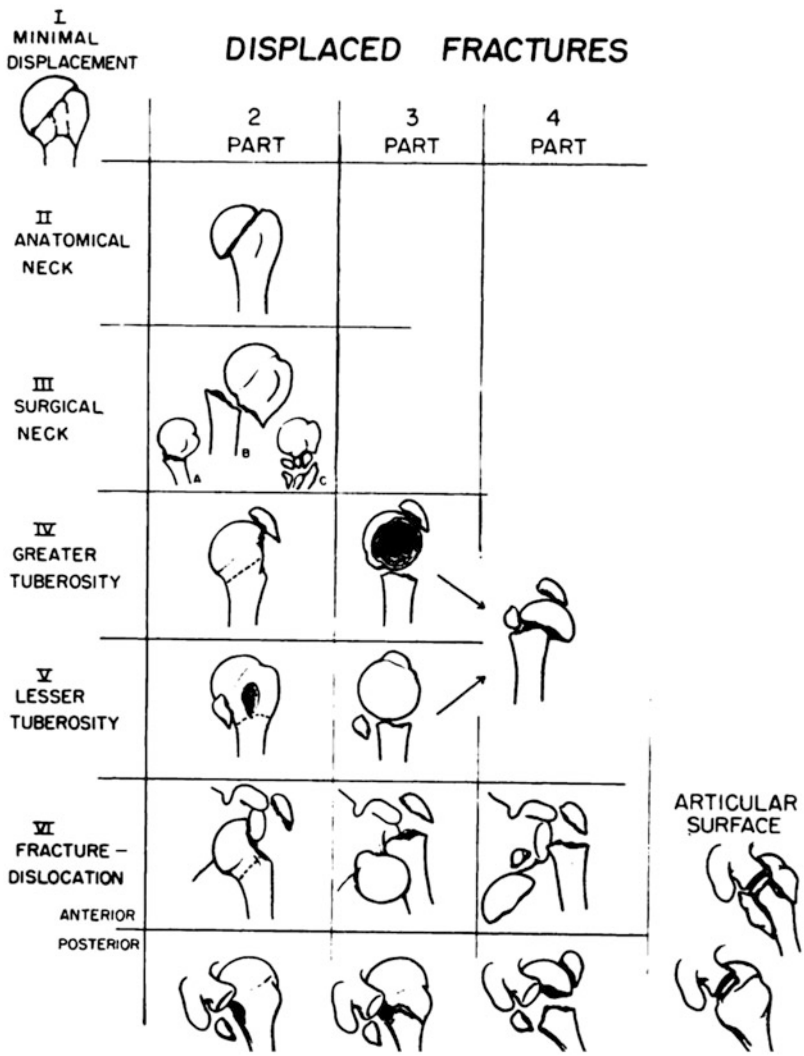

Fig. 1.13 Neer classification scheme as originally depicted in 1970 (Reprinted with permission from ref. [44])

to use in description of fractures that they felt simplified classification (Fig. 1.16). Their paper found good inter- and intra-observer reliability using this system and found their classification system to be superior to both the Neer and AO systems in inter- and intra-observer agreement.

Neer Classification System

The Neer classification system is the most commonly used system today. Neer sought to create a system in which the fracture classification would help guide the surgeon to the most appropriate treatment. When Neer devised his system he felt that there were deficiencies in the existing classification systems [44]. He felt the systems based on level of fracture were ambiguous and led to inconsistent classification of fractures in the literature. These systems also led to non-displaced fractures being displaced in the same group as displaced fractures. Systems based on mechanism of injury failed to appropriately describe the fracture. He felt the terms “abduction fracture” and “adduction fracture” were not accurate descriptors of the true injury pattern in proximal humerus fractures. The typical pattern of angulation could be described using either term based

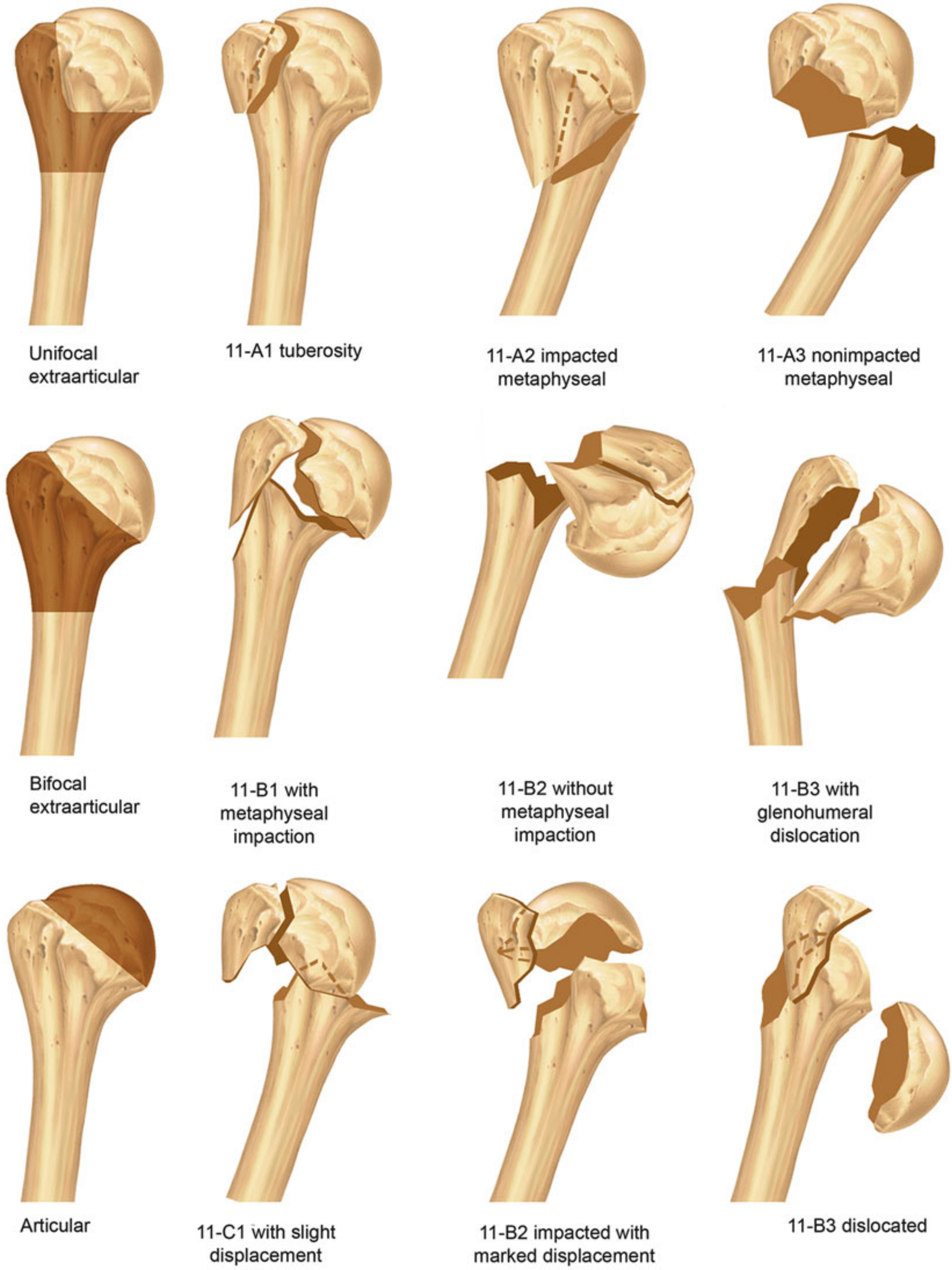

Fig. 1.14 The AO/ASIF classification scheme has nine groups of fracture that each has three subgroups for a total of 27 different fracture types (Courtesy of Carol Capers)

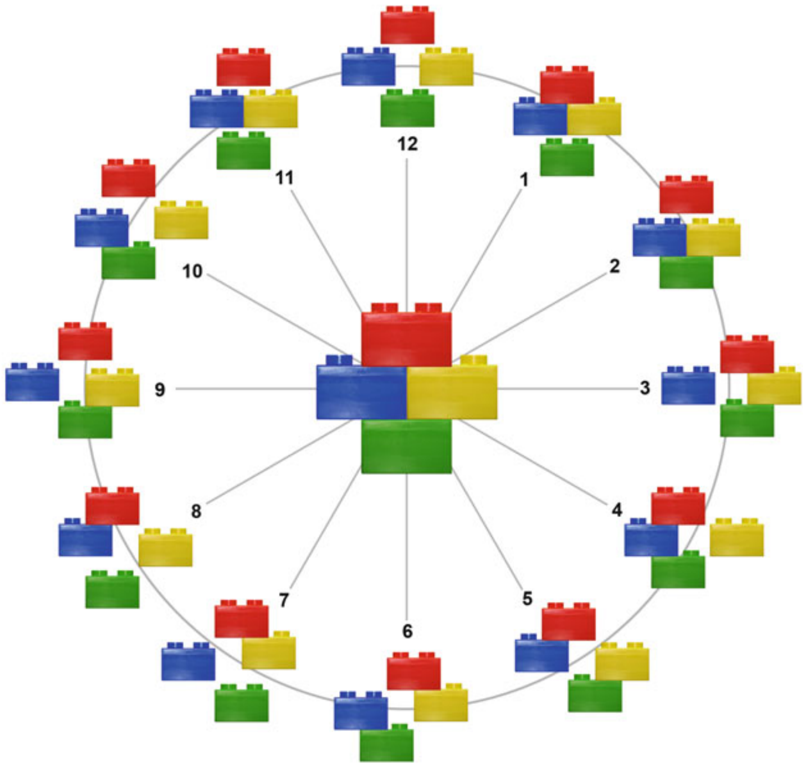

Fig. 1.15 In the binary descriptive system the five possible fracture planes account for 12 possible fracture patterns (Courtesy of Carol Capers)

on different rotation of the arm while shooting radiographs. Neer felt the literature was confusing as to what exactly constituted a fracture-dislocation. He also felt the role of muscle attachments in producing displacement had received far too little attention in the previous literature.

Neer's four segment classification system built upon the idea of four possible fracture segments as described by Codman [41, 44]. He felt that non-displaced fractures would behave similarly regardless of their fracture lines. However, displaced fractures required accurate description to predict the behavior of fracture fragments, the risk of avascular necrosis, and the continuity of the articular surface. He described a displaced segment as any segment displaced more than 1 cm or angulated greater than 45°.

Neer described minimally displaced or one-part fractures as fractures in which no segment had met the above-mentioned criteria to be considered displaced (Fig. 1.17). Regardless of the number of fracture lines these fractures presented a similar set of clinical issues to be addressed. They were treated with brief immobilization followed by early physical therapy.

Two-part fractures have one displaced fragment. The most common fracture pattern is a displaced surgical neck fracture in which the tuberosities remain attached to the head fragment. Neer described three different types of two-part surgical neck fractures. The first is an "angulated" surgical-neck fracture where the fracture is impacted but angulated greater than 45°. The posterior periosteal sleeve remains intact (Fig. 1.18). If left untreated the residual angulation will cause limitations in elevation and abduction. The second type is a "separated type" surgical neck fracture. The periosteum is completed disrupted and the pectoralis major pulls the shaft fragment anteriorly and medially (Fig. 1.19). The third type is the "comminuted" surgical-neck fracture in which comminution is seen extending distally from the surgical neck (Fig. 1.20). A second common two-part pattern is a displaced greater tuberosity fracture without

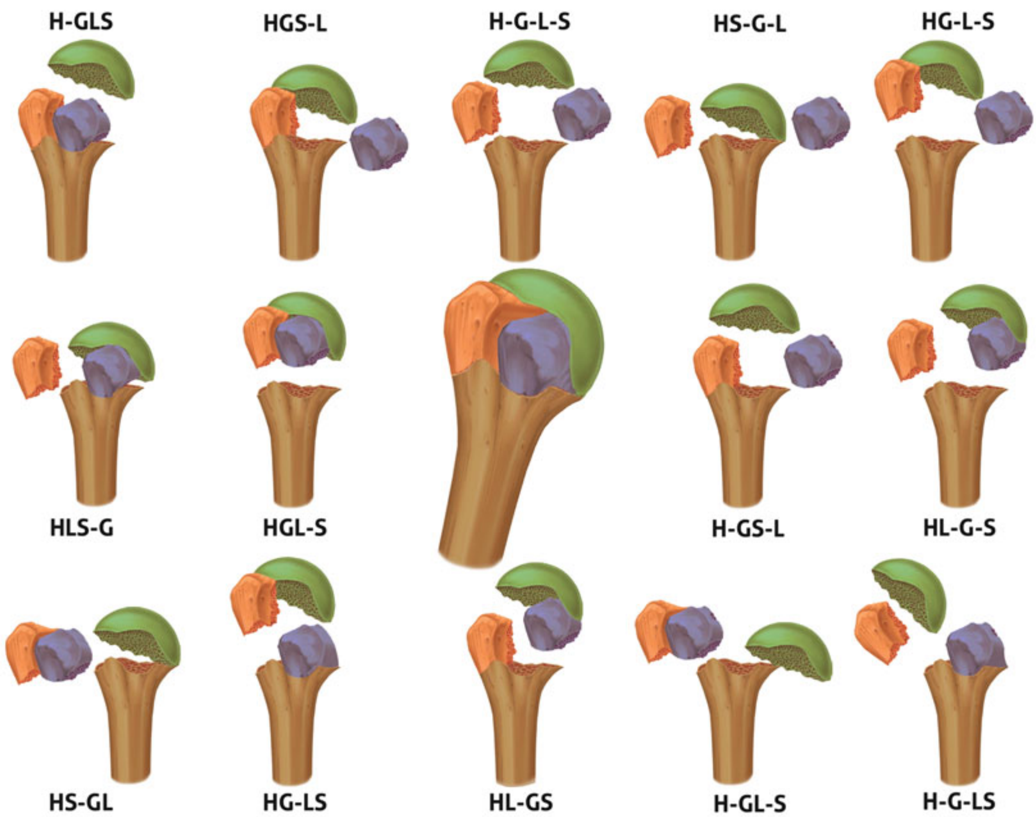

Fig. 1.16 Using the HGLS classification system the fracture lines between any of the four major segments can be classified (Courtesy of Carol Capers)

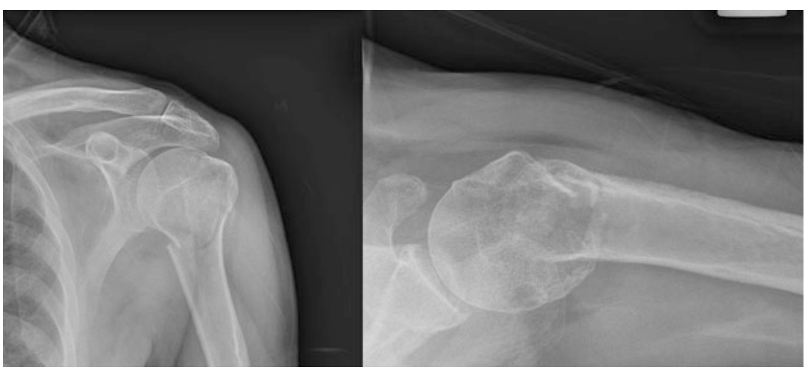

Fig. 1.17 Radiographs show minimally displaced two-part fracture without significant angulation or displacement of the fracture fragments

fracture of the surgical neck (Fig. 1.21). This pattern of injury is commonly seen after anterior dislocation of the shoulder. Lesser tuberosity fractures are rare (Fig. 1.22) and isolated anatomic neck fractures are quite rare (Fig. 1.23). Three-part fractures are most commonly fractures of the surgical neck accompanied by greater tuberosity fractures (Fig. 1.24). A less common variant is a surgical neck fracture with lesser tuberosity fracture (Fig. 1.25).

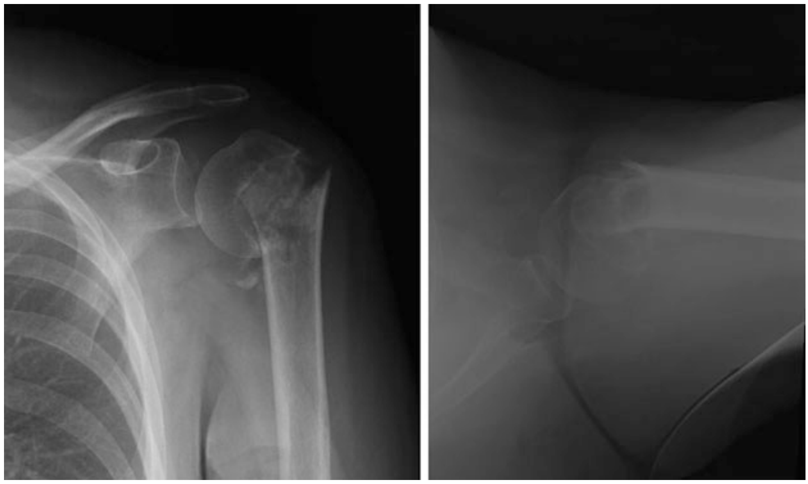

Fig. 1.18 X-ray images show impacted fracture with significant angulation of the fracture fragments

Fig. 1.19 Radiographs of separated two-part surgical neck fracture with medial and anterior displacement of shaft fragment

Fig. 1.20 Images of comminuted two-part surgical neck fracture show comminution extending into the diaphysis of the humerus

Fig. 1.21 This two-part greater tuberosity fracture is best visualized in the AP radiograph. The comminuted tuberosity fragment is displaced by the pull of the rotator cuff tendons

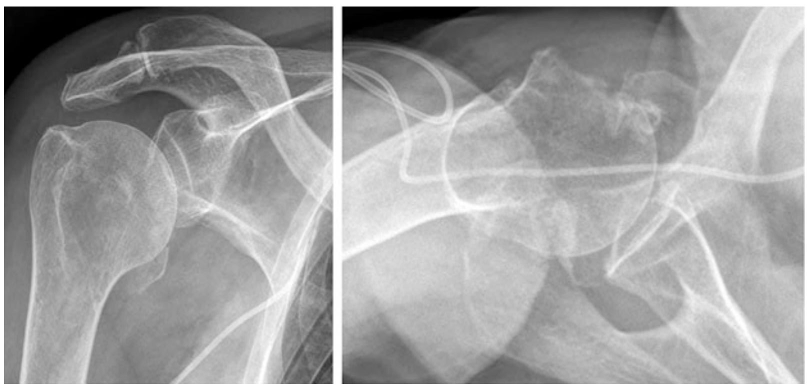

Fig. 1.22 These AP and axillary lateral X-rays show the uncommon two-part lesser tuberosity fracture

Four-part proximal humerus fractures result in the articular surface being completely separated from the other fragments. Fractures meet this classification even if the tuberosity fragments remain attached to each other [35, 44]. In the classic four-part fracture pattern the head is dislocated out of the glenoid and has no soft tissue attachments to the tuberosities (Fig. 1.26). In the valgus-impacted four-part pattern the head faces superiorly and there is medial soft tissue hinge that remains attached to the head fragment (Fig. 1.27). Neer's initial description did not differentiate between the two types of four-part fractures. Later articles emphasized the difference in behavior of these two fracture types [17]. In his 2002 review of his classification scheme [52] Neer included the valgus-impacted four-part fracture and noted that he felt that it was an intermediate on the continuum between minimally displaced fractures and the classic four-part fracture.

Neer classified fracture-dislocations as injuries in which there was a true dislocation of the glenohumeral joint. This indicated ligamentous injury and injury outside the joint. He classified these injures by direction of dislocation and whether they were two-part, three-part, or four-part fractures (Fig. 1.28). Three-part fracture dislocations maintained some soft tissue attachment to the head and Neer felt the blood supply to the head was maintained in these injuries. In four-part injuries the head was devoid of soft tissue attachment and blood flow. Neer grouped head-splitting and impaction fractures together as fractures that involve the articular surface (Figs. 1.29 and 1.30). He felt that any

Fig. 1.23 The rare two-part anatomic neck fracture is seen in this AP image

Fig. 1.24 A three-part greater tuberosity fracture is visualized in this AP image with displacement of both the surgical neck and greater tuberosity

fracture that included a head split or impaction fracture could be considered to have articular loss. These fracture patterns had a poor prognosis and needed treatment with prosthetic replacement [28].

Neer's initial classification system used Roman numerals to group fractures. Fracture patterns were grouped into possible injury patterns to one

Fig. 1.25 An uncommon three-part lesser tuberosity fracture is shown. The greater tuberosity fragment is minimally displaced, but displaced fractures of the surgical neck and lesser tuberosity are visualized (Image reprinted with permission from Medscape (http://www.medscape.com/), 2013, available at: http://www.medscape.com/viewarticle/420763)

Fig. 1.26 This X-ray of a classic four-part fracture pattern shows the head fragment is completely dislocated from the glenoid and separated from the tuberosity fragments

Fig. 1.27 AP radiograph of a valgus-impacted four-part fracture show the head fragment facing superiorly as medial soft tissue attachments to the fragment are maintained

Fig. 1.28 AP image of an anterior four-part fracture dislocation with the articular surface dislocated anteriorly and detached from both tuberosity fragments

Fig. 1.29 A posterior dislocation with an impaction fracture of the humeral head on the glenoid is visualized in this axillary lateral X-ray

Fig. 1.30 This head-split fracture is visualized on the AP radiograph as a double density of the humeral head

of the four proximal humeral segments; minimally displaced fractures and fracture-dislocations were each considered a separate group. This was modified to the use of descriptive terms that tell the number of displaced fragments and the most significant displaced fragment. The original Neer classification system recognized 16 different fracture classifications. The recognition of valgus-impacted four-part fractures added an additional group to the Neer system. Later authors have advocated a simplified Neer classification system in which the quite rare anatomic neck fractures are omitted and the direction of dislocation is ignored (Fig. 1.31) [35, 53].

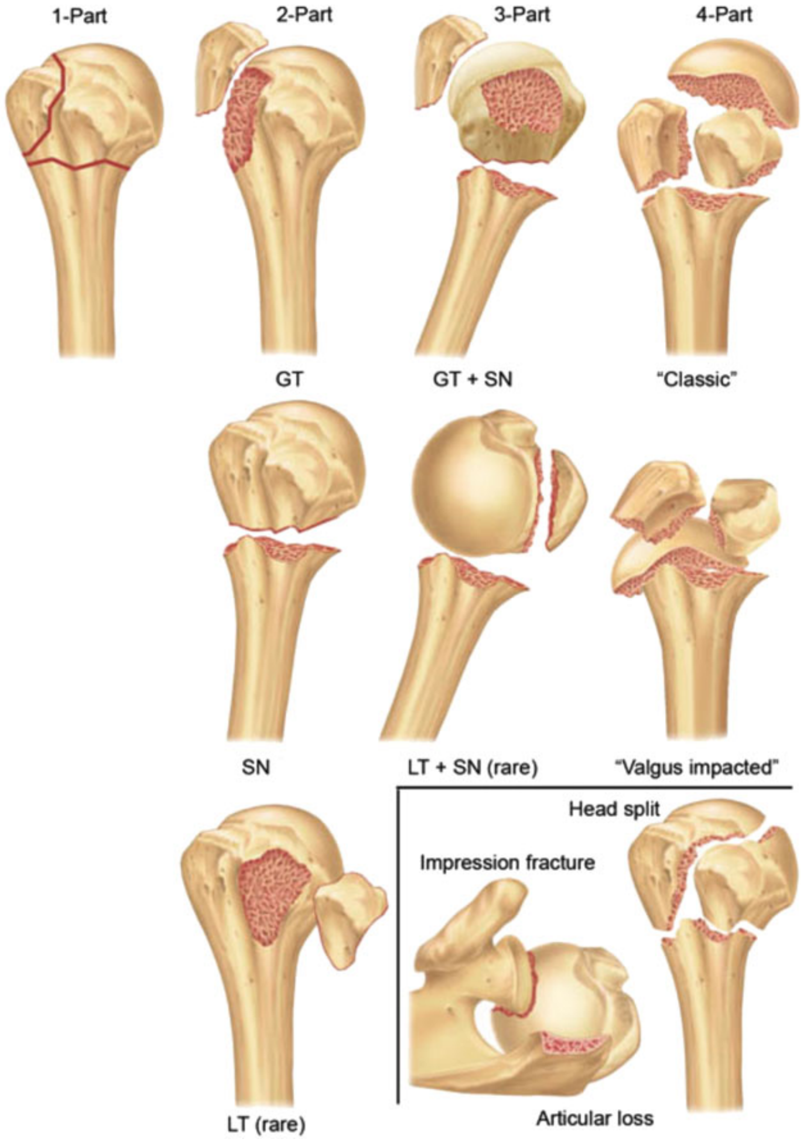

Fig. 1.31 Simplified Neer system

As the most widely used system for classification of proximal humerus fractures, there have been multiple studies to assess the usefulness and reliability of Neer's system. In their 2009 study Tamai et al. [54] retrospectively reviewed radiographs of 509 proximal humerus fractures. They felt that 98 % of the fractures could be classified under the revised Neer classification system and that it was a clinically useful system. Other authors have done studies to assess the intra- and inter-observer reliability of the system. Kristiansen et al. [55] evaluated the intra-observer reliability of the system when using an AP and lateral radiograph. They found poor reliability of the system, particularly amongst inexperienced evaluators. They did not include a full trauma series in their evaluation and did not assess inter-observer reliability. Sidor et al. [56] found moderate reliability between all levels of observers with average kappa reliability coefficients of 0.48 and 0.52 at different viewing times. Attending orthopedic surgeons showed slightly better agreement than orthopedic residents (0.52 vs. 0.48). The shoulder specialist showed the best intra-observer reliability with a reliability coefficient of 0.83; however, the musculoskeletal radiologist only measured 0.5. The average intra-observer reliability coefficient was good with a reliability coefficient of 0.66. Siebenrock and Gerber [49] had five orthopedic surgeons review radiographs of 95 patients to assess the inter- and intra-observer reliability of the Neer system. They found poor inter-observer reliability with a reliability coefficient of 0.40. Intra-observer reliability was fair with a reliability coefficient of 0.60. Only 37 % of their patients included a full trauma series but when compared to patients without a full radiographic evaluation the reliability was not improved.

The effect of utilizing CT imaging to assist in classification of proximal humerus fractures using the Neer system has been studied. Bernstein et al. [57] evaluated radiographs and CT images of proximal humerus fractures. They found intra-observer reliability was improved, but inter-observer reliability did not change with the addition of two-dimensional CT imaging. Sjoden et al. [58] showed only moderate inter-observer reliability with the addition of CT imaging. The use of three-dimensional CT imaging has been evaluated with mixed results. Sallay et al. [59] did not feel the addition of three-dimensional imaging improved the reliability of classification. In contrast, Brunner et al. [39] found moderate inter-observer reliability with plain radiographs and two-dimensional CT that improved to good with the addition of three-dimensional imaging.

The literature that is critical of the Neer system does have some weaknesses. The papers on the system are based solely on the radiographic evaluation of the fractures. Neer did not feel like his system was meant to be a solely radiographic classification system, but rather a system based on pathoanatomy [52]. Classification can often be made solely on imaging studies, but surgical findings are sometimes needed before the final classification can be made. One limitation of studies that are purely radiographic is the fact that they are limited by the quality of the images in those studies. The reliability scores are also lowered by including inexperienced observers in some of the studies. An important factor that will lower the reliability of the Neer classification scheme is that the presence of injuries with marginal displacement will always lead to some disagreements in classification of these fractures. It has been shown that further education on the Neer system does improve inter-observer reliability [60, 61].

Conclusion

Accurate classification of proximal humerus fractures remains a challenge for orthopedic surgeons. A combination of quality radiographs and an experienced observer improves the reliability of classifying these fractures. Conversely, complex anatomy that is difficult to image and poor radiographs are often impediments to accurate assessment of the fracture. Despite literature questioning the reliability of the system, the Neer classification system continues to be the most widely used classification system today. It allows us to correlate fracture pattern to treatment. It is comprehensive enough to include most fracture types but remains concise enough to allow surgeons to use it clinically and communicate effectively using the system. Complex proximal humerus fractures continue to be a difficult fracture to assess. However, experienced surgeons with good imaging can accurately classify fractures and use this classification to guide treatment.

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2 Nonoperative Treatment of Proximal Humerus Fractures

Todd Twiss

Introduction

Proximal humerus fractures are common but debilitating injuries, which result in significant dysfunction for the patient and both diagnostic and treatment challenges for the physician. Knowledge of the complex bone and soft tissue anatomy of the shoulder is paramount in successful treatment of proximal humerus fractures. Proximal humerus fractures account for 5 % of all fractures, and they are third in frequency among the most common types of fractures [1–3]. In general, there is a unimodal distribution of these injuries. The vast majority are low energy fractures occurring in elderly individuals with more high energy and complex fractures in younger patients happening less frequently [4–6]. Incidence does tend to increase with age, and elderly individuals who sustain these fractures are more commonly female, over the age of 60, and have a history of osteoporosis [3, 7, 8]. Nearly ¾ of proximal humerus fractures occur in patients older than 60 who have fallen from a standing height [2, 4]. The majority of proximal humerus fractures in this demographic are relatively non-displaced and can be treated successfully without surgery [9]. Risk factors for proximal humerus fractures include elderly patients, low bone mineral density, impaired vision and balance, no history of hormone replacement therapy, smoking, >3 chronic illnesses, and previous fragility fracture [4, 10, 11]. Younger patients sustain proximal humerus fractures as a result of motor vehicle accidents, seizures, electric shock, and fall from greater than a standing height [12]. These injuries tend to involve more significant bony and soft tissue disruption and accordingly are treated with surgical intervention [2, 11].

Regardless of the age of the patient or mechanism of injury, restoration of pain-free functional range of motion remains the primary treatment goal of these injuries [13]. Some difficulty in clinical assessment and classification of proximal humerus fractures has resulted in a lack of standardization over treatment protocols [9]. Numerous factors contribute to post injury functional outcomes; therefore, a large debate exists over appropriate treatment [14, 15]. In addition, a lack of high-level evidence with regards to treatment and outcomes after proximal humerus fractures despite the relative frequency of the injury has resulted in a lack of consensus based protocol driven treatment [14, 16, 17]. Recent advances in technology have provided new treatment options without substantiation over historical options [9]. There currently exists several dilemmas such as when to perform surgery and which surgery is the most appropriate method of treatment, which have yet to be definitively determined. High-level outcome based studies are currently being performed to help answer questions but uncertainty still remains [18]. Regardless of

T. Twiss (✉)
Department of Orthopaedic Surgery, Freeman Health System, 3105 McClelland Boulevard, Joplin, MO 64804-1640, USA
e-mail: toddtwiss@yahoo.com

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treatment selected, early active mobilization has led to improved outcomes [19, 20].

Anatomy

Several anatomic characteristics must be considered when deciding appropriate treatment of proximal humerus fractures. The shoulder is an unconstrained ball-and-socket articulation, which relies on both a complex bone and soft tissue anatomy for stability and function. It has more inherent motion than any major joint in the body, therefore any injury disrupting the bone and soft tissue restraints can lead to both instability and dysfunction. Moderate loads to the glenohumeral joint are offset by dynamic restraints such as the deltoid and rotator cuff, whereas, larger loads are counteracted by the capsulolabral structures and the bone [12].

Bone anatomy of the proximal humerus can be subdivided into four main parts based off classification of typical injury patterns [21]. The proximal humerus consists of the humeral head, lesser tuberosity, greater tuberosity, and shaft fragments. The head fragment is spherical in shape and has an average diameter of 46 mm (37–57 mm) [22]. The height of the head is 8 mm superior to the greater tuberosity with an offset 3 mm posterior and 7 mm medial to the shaft [23, 24]. The head has an average of 20° retroversion with a high anatomical variance (6.7° anteversion–47.5° retroversion), and it is inclined 130° with respect to the shaft [23, 25]. The anatomical neck separates the head and tuberosities and serves as a site of attachment for the capsular structures. Injury at this location portends to a poor prognosis as it disrupts the entire blood supply to the head [26]. Bone quality of the proximal humerus can be predicted by the cortical thickness of the proximal diaphysis [27]. The subchondral bone underlying the articular surface is the densest, and there is a particular decrease in density in the humeral head when moving from superior to inferior and from posterior to anterior [27–30].

The tuberosity fragments serves as anatomical attachment sites of the rotator cuff. These soft tissue attachments lead to displacement through predictable force vectors. Greater displacement of fragments leads to greater soft tissue disruption and loss of blood supply [3]. The supraspinatus, infraspinatus, and teres minor tendons all attach on separate facets of the greater tuberosity. These attachments result in the typical posterior and a superior displacement seen with fractures of the greater tuberosity. The lesser tuberosity serves as a site of attachment for the subscapularis tendon and results in medial displacement of the fractured lesser tuberosity fragment [3]. The bone of the tuberosities tends to be denser at the rotator cuff insertion site, and the tendons are usually stronger than the bones at the sites of attachments [31]. The bicipital groove separates the greater and lesser tuberosities, and the distal groove the slightly internally rotated with respect to the proximal portion of the groove [32]. Fractures between the tuberosities typically occur posterior to the bicipital groove [33]. The tuberosities are separated from the shaft fragment via the surgical neck, which is an indistinct region of metaphyseal bone below the tuberosities and above the shaft. Fractures of the tuberosity dysfunctions the attached rotator cuff muscles, and malunion secondary to displacement can lead to subacromial and subcoracoid impingement [34, 35].

The proximal humerus articulates with both the glenoid and coracoacromial arch. The head articulates with the glenoid, which is a convex structure shaped like an inverted pear. The capsulolabral structure attaches both and can be disrupted with injuries to the proximal humerus [12]. The coracoacromial arch is made up of the acromion, coracoacromial ligament, and coracoid. This rigid bony and ligamentous structure imparts stability on the shoulder, and fracture and subsequent displacement can disrupt normal gliding between the arch and proximal humerus causing impingement and dysfunction [26]. In addition, the subdeltoid and subacromial bursa can become thickened, fibrotic, and scarred as a result of fracture causing adhesions and limits of motion. Early motion is theorized to limit these adhesions [20].

The proximal humerus has an extensive vascular network (Fig. 2.1). The anterior and posterior humeral circumflex arteries, creating a

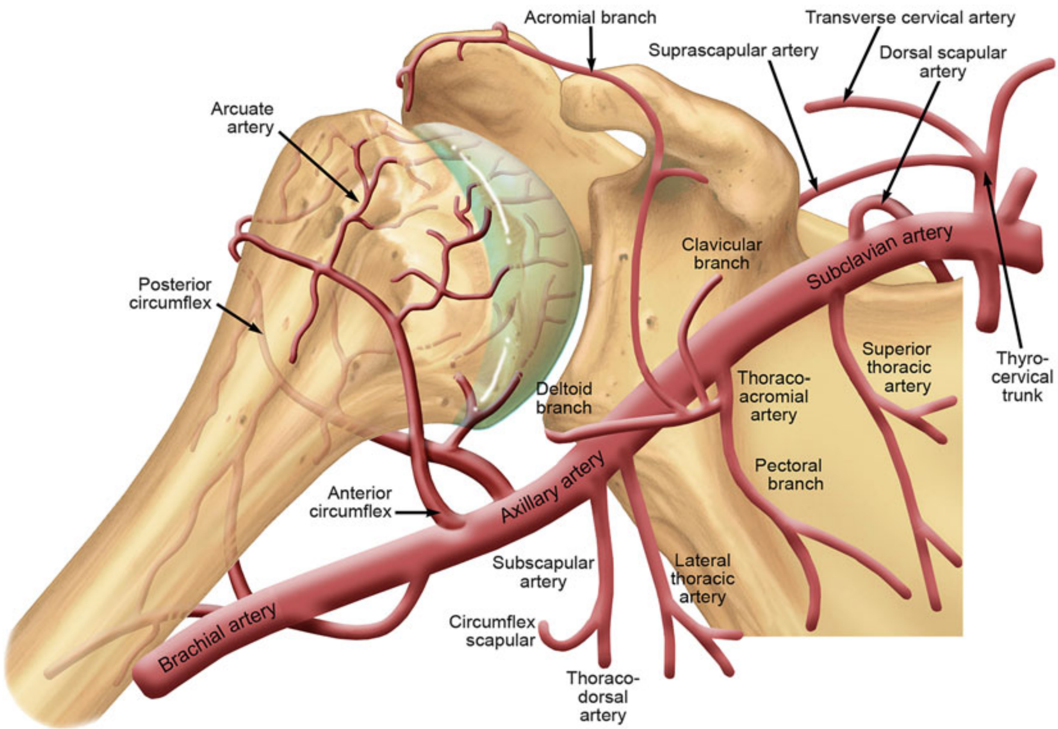

Fig. 2.1 Vascular network of the proximal humerus

vascular leash, surround the proximal humerus. The anterior humeral circumflex artery arises from the axillary artery at the inferior border of the subscapularis, and it provides the majority of the vascular inflow for the humeral head along with its interosseous branch the arcuate artery [36–38]. More significant soft tissue displacement and higher energy fractures are associated with increasing vascular disruption to the humeral head. Injury to the arcuate artery in proximal humerus fractures is associated with AVN, but extraosseous collateral circulation can perfuse the humeral head despite arcuate artery injury [39–41]. The posterior humeral circumflex artery travels with the axillary nerve posteriorly to supply the posterior rotator cuff and posterior capsule. In some proximal humerus fractures, the posterior humeral circumflex artery and its branches to the posterior capsule can maintain humeral head perfusion alone [41]. Comminution of the medial metaphysis with an articular segment of less than 1 cm has been associated with avascular necrosis after proximal humerus fracture due to disruption of the anterior and posterior humeral circumflex vessels [22, 41]. Severe vascular injury can be seen in 5–6 % of proximal humerus fractures [12]. The axillary artery is most commonly injured and is seen in patients with comorbid conditions [42].

With their close proximity to the proximal humerus, neurologic structures are at risk for injury after proximal humerus fracture. Neurologic injuries generally occur secondary to traction but can happen secondary to blunt trauma as well [43]. The axillary nerve is most commonly injured. It has a distance of 6.1 cm from the superior aspect of the proximal humerus and 1.7 cm from the surgical neck [43, 44]. Injury can occur in any of the three branches to the deltoid, teres minor, or the superior lateral cutaneous nerve. Suprascapular neuropathy can occur secondary to traction at either the exit from the upper trunk of the brachial plexus or under the transverse scapular ligament [43, 45]. Musculocutaneous nerve injury is uncommon but can occur with blunt trauma as it enters the conjoint tendon 3.1–8.2 cm from the tip of the coracoid [46, 47]. In addition, there is a high association of brachial plexopathy with axillary artery injuries [42].

Epidemiology

Proximal humerus fractures are an age related phenomenon that can only be expected to rise with an increasingly aging population [48]. As stated previously, proximal humerus fractures represent the third most common fracture related injury in patients over the age of 60, and they represent 5 % of all injuries to the extremities [1, 3, 37, 49]. Incidence of the injury seems to increase with age, and females are more likely to sustain proximal humerus fractures in comparison to males [3]. Population studies have shown that as many as 70–80 % of all proximal humerus fractures occur in women [4, 50–52]. These injuries are less common in Japanese populations than Europeans or white Americans [53, 54]. In addition, white Americans sustain proximal humerus fractures at a greater frequency than black Americans [55]. The incidence of proximal humerus fracture is 63–105 fractures per 100,000 populations per year [4, 51, 52, 55, 56]. The prevalence of the injury is expected to continue to rise in conjunction with the shifting population demographics [8]. There is a unimodal elderly distribution curve of the injury with a low incidence under the age of 40 and a sharp increase thereafter [50]. The majority of proximal humerus fractures occur in the elderly who have a history of osteoporosis and sustain low energy injuries. In patients over the age of 60, 97 % of proximal humerus fractures are secondary to a fall with a direct blow to the shoulder [4, 57]. Due to this shifting demographic, the incidence of osteoporotic fractures is expected to triple over the next three decades [58]. Long-term Finnish studies have confirmed the correlation of increasing incidence of proximal humerus fractures with age [59]. Women who are over the age of 60 have an 8 % lifetime risk of proximal humerus fracture [60]. The correlation of osteoporosis with proximal humerus fractures can complicate both fracture treatment and patient management of post fracture complications. Risk factors for sustaining a proximal humerus fracture include osteoporosis and frequent falls [61–63]. In prospective and consecutive osteoporosis screening only 13 % of 239 hospitalized fracture treatment patients had a normal bone density [64]. In addition, history of poor balance and impaired vision has been correlated with an increase in fracture risk [9]. In contrary to the high-energy high-displacement injuries seen in younger patients, nearly 80–85 % of all proximal humerus fractures are minimally displaced, and therefore can be treated safely without surgery [21]. If surgery is indicated, osteoporosis complicates surgical management. Fixation failure is likely with decreasing bone mineral density, and osteoporosis can compromise both functional and radiographic outcomes associated with fracture healing [65]. The majority of proximal humerus fractures are fragility fractures, and the greatest risk factor for future fragility fracture is a history of previous fragility fracture [9]. To prevent any future complications, osteoporosis treatment should be part of the global care given to any patient who sustains a proximal humerus fracture [3].

Etiology

While the majority of proximal humerus fractures arise secondary to low energy injuries, mechanism of injury is directly correlated with the age of the patient. The injury occurs the most frequently in the elderly population, and most injuries occur as a result of a fall onto an outstretched hand from a standing height in patients over the age of 60 (Fig. 2.2) [5, 8, 59]. Nearly ¾ of proximal humerus fractures occur after a low energy domestic fall [4, 51, 52, 55]. Younger patients without osteoporosis generally sustain a proximal humerus fracture after motor vehicle accidents, falls from greater than a standing height, seizures, or electric shock [2, 66, 67].

The biomechanics of the fracture and general bone quality of the patient tend to produce varying injuries in the proximal humerus. In general,

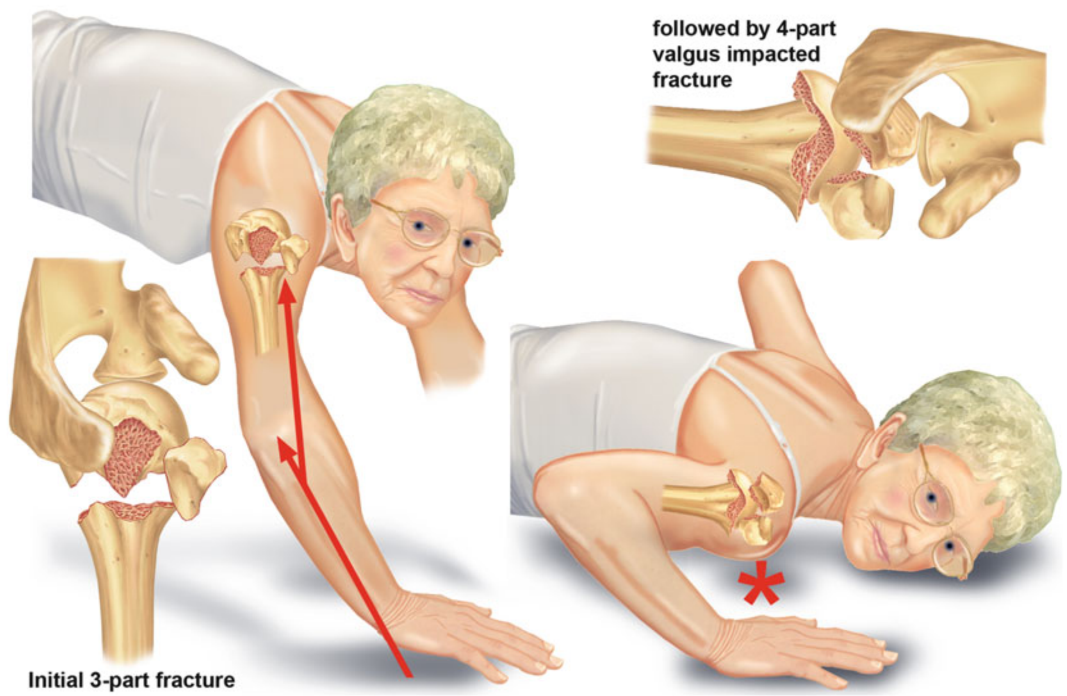

Fig. 2.2 Common mechanism for low energy proximal humerus fractures in elderly patients

fractures occur as either a direct blow to the shoulder of from indirect force transfer from a fall onto an outstretched hand [3, 9, 12]. The impact drives the proximal humerus into the glenoid resulting in significant energy transfer to the proximal humerus. The glenoid bone is generally harder and denser than the proximal humerus, and therefore acts as an "anvil" on which the proximal humerus is impacted [68]. The combination of the direction of the blow to the humerus, quality of bone in the proximal humerus, as well as the pull of the soft tissues produces the various types of fracture patterns [9].

Medical comorbidities both increase the risk for fracture and type of fracture sustained. Proximal humerus fractures are seen in a greater frequency in patients with a depleted neuromuscular response [69–71]. It has been suggested that patients who sustain proximal humerus fractures are frailer than those who sustain distal radius fractures [72]. The proximal humerus is injured more frequently in patients with decreased neuromuscular response who cannot raise their arm quickly enough to break a fall [73, 74]. Risks factors such as delayed reaction time; cognitive impairment, neuromuscular disorder, impaired balance, and intoxication are all associated with proximal humerus fracture [75]. Middle-aged patients who sustain proximal humerus fractures are physiologically older with a higher incidence of medical comorbidities, alcohol, tobacco, and drug usage [76, 77]. Early menopause is the most common physical aging comorbidity associated with proximal humerus fractures [9]. In addition to osteoporosis, pathologic fracture from either primary malignancy or metastatic disease can occur secondary to minimal trauma [5].

Clinical Evaluation

During initial evaluation of proximal humerus fractures, a complete history and physical must be performed. The history should initially determine whether the injury is a high or low energy injury and proceed accordingly. With a high-energy injury after a motor vehicle accident, fall from greater than standing height, or similar injury, ATLS protocol should be initiated. Chest injuries associated with high-energy proximal humerus fractures can include pneumothorax, rib fracture, and hemothorax [9]. Cervical spine injuries are commonly associated with significant shoulder fractures secondary to high-energy trauma [9]. Rare case reports of intrathoracic and retroperitoneal proximal humerus fracture dislocation exist [78, 79].

A thorough history should include mechanism, pre injury level of function, occupation, hand dominance, history of malignancy, history of previous fragility fractures, and rehabilitation potential. The presence concomitant extremity injuries should be assessed. Patients with proximal humerus fractures can present with injuries to the hip, elbow, wrist, and hand, and any tenderness or pain in those areas should be thoroughly addressed. Conversely, patients with more distal extremity fractures with pain in the shoulder should be evaluated for proximal humerus fracture.

A complete physical examination should assess the entire upper extremity and focus on other areas of concern. The skin envelope is robust around the shoulder, and open fractures are exceedingly rare [9]. Occasionally, a significantly displaced humeral shaft in slim individuals can create pressure necrosis on the skin. The rate of skin compromise is approximately 0.2 % and commonly associated with significantly displaced two part surgical neck fractures [80]. Mechanism for skin penetration involves blunt trauma to the shoulder, and can either occur by initial penetration or delayed opening secondary to skin tenting [80]. Significant ecchymosis occurs often in a delayed fashion, and due to gravity, tracks down fascial planes. As a result, swelling and bruising can be pronounced at the elbow. Anterior and posterior fracture dislocations can cause an increased swelling and fullness in the anterior and posterior aspects of the shoulder respectively (Fig. 2.3) [67]. Very severe swelling can occasionally be associated with vascular injury, but nearly all proximal humerus fractures have some degree of swelling associated with the injury [42]. For more subtle injuries, specific palpation of the proximal humerus should be performed. Non-displaced and

Fig. 2.3 Anterior proximal humerus fracture-dislocation

minimally displaced fractures of the greater tuberosity are overlooked in nearly 53 % of all initial examinations [81]. A thorough neurovascular examination should include inspection of the distal circulation, axillary nerve, as well as distal neurologic status. A thorough secondary survey for other extremity injuries and head, neck, chest, and facial trauma should be performed.

Neurologic injuries are common after significant proximal humerus fractures and often overlooked [82]. The axillary nerve arises from the C5 and C6 nerve roots and in the axilla splits from the brachial plexus via the posterior cord. The axillary nerve carries three branches, a sensory branch supplying the skin overlying the lateral deltoid, and two motor branches to the deltoid and teres minor, respectively. The axillary nerve travels around the inferior aspect of the subscapularis and posteriorly along the surgical neck. It travels through the quadrangular space with the posterior humeral circumflex artery. Incidence of neurologic injury with proximal humerus fracture ranges between 6.2 % and 67 % with axillary nerve injuries being the most common [83]. The axillary nerve is susceptible to a tethering type injury with significant displacement of the surgical neck and particularly in anterior fracture-dislocations [43]. Brachial plexopathy can occur via direct blow from displaced fragments, and multiple nerves are at risk during treatment for proximal humerus fractures [43, 45, 82]. A complete neurologic evaluation can be difficult due to pain and guarding secondary to fracture, but a full axillary nerve and peripheral nerve exam should be performed with each injury. Both the brachial plexus and peripheral nerves are at risk during operative treatment, and risk facture such as cervical spine disease, low BMI, diabetes mellitus, and delay of operative treatment for more than 14 days are associated with an increased incidence of nerve dysfunction [83].

A large vascular leash surrounds the proximal humerus, but major vascular injury is only rarely associated with proximal humerus fractures [84]. Even when a vascular injury occurs, a rich collateral circulation exists in the upper extremity, so obvious signs such as expansile hematoma, pulsatile external bleeding, unexplained hypotension, and plexus injury should raise suspicion of vascular injury [9]. Significant medial displacement of either the head or the shaft can result in an axillary artery injury [42, 43]. Vascular injury should be assumed with a four-part proximal humerus fracture with axillary dislocation of the head. When fracture is associated with dislocation, risk of blood vessel injury increases 30 % [85]. Distal circulation should be assessed in all patients with proximal humerus fractures.

Soft tissue injury associated with proximal humerus fracture is commonly encountered, and it should be expected if injuries do not follow typical clinical course [86]. Superficial muscle perforation can occur after significant displacement of fracture fragments. With fractures of the greater or lesser tuberosity, the rotator cuff is essentially defunctioned, and rotator cuff dysfunction should be expected [9]. A complete rotator cuff examination cannot usually be performed in an acute setting due to pain and swelling, but rotator cuff function should be followed throughout the typical clinical course to ensure adequate function. Due to the age of most patients who sustain proximal humerus fractures, previous rotator cuff disease is likely, and certainly a new rotator cuff tear can occur in conjunction with proximal humerus fractures [86]. With less severe bony injuries that do not follow the typical healing course, labral pathology should be suspected as well. Case reports of isolated SLAP lesions and combined SLAP and rotator cuff injuries after nondisplaced proximal humerus fractures exist [87]. In this report, patients continued to have shoulder pain and dysfunction despite appropriate bony healing that resolved with arthroscopic repair of rotator cuff and labral injuries [87].

A complete radiologic evaluation should be included in every clinical evaluation of proximal humerus fractures. A trauma series should include an AP and lateral taken in the scapular plane along with an axillary lateral. Due to the anatomic positioning of the glenoid in relation to the thorax, the standard anteroposterior radiograph taken in most emergency departments is generally unsatisfactory to assess shoulder anatomy. In general, most AP radiographs taken of the shoulder are mainly views of the upper quadrant and have significant overlap of anatomic structures such as the coracoid, glenoid, humeral head, and scapula. The surgeon must be able to specify to the radiology technician appropriate methods to obtain a true AP of the shoulder. The patient's affected shoulder should be placed against the X-ray plate and the opposite shoulder is tilted approximately 40° towards the beam [9]. This positioning will ensure a direct view through the glenohumeral joint. To obtain an appropriate scapular lateral, the anterior shoulder is placed on the X-ray plate with the unaffected shoulder tilted forward 40°. The beam is placed posteriorly and directed along the scapular spine [12]. An axillary lateral view is paramount to assess anterior or posterior displacement of the humeral head in relation to the glenoid. To obtain the view the arm must be abducted as close to 90° as possible. The cassette is placed on the superior aspect of the shoulder and the beam directed from inferior perpendicular to the cassette [12]. Due to the nature of the injury, abduction of the shoulder can usually not be achieved after proximal humerus fracture. Therefore, a modified axillary view or Velpeau view can be substituted for an axillary lateral [12, 88]. The view allows the patient to remain in the sling; therefore, it is much less painful for patients. The view is

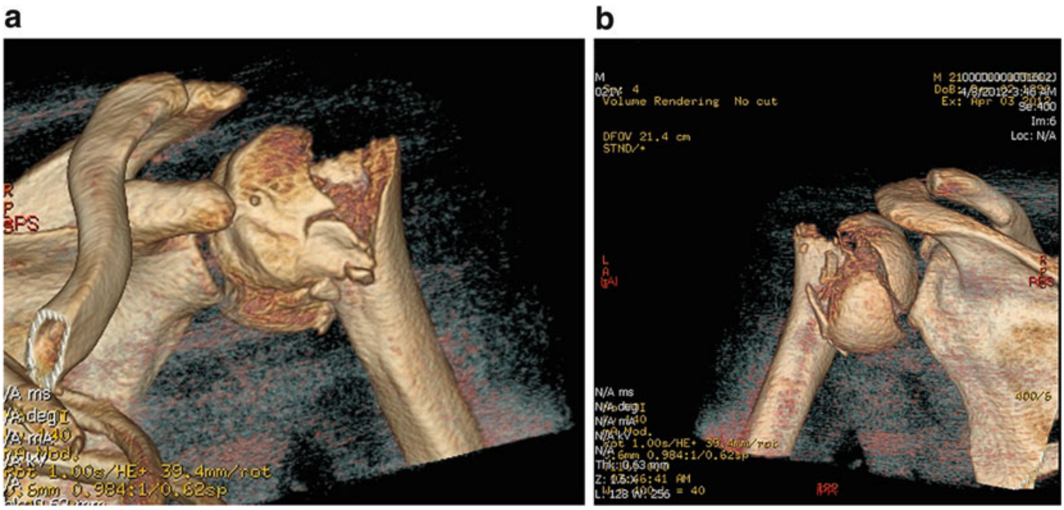

Fig. 2.4 3D CT images providing enhanced detail of a complex proximal humerus fracture seen from (**a**) anterior and (**b**) posterior views

obtained by leaning the patients over a table on which the cassette lies. The beam is then directed from superior to inferior. In cases where a more subtle greater tuberosity fracture of Hill Sachs lesion is suspected, internal and external rotation views can be obtained to further evaluate the anatomy of the humeral head [12]. A complete X-ray examination can provide information with regards to the typical displacement seen after proximal humerus fracture. The internal rotation views, axillary or scapular lateral will show typical greater tuberosity posterior displacement due to the pull of the infraspinatus and supraspinatus [3]. Both the anteroposterior and lateral views showcase the medial displacement of the lesser tuberosity and shaft consistently produced by the pectoralis major and subscapularis muscles [89]. Head displacement is typically variable and related to remaining soft tissue attachments. The axillary lateral view is needed to evaluate for humeral head dislocation [3]. Posterior dislocation of the humeral head associated with proximal humerus fractures is typically missed without an appropriate axillary lateral view [13].

Computed tomography analysis of proximal humerus fractures can provide enhanced bony detail and greater understanding of fracture patterns and displacement (Fig. 2.4a, b). CT provides an enhanced understanding of tuberosity displacement, fracture comminution, impaction, humeral head involvement, and glenoid articular surface injury [5, 67]. Both two-dimensional and three-dimensional images can be obtained through software programs at most institutions to provide even greater detail of complex fracture patterns [90]. CT scan with 3D reconstructions has been shown to provide the highest interobserver agreement with regard to classification and treatment recommendations among upper-extremity specialists [91].

Magnetic Resonance Imaging provides very little benefit to the initial evaluation of proximal humerus fractures. If pathologic fracture is suspected, an MRI can aid in staging of the disease prior to treatment [12]. If either rotator cuff or labral injury is suspected after bony healing, MRI can be helpful in assessing for these injuries [87]. In the acute setting, bleeding from the fracture and soft tissue swelling can make the use of MRI difficult in assessing soft tissue injury after a fresh proximal humerus fracture [9].

Clinical Decision Making

When deciding the appropriate treatment method for proximal humerus fractures, the surgeon must have a clear understanding of the primary goals for treatment. The goal of treatment of proximal humerus should be to minimize pain and maximize shoulder function [33]. Achieving the goal is paramount regardless if it is through surgical or nonsurgical means. Multiple factors play into treatment decision making, but all surgeons should strive for complication free healing to produce a pain free, mobile, stable, and functional shoulder [9].

Factors related to the patients, surgeon, and injury all determine appropriate treatment methods. When deciding between operative and nonoperative treatment, patient characteristics such as age, mental status, substance abuse, medical comorbidities, osteoporosis, rehabilitation potential, functional expectations, and limited life expectations should all effect treatment methods [9, 12, 13]. In general, a lower demand individual with significant medical comorbidities is more appropriately treated nonsurgically with the goal of establishing early functional pain-free motion [19]. Older patients tend to have worse functional outcomes after treatment for proximal humerus fractures [92]. This trend has been attributed to such factors as fragility, cognitive deficits, rotator cuff injuries, osteoporosis, and poor rehabilitation potential [63, 70, 93, 94]. Patient factors have been proven to effect treatment related outcomes after both surgical and nonsurgical management. Complications such as infection, nonunion, osteonecrosis, fixation failure, and compliance with rehabilitation can all be related to medical comorbidities [9]. Specifically, alcohol abuse increases the risk of noncompliance and nonunion, and tobacco usage increased a patients risk of nonunion [77, 95]. Osteoporosis is associated with increased rates of comminution, defects due to impaction, and loss of fixation and reduction after surgical management [3].

Injury related factors influencing treatment decision include fracture type, displacement, soft tissue injury, and concomitant injuries. The majority of all proximal humerus fractures are minimally or non-displaced, and therefore can be successfully managed without surgery [5, 96]. Approximately only 20 % of proximal humerus fractures are either comminuted or displaced sufficiently that they require operative intervention [5, 97]. Fracture type alone has been seen as a limited predictor of overall outcome [5, 97]. Bone quality, comminution, displacement, rotator cuff status and vascular risk can all be related to varied outcomes [9, 12]. Treatment controversy exists when considering injury related factors alone, and traditional guidelines for treatment proposed by Neer are not the gold standard according to current evidence based medicine [21, 98–101]. Near functional normality can only be expected after simple injuries to the proximal humerus [20, 92, 102–104]. For patients with more severe and complex proximal humerus fractures proper counseling prior to either nonoperative or operative treatment is paramount to establish patient expectations and goal prior to proceeding with treatment [96, 105]. Investigation of outcomes after displaced four part proximal humerus fractures show that both operative and nonoperative treatment can achieve similar outcomes, although several limitation exist when comparing studies of different patient selection criteria, procedures, and outcome measures in small patient populations [101]. Proper patient selection is the most important factor in achieving a good outcome with treatment [33].

Surgeon expertise, comfort, and experience influences appropriate treatment of proximal humerus fractures as well. With modern advances in orthopedic technology, the surgeon has an armamentarium of options to treat fractures of the proximal humerus. From nonoperative treatment to limited percutaneous fixation, open reduction internal fixation with standard plating, locked plating techniques, intramedullary nails, suture fixation, various bone grafting options, and arthroplasty, the surgeon has multiple options to address various injuries to the proximal humerus [18, 52, 106–110]. Each option has various advantages and disadvantages associated with treatment, and the surgeon must be familiar with each prior to proceeding with treatment and determining which method is the most appropriate for each individual patient. Overall, results after nonoperative treatment will be superior to a

Fig. 2.5 Non-displaced proximal humerus fracture with mild "pseudosubluxation" (**a**) seen on injury AP radiograph, with resolution (**b**) 3 weeks later

poorly performed operative procedure regardless of the method of fixation [9].

General indications for surgical management are open fractures, significant displacement, and segmental injuries in patients who are healthy enough for surgery [14, 18, 70, 80, 111]. Nonoperative treatment is indicated in simple and non-displaced proximal humerus fractures, but can be utilized effectively in more complex injuries and patients unfit for surgery [20, 92, 101–104]. Most current treatment recommendations are based off of expert opinion and low powered studies [112]. Until larger and higher level comparative studies are performed, treatment of proximal humerus fractures likely will depend on surgeon experience and preference [3].

Nonoperative Treatment

As stated previously, the majority of proximal humerus fractures are stable fracture patterns and very amenable to nonoperative treatment [5, 96]. Relatively non-displaced two and three-part fractures rely on surrounding soft tissue restraints for both healing and stability. The rotator cuff, periosteum and surrounding joint capsule provide and internal sling for the fracture fragments and resist any further displacement of fracture fragments [3]. Minimal tuberosity displacement with shaft impaction into the shaft reduces the risk of nonunion [9]. Absolute stability is difficult to determine on an initial examination. X-ray characteristics such as minimal comminution, three or less fragments, absence of significant tuberosity displacement, cortical contact, relative impaction of the stem into the head, and no history of dislocation suggest relative stability of the fracture fragments [2, 21, 91, 92, 113]. On physical examination, gentle rotation of the elbow and forearm can be performed with simultaneous palpation of the humeral head. Fracture stability is implied if the fragments appear to move as a unit [12]. Despite appropriate X-ray and examination findings, late displacement of fragments can occur, therefore, serial X-ray examinations over the first 2–3 weeks post injury are recommended to ensure late displacement does not occur [114]. The appearance of slight inferior subluxation of the glenohumeral joint in conjunction with a proximal humerus fracture or "pseudosubluxation" is not an indicator of an unstable fragment [58, 115]. Factors such as deltoid atony, deltoid inhibition, neuropraxia, hemarthrosis, and rotator cuff dysfunction all contribute to the appearance of mild inferior subluxation [58, 115]. This finding is common after proximal humerus fracture and tends to be self-resolving during the typical healing course (Fig. 2.5a, b).

Unlike fractures in the humeral shaft, closed reduction and functional bracing is a rare option for treatment. Fractures of the humeral shaft can be effectively immobilized with a fracture brace [116]. Sarmiento showed high healing rates and acceptable functional outcomes after nonoperative treatment with functional bracing of the humeral shaft [117]. The surrounding soft tissue envelope and ability to control fragments proximal and distal to the fracture site allow successful treatment of humeral shafts [117]. Unfortunately, the proximal humerus has multiple complex deforming forces, which cannot be neutralized with a brace, and control of the bone proximal to the fracture fragments is impossible with an external brace [13]. For historical purposes, airplane splints and shoulder spica casting with the arm placed in abduction and forward elevation can neutralize some deforming forces of the proximal humeral shaft, but this method of treatment is poorly tolerated and not currently indicated in treatment of proximal humerus fractures [13].

Rarely, an unstable two-part proximal humerus fracture can become stable with closed reduction [118]. Tuberosity displacement is difficult to reduce without operative fixation, but shaft displacement can potentially be managed with reduction [13]. A displaced surgical neck fracture usually results in medial and anterior displacement of the humeral shaft secondary to the pull of the pectoralis major muscle [89]. The reduction maneuver for a proximal humeral shaft involves longitudinal traction with adduction and a posterior directed force on the humeral shaft [119, 120]. This maneuver attempts to neutralize the pectoralis and align the head and shaft. After alignment, the shaft must be impacted into the head to achieve a stable position. If a stable reduction is achieved, nonoperative treatment can achieve an acceptable outcome [118].

Bracing options include a standard sling, shoulder spica cast, hanging arm cast, and airplane splint. A standard sling provides adequate immobilization for all proximal humerus fractures treated nonoperatively [121]. A sling allows slight gravity distraction to the bone ends to aide in initial pain relief [97]. Hanging arm casts provide no advantage over a standard sling, and excessive distraction of the bone ends by a hanging arm casts can promote to nonunion, and other methods of immobilization are poorly tolerated [96, 105, 122].

Initial pain control after the injury is difficult, but a combination of oral medications, topical modalities, and sling immobilization provides adequate pain control over the first several days after injury. Some patients will have difficulty with sleeping in a bed after proximal humerus fractures, therefore, sleeping in a sitting position in a recliner should be recommended for individuals after proximal humerus fracture. Most patients can be managed as an outpatient with these injuries, but frail elderly individuals who live alone occasionally will require hospital admission. More incapacitated patients can benefit from hospital admission for both pain control and rehabilitation to aide with activities of daily living after discharge [9].

Early protection with gradual mobilization is the primary tenant of nonoperative treatment of proximal humerus fractures [20, 105, 113, 123, 124]. Absolute sling immobilization should only be performed over the first 7–10 days post injury [19, 20, 125]. Excessive immobilization has not been shown to improve outcomes [20]. Prolonged immobilization can result in increases in pain and decrease in ultimate range of motion and function [19, 20, 125].

The functional recovery improves when physical therapy is instituted as close to the injury as possible [19, 20, 125]. Both the timing and type of exercises performed after proximal humerus fracture will contribute to a successful outcome [20]. Distal extremity exercises should be started immediately after the injury, and shoulder range of motion should be initiated within 10 days of the injury if pain allows [19]. Koval et al. showed improved outcomes when physical therapy was instituted within 14 days of the injury [20]. Exercises instituted by the 14-day mark resulted in decreased rates of stiffness and improved function and ability to perform activities of daily living. It is important to remember close radiographic follow-up to ensure no further angulation or displacement of fracture fragments after initiation of physiotherapy [114]. Some form of therapy, whether a supervised or structured home program, should continue until maximal functional recovery, which can take up to a year after injury [20, 105]. Even minimal therapy is better than a complete absence of treatment [126]. A single therapy session with subsequent performance of exercises at home can be as effective as a supervised therapy program [126]. More involved therapy modalities such as hydrotherapy or pulsed electrotherapy does not seem to improve outcomes [5, 127].

Successful Rehabilitation should include a standard therapy protocol of exercises that maintain motion and increase strength as fracture healing allows. Active elbow, wrist, and hand exercises should be initiated immediately after injury. Shoulder pendulum exercises should be initiated immediately, and attempts at assisted shoulder flexion, abduction, and rotation should begin at 1-week post injury [125]. Isometric deltoid and cuff exercises should be initiated at 3 weeks, and progressive strengthening and stretching can usually be initiated between 6 and 12 weeks [20].

When examining functional outcomes after non-displaced proximal humerus fractures, Koval et al. proposed a protocol, which improved outcomes if initiated within 2 weeks after injury [20]. They utilized sling for initial pain relief, then at 1 week everyone was instructed on range of motion exercises and referred to physical therapy. Therapy consisted of biweekly visits where active hand, elbow, and wrist exercises were performed in conjunction with passive shoulder motion. Initially, shoulder exercises were performed in the supine position and included forward elevation, external rotation, and internal rotation to the chest. The sling was continued for 4–6 weeks, and exercises were performed four times daily at home. Once clinical fracture union was confirmed, the sling was discontinued. Active range of motion and deltoid and rotator cuff isometric strengthening was added. Active exercises were initiated in the supine position and progressed to the seated position. As range of motion improved, active resistance deltoid and rotator cuff exercises were begun. Three months after the injury, an aggressive stretching and strengthening program was continued until final outcome was achieved [20].

Outcomes

In the absence of complications, most elderly patients with stable proximal humerus fractures will have a functional pain-free shoulder [9]. Functional improvement can occur up to 2 years after the injury, but rapid improvement are made in the first 6 months and near full improvement occurs at 1 year [128–130]. Patients should be counseled that their shoulder would most likely never be completely normal after a proximal humerus fracture [9]. Most patients can expect minor aches with vigorous activity, but most should be able to perform activities of daily living [121]. Fortunately, functional expectations in elderly individuals are diminished in comparison to younger patients, thus a less than satisfactory result for a young patient can be a completely acceptable result for an elderly individual [105, 113, 131]. Even with decreased outcome scores, elderly patients perception of outcome and quality of life can be acceptable [92]. Court-Brown reported a series of 125 valgus-impacted fractures treated nonoperatively. One year after injury, 80 % of the primarily elderly patients have a good to excellent outcome, despite residual deficits in strength and range of motion [92].

Anatomic classifications utilized to determine treatment provide prediction of outcomes. Nonsurgical treatment of comminuted four part fractures has yielded poor outcome results [14]. Despite poor constant scores, patient satisfaction levels remained high at 10-year follow-up [132]. In a prospective cohort study, Caceres et al. examined nonoperative treatment in both displaced and non-displaced proximal humerus fractures [132]. While healing occurred in most patients, constant scores worsened with worsening severity of fracture [132]. Functional outcomes improved progressively from four part to three part and subsequently two part fractures. Pain outcomes worsened with three and four part fractures in relation to two part injuries, and individuals who were under the age of 75 and had non-displaced injuries had improved functional outcomes [132]. The authors concluded that nonoperative treatment of proximal humerus fractures in elderly can provide pain relied with limited functional outcome, but this did not seem to effect quality-of-life perception. Patients with more severe and displaced fractures should be counseled of the possibility of inferior outcomes [132].

Recently, patterns of displacement have been correlated to outcome in nonoperatively treated proximal humerus fractures [133]. Radiographic and CT studies were used to classify patterns of displacement into posteriormedial (varus) impaction, lateral (valgus) impaction, isolated greater tuberosity, and anteriomedial impaction. Factors such as head orientation, impaction of the surgical neck, and displacement of the tuberosity correlated strongly with outcome [133]. Lateral impaction fractures had a worse outcome than other patterns. As both posteriormedial and greater tuberosity displacement increased, outcome worsened [133]. Overlap of the greater tuberosity was associated with a worse outcome if it overlapped the posterior articular surface [133]. In varus, or posteriormedial, impaction, outcome worsened as the articular surface displaced inferiorly and increased the distance from the acromion. Functional outcome is difficult to assess, and many variables contribute to a successful patient outcome [133].

Standard radiographic measurements can be used to predict functional outcomes. Humeral head angulation on initial radiographs correlates with ultimate functional outcome [134]. Angulation of the humeral head on both a standard AP projection and scapular lateral view had a significant association with Constant-Murley outcome. The optimum predictive angulation was a Y view of 55° of angulation at the time of fracture. Initial and 1 week Y view measurements were the most important predictors of the decreased functional outcome at a median of 2.2 years follow-up [134].

Very little high level evidence exists assessing outcomes after proximal humerus fractures [14, 16, 17, 135]. A lack of consistently successful surgical techniques and common complications has resulted in a preference for nonoperative treatment over surgery [13]. Also, there are few significant comparison studies of operative and nonoperative treatment. In a prospective randomized study, Zyto et al. could find no functional differences between patients with three- and four-part fractures treated with tension band fixation verses conservatively [18]. Retrospective studies of elderly populations with three-part and valgus impacted fractures show favorable results regardless of surgical versus nonsurgical treatment [15, 92]. Meta-analysis of three- and four-part fractures revealed that patients treated conservatively had more pain and worse range of motion than those treated with either fixation or arthroplasty [14]. Overall, conflicting results exist with some studies favoring operative intervention with others failing to show a large benefit for more displaced and unstable fractures [136]. A prospective case series examined nonoperative treatment of multiple fracture types in 160 patients [121]. The injuries included 75 one-part, 60 two-part, 23 three-part, and 2 four-part and head splitting fractures. After 1 year, the difference in constant score was 8.2; DASH was 10.2 with the uninjured shoulder. Risk of nonunion was 7.0 %. Nine patients underwent surgery (four fixation, five arthroscopic subacromial decompression). The authors suggest that these results make it difficult to demonstrate significant benefit of surgery over nonoperative treatment for proximal humerus fractures [121].

Complications

Major complications following nonoperative treatment of proximal humerus fractures include osteonecrosis, nonunion, stiffness, and rotator cuff dysfunction [20, 41, 104, 137]. Although relatively rare with nonoperative treatment, complications adversely effect outcomes and often require additional intervention [62, 105, 106, 138]. Both patient and injury related factors can increase complication risk with proximal humerus fracture. Increased age, osteoporosis, medical comorbidity, worsening fracture comminution and displacement, and increasing soft tissue injury are all associated with increased risk of complications with proximal humerus fractures [9]. Complication rates are extremely low with nonoperative treatment of non-displaced and minimally displaced proximal humerus fractures, but complication rates increase with conservative treatment of proximal humerus fractures in elderly patients and in displaced multipart fractures [62, 105, 113, 138].

Osteonecrosis occurs after a loss of blood supply to the subchondral bone with subsequent collapse, irregularity of the articular surface, and clinical symptoms of pain and stiffness [39, 41, 139, 140]. With increasing comminution and displacement, an increased injury to the soft tissues and subsequently the vascular supply to the humeral head is expected [39–41]. Hertel et al. assessed risk factors for development of aseptic necrosis after proximal humerus fracture. They found that humeral head ischemia increased after anatomic neck fracture, metaphyseal head extension of less than 8 mm, and medial head disruption of more than 2 mm [41]. The combination of these three factors had a 97 % positive predictive value for humeral head ischemia (Fig. 2.6) [41]. Gerber noted that outcomes with osteonecrosis improved with anatomic fracture alignment [139]. Osteonecrosis was much better tolerated in patents whose fractures healed with anatomic alignment over those with some degree of malunion [139]. Extent of head involvement can affect outcome. Osteonecrosis is a rare occurrence after three-part fracture, and when it does occur usually involves only a portion of the humeral head and causes little discomfort [139].

With a robust soft tissue envelope, fracture healing rates are high in the proximal humerus, but nonunion can occur and result in persistent pain and dysfunction [99, 137]. Total incidence of nonunion with proximal humerus fracture is 1.1 %. These rates increase if metaphyseal comminution is present (8 %) and with significant displacement of the surgical neck (10 %) [137]. Most fractures that fail to unite, regardless of classification, have metaphyseal comminution and loss of cortical contact [137]. Patient factors increase nonunion risk with patients with osteoporosis, medical comorbidities, drug treatment, smoking history, and alcohol abuse being most at risk to develop a nonunion [95]. Preinjury stiffness secondary to degenerative joint disease or

Fig. 2.6 Proximal humerus fracture with medial head disruption >2 mm

inflammatory causes can predispose nonunion [141]. In addition, inappropriate immobilization with a hanging arm cast or overzealous mobilization can result in nonunion [99].

With nonoperative treatment of proximal humerus fractures with displacement, some form of malunion occurs with each fracture. This common complication can frustrate the patient and present a treatment dilemma for the surgeon [142–145]. While slight malunion of the head and shaft is well tolerate, tuberosity malunion can cause stiffness, pain, and loss of function [144–148]. Biomechanical data shows a 5 mm superior malunion of the greater tuberosity increases the deltoid force for abduction by 16 % [149]. With posterior and superior displacement of the greater tuberosity, deltoid force for abduction increases 29 % [149]. While tuberosity malunion in elderly individuals with low functional expectations does not usually adversely effect outcomes, the secondary impingement and functional compromise caused by tuberosity malunion in younger patients is poorly tolerated [9].

Some degree of stiffness is nearly expected after all proximal humerus fractures [12]. The cause of stiffness is multifactorial after proximal humerus fractures [145]. Adhesions can form secondary to the trauma of the injury and after immobilization. Absolute immobility greater than 2 weeks after injury with nonoperative treatment leads to increasing rates of stiffness [20]. Hodgson showed that immobilization longer than 3 weeks prolonged recovery from 1 to 2 years [19, 125]. Factors such as capsular contracture, malunion, complex regional pain syndrome, impingement, rotator cuff dysfunction, delayed rehabilitation, and non-compliance with rehabilitation all contribute to the development of stiffness [9]. Ultimately, early mobilization is the best method to prevent stiffness in the proximal humerus fracture treated without surgery [19, 20, 125].

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Closed Reduction and Percutaneous Fixation of Proximal Humerus Fractures

3

Alexander Auffarth, Philipp Moroder, and Herbert Resch

Introduction

Up to date, a general trend towards minimally invasive surgery has developed which recently has also been established for surgical fracture treatment. The use of such procedures is to minimize soft tissue damage by smaller incisions and thus prevent further deterioration of the blood supply of an already damaged area. Especially for the treatment of proximal humerus fractures in the elderly, the preservation of the osseous blood supply which often already is compromised plays an important role in precluding an avascular necrosis of the humeral head. Apart from this, less soft tissue damage does help prevent postoperative infections in general. Additionally, smaller incisions mostly provide favorable cosmetic results.

Especially for the treatment of proximal humerus fractures, this general trend of minimally invasive surgery is not new though. Bohler [1] had already in 1962 described a technique of percutaneous pinning. Even though initially widely spread, this technique had constantly been less favored because of minor results achieved with it especially when treating three- or four-part fractures of the proximal humerus [2, 3]. So, over the years, the idea if percutaneous pinning of proximal humerus fractures had more and more been abandoned. As a consequence, conservative management even of comminuted fractures in the elderly patient was given a thought [4]. Then, as an alternative to percutaneous pinning alone with the well-known problem of K-wire migration, the humerusblock was developed. This solved the above-mentioned problem and led to frequent use of this implant at the author's institution.

In contrast to other procedures for treating proximal humerus fractures though a longer period of postoperative immobilization is needed. Because of the minimized soft tissue damage with this procedure, no excessive impairment of the shoulders range of motion has to be expected.

The aim of any fixation technique is to get the fracture healed in an acceptable position and to accomplish a subjectively satisfying shoulder function for the patient. The latter can be measured applying common scoring systems, such as the Constant Score, the Oxford Shoulder Score or the DASH Score. Individually different conditions, such as the number of fragments, extent of displacement among fragments, size of fragments, as well as secondary conditions that influence healing, such as osteoporosis, metabolic diseases or impaired perfusion may greatly influence the expectable clinical result. This in turn means that results often cannot directly be compared to another. Therefore, general recommendations on how to treat which fracture pattern can hardly be defined, so the

A. Auffarth (✉) • P. Moroder • H. Resch
Traumatology and Sports Injuries, Paracelsus Medical University Salzburg, Muellner Hauptstrasse 48, 5020 Salzburg, Austria
e-mail: a.auffarth@salk.at; philipp.moroder@salk.at; h.resch@salk.at

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method of treatment remains an individual decision taking into account the patient's age, need and the above-mentioned factors.

Anatomical Remarks

We do not want to discuss the anatomical conditions in detail at this point, but point out some particularly important facts in connection with this surgical technique. Since the blood supply to the humeral head via the rotator cuff is mostly decreased in the elderly, the terminal branches of the circumflex humeral anterior and posterior arteries out of the axillary artery remain the relevant vessels. According to Brooks [5], the arcuate artery from the anterior humeral circumflex artery is the most important vessel to grant blood supply of the humeral head. Any damage to this vessel like it could occur by dislocation of the greater tuberosity thus carries an increased risk to result in a necrosis of the humeral head.

Apart from the circulation, the integrity of the periosteal hinge between the individual fragments greatly affects potential healing. The healing progress will decrease with an increased number of fracture fragments and an increased displacement among these. Any displacement of the shaft that is more than 9 mm laterally and 6 mm medially will most likely result in a rupture of these periosteal bridges [6]. Blood supply of the head fragment is already reduced with a medialisation of the shaft by 2 mm and an 8 mm shortening of the dorsomedial metaphyseal head extension [7]. This underlines, that especially the medial periosteum at the anatomical neck of the humerus is vital as far as blood circulation is concerned, and must be protected during any surgical procedure.

Primary Considerations

Closed reduction and percutaneous fixation of proximal humerus fractures is based on manual manipulation of the fragments, supported by instrumental repositioning through stab incisions. In order to succeed with this technique, it is mandatory, to know what to expect. In this respect, knowledge of the fracture pattern and number of the fragments must be acquired prior to surgery. Assessing the fracture's nature, one can estimate the integrity of the vascular supply of the individual fragments regarding their individual displacement. Further, by it is possible to benefit from the ligamentotaxis effect during the reduction with intact periosteal connections. This means that, in addition to an X-ray in anteroposterior view, axial imaging is always required for sufficient information about the condition of the lesser tuberosity. The 3D reconstruction of an additional CT has also proven very helpful for understanding the fracture pattern and the positional relationship of the individual fragments in relation to each other (Fig. 3.1a–d).

Depending on which parts of the periosteum are intact or destroyed, individual fragments can follow applied traction to different degrees. Regarding the distances of the fragments between each other it is possible to draw conclusions on the quality of the periosteal connections [6].

The main goal of percutaneous reduction and fixation of a proximal humerus fracture is not necessarily achieving a perfectly anatomical reduction. More than this, it is the goal to gently manipulate a strongly displaced fracture to correctly align the fragments among each other and revert the fracture into an only minimally displaced one.

Indications for Percutaneous Reduction and Fixation

Most appealing clinical and radiological results can be achieved using this technique, just like with other fixation methods in fractures with little displacement and largely preserved periosteal bridges. The valgus-impacted three- and four-segment fractures with practically always intact soft tissue connections are especially suitable for stabilization with the humerus block in combination with cannulated screws for fixation of the tuberosities. An additional factor which can determine the success or failure of any

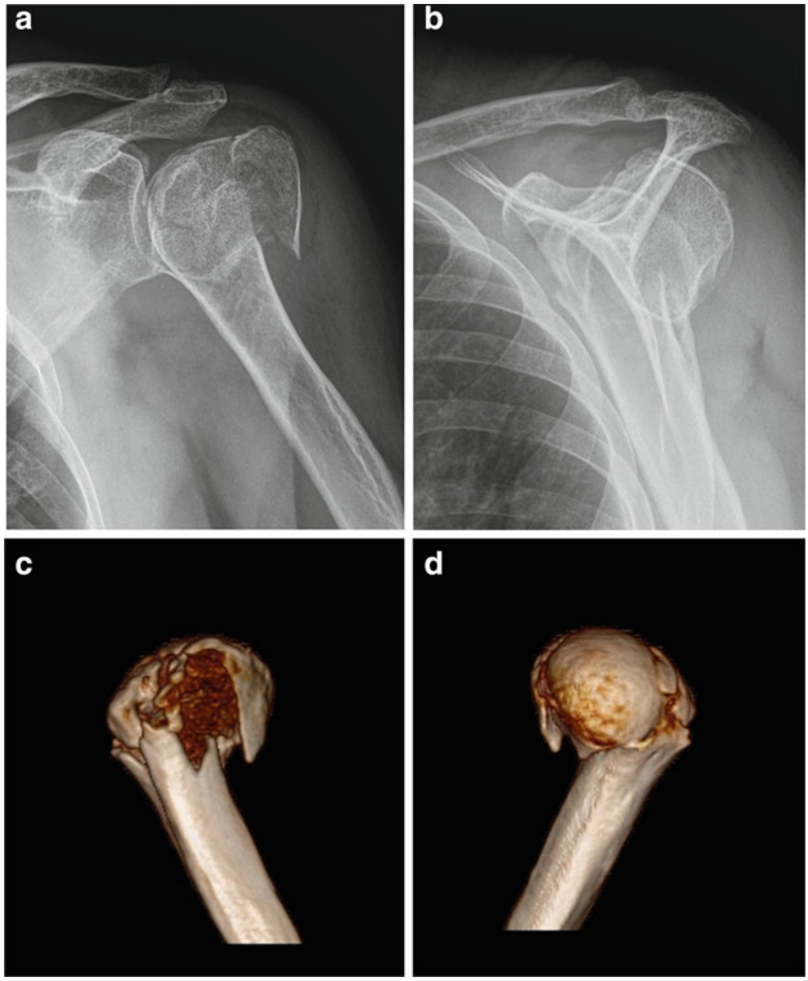

Fig. 3.1 (**a**) A.p. X-ray of a four-segment fracture impacted in valgus position. (**b**) Transscapular X-ray of a four-segment fracture impacted in valgus position. (**c**) 3D reconstruction of a four-segment fracture impacted in valgus position, lateral view. (**d**) 3D reconstruction of a four-segment fracture impacted in valgus position, medial view

surgical approach is the individual bone quality of the proximal humerus. In order to obtain sufficient support for screws with angle stable plate osteosynthesis the cortical bone of the humeral head should not be less than 4 mm thickness [8]. Even though an osteosynthesis using the humerus block naturally benefits from good bone quality as well; however, this is not as relevant to the outcome as with rigid fixation methods. With this implant, reduction can mostly be maintained and the fracture will consolidate even in elderly patients with osteoporotic bone quality [9].

Head split fractures, in contrast are significantly harder to sufficiently reduce and tend to a loss of reduction. In such cases, however, other fixation techniques with open procedures may also rarely guarantee a sufficient stability. Therefore the therapy of choice will increasingly be shoulder arthroplasty.

The Implants

The Humerus Block (DePuySynthes, West Chester, PA, USA)

The cartilage-covered head fragment is fixed by two K-wires which are held by the humerus block. This block, in the form of a cylinder (Fig. 3.2) is fixed onto the shaft of the humerus by a cannulated screw while it is held by the guiding instrument (Fig. 3.3). The block holds two K-wires of up to 2.5 mm in diameter. These

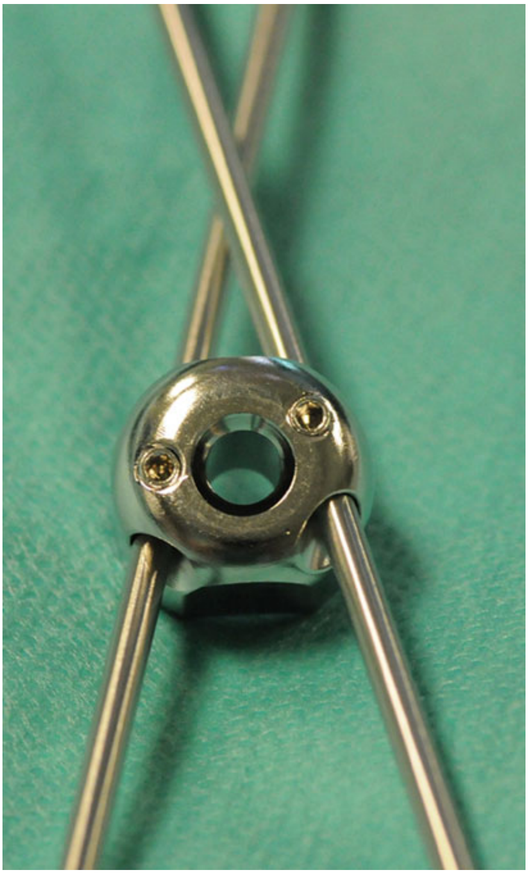

Fig. 3.2 The humerus block with two 2.5 mm K-wires

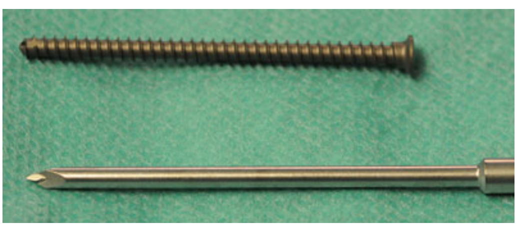

Fig. 3.3 Cannulated K-wire and titanium fracture screw

intersect at an angle of 25° proximal to the block and run through the block at an angle of 35° to the base of the cylinder. After the K-wires are positioned, they are locked inside the block with a grub screw to prevent migration. In this way, a three-point support of the K-wires is granted: within the block, at the lateral cortex of the humeral shaft and in the subchondral bone of the humeral head. This allows for both rotational and axial stability.

Fig. 3.4 Guiding instrument to set the humerus block and 2.5 mm K-wires

The Fracture Screws (Arthrex, Naples, USA)

In cases of three- or four-segment fractures, with displaced tuberosities, they are reduced and fixed percutaneously by cannulated screws of 3 mm in diameter. The main tool here is a cannulated drill which basically looks like a cannulated K-wire. It holds a guide wire of 1.1 mm diameter, which completes its tip. This way, it can be used for fragment's reduction and fixation just like a regular K-wire. Once, a satisfactory reduction is achieved, the drill is removed while the guide wire remains in place. Then, a cannulated screw of desired length is slid over the guide wire which can be removed when the screw is in place (Fig. 3.3).

A Guide to Closed Reduction and Percutaneous Fixation

Getting the Humerus Block in Place

The patient is placed in a beach-chair position with the upper body elevated at 30°. The affected shoulder must slightly overlap the edge of the table and the lower arm should be flexibly covered so that it can be moved freely during surgery.

When one image intensifier is used, it should be placed behind the head of the patient, just next to the operating table, thus also allowing for an axial view by tilting the device.

If, as an alternative, two image intensifiers are used, one is positioned as described above (for the axial view) and a similar device is placed on the opposite side of the patient for the a.p. view, similar to the arrangement for, e.g., a femoral neck screw.

In the first step, the humerus block is placed 5 cm below the subcapital fracture (Fig. 3.5). Through a 3 cm skin incision and sharp dissection of the subcutaneous tissue, the deltoid fibers are split by blunt dissection. The block then has to be fixed in the middle of the lateral face of to the humeral shaft. In order to ensure correct lateral positioning, an assistant must hold the arm in neutral rotation. After checking the position with the image intensifier, a 1.2 mm K-wire is introduced through the center hole of the block and drilled though both the lateral and medial cortex of the humeral shaft. Now, before placing the cannulated center screw, the position of this guide wire should be checked in axial view to ensure that it is positioned in the middle of the shaft (Fig. 3.6). If the block was placed too far anterior or posterior, it could happen that one of the two K-wires would not run intramedullary, but tangential to the outer cortex of the shaft and miss the head fragment. So when the guide wire for the center screw is placed correctly, the lateral cortex of the shaft is perforated by a cannulated drill, while the inner cortex is not completely perforated, so the guide wire won't be lost while retracting the drill. As the next step, the block is fixed to the humeral shaft by a cannulated cortical screw.

However, this central screw, which is available in various lengths, will not be firmly tightened initially. Because the angle at which the 2.5 mm K-wires run through the block is set at 35° in the coronal plane, the point that can be reached by the tips of the K-wires is more or less preset. In cases where the block was positioned a bit too far distal to the fracture level, they would not reach the cranial part of the humeral head. Therefore, the center screw of the block is initially not tightened for maximum purchase, so the block can be tilt in the coronar plane. Thereby the aiming point of the K-wires can be adjusted.

The guide sleeves for the K-wires are placed in the setting instrument. Via two stab incisions at the lateral upper arm, they are pushed forward to touch the humerus shaft. Now two K-wires of 2.5 mm diameter are inserted and driven into the shaft just below the fracture. In case the two K-wires reach the lateral cortex of the humeral shaft at a very flat angle, as an alternative, the cortex of the shaft can be perforated with a 2.5 mm drill in order to prevent the K-wire tips from sliding cranially along the shaft, which avoids multiple drilling attempts.

Already at this point of the procedure, the target direction of both the K-wires must be

Fig. 3.5 Defining the height at which the humerus block is to be fixed to the humeral shaft

Fig. 3.6 Axial view of the guide wire to set the center screw

correctly set: first in the coronal plane, then in the sagittal plane. The latter position of the K-wire tips in the coronal plane is determined by tilting the setting instrument that holds the block (as described above). The tips of the K-wires must not point towards the glenoid, but be positioned in the middle, between the cranial pole of the humeral head and the top edge of the glenoid. Otherwise, the glenoid may be endangered by perforating K-wires, once the head fragment settles to gain contact to the humeral shaft. This could cause glenoid abrasion when passive or active motion is allowed.

For orientation in the sagittal plane, as above mentioned it is most important that the center screw that holds the block was positioned in the middle of the humeral shaft. When correctly positioned, the lateral humeral epicondyle as the reference point shall lie in the middle of the lateral ends of the K-wires that outstand their guiding sleeves.

After both K-wire tips are inserted just below the level of the fracture (Fig. 3.7), the precise reduction is done. Based on the author's experience, like other fractures, proximal humerus fractures can practically be classified as varus and valgus types which are determined by the position of the head fragment. Additionally, impacted fracture types can be differentiated from avulsed ones. In the following section, four of the most common fracture types [10] based on these considerations are outlined, and the need for miscellaneous techniques of reduction and fixation are explained. Hereby, practically all relevant steps of percutaneous reduction maneuvers to treat proximal humerus fractures will be described. If needed, they can be combined with fracture types that differ from those outlined below.

Fig. 3.7 2.5 mm K-wires in "waiting position"

Special Techniques of Reduction and Fixation

The Two-Segment Fracture Impacted in Varus Position

Preliminary Notes

Here, the shaft fragment is medially impacted into the head fragment with an intact lateral periosteum which is expected lacking fracture gap. The two fragments are usually anteriorly angled in relation to each other. A certain residual stability remains with the intact periosteum and the impaction.

Technique of Reduction and Fixation

At first the impacted shaft fragment just needs to be mobilized. To do so, it is usually sufficient to apply axial traction, while the humerus shaft is held at a slightly abducted position. At the same time, pressure in the antero-posterior direction should be applied to the subcapital region using one's thumb in order to correct the anterior-directed angle. During this maneuver, it must be ensured that the medial cortex of both fragments is reduced as precisely as possible. As soon as this is accomplished, the assistant drives in the K-wires that are "sitting in waiting position" below the subcapital fracture level and places them just subchondral in the humeral head.

If the impaction cannot be released with this manual manipulation, an elevator should be inserted through a stab incision for the purpose of lifting the humeral head. A stab incision is performed about 5 cm below the fracture. An elevator is introduced on the anterior side of the shaft and advanced to the medial calcar always gliding on the bone. With the arm in slight abduction and traction the head fragment is raised by means of the elevator. When the successful reduction is achieved in this way, the K-wires will be placed as described above.

The Avulsed Two-Segment Fracture in Varus Position

Preliminary Notes

Such cases show a complete separation of the head and shaft fragments, which indicates destroyed periosteal bridges and thereby a highly unstable fracture. The head fragment is rotated to a varus position caused by the traction of the supraspinatus muscle. The shaft in opposite is drawn to the anterior and medial direction by traction of the pectoralis major muscle.

Technique of Reduction and Fixation

While one hand maintains constant traction to the humerus shaft, the surgeon's other hand clasps the humerus shaft more proximally below the fracture, and directs the shaft laterally and dorsally until both fragments meet to align in the correct axis. In the next step, through a stab incision in the medial third segment above the subacromial area a bone hook with a small radius is inserted. The tip of this instrument is hooked into the greater tuberosity at the footprint of the supraspinatus tendon. Now, by applying traction to the hook, the traction of the tendon can be neutralized which allows to rotate the humeral head out of the varus back to neutral position. As soon as this is accomplished, the two "waiting" K-wires are advanced and positioned in the subchondral bone of the humeral head.

The Avulsed Three-Segment Fracture in Varus Position

Preliminary Notes

If the greater tuberosity is severely dislocated (according to a Neer-type three-segment fracture), a varus position of the head caused by traction of the supraspinatus muscle will result. Now, because of the separation of the greater tuberosity, this effect will be less distinct than in the above described two-segment fracture. In addition, now unbalanced traction of the subscapularis muscle causes an internal rotation of the humeral head. This condition will be the more obvious the more the greater tuberosity is displaced. Because all periosteal bridges between humeral head and humerus shaft, as well as between the greater tuberosity and the humerus shaft, are destroyed, this displays a highly unstable fracture. Due to the eminent instability of all three fragments in relation to each other, closed reduction of these fractures is especially challenging also to the experienced surgeon with this technique.

Technique of Reduction and Fixation

Traction is applied to the humerus shaft as it is directed laterally and dorsally, until a reduction of the humeral head in relation to the shaft is accomplished. As this position is maintained, through a stab incision a bone hook is placed at the anterior subacromial area. Now, the tip of the instrument is hooked into the lesser tuberosity. By applying traction to the hook, the humeral head is derotated from internal to neutral rotation under fluoroscopy in the a.p. view so that the tuberosities contour suggests correct rotation. Any remaining varus malposition can then be corrected by abduction of the humerus shaft. As soon as the head and shaft are satisfactorily positioned in relation to each other, the two K-wires are driven in so that their tips touch the subchondral bone of the head fragment. The quality of reduction of the two main fragments should then also be checked under axial fluoroscopic view with the arm held in 80° of abduction.

As the next step, a bone hook is inserted via a stab incision at the junction between the anterior and middle third of the width of the humeral head. To grab the greater tuberosity, the hook is then directed posterior. With the hook in place, the greater tuberosity is pulled in an anterior and inferior direction because it always is displaced posteriorly by traction of the infraspinatus muscle and cranially by that of the supraspinatus muscle. As soon as the greater tuberosity is reduced by this maneuver, it is fixed with two or three percutaneously inserted cannulated screws. Ideally placed, one screw should be facing cranially with its tip in the subchondral area and a second screw should be divergently oriented aiming caudally with its tip perforating the intact calcar of the shaft, because in these areas one can expect good screw purchase, even in otherwise osteoporotic bone.

Three- or Four-Segment Fractures Impacted in Valgus Position

Preliminary Notes

In such cases, the head fragment is laterally impacted into the metaphysis of the humerus, with no significant angulation in the sagittal plane. Only the greater tuberosity or both tuberosities may be fractured. Usually they were pushed aside by the impacted head fragment in posterior or anterior direction, respectively. Because of the approximation of head and shaft fragments and moderate displacement of the tuberosities, the periosteum usually stays intact between the head and shaft fragment as well as between the tuberosities and shaft. If there is no displacement of the head fragment relative to the shaft in the coronar plane, it can be assumed that the medial periosteum has also remained intact. This periosteal bridge is important for the humeral head's blood supply and additionally serves as a mechanical hinge for reduction.

Technique of Reduction and Fixation

In the first place, the impaction of the head fragment into the metaphysis of the shaft is relieved. To do so, slight axial traction is applied to the humerus shaft. Via a stab incision in the middle third of the width of the humeral head an elevator is guided into the subcapital fracture gap and positioned laterally under the head fragment (Fig. 3.8). In order to find the right entry point for this incision, the width of the humeral head is palpated between thumb and index finger and the distance approximately divided into an anterior, a medial and a dorsal third. Then under fluoroscopic view, the fragment is lifted until the shape of the humeral head appears restored.

In some cases, regarding the calcar region in the a.p. view, the head fragment may either be displaced laterally or medially to the humeral shaft. In cases with a lateralization of the head fragment, the elevator again is positioned below the head fragment. Then, while the head is carefully lifted, the shaft is held under axial traction as it is gently pulled laterally.

Fig. 3.8 Reduction of the head fragment using the elevator

If the head fragment medially overlaps the shaft, an anterior stab incision is done. The elevator is then guided cranially along the humerus shaft to reach the calcar. Then the head fragment is lift up and shifted laterally while the arm is held under axial traction. With these maneuvers, special attention must be paid to ensure that the medial cortex of the head and shaft fragments are reduced as precisely as possible. When this is accomplished both K-wires are positioned in the subchondral cortical bone to support the head fragment (Fig. 3.9).

Because the tuberosities stay connected to the humerus shaft when the periosteum is intact, these fragments partially are reduced by themselves just by applying axial traction to the shaft while reducing the head fragment. If this should not be the case, a bone hook is placed at the footprint of the supraspinatus tendon via a stab incision where the anterior and medial third of the width of the humeral head meet. Then, the greater tuberosity is pulled in an anterior and caudal direction. When the greater tuberosity is reduced, it is fixed with two or three screws.

Fig. 3.9 Placing the 2.5 mm K-wires in subchondral bone of the humeral head

Fig. 3.10 Fixation of the reduced grater tuberosity by two cannulated fracture screws

Fig. 3.11 Cannulated K-wire placed to fix the lesser tuberosity

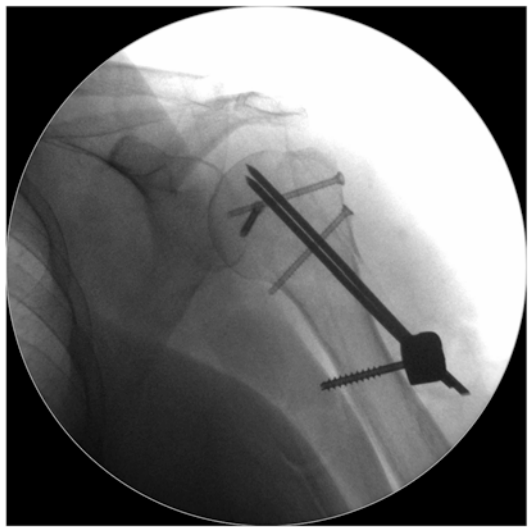

Fig. 3.12 A.p. appearance at the end of the operation

During this, it must once again be ensured that the screws are successfully anchored cranially in the subchondral bone of the humeral head, and in the cortex at the calcar (Fig. 3.10).

With the lesser tuberosity additionally fractured and remaining displaced it is reduced and fixed under axial view with the arm abducted at 70°. Under axial view, a stab incision is performed anteriorly above the tip of the lesser tuberosity before it is grasped with the bone hook at the insertion of the subscapularis tendon. After reduction by traction in the lateral direction it is fixed with one or two screws (Fig. 3.11). While this maneuver special attention has to be paid to the neurovascular bundle when the arm is abducted up to 70°. Inserted instruments must always stay in contact to the bone, especially

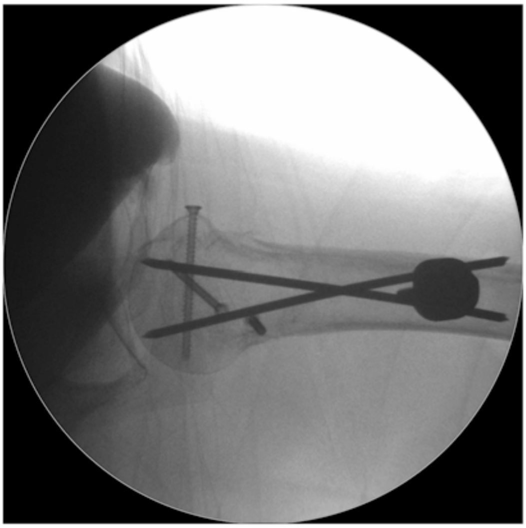

Fig. 3.13 Axial appearance at the end of the operation

when the hook is used (Figs. 3.12, 3.13, and 3.14).

Fig. 3.14 A.p. X-ray appearance 4 weeks postoperatively at the day of removal of the sling

What Can Be Expected?

Our first analyses of results with the K-wires only in 1997 [11] provided quite satisfactory data for both three- and four-segment fractures. The group at an average age of 54 years (25–68), reached a constant score of 85–82 points. A further investigation [12] sought to analyze the results with the humerus block in elderly patients only. Here, 48 patients at an average age of just below 80 years (70–96) were examined after an average of 2.8 years. The mean constant score for three-segment fractures was 61.2 points, which corresponded to about 85 % of the contralateral shoulder. For four-segment fractures, the average value was significantly lower at 49.5 points, which corresponded to 69 % of the contralateral shoulder. Follow-up examinations showed that in a total of 7.8 % of such cases, an avascular necrosis of the humeral head had developed. This affected three of the four-segment fractures and one of the three-segment fractures.

Another study on the humerus block with a somewhat younger collective of 58 patients with an average age of 70.5 years (32–95) was published by Brunner et al. [9] in 2010. For the 39 patients whose proximal humerus fracture had been treated using the humerus block only, the average constant score was at 73.6 points. Overall, a score of more than 80 % of the contralateral shoulder could be attained in 30 of 39 patients (77 %) which the authors referred to as a good result. On the other hand, it must be mentioned that fractures of Type A according to the Orthopedic Trauma Association were included in this study as well. According to the authors, these obtained significantly better scores than, e.g., type B and C injuries even if clinical results did not differ significantly.

A modification of the humerus block was recently presented by Roberts et al. [13]. Here, 32 patients with three- or four-segment fractures were treated. Individual fragments were initially fixed percutaneously using 1.6 mm K-wires. Then using these as guide wires, cannulated screws of 4 mm in diameter were placed. At follow-up after an average of 3.8 years the authors reported a constant score averaging 79 points for three-segment fractures, and 72 points for four-segment ones. Again—just like in all previous studies—there was a significant correlation of lower constant score with greater patient's age and the number of fragments.

Discussion

Doubtless, the techniques described here involve a certain learning curve. However, as long as the level of the subcapital fracture does not lay too far caudal, virtually all proximal humerus fractures at our department are treated with the humerus block. Still, closed reduction can prove challenging especially with destroyed periosteal bridges of the fragments involved. Nevertheless, reduction and fixation of such fractures can sometimes prove a major challenge in open procedures as well. Overall, the age of the patient (and therefore the bone quality), as well as the fracture type, indeed seem to affect the expectable results significantly. Therefore prior to surgery, the individual condition of the patient, the fracture type and the patients' individual needs need to be evaluated [14]. With the humerus block, it is possible to treat the majority of all fractures and achieve good long-term results, even in elderly patients.

With this semi-rigid fixation, subsequent lowering of the cartilage-bearing head fragment along the K-wires is possible—and also desired. This improves the contact at the level of the fracture, although, it may also result in perforation of the humeral head. Prior to the start of physiotherapy after removal of the sling, the K-wires may therefore need to be shortened in order not to damage the glenoid. An advancement of the implant in this regard, the humerus block NG [15] might eradicate this problem in future. Yet, for this modification, clinical studies are needed apart from the highly promising biomechanical results.

We have to admit though, that, in cases of severely dislocated four-segment fractures sometimes the question arises whether it could be advantageous to primarily implant a prosthesis rather than attempt reconstruction. As far as this is concerned results [16, 17] of hemiarthroplasty were disappointing, primarily because the tuberosities did not show sufficient healing [18]. In contrast, significantly better results at a 5-year follow-up have been reported after inverse shoulder arthroplasty [19]. Despite these good results, primary treatment of proximal humerus fractures by arthroplasty at our department will only be considered in cases where chances of adequate reduction, healing and postoperative function seem very little. This affects about 5 % of the humerus fractures admitted. In all other cases, as long as the rotator cuff is intact, we favor reconstruction because the tuberosities practically always heal, which leaves the opportunity to implant an anatomical prosthesis as a secondary procedure which in turn may improve the clinical outcome.

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Tuberosity Fractures

4

Robert G. Lewis, Domenic Scalamogna, and Parthiv Patel

Epidemiology

Fractures of the proximal humerus are very common, accounting for almost half of all humerus fractures and composing nearly 5 % of all fractures [1]. Greater and lesser tuberosity fractures usually are identified as components of the comminuted three-part or four-part proximal humerus fractures or associated with shoulder fracture-dislocations. Isolated fractures of the lesser and greater tuberosities of the humerus are uncommon, comprising a smaller but important fracture subset requiring special treatment consideration.

Lesser Tuberosity Fractures

The most common type of isolated injury described in the literature is an avulsion fracture of the lesser tuberosity, accounting for approximately 2 % of all proximal humerus fractures [2, 3] (Fig. 4.1). Although approximately 100 cases have been described in the literature in various case reports and case series, very little is known regarding the true prevalence of these injures. They often are missed or misinterpreted on plain radiographs, so the true prevalence is likely higher than what has been reported (Fig. 4.2).

In 1895, Hartigan [4] first described an isolated lesser tuberosity separation in conjunction with a humeral shaft fracture in a 17-year-old boy who fell from the top of a barn. Robinson et al. [5] more recently estimated the annual incidence of isolated lesser tuberosity fractures and those associated with posterior fracture-dislocations in adults at 0.46 per 100,000 people. In their case series and review of all cases reported on isolated lesser tuberosity fractures, Ogawa et al. [6] identified that most of these injuries occur in male patients. They also noted that the peak incidence of these fractures was bimodal. The first peak occurred in adults between their second and fifth decades, and the second peak occurred in adolescents aged 12–15 years with open proximal humeral physis [6, 7]. Historically speaking, isolated lesser tuberosity fractures have been considered rare in adolescents, but authors of recent case series have shown that their numbers are increasing due to this young population engaging in high-energy sports activities [2, 7–9]. Thus, unlike low-energy, osteoporotic, comminuted, proximal humerus fractures, these fractures require a higher level of energy, such as that generated from greater fall heights or sports activities.

R.G. Lewis (✉)
St. Francis Orthopaedic Institute, St. Francis Hospital, 2300-A Manchester Expressway, Woodruff Pavilion, Suite 101-A, Columbus, GA 31904, USA
e-mail: lewisr@sfhga.com

D. Scalamogna • P. Patel
St. Francis Orthopaedic Institute Shoulder Center, St. Francis Hospital, 2300-A Manchester Expressway, Woodruff Pavilion, Suite 101-A, Columbus, GA 31904, USA
e-mail: scalamognad@sfhga.com; patelp@sfhga.com

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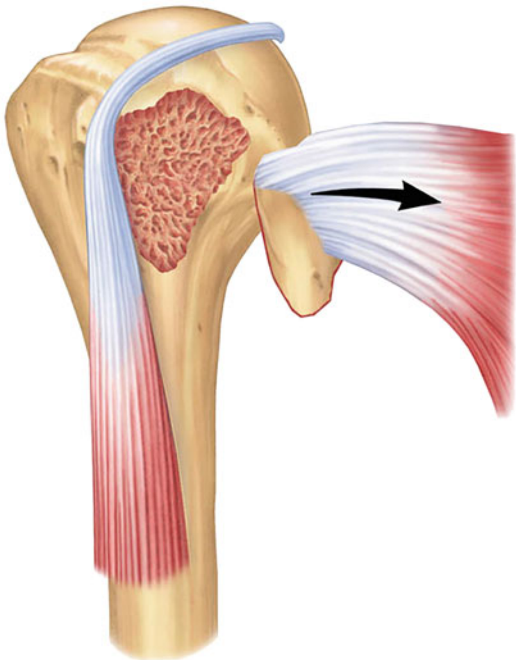

Fig. 4.1 Two-part lesser tuberosity fracture. Reprinted with permission from Lewis RG. Proximal humerus fractures. In: Gaunt BW, McCluskey GM 3rd, editors. A systematic approach to shoulder rehabilitation. Columbus (GA): Human Performance and Rehabilitation Centers, Inc.; 2012. p. 140–55

Greater Tuberosity Fractures

In a prospective study of the epidemiology of 1,027 proximal humerus fractures, Court-Brown et al. [10] found that the incidence of isolated greater tuberosity fractures was 19 %. Greater tuberosity fractures also have been reported to be present in 15 % of glenohumeral dislocations [11].

Proximal humerus fractures typically occur in elderly women who have osteoporosis and sustain low-energy traumas, such as falls from a standing height onto the affected shoulders [12]. However, isolated fractures of the greater tuberosity usually occur in a younger, predominantly male population with fewer medical comorbidities than patients sustaining all other proximal humerus fractures [13–15] (Fig. 4.3). The demographics of patients sustaining lesser and greater tuberosity fractures allows one to conclude that these fractures are clinically distinct and may require a more aggressive treatment algorithm to optimize functional outcomes for patients with higher demands [3].

Developmental and Relevant Anatomy

Developmental Anatomy

The proximal humerus has three ossification centers: humeral head, greater tuberosity, and lesser tuberosity (Fig. 4.4). The ossification center for the humeral head appears between 4 and 6 months of age; the greater tuberosity, at 3 years; and the lesser tuberosity, at 4–5 years. The tuberosity ossification centers fuse together at 5 years of age [16], and this combined ossification center fuses with the humeral head ossification center between ages 7 and 13 years [17]. The combined humeral epiphysis fuses with the shaft by age 19 years [17]. This period of growth and maturation when the three centers combine to form a common humeral epiphysis may reflect a relative time of weakness in the apophysis of the lesser tuberosity, which may account for the higher incidence of isolated avulsion lesser tuberosity fractures in the adolescent population. In fact, Codman [18] and Neer [19] observed that fractures of the humeral head tend to occur along physeal scar lines, which ultimately form the basis for tuberosity fracture propagation. Researchers have hypothesized that a lesser tuberosity fracture propagates through a thin connection between the lesser tuberosity apophysis and the rest of the proximal humerus apophyseal segment, resulting in a “transitional” fracture in adolescents similar to those seen in tibial tubercle and juvenile Tillaux fractures [8, 20].

The humeral head develops in a retroverted position relative to the long axis of the humerus, which results in medial displacement of the intertubercular groove (Fig. 4.5). Consequently, the lesser tuberosity displaces medially and is smaller than the greater tuberosity. The tendon of the long head of the biceps runs through the intertubercular groove, with the greater and lesser tuberosities forming its medial and lateral

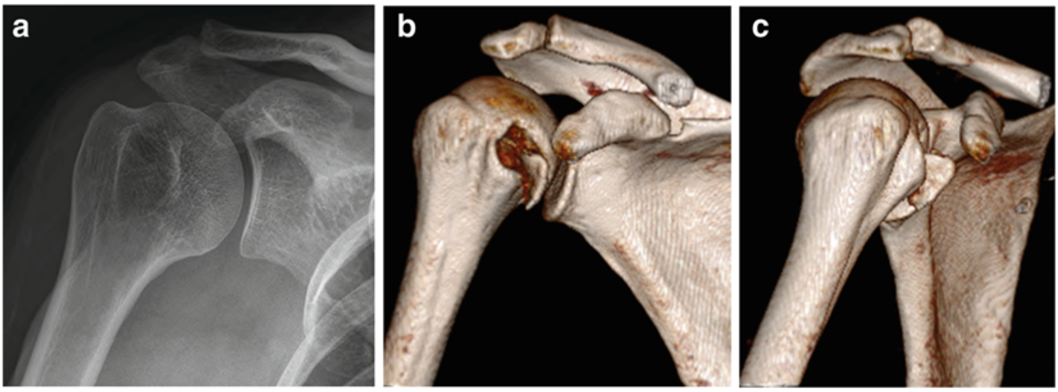

Fig. 4.2 Lesser tuberosity fracture. (**a**) Radiographic view. (**b** and **c**) Computed tomography scans

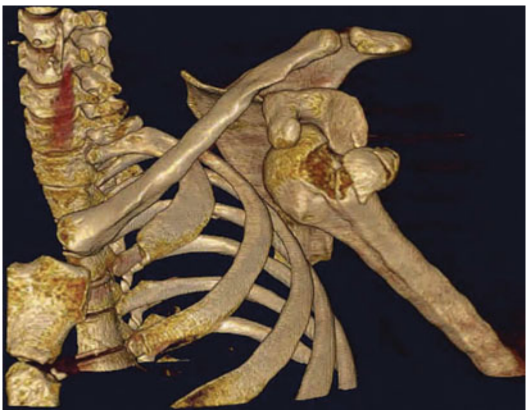

Fig. 4.3 Three-dimensional reconstruction of an anterior glenohumeral dislocation with an associated greater tuberosity fracture. Reprinted with permission from Lewis RG. Proximal humerus fractures. In: Gaunt BW, McCluskey GM 3rd, editors. A systematic approach to shoulder rehabilitation. Columbus (GA): Human Performance and Rehabilitation Centers, Inc.; 2012. p. 140–55

Fig. 4.4 Centers of ossification

walls, respectively [16]. The subscapularis muscle inserts on the lesser tuberosity, with the most superior portion resembling a distinct tendinous structure [16]. Muscular deforming forces from the subscapularis result in medial and inferior displacement of the lesser tuberosity fracture fragment. The biceps tendon within the groove is stabilized by the transverse humeral ligament and by fibers from the most superior portion of the subscapularis tendon (Fig. 4.6). In a clinical anatomic study, Arai et al. [21] demonstrated that the most superior insertion of the subscapularis tendon and the superior part of lesser tuberosity are important stabilizers, preventing medial dislocation of the biceps tendon.

Vascular Anatomy

A thorough understanding of the vascular supply of the humeral head is essential for treating proximal humerus fractures, allowing the surgeon to avoid damaging vital structures either by direct means or indirectly through aberrant retractor placement and inadvertent disregard for the soft tissue envelope (Fig. 4.7).

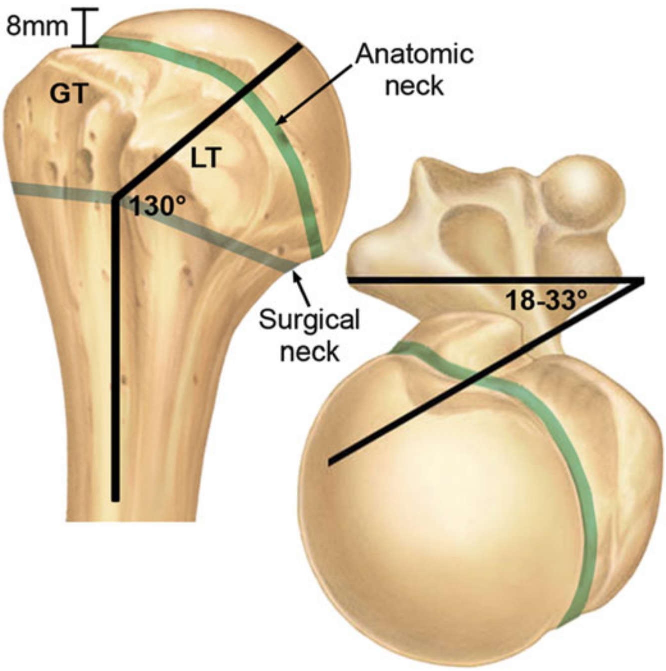

Fig. 4.5 Normal humeral neck-shaft angle (145°) and humeral head retroversion (30°). *GT* greater tuberosity, *LT* lesser tuberosity. Reprinted with permission from Lewis RG. Proximal humerus fractures. In: Gaunt BW, McCluskey GM 3rd, editors. A systematic approach to shoulder rehabilitation. Columbus (GA): Human Performance and Rehabilitation Centers, Inc.; 2012. p. 140–55

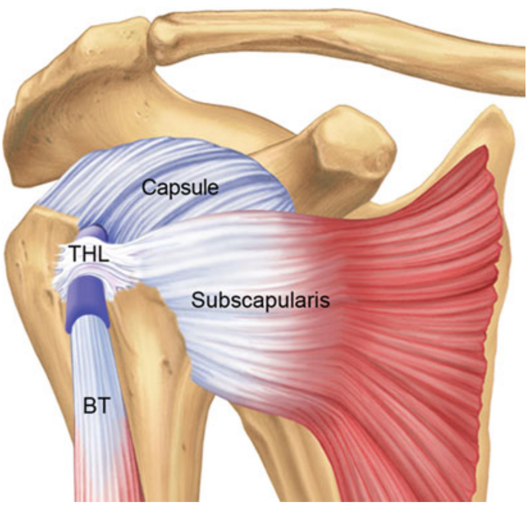

Fig. 4.6 The transverse humeral ligament (THL) and subscapularis stabilizers stabilize the biceps tendon (BT) in the groove

The blood supply to the humeral head consists of an extensive anastomic arterial network arising from branches of the subclavian and axillary arteries. The primary blood supply to the rotator cuff is derived from the ascending branch of the anterior humeral circumflex artery, the acromial branch of the thoracoacromial artery, the posterior humeral circumflex artery, and the suprascapular artery [22]. The main supply to the humeral head is divided between the anterolateral branch of the anterior humeral circumflex artery and the posterior humeral circumflex artery. In their qualitative anatomic study, Gerber et al. [23] concluded that the primary blood supply to nearly the entire humeral epiphysis derived from the anterolateral branch of the anterior humeral circumflex artery, whereas the posterior humeral circumflex artery vascularized the posterior aspect of the greater tuberosity along with a small posteroinferior aspect of the humeral head. Hettrich et al. [24] contradicted this finding in a more recent quantitative study, elegantly showing that the posterior humeral circumflex artery supplies 64 % of the blood supply to the overall humeral head and the anterior humeral circumflex artery is responsible for 36 % of the vascular load. When open approaches to the

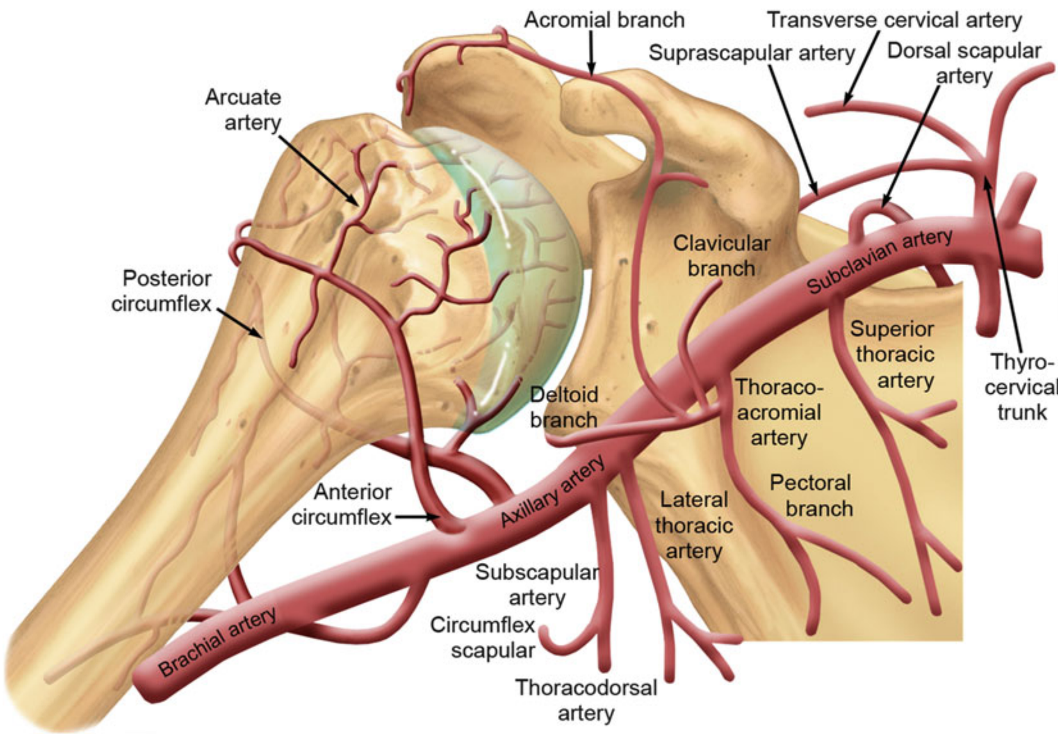

Fig. 4.7 The vascular anatomy of the humeral head

shoulder are performed, protection of the posterior soft tissue envelope and careful manipulation of fracture fragments are critical to avoiding further vascular insult to the humeral head.

Through small tributary branches, the anterior humeral circumflex artery supplies the lesser tuberosity and the subscapularis tendon as it inserts on the tuberosity before it divides into the terminal arcuate artery [16] (Fig. 4.7). The arcuate artery enters the intertubercular groove to provide the major intraosseous supply to the humeral head [25]. The tuberosities also receive vascularity from multiple extraosseous anastomoses between circumflex arteries and surrounding thoracoacromial, suprascapular, and subscapular arteries, which explains the low incidence of humeral head osteonecrosis with isolated tuberosity fractures [3].

Muscular Anatomy

The greater and lesser tuberosities serve as attachment points for the rotator cuff muscular network. Familiarity with the insertion pattern is critical to understanding tuberosity fractures, as displacement can occur along the lines of pull for these muscles. The subscapularis insertion onto the lesser tuberosity measures approximately 6.0 cm and consists of two anatomically distinct regions: an upper 60 % tendinous portion designed for strength and a lower 40 % muscular insertion allowing for further excursion [26]. The greater tuberosity, which can be divided into the superior, middle, and inferior facets, serves as the insertion for the supraspinatus, infraspinatus, and teres minor (Fig. 4.8). The supraspinatus attaches to the superior facet and the superior half of the middle facet, whereas the infraspinatus attaches to the entire length of the middle facet, overlapping the supraspinatus on the bursal side at the superior half of the middle facet (Fig. 4.9). The teres minor inserts onto the inferior facet of the greater tuberosity [27]. Fractures of the lesser tuberosity, therefore, tend to displace medially along the pull of the subscapularis, whereas fractures of the greater tuberosity tend to displace proximally and posteriorly along the pull of the external rotators. Inferior

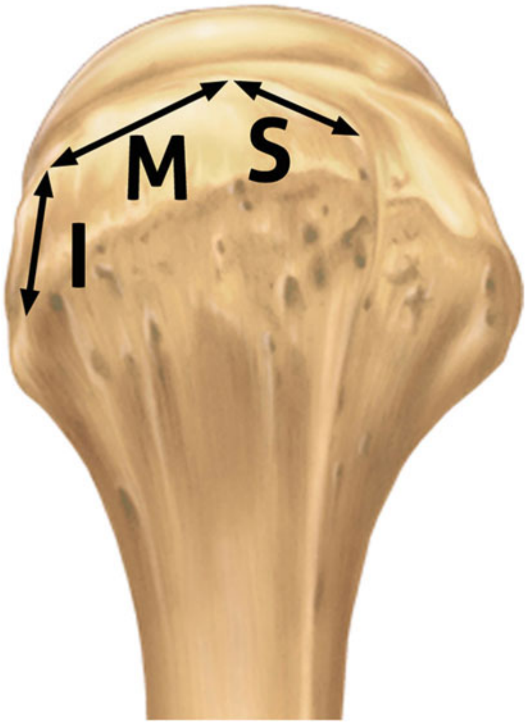

Fig. 4.8 The inferior (I), middle (M), and superior (S) facets of the greater tuberosity

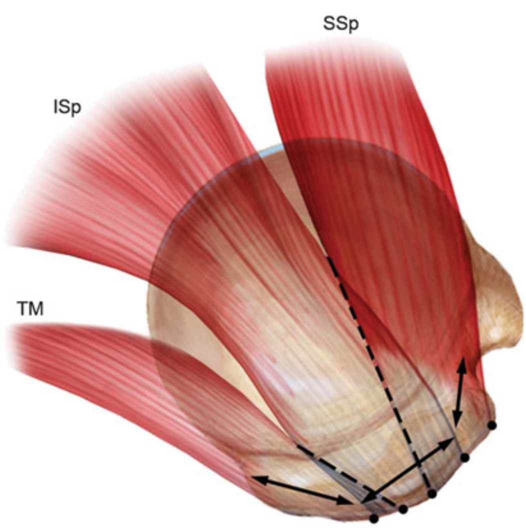

Fig. 4.9 Muscle-tendon insertions at the greater tuberosity. *TM* teres minor, *ISp* infraspinatus, *SSp* supraspinatus

displacement of the greater tuberosity fragment also has been described and is most likely the result of the mechanism of injury rather than the pull of the rotator cuff muscles [28].

Mechanism of Injury

Lesser Tuberosity

The lesser tuberosity is protected from direct injury by its small size and its location on the medial side of the humeral head. Authors of larger case series reporting on isolated lesser tuberosity fractures in adults have demonstrated that these fractures typically occur in young to middle-aged men and often result from high-energy events, such as falls from a height, motorcycle accidents, or high-contact sports [5, 6, 29]. Most patients cannot describe the exact details of injury because of the rapid sequence of energy transfer during the injury. However, the injury can be hypothesized to occur from a fall on an outstretched upper extremity with avulsion of the lesser tuberosity due to eccentric contraction of the subscapularis tendon when the extremity is forced into abduction or external rotation [3, 5]. A second mechanism of injury resulting in isolated lesser tuberosity fractures is described in the adult population with two-part posterior fracture-dislocations. These patients have injuries from seizures or electroconvulsive therapy for psychiatric disorders that result in posterior shoulder dislocations. As the shoulder dislocates posteriorly, sudden involuntary contraction of the subscapularis combined with a shear force on the lesser tuberosity against the anterior glenoid rim results in a tuberosity fracture [30]. In patients with locked posterior fracture-dislocations, the lesser tuberosity fracture propagates from the acute osteochondral fracture on the anterior humeral head (reverse Hill-Sachs defect) as it engages on the posterior glenoid rim [30–32].

In adolescents, isolated lesser tuberosity fractures result from high-energy falls during sports [6, 33, 34]. More specifically, contact sports, such as martial arts or wrestling [6], and overhead sports [35–37] have been identified. Three different mechanisms have been described to account for these injuries. Similar to adults, the first and most common mechanism is an avulsion through the lesser tuberosity apophysis with the shoulder in a forced sudden abduction and external rotation movement and the subscapularis muscle eccentrically contracting to resist this force [6, 33]. The second mechanism is an axial load along the long axis of the humerus applied to the extended and externally rotated shoulder. For example, when an athlete falls down backward with the upper extremity extended, the contact of the hand against the ground results in an axial load, causing anterosuperior migration of the humeral head and increasing tension on the subscapularis and superior glenohumeral ligament. This sudden increase in tension results in a fracture from traction on the lesser tuberosity through eccentric contraction of the subscapularis [35]. The third mechanism of injury occurs in adolescent overhead throwing athletes and results from microtrauma or repetitive injury leading to an incomplete traction injury of the lesser tuberosity. In these patients, repetitive contraction of the subscapularis results in a fatigue failure of the lesser tuberosity, and occasionally slow displacement of all or a portion of the tuberosity occurs over time [36, 37].

Greater Tuberosity

Various mechanisms of injury for tuberosity fractures have been proposed in the literature; however, the exact pathomechanics remain controversial [3, 38]. Some researchers have proposed an avulsion-type mechanism where the rotator cuff musculature pulls against a dislocating shoulder, resulting in an avulsion of the greater or lesser tuberosities [39–41]. This type of mechanism seems likely in a pediatric patient in whom unfused ossification centers are relatively weak compared with the strong tendon attachment, subsequently resulting in a Salter-Harris type of avulsion fracture.

Bahrs et al. [28] concluded that a specific mechanism of injury must exist either directly, such as a direct blow to the shoulder or a fall onto the shoulder, or indirectly, such as through a fall on the outstretched upper extremity, flexed elbow, or extreme abduction and external rotation. We submit an elaboration to the theory of an avulsion mechanism, contending that all fractures of the tuberosities are direct creations of a “subcortical weak link.” This weak link is created through a direct impact-type mechanism *and* the forceful eccentric load of the rotator cuff. This direct impact could be with the acromion, coracoid, or glenoid rim and may occur in the setting of humeral head malposition, dislocation, or subluxation during an injury.

Presentation and Clinical Evaluation

As with any orthopedic injury, initial evaluation begins with a detailed patient history aimed at obtaining patient characteristics, such as hand dominance, occupation, activity level, participation in overhead sports or recreational activities, and previous shoulder girdle injuries. Additional factors to consider include overall patient health, medical comorbidities, and ultimate recovery goals. The mechanism of injury is likewise critical to consider, as the clinician must take into account other associated injuries for patients with high-energy mechanisms compared with low-energy mechanisms of injury.

Lesser Tuberosity

Both adolescents and adults with lesser tuberosity fractures present with similar symptoms. They are often unaware of the details regarding the mechanism of injury. Most patients present with the injured extremity held close to the axial skeleton in an antalgic position and report nonspecific tenderness over the anterior aspect of the shoulder. In the acute setting, patients have symptoms similar to those with a rotator cuff tear, including nighttime pain and activity-related pain exacerbated by placing the shoulder in an externally rotated position [3].

Physical examination should include a thorough evaluation with inspection, palpation, range-of-motion testing, strength testing, neurovascular examination, and provocative testing of the shoulder for early diagnosis and treatment. Inspection of the shoulder may reveal swelling and ecchymosis extending into the axilla and distally into the arm. Tenderness over the anterior aspect of the shoulder, the lesser tuberosity, and even coracoid may or may not be present depending on the chronicity of the injury. Range-of-motion testing reveals pain with passive external rotation in the acute setting; however, patients often present with hyperexternal rotation and decreased internal rotation of the involved extremity compared with the contralateral side in the chronic setting [6]. Patients may not be able to tolerate manual muscle testing with resistance to internal rotation due to pain. Examination findings of weakness with internal rotation on manual muscle testing and weak lift-off and positive belly-press signs should increase the examiner's suspicion for a lesser tuberosity injury and heighten the process to confirm or refute this suspicion [2, 7]. With acutely or chronically displaced lesser tuberosity fragments, patients often have impingement with the coracoid or conjoined tendon [42, 43]. In the chronic setting, patients often present with significant anterior apprehension with the upper extremity in 90° of abduction and external rotation. It is unclear if this apprehension occurs due to a loss of the anterior stabilizing effect of the subscapularis or due to associated capsuloligamentous injuries [33, 44]. Patients with associated dislocation of the long head of the biceps tendon often present with pain in the bicipital groove, weakness on strength testing, and a provocative Speed's or O'Brien's test [34, 45].

In a recent case series involving adolescent overhead athletes who had delayed presentations with displaced lesser tuberosity avulsion fractures, Neogi et al. [35] presented a diagnostic treatment algorithm for early detection of these injuries via physical examination and appropriate imaging to avoid long-term sequelae of missed injuries in patients who have confounding initial presentations (Fig. 4.10).

Fig. 4.10 Axillary lateral view of a lesser tuberosity fracture

Greater Tuberosity

The presence or history of previous anterior dislocation should alert the examiner to the possibility of a greater tuberosity injury. The presence or history of a posterior dislocation instead should alert the examiner to the possibility of a lesser tuberosity fracture. Documentation of a detailed neurovascular examination is imperative to ruling out a concomitant arterial or nerve injury that can be associated with these fractures.

In non-displaced or minimally displaced fractures of the tuberosities, physical examination findings frequently are similar to those seen in acute rotator cuff pathologic lesions. In both scenarios, pain is present on palpation of the tuberosity and also is elicited during resisted muscular testing of the rotator cuff [46]. The examiner must possess a high index of suspicion because isolated fractures of the greater tuberosity can be overlooked or misdiagnosed as rotator sprains or rotator cuff tears. Ogawa et al. [46] determined that the rate of missed diagnosis was 64 % in one-part isolated greater tuberosity fractures and 27 % in two-part fractures. Most missed fractures occurred at the supraspinatus fossa of the greater tuberosity, with smaller fragments possessing a significantly higher rate of missed diagnosis [46].

Imaging

Appropriate radiographs allow the examiner to evaluate fracture displacement, comminution, associated glenohumeral dislocation, and associated bony injuries to the glenoid frequently encountered with glenohumeral dislocations. A standard radiographic trauma series of the

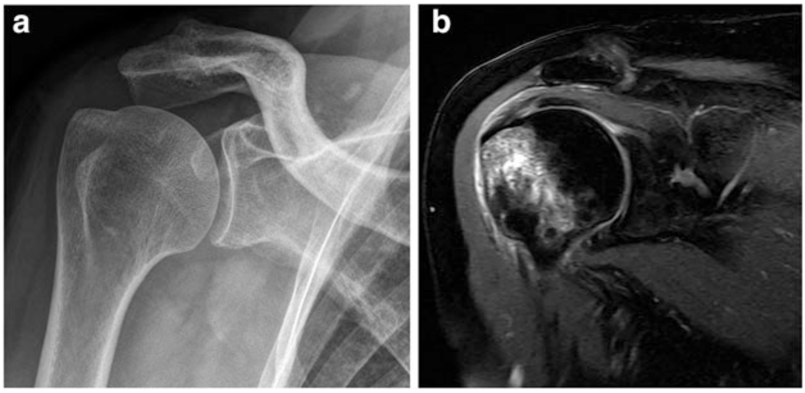

Fig. 4.11 Non-displaced greater tuberosity fracture. (**a**) No fracture was apparent on anteroposterior radiographs. (**b**) One week later, magnetic resonance imaging showed a non-displaced fracture of the greater tuberosity

shoulder includes a true anteroposterior (AP) view in the plane of the scapula, a scapular Y view, and a trauma axillary lateral view. A Velpeau view can be substituted for the axillary lateral view if pain precludes the necessary positioning of the shoulder. In a cadaver model, Parsons et al. [47] showed that diagnosis of displacements less than 5 mm is performed most accurately using an AP view of the shoulder in external rotation and an AP view with 15° of caudal tilt.

Multiple researchers reviewing case series on isolated lesser tuberosity fractures in the literature have identified that the axillary lateral view is believed to be the most diagnostic view for these injuries and missed injuries often were found in patients who did not have this view on initial evaluation (Fig. 4.10) [7, 48, 49]. In other case series, investigators also have demonstrated usefulness of a true AP view with maximal internal rotation in detecting lesser tuberosity fractures [6, 29]. Most fractures can be identified on plain radiographs; however, with a small lesser tuberosity fragment displaced inferiorly and medially, it easily can be misdiagnosed as calcific tendinitis of the subscapularis or an osseous Bankart lesion [29]. Furthermore, the exact amount of displacement and size of fragment are difficult to assess on plain radiographs [6].

The role of computed tomography (CT) scans in the workup of tuberosity fractures has received mixed reviews in the literature, with Mora Guix et al. [50] determining that the characterization of tuberosity fractures does not improve with the addition of CT scan. In another radiographic study, Sjödén et al. [51] showed low consistency with the Neer and AO fracture classification and no improvement after adding CT scans. Given that these researchers evaluated only axial CT scan slices, the value of adding coronal, sagittal, or three-dimensional reconstructions in the setting of isolated tuberosity fractures has not been studied. Computed tomography scans are valuable in identifying specific fracture characteristics, such as occult fracture line in non-displaced fractures, amount of displacement, size of the fragment, degree of comminution, intra-articular fracture extension, or bicipital groove involvement [6, 9]. This information allows for early diagnosis and can be used for surgical planning to determine appropriate approach, technique, and implant.

Ultrasonography and magnetic resonance imaging (MRI) have been shown to be useful in detecting occult non-displaced tuberosity fractures when initial plain films are negative (Fig. 4.11) [3]. They are particularly useful in illustrating the continuity of the subscapular tendon to the fragment and identifying associated soft tissue injuries, such as biceps tendon or labral tears. Whereas ultrasound is a noninvasive and inexpensive imaging modality that can identify cartilaginous structures, its use is not widespread, and diagnostic potential depends on the skill of the operator [20]. With a growing incidence of young adolescent athletes who sustain isolated apophyseal avulsion fractures or incomplete lesser tuberosity fractures from overuse, MRI has become the imaging modality of choice in this patient population [7]. A high index of

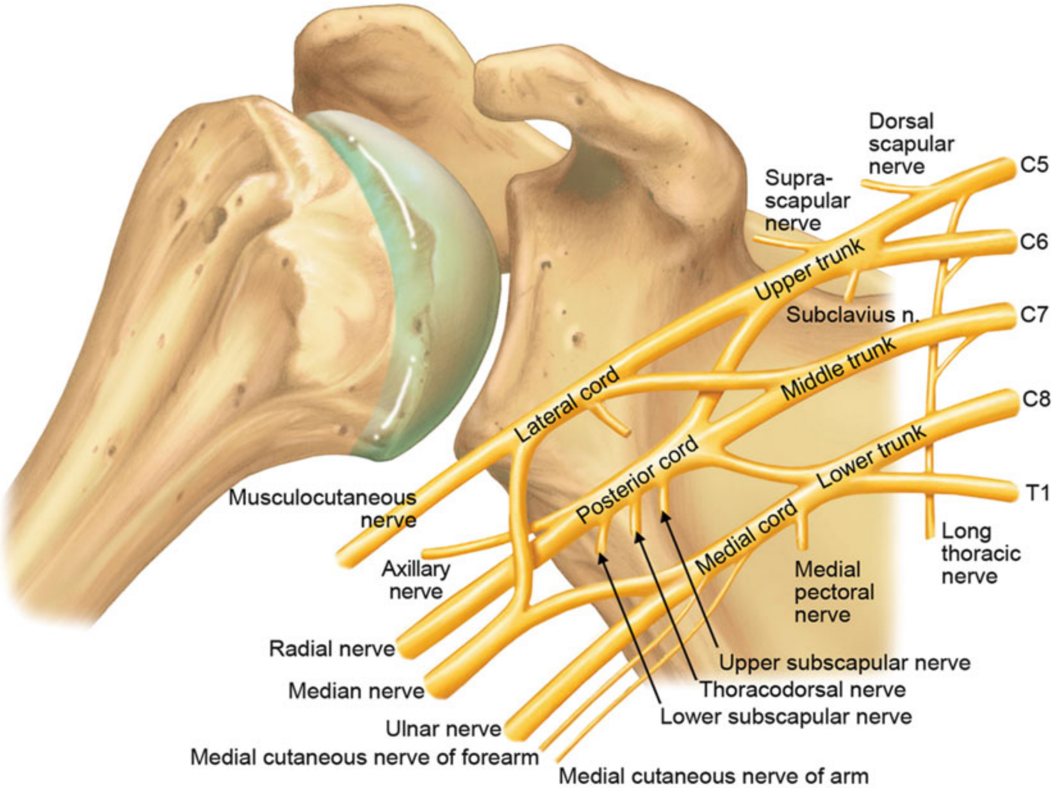

Fig. 4.12 The brachial plexus

suspicion is required, particularly in patients between 12 and 15 years of age who sustain abduction and external rotation sports injury. An MRI is indicated in any patient with persistent rotator cuff weakness and to allow early diagnosis of tuberosity injuries [35]. It may help play a role in the identification of occult greater tuberosity fractures and evaluation for tears of the rotator cuff. Zanetti et al. [52] found radiographically occult fractures of the greater tuberosity in 9 of 24 patients with clinically suspected traumatic tears of the rotator cuff. The authors also reported seven partial and six complete lesions of the subscapularis in the traumatic group, all occurring in patients older than 40 years [52]. In young athletes, MRI also has become helpful in detecting commonly concomitant biceps tendon subluxation/dislocation and humeral avulsion of the glenohumeral ligament or bony humeral avulsion of glenohumeral ligament lesions [7, 43, 48].

Associated Injuries

Injuries associated with tuberosity fractures frequently occur in the setting of a traumatic shoulder dislocation. Toolanen et al. [53] reported concomitant axillary nerve injuries occurred in nearly 50 % of patients more than 40 years of age who had sustained a glenohumeral dislocation with subsequent ultrasonographic and electromyographic evaluation. Nerve injuries also can be found in suprascapular, radial, and musculocutaneous nerves, with significantly more nerve injuries occurring in older patients and in those with hematomas. de Laat et al. [54] found that recovery typically occurred partially or completely within 4 months or less, with 8 of 101 patients experiencing persistent motor loss. Brachial plexus injuries in the setting of glenohumeral fracture-dislocations also may occur and typically affect the axillary nerve and additional peripheral nerves (Fig. 4.12) [55].

The presence of deltoid atony as evidenced by inferior subluxation of the glenohumeral joint also may be evidence of a poorly functioning axillary nerve and should be followed both clinically and radiographically. An electromyograph of any nerve injury should be obtained if recovery is not seen by 3 months.

Although rare, arterial injuries in the setting of a proximal humerus fracture, glenohumeral fracture-dislocation, or glenohumeral dislocation can take the form of arterial rupture, pseudoaneurysm, or venous thrombosis [56, 57]. The index of suspicion for arterial injuries should be heightened in elderly patients, as age-related changes and sclerosing of the arteries cause tearing rather than stretching of these vessels. A diminished or absent radial pulse together with an expanding hematoma in the axillary region should prompt a vascular consult for further evaluation with angiography.

Kim reported that arthroscopic examination in symptomatic shoulders treated nonoperatively for minimally displaced greater tuberosity fractures revealed a partial-thickness articular-sided rim-rent rotator cuff tear adjacent to the bony insertion in all 23 patients [58]. In their preoperative arthroscopic assessment of proximal humerus fractures, Schai et al. [59] discovered a significant number of labral, capsuloligamentous, and rotator cuff lesions and articular cartilage damage, obviating the need not to underestimate the associated soft tissue pathologic conditions associated with these fractures.

Indications for Surgical Intervention

The indications for the treatment of isolated greater tuberosity fractures have been refined since Neer [19] first proposed his classification system for proximal humerus fractures. Given that the humeral articular surface rises approximately 8 mm above the greater tuberosity, even small superior displacements of the greater tuberosity can lead to subacromial impingement [60]. In addition, Bono et al. [61] found that superior displacement of 0.5 mm and 1 cm increased the abduction force that the glenoid required by 16 % and 27 %, respectively, suggesting that even small amounts of residual displacement result in alterations in the forces required to elevate the upper extremity. Neer's [19] classic criteria of 1 cm and 45° to consider a fracture fragment displaced is not very applicable to fractures of the greater tuberosity, and more stringent criteria need to be applied.

Minimally displaced fractures of the greater tuberosity (<3 mm) can be reliably treated nonoperatively. In a retrospective review of non-operative treatment of minimally displaced fractures of the greater tuberosity, Rath et al. [62] reported good clinical recovery in all their patients and found no statistical difference in outcomes between patients who had non-displaced fractures and those who had minimally displaced fractures. Platzer et al. [63] demonstrated 97 % good to excellent results in patients with fractures of the greater tuberosity displaced less than 5 mm at a mean follow-up of 3.7 years. More displacement is accepted posteriorly than superiorly because of the greater likelihood of subacromial impingement with superior displacement. Associated soft tissue injuries in younger patients who sustain minimally displaced fractures of the greater tuberosity may lead to chronic shoulder pain and require further evaluation to exclude injury to the labrum and rotator cuff [41].

Numerous authors have retrospectively evaluated the outcomes in operatively treated fractures of the greater tuberosity [13, 38, 64]. In particular, Platzer et al. [63] directly compared the outcomes of operatively versus nonoperatively treated fractures of the greater tuberosity with greater than 5 mm of displacement and showed significantly better shoulder function in the operatively treated group.

The activity level more than the age of the patient influences the decision to operatively manage greater tuberosity fractures with borderline displacement. Active patients generally have much pain and dysfunction associated with this fracture. The current consensus for the operative treatment of greater tuberosity fractures includes displacement of greater than 5 mm or greater than 3 mm in athletes or in patients performing frequent overhead activities [65, 66].

Although recommendations exist to surgically treat lesser tuberosity fractures that are displaced and block internal rotation, no firm recommendations exist. Lesser tuberosity fracture displacement is poorly tolerated, as this results in significant subcoracoid impingement. Therefore, any displacement resulting in persistent internal rotation weakness, a block to internal rotation, or subcoracoid impingement that does not resolve within the first 4 weeks after the injury is an indication for operative intervention.

Surgical Technique

Choice of the appropriate surgical technique and fixation method is dictated by numerous factors to include degree of comminution, fracture displacement, bone quality, and size of the fracture fragment. The open approach remains the gold standard; however, results from arthroscopic reduction and internal fixation have shown promise in the appropriately selected fracture pattern.

For open reduction and internal fixation (ORIF) repairs, the patient is positioned in the semi-recumbent beach-chair position. The operative shoulder is placed slightly off the edge of the bed to facilitate exposure and intraoperative fluoroscopic imaging. Before sterile preparation and draping, adequate imaging is confirmed with large C-arm fluoroscopy entering from the head of the table. The fracture can be approached via two separate approaches: a standard deltopectoral approach or an anterosuperior deltoid-splitting approach.

We prefer to use the standard deltopectoral approach. The operative treatment options include ORIF with heavy nonabsorbable sutures incorporated into the rotator cuff tendon and ORIF with screws and washers (Fig. 4.13). Using screws and washers with greater tuberosity fractures is often difficult because of the small size of the fragment and comminution. Cortical thinning in the tuberosities is also a reason for employing a suture technique.

The primary goal is to reduce the bony fragments to avoid any postoperative impingement issues and restore the biomechanics of the rotator cuff. Tension-band creation to convert tension to compression is recommended, and depending on the tuberosity being repaired and its corresponding rotator cuff, the tension band has either a vertically or horizontally oriented configuration. Greater tuberosity fractures involving the facet for the supraspinatus require a vertically oriented tension band, whereas greater tuberosity fractures involving the more posterior facets for the infraspinatus and teres minor require a less vertical and even transitioning into a more horizontal configuration. Lesser tuberosity fractures also require a more horizontal configuration while avoiding the long head of the biceps in the bicipital groove (Fig. 4.14).

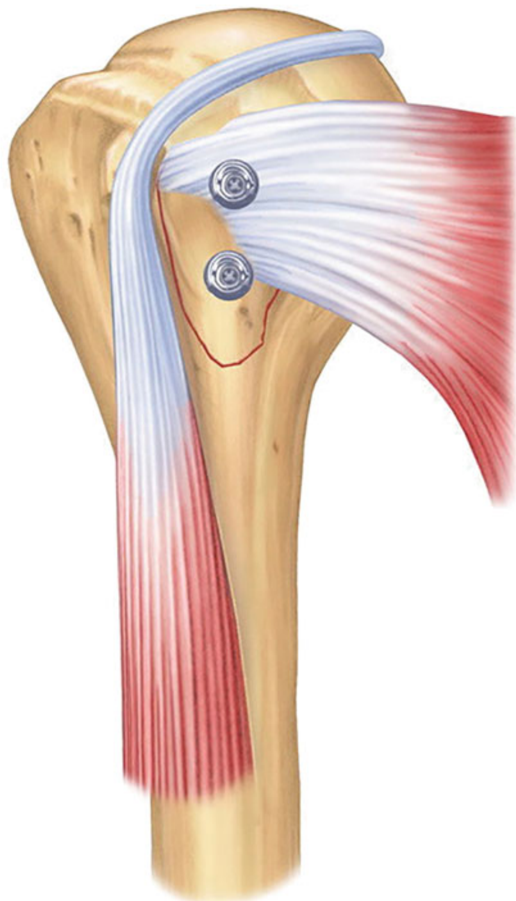

Fig. 4.13 Screw-and-washer fixation used to treat a lesser tuberosity fracture. Reprinted with permission from Lewis RG. Proximal humerus fractures. In: Gaunt BW, McCluskey GM 3rd, editors. A systematic approach to shoulder rehabilitation. Columbus (GA): Human Performance and Rehabilitation Centers, Inc.; 2012. p. 140–55

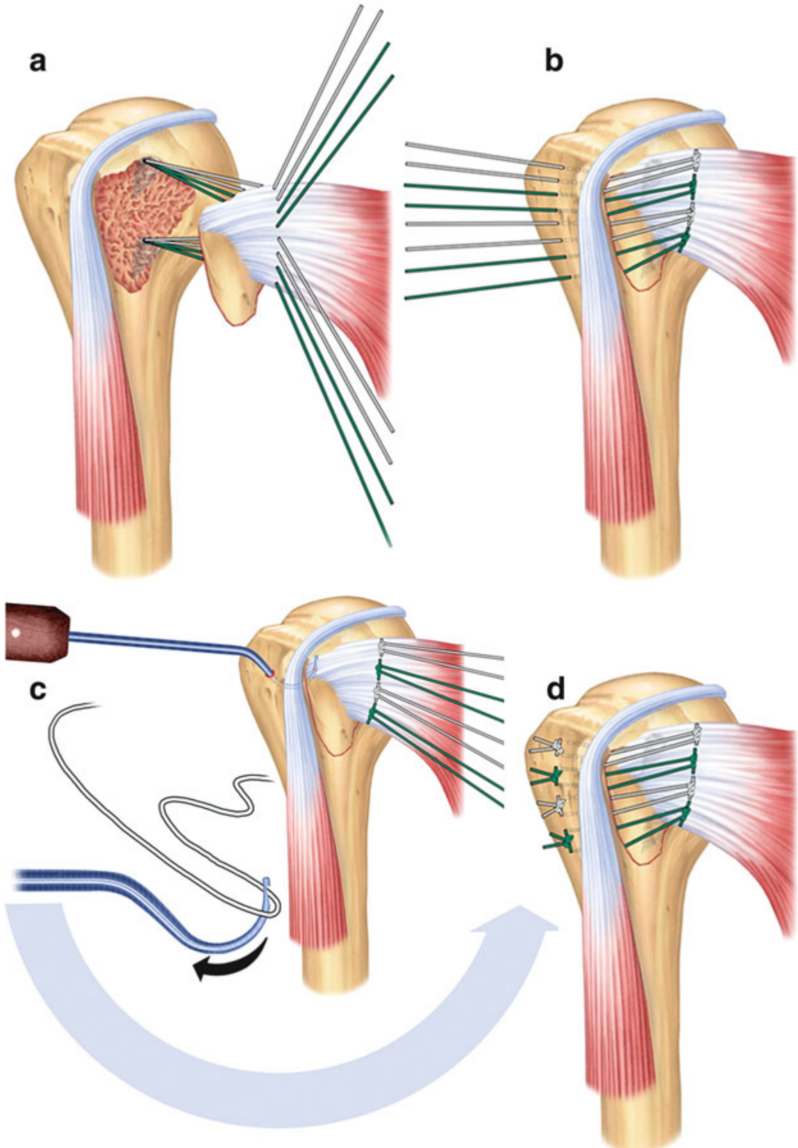

Fig. 4.14 (**a–d**) The technique for tuberosity fixation involves suture anchors and transosseous tunnels. Adapted with permission from Lewis RG. Proximal humerus fractures. In: Gaunt BW, McCluskey GM 3rd, editors. A systematic approach to shoulder rehabilitation. Columbus (GA): Human Performance and Rehabilitation Centers, Inc.; 2012. p. 140–55

A newer technique of arthroscopic repair with suture anchors is available to manage this injury. Arthroscopic reduction and internal fixation may be an effective choice in the treatment of small comminuted fractures of the greater tuberosity that are not severely displaced [67]. If reduction cannot be adequately achieved using arthroscopy, the same suture technique can be used in an open approach. Arthroscopic reduction and internal fixation of greater tuberosity fractures involves fixation with suture anchors. Two anchors are placed at the superomedial aspect of the rotator cuff footprint. The sutures from these anchors are passed through the greater tuberosity bone-tendon interface via arthroscopic cannulas and suture passers (Fig. 4.15a). Next, the greater tuberosity fragment is reduced, and the sutures are tied arthroscopically, creating horizontal mattress-suture configurations. Only one suture strand is cut from each knot for later use in creating a tension band over the fracture fragments (Fig. 4.15b). A third suture anchor is

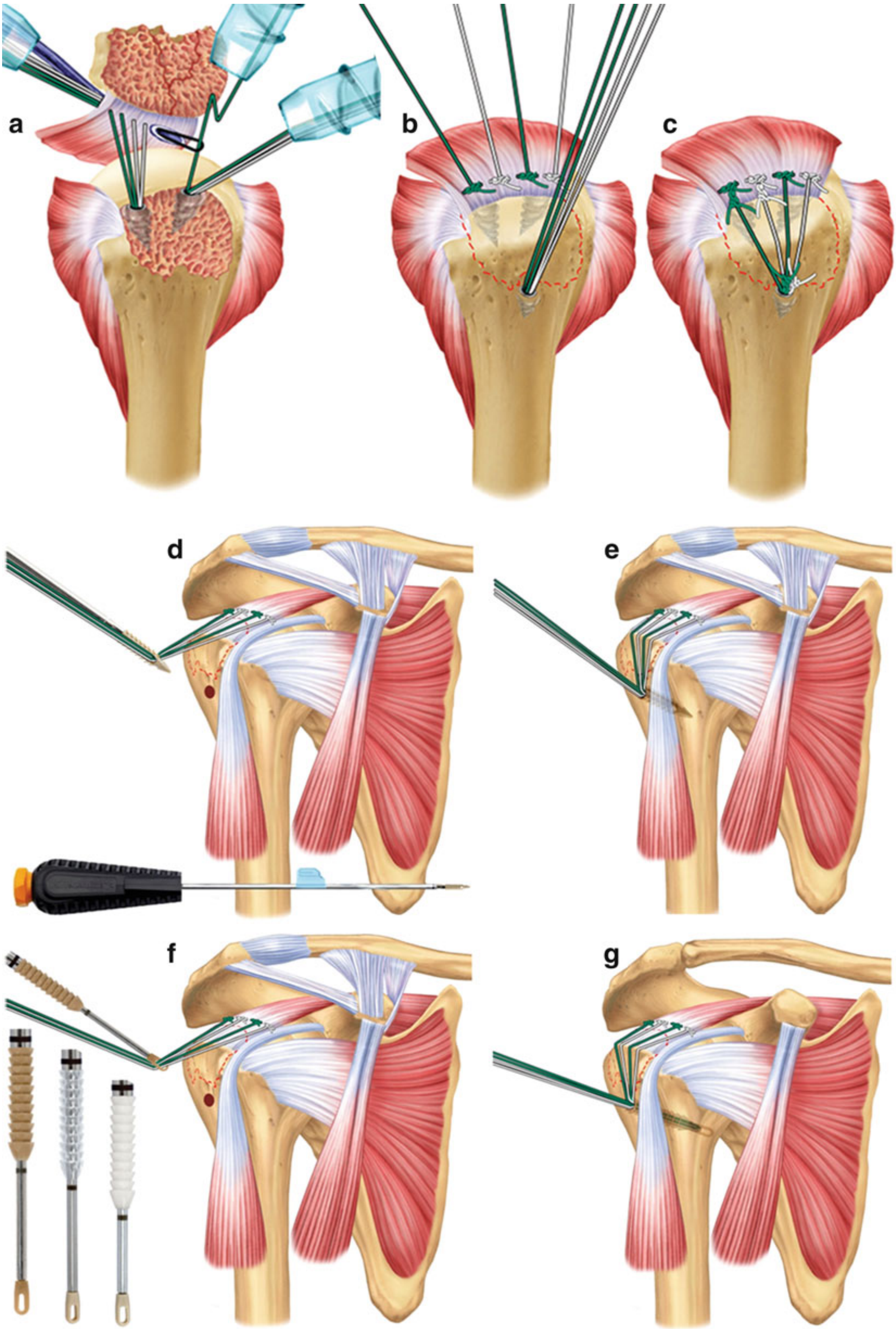

Fig. 4.15 (**a**–**f**) Arthroscopic technique for suture-anchor repair of a greater tuberosity fracture. (**a**–**c**) Anchor placement. (**d** and **e**) FOOTPRINT PK (Smith & Nephew, Inc., Andover, MA). (**f** and **g**) PushLock (Arthrex, Inc., Naples, FL). Adapted with permission from Lewis RG. Proximal humerus fractures. In: Gaunt

placed at the inferolateral aspect of the greater tuberosity footprint. The bone must be predrilled *and* tapped to avoid fracturing the cortical bone when placing this anchor. One strand from the third anchor is tied arthroscopically to a suture limb from the superomedial anchors, effectively creating compression of the greater tuberosity fracture fragment within the fracture bed in a tension-band fashion (Fig. 4.15c). Surgeons also may use a suture-bridge technique as the distal point of fixation using either a FOOTPRINT PK (Smith & Nephew, Inc., Andover, MA) (Fig. 4.15d, e) or PushLock (Arthrex, Inc., Naples, FL) implant (Fig. 4.15f, g). The surgical principles always should be followed and include adequate reduction of the fracture fragments to avoid impingement and restore the biomechanics of the rotator cuff.

Postoperative Rehabilitation

Rehabilitation regimens are individualized and adapted to accommodate associated bony or soft tissue injuries, strength of fixation, and anticipated patient compliance. After ORIF or open transosseous fixation of isolated lesser tuberosity fractures in adults and adolescents, a protocol similar to the one used after rotator cuff repair is employed [3, 5, 7, 20]. Postoperatively, the patients rest in a shoulder sling. Pendulum exercises are commenced immediately and are followed by passive motion exercises for forward flexion, internal rotation, and external rotation at waist level for 6 weeks under the supervision of a therapist. Early abduction-external rotation or abduction of the shoulder to more than 90° is avoided during this 6-week period. At 6–8 weeks, active and active-assisted range-of-motion and mild resistance exercises are initiated. Isometric rotator cuff strengthening exercises begin at 3 months and are continued for 6 months with a graduated home exercise program.

In case reports describing arthroscopic reconstruction of isolated lesser tuberosity fractures, researchers have documented more conservative rehabilitation protocols to protect the repair during the initial 6-week period [33, 68]. The affected upper extremities of these patients are placed in a sling for 3 weeks after surgery. Early supervised passive motion exercises are initiated; however, motion is restricted to 90° of flexion, 60° of abduction, and internal rotation for the first 4 weeks. External rotation is limited to 0°, and the patients are instructed to avoid active internal rotation for this 6-week period. The patients initiate active and active-assisted range-of-motion exercises at 6 weeks and begin isometric exercises at 3 months.

Conclusions

Tuberosity fractures of the proximal humerus can be somewhat elusive and challenging to treat. Further understanding the mechanism of injury as a combination of high energy with an impingement event and eccentric contraction will enhance the investigation and appropriate workup of a suspected tuberosity injury. Tuberosity fractures involve tendinous insertions and should be treated with the tendon and related function in mind. These are soft tissue injuries overlying fractures.

The tolerance of tuberosity displacement is poor, especially in the active, more demanding population. The indications for operative treatment of greater tuberosity fractures include displacement of greater than 5 mm or greater than 3 mm in athletes or in patients performing frequent overhead activities. Although no exact number exists for lesser tuberosity fracture displacement, one certainly can consider any displacement resulting in persistent internal rotation weakness, a block to internal rotation or subcoracoid impingement that does not resolve within the first 4 weeks after the injury to be an indication for operative intervention.

Fig. 4.15 (Continued) BW, McCluskey GM 3rd, editors. A systematic approach to shoulder rehabilitation. Columbus (GA): Human Performance and Rehabilitation Centers, Inc.; 2012. p. 140–55

When the decision for operative intervention has been made, the surgical principles should always be followed and include adequate reduction of the fracture fragments to avoid impingement and restore the biomechanics of the rotator cuff.

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5 Intramedullary Locking Nail Fixation of Proximal Humerus Fractures: Rationale and Technique

Pascal Boileau, Thomas d'Ollonne, Armodios M. Hatzidakis, and Mark E. Morrey

Introduction

Proximal humerus fractures (PHFs) can be classified in two-, three-, or four-part according to the Neer classification [1]. Approximately 20–50 % of patients with displaced, unstable two-, three-, and four-part PHFs with a vascularized, attached head fragment may benefit from operative management with reduction and internal fixation [2]. Optimal treatment for displaced or unstable two-, three-, and four-part proximal humerus fractures remains controversial [3–8]. Although no stabilization device has attained definitive superiority yet, most experts agree that minimal soft-tissue dissection and adequate fixation strength should be the goals of any internal fixation device [9].

Intramedullary fixation with a locked nail may be an attractive option, compared to locked-plate fixation, as it provides adequate (i.e., equivalent) fixation strength with minimal soft-tissue dissection. The Aequalis IM locking nail (Tornier, Minneapolis, USA) is an intramedullary stabilization device for proximal humeral fractures, designed specifically to optimize tuberosity-fragment fixation and to provide stable support for the humeral head, improving proximal humeral reconstruction and fixation in osteopenic bone.

The goals of this chapter are (1) to summarize briefly the complications and problems encountered with pinning and plating of proximal humerus fractures; (2) to analyze the common complications and technological problems related to previous conventional IM Nails; (3) to define the rationale and characteristics of the ideal intramedullary (IM) locking nail; (4) to describe the unique features of the design of the Aequalis IM locking nail; (5) to describe the percutaneous guided technique for two-part fractures and (6) the superior mini-open approach for three- and four-part fractures; and finally (7) to report the early functional and radiological results obtained with this new IM locking nail.

Complications and Technological Problems Related to Pining and Plating

Although significant advancements have been made in fixation devices, the ideal fixation technique for proximal humerus fractures remains unclear.

Percutaneous pinning is attractive but does not allow immediate mobilization because of the risk of displacement of the bone fragments (Fig. 5.1).

P. Boileau (✉) • T. d'Ollonne
Department of Orthopaedic Surgery and Sports Traumatology, L'Archet 2 Hospital, 151, route de St Antoine de Ginestière, Nice 06200, France
e-mail: boileau.p@chu-nice.fr

A.M. Hatzidakis
Western Orthopaedics PC, 1830 Franklin Street, Suite 450, Denver, CO 80218-1126, USA
e-mail: armandhatzi@yahoo.com

M.E. Morrey
Department of Orthopedics, Mayo Clinic, 200 1st St. SW, Rochester, MN 55902, USA
e-mail: morrey.mark@mayo.edu

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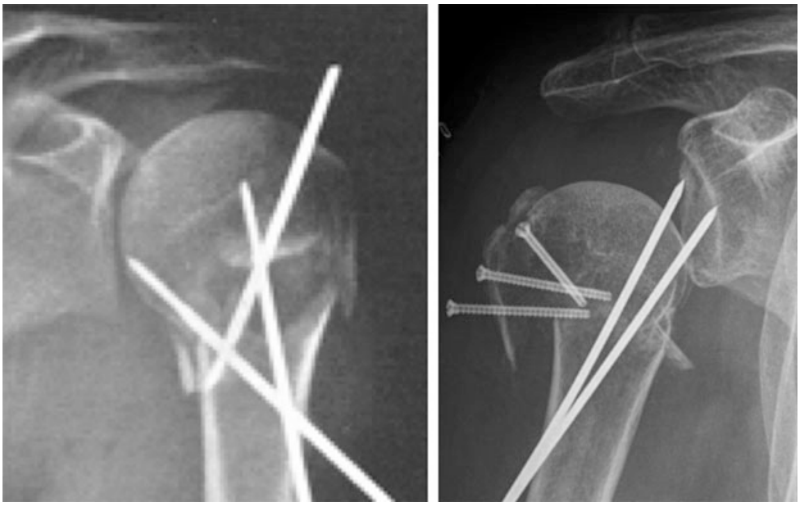

Fig. 5.1 Insufficient stability of the fixation with pinning and example of early loss of reduction

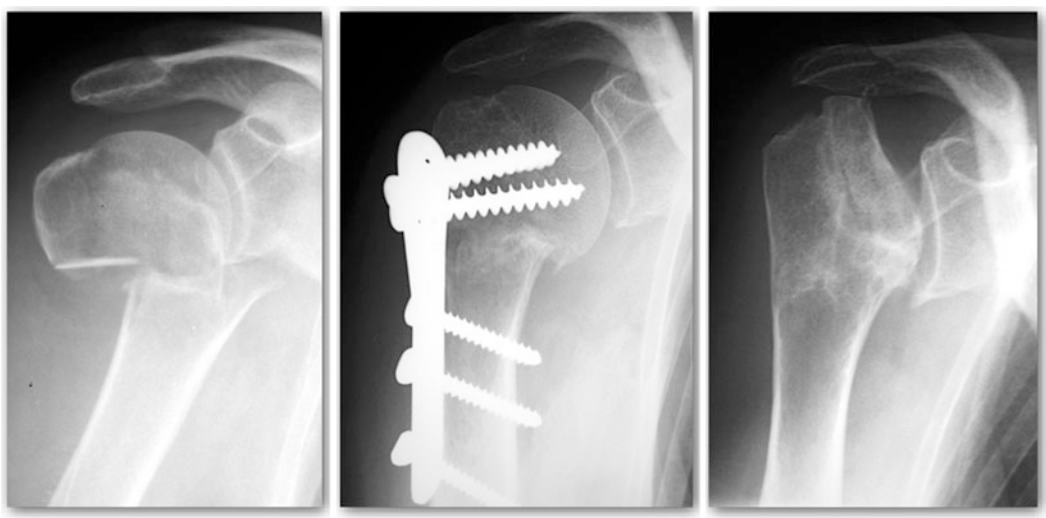

Fig. 5.2 Avascular necrosis of the humeral head after plating

Fixed-angle locked plates are very popular at the moment and have become a kind of "gold standard" for the treatment of PHFs [10]. However, there is some risk of complications, including hardware failure, screw penetration, and loss of reduction [11–15].

In case of two-part fractures, the risk of humeral head necrosis because of additional bone devascularization can occur (Fig. 5.2).

In case of three-and four-part fractures, we feel that locking plates provide inadequate biomechanical fixation because the screws are head-oriented, instead of being tuberosity-oriented. This may lead to what we have called the "unhappy triad after locking plate" which combines (1) humeral head necrosis, (2) loss of reduction and posterior migration of the greater tuberosity (i.e., a massive, retracted posterosuperior rotator cuff tear) because of the inadequate orientation of the screws, and (3) glenoid erosion and destruction because of screw penetration (Fig. 5.3).

Fig. 5.3 "Unhappy" triad: humeral head necrosis, tuberosity migration, glenoid erosion

The catastrophic results after failures of three- and four-part fracture plating have been clearly underestimated. The fact is that a failure after a locking plate burns all the bridges. A revision with hemiarthroplasty is not possible because of glenoid erosion and GT migration. An anatomical TSA is not possible either, for the same reasons, and more specifically because of the posterosuperior cuff insufficiency. The surgeon has to discuss the indication of reverse shoulder arthroplasty (RSA) often in a young patient. Unfortunately, it will be a RSA with poor functional results because of stiffness and absence of external rotator muscles.

Complications and Technological Problems Related to Previous Conventional IM Nails

Some reports on IM nails for displaced proximal humerus fractures have reported a high complication rate of 40 % [16–24] and a high revision rate of up to 45 % [25–29]. Based on our own experience, most of the complications and problems observed with existing IM nails are related to inadequate design of the nail itself, the inadequate orientation of proximal screws, the absence of locking mechanism for proximal screws and the inadequate accompanying instrumentation.

Iatrogenic rotator cuff tears are seen when surgeons use a lateral entry portal to insert the IM nail, which is unavoidable with a proximally bent IM nail (Fig. 5.4).

The obvious advantage of a straight and low-profile nail is that it can be inserted through the muscular (not the tendinous) part of the supraspinatus and the superior part of the humeral head (not the greater tuberosity and the tendon footprint).

Acromial impingement (secondary to protrusion of the proximal end of the nail) is related to poor instrumentation and use of bended nail (Fig. 5.5). It can be avoided by using a precise and radiolucent instrumentation and a straight nail. Both iatrogenic cuff tears and nail protrusion are sufficient to explain the 20–45 % of postoperative shoulder pain reported in the literature after intramedullary nailing of humeral fractures.

Surgical-neck non-union is related to the unsuitable design of some nails, which are too long and too large distally, leading to premature "locking" through interference inside the distal medullary canal and distraction at the fracture site (Fig. 5.6). This complication can be easily

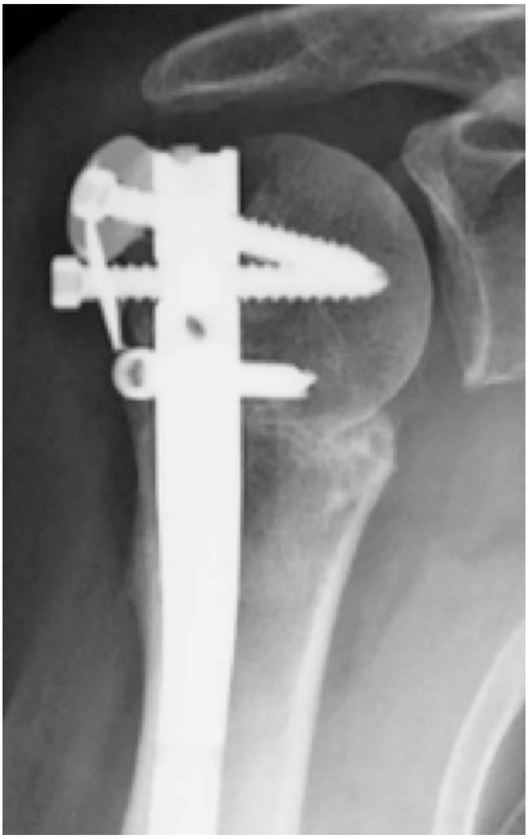

Fig. 5.4 Bent nail and its lateral entry point, leading to cuff tendon injury

Fig. 5.5 Proximal hardware protrusion and associated sub-acromial impingement

avoided by using a short, and small-diameter IM nail (low-profile) and by intraoperative compression of the fracture site.

Surgical-neck malunion in internal rotation is related to the absence of adapted instrumentation to control fracture and nail rotation. The most commonly committed error is to fix the fracture with the arm in internal rotation (the hand on the abdomen), which leads to an internal-rotation malunion of the diaphysis. Control of humeral retroversion and nail rotation is therefore of paramount importance.

Screw backout (and loss of tuberosity reduction) has a reported prevalence of 10–24 % with conventional intramedullary devices (Fig. 5.7). This complication is due to the absence of a locking mechanism for proximal screws: the screws are simply threaded into the interlocking holes in many IM nails. These conventional IM nails fail as they rely only on screw torque in the bone to provide stabilization (Head-based fixation). The locking technology applied to the proximal screw holes, almost eliminates the possibility of screw backout.

Screw protrusion (and glenoid erosion) is another potentially disastrous complication seen with conventional IM nails (and locking plates) (Fig. 5.8). Again, this complication is related to the fact that the screws are oriented toward the head (Head-based fixation) and consequently toward the glenoid surface. Screw placement into the tuberosities rather than in the humeral head avoids the risk of this complication (Tuberosity-based fixation).

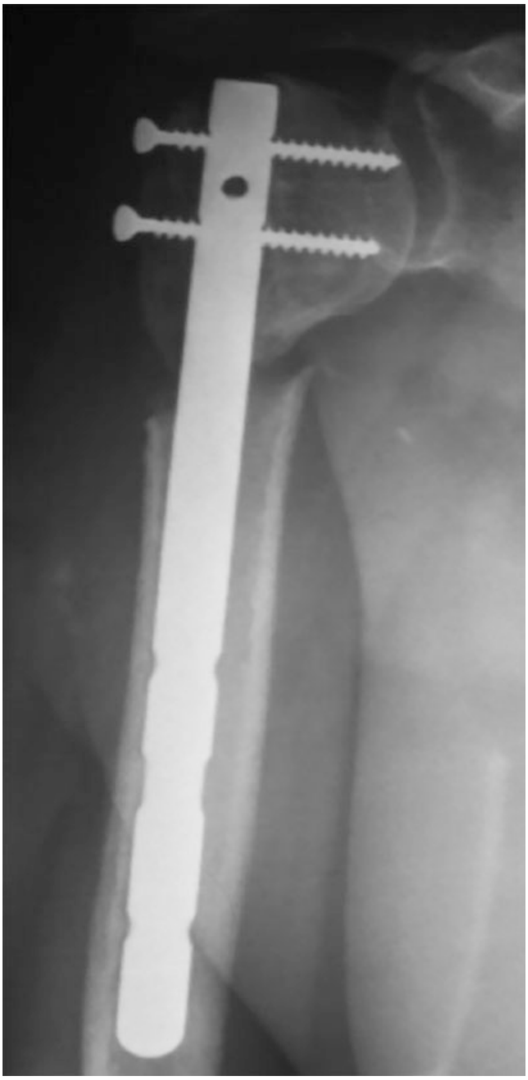

Fig. 5.6 Distraction at the fracture site

Nail toggling and fracture malreduction (Fig. 5.9). Fracture comminution and poor bone quality are not uncommon in elderly patients. This can lead to loss of fracture reduction and fixation. Varus bending represents a frequent physiologic displacement of proximal humerus fractures.

Based on the analysis of these pitfalls, the specifications of the ideal device can be defined (Table 5.1).

Fig. 5.7 Screw backout and loss of reduction

Design of the Aequalis IM Locking Proximal Humerus Nail

The novel design of the Aequalis Proximal Humerus Nail combines unique features that allow a less invasive surgical intervention, maintenance of the vascularization of the fracture fragments, angular stability of proximal fixation, and optimal screw orientation for fixation of the tuberosities.

The design of the Aequalis Proximal Humerus Nail is based on five principles: fixation of the tuberosities, supporting the humeral head, angular-stable locked screws, centering within the medullary canal, and medial articular insertion point (Fig. 5.10).

Fig. 5.8 Articular penetration of the screws and glenoid erosion

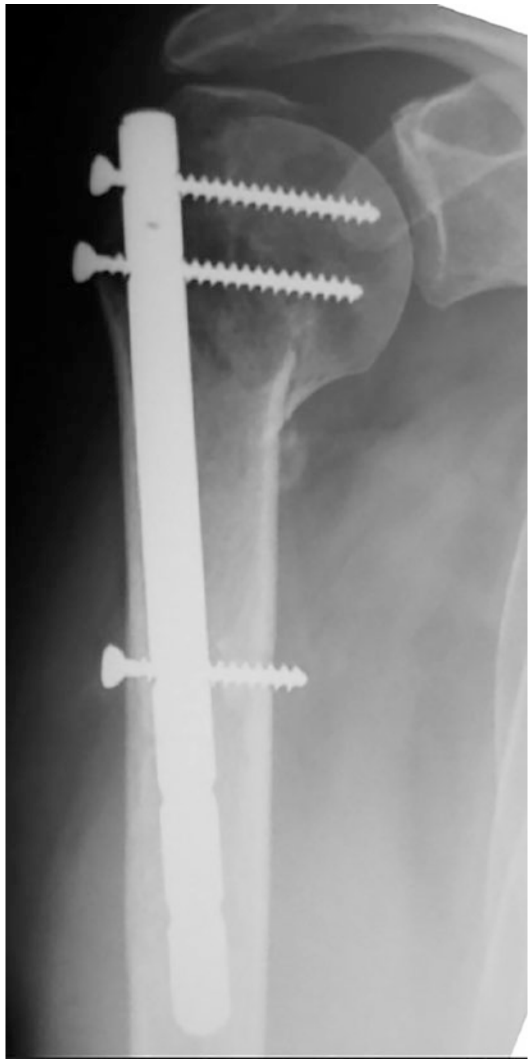

Fig. 5.9 Nail toggling, tuberosity migration, and varus displacement leading to malreduction

This straight, cannulated titanium nail, 130 mm long, offers several unique design features that support these five principles. The straight design of the nail avoids insertion through the rotator cuff tendon and reduces the potential for a varus reduction, and cannulation allows for a minimally invasive percutaneous technique. The divergent tuberosity based fixation provides optimum independent fixation of the greater and lesser tuberosities (Fig. 5.11), which also serves to maintain positioning of the humeral head without requiring screws to enter the central humeral head (Fig. 5.12).

The proximal screws are "locked" in the nail via a polyethylene bushing, providing angular stability for tuberosity and humeral head fixation.

Two interlocking screws that are divergent accomplish distal fixation by 20°, which minimizes toggle of the nail and allows for distal centering in cases of a large humeral canal.

A radiolucent targeting guide facilitates accurate insertion and positioning of the nail and screws, with easy fluoroscopic visualization.

A version-rod, aligned with the forearm, can help achieve accurate rotational alignment of the proximal (epiphyseal) bone fragment in reference to the diaphysis.

The nail's design and optimal screw orientation must be chosen after extensive study of the three-dimensional morphology and geometry of

Table 5.1 Complications and problems related to existing IM nails, their causes, and possible technologic/design-related solutions

Complications	Cause	Technologic solution
1. Nail design		
Rotator cuff tendon tears	Bent, large-diameter nail with lateralized entry point	Straight, small-diameter nail for medialized entry point
Iatrogenic greater-tuberosity fracture through entry point	Bent, large-diameter nail with lateralized entry point	Straight, small-diameter nail + awl + reamer to facilitate medialized entry point
Acromial Impingement secondary to nail protrusion	Proud/lateral (bent) nail + poor instrumentation	Straight, low-profile nail with accurate targeting device
Surgical neck non-union	Excessive nail length and size; obligatory distal locking	Shorter nail with fluted distal tip
2. Proximal screws		
Loss of tuberosity reduction and fixation	Poor (*humeral head-based*) screw orientation (=*latero-medial*)	Optimal (*tuberosity-based*) screw orientation (=posteroanterior)
	Poor or absent locking mechanism for proximal screws (=*bone-based fixation*)	Secure locking into nail through threaded holes (=*nail-based fixation*)
Proximal-screw loosening and back-out	Unlocked proximal screws (=*bone-based fixation*)	Secure locked proximal screws (=*nail-based fixation*)
Proximal-screw penetration through articular cartilage	Poor screw orientation (latero-medial)	Locking screws with posteroanterior orientation
Axillary nerve damage	Low/oblique proximal-screw positioning	Optimal screw position (high enough, horizontal)
Long-head-of-biceps tendon and bicipital groove damage	Uncontrolled nail rotation = penetration of bicipital groove	Control of nail rotation through instrumentation
3. Distal screw instrumentation		
Nail toggling, fracture displacement, malalignment	Aligned (non-divergent) distal screws	Divergent distal screws allowing nail centering and adding stability
Nail malrotation and surgical neck malunion	Uncontrolled nail and fracture rotation	Specifically designed instrumentation allowing accurate rotational control

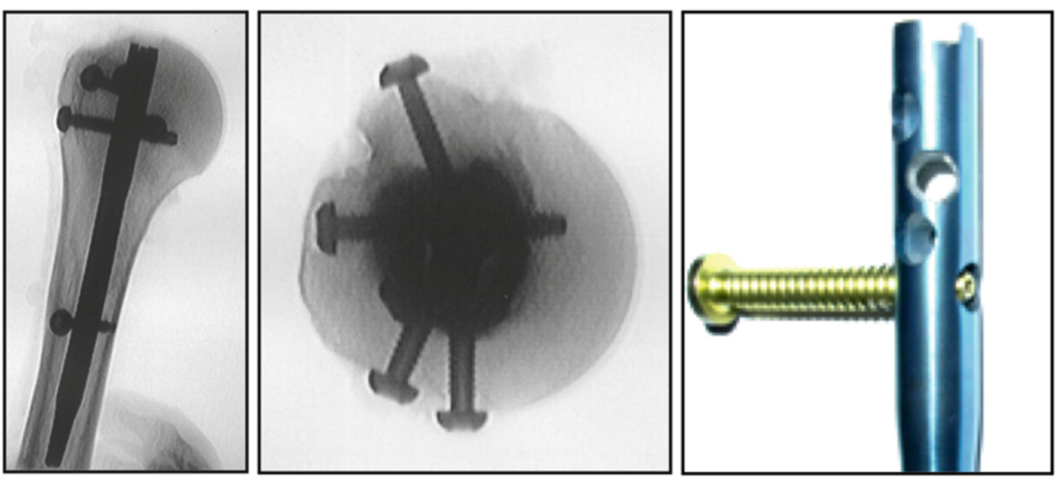

Fig. 5.10 Design of the Aequalis Nail

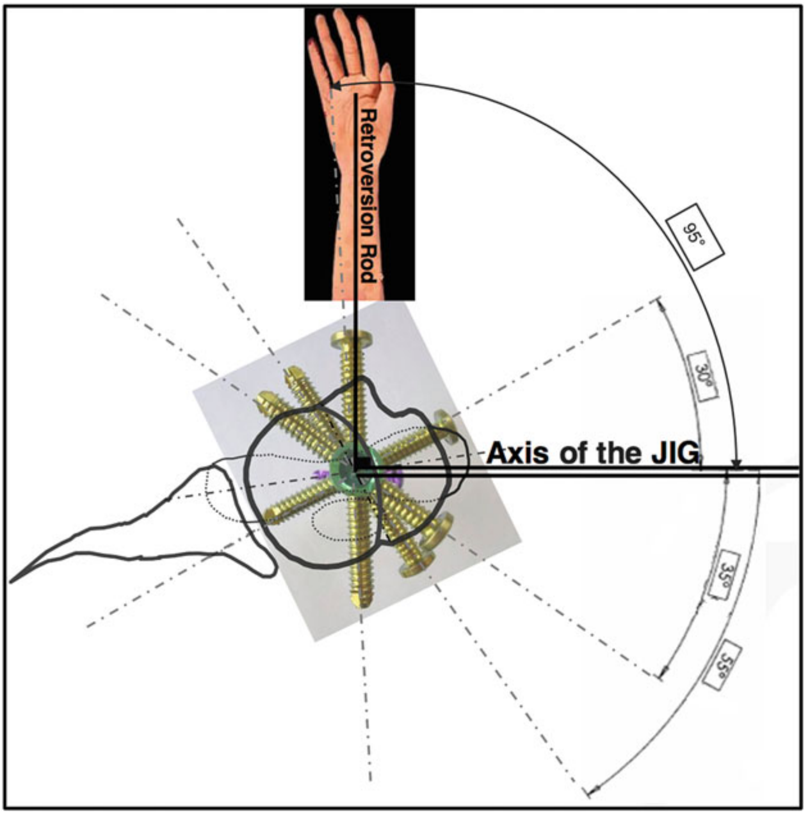

Fig. 5.11 Tuberosity based orientation of the proximal screws

Fig. 5.12 No screw directed towards the head

the proximal humerus [30] and of the pathophysiology of displaced unstable two-, three-, and four-part fractures [31–34].

The nail is indicated for two-, three-, and four-part fractures according to Neer's classification, non-unions, malunions, and impending pathological fractures. The design of the nail and its instrumentation allows effective insertion through an open or percutaneous approach.

Two-Part Surgical Neck Fracture with a Percutaneous Technique

Rationale

In two-part (surgical-neck) fractures, the epiphysis is correctly oriented and has a fixed position, because the internal-rotator and external-rotator

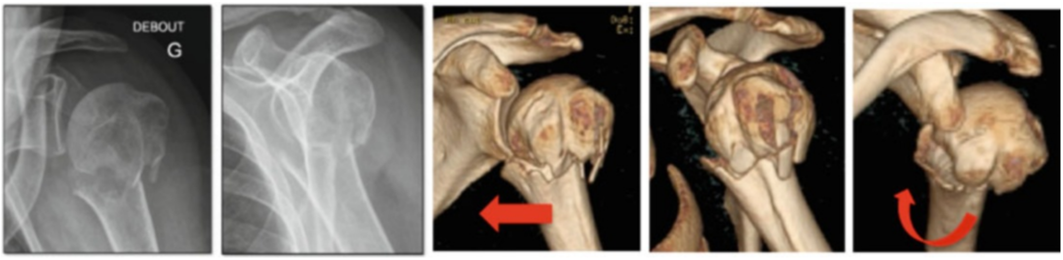

Fig. 5.13 Action of the muscles in case of surgical neck fracture: Adduction and internal rotation of the diaphysis

muscles are still attached and balanced. In other words, the head is facing the glenoid and is stable. The diaphysis is medially displaced (due to the medial pull of the pectoralis major, latissimus dorsi, and teres major) and in internal rotation (because the forearm is usually held against the belly) (Fig. 5.13).

Two main complications are specifically encountered with two-part (surgical neck) fractures, and must be anticipated:

1. *Rotational malunion* which occurs when the nail is locked proximally and distally with the arm in internal rotation; this leads to decreased humeral retroversion and consequently, external rotation. This complication can be avoided by using the outrigger alignment guide as described above.
2. *Surgical neck non-union* that occurs in cases of persistent distraction at the fracture site. This complication can be avoided by using a "backslap technique": consisting in retrograde hammering after first distal locking, which impacts the surgical neck fracture site, preventing non-union.

Percutaneous "Backslap" Technique

In two-part (surgical neck) fractures, the procedure can be performed percutaneously. The starting point is located either anterior or posterior to the acromio-clavicular joint, depending on the displacement of the epiphyseal fragment. The anterior portal is preferred in instances where the epiphyseal fragment is displaced in valgus whereas the posterior location or the "Neviaser" portal is preferred in instances where the epiphyseal fragment has varus angulation (Fig. 5.14).

Fig. 5.14 Starting points of the percutaneous approach (left shoulder)

These entry points avoid the insertion point of the rotator cuff by staying medial to the tendon insertion and passing though the muscle fibers of the supraspinatus. The goal is to enter the humeral head medially and to leave about 5-mm of cartilage lateral. The surgeon must never try to enter the greater tuberosity and should not be afraid to pass through the cartilage of the humeral head: the hole in the cartilage will be filled with fibrous tissue and there is no functional consequence.

After location of the starting point under fluoroscopy with a spinal needle, an incision is made which is large enough (about 8-mm) to allow passage of the humeral nail. A blunt Kelly forceps is used to spread the muscle fibers down to the humeral head (Fig. 5.15).

A specific cannulated awl is then introduced into the incision and with a twisting motion and downward pressure advanced into the humeral head. The awl can then be used to manipulate the head fragment and allow for the passage of

Fig. 5.15 Control of the location under fluoroscopy. Patient positioning should allow access of the C-arm to obtain adequate radiographs

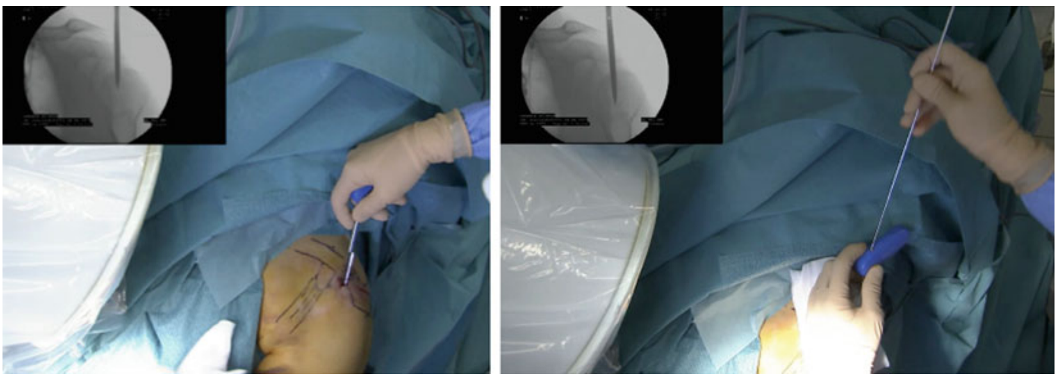

Fig. 5.16 Insertion of the guide wire through the awl

the guide-wire. It is crucial that the entry point for the nail is medial enough and enters the cartilage and not the greater tuberosity and the supraspinatus insertion. The guide wire is inserted through the awl and image intensification is used to confirm the awl and guide-wire position in the humeral head and the distal humerus (Fig. 5.16). The cannulated reamer is used to open the proximal portion of the bone and the nail is inserted with the attached targeting jig.

The Aequalis IM nail, which is cannulated, is introduced percutaneously, along the guide-wire first through the epiphysis and then through the diaphysis. The depth of the nail is confirmed under fluoroscopy utilizing a K-wire placed through the lateral side of the jig. The nail is inserted somewhat more deep (2 or 3 mm) to allow for backslapping and compression. The K-wire should be at the level of the top of the GT, slightly below the level of the head to ensure the proper depth (Fig. 5.17).

At this stage, the diaphysis is still independent of, and can be rotated around, the epiphyseal fragment. The patient's arm must then be brought in neutral rotation to help with rotational alignment: this allows for the correct rotation of the diaphysis relative to the humeral head, which is again confirmed under fluoroscopy. A version rod "outrigger" is attached and aligned with the supinated forearm: this allows for the correct rotation of the nail inside the humerus, and consequently the correct orientation of the proximal and distal screws.

The first distal trocar for the static screw is then introduced and drilled with a calibrated drill. The correct screw placement is confirmed under fluoroscopy (Fig. 5.18). The second distal

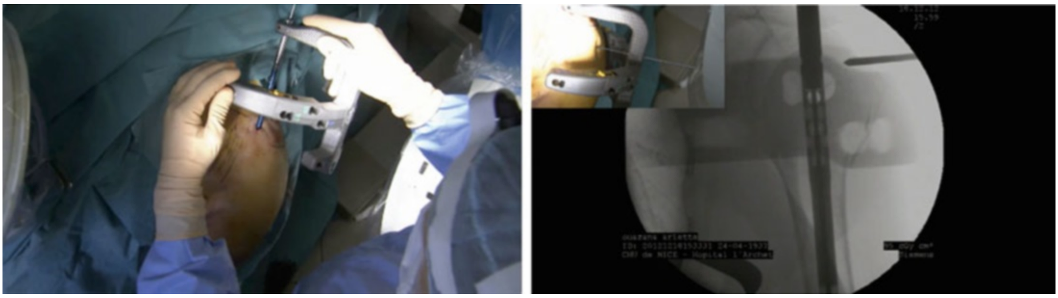

Fig. 5.17 Introduction of the nail and assessment of its depth

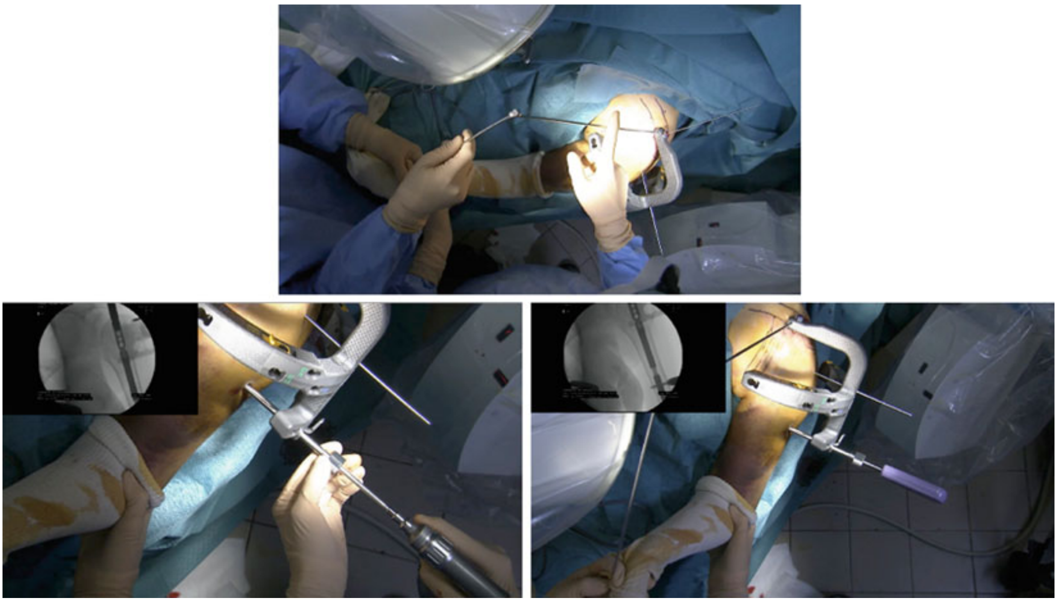

Fig. 5.18 As in the four-part fracture, the diaphysis can be rotated around the head fragment. In order to obtain the correct reduction the version outrigger is attached and aligned with a supinated forearm. This allows for the correct position of the diaphysis relative to the metaphysis, which can be confirmed under fluoroscopy. The distal trocar is then introduced, drilled with a calibrated drill and the correct screw placed through the trocar and length confirmed again under image intensification

screw ensures that the nail is centered within the diaphysis. The distal screws are small (3.5-mm) in diameter and their length is usually 22 or 24-mm. Following screw placement distally, the slap hammer can be attached to the nail and by “backing the nail out” utilized to compress the fracture fragments. The slot in the guide should be flushed with the top of the humeral head: this allows for confirming that the nail is at the right height. Fluoroscopy is used to confirm compression at the fracture site and correct height positioning. The outrigger ensures correct rotation is maintained during compression (Fig. 5.19).

Next, the tuberosity screws are placed superiorly to lock the distal and proximal bone fragments in the correct orientation. A similar approach is used superiorly by placing trocars through the guide-sleeves followed by drilling, screw placement and confirmation via

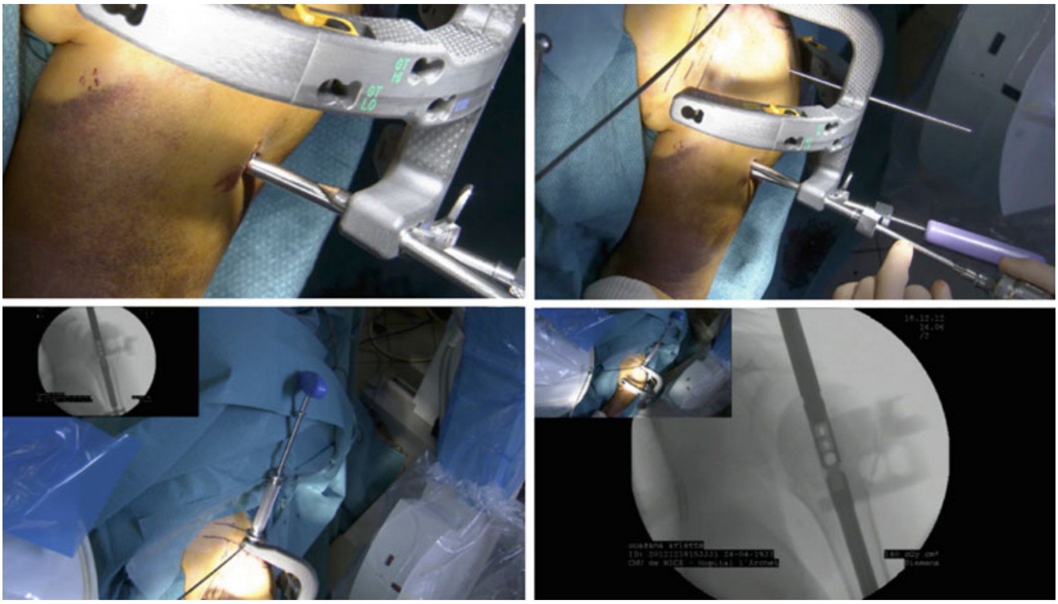

Fig. 5.19 The second screw is placed centralizing the nail in the diaphysis. The slap hammer is applied and utilized to compress the fracture fragments. The top of the slot should be level with the top of the humeral head and fluoroscopy used to confirm compression at the fracture site

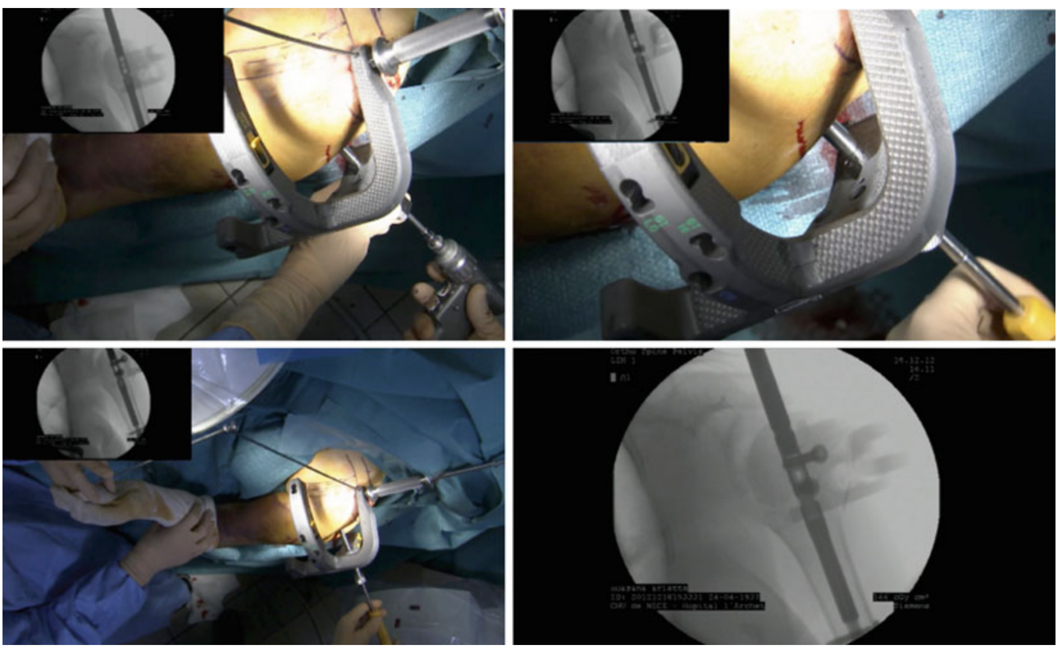

Fig. 5.20 Proximal locking

fluoroscopy. The version rod is again used to ensure the distal segment does not shift relative to the proximal segment, but once a single screw is placed, the rotation is locked at this point. The fluoroscopic images again confirm correct screw placement (Fig. 5.20).

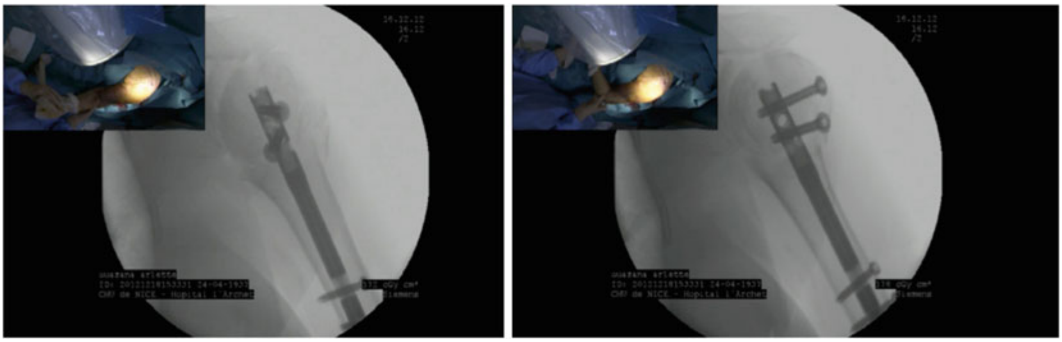

Fig. 5.21 The final fluoroscopic images confirm excellent compression and appropriate rotation of the entire humerus with external and internal rotation images or "live" fluoroscopy

The proximal guide is removed and the final fluoroscopic images are made to confirm the compression and appropriate rotation of the entire humerus with external and internal rotation images. These can be done under "live" fluoroscopy (Fig. 5.21). The skin is closed routinely.

Pearls and Pitfalls

In a two-part (surgical neck) fracture, two screws are inserted proximally (one in the GT and one in the LT) and two distally in the diaphysis. However, two screws only (one proximal and one distal) may be enough for a two-part fracture. We do not recommend dynamic distal fixation of the nail because the upper limb is subjected to more distraction rather than compression forces (as the femur or tibia). This may, in part, explain the rate of non-union after surgical neck fracture. We recommend *static distal fixation*: the distal screw(s) placement in the diaphysis first, followed by backslapping to impact the fracture site at the surgical neck, and then proximal fixation of the epiphysis. This technique allows for immediate compression of the fracture site, thus avoiding nonunion. The rotational control provided by the outrigger version rod allows for avoiding rotational malunion. Finally, the surgeon must understand that the proximal screws are locked by insertion through a polyethylene bushing located inside the nail, thus avoiding a possible screw backout. This locking technology applied to the nail means that there is no need to catch the bone with long proximal screws: short (32 or 36-mm) screws are long enough since they are captured inside the nail. The metallic cannulas must be in contact with the bone: this ensures that the screws will follow the right direction (entering the holes of the nail) and will have the correct length. Each screw must be tightened until the slot of the screwdriver is flush with the entry of the metallic cannula.

In case of three-part GT fracture, the head fragment is internally rotated by the pulling of the subscapularis muscle. The main goal must be to derotate and anatomically reduce and fix the GT, which will effectively convert the three-part fracture into a two-part fracture. The "derotation" technique can be accomplished before or after nail insertion. The reduction is maintained by a bone hook inserted percutaneously or through a small transdeltoid incision.

Four-Part Fracture with a Superior Transdeltoid Technique

Rationale

In unstable three- and four-part fractures, displacement occurs because of the pull of the rotator cuff muscles on their attached tuberosities in the transverse plane, widening the gap created by the fracture plane posterior to the bicipital groove. In addition, there is internal rotation

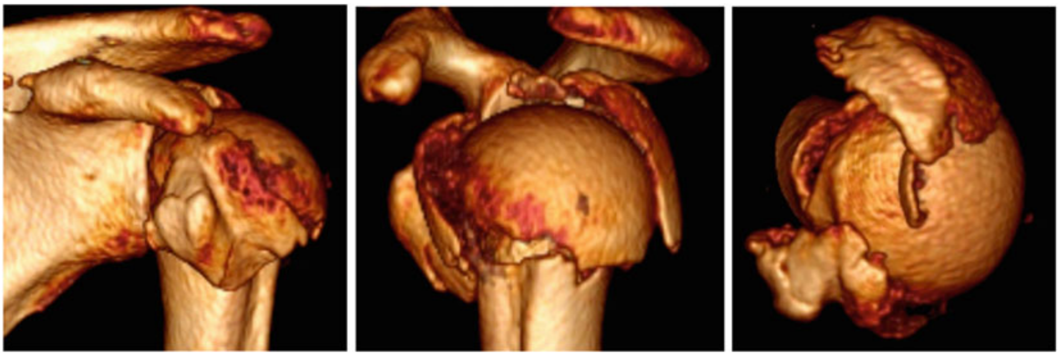

Fig. 5.22 3D CT-Scan showing the characteristic displacement of the tuberosities

Fig. 5.23 Plain radiographs, CT and CT with 3D reconstruction of a valgus impacted four-part fracture. Note the fracture line is posterior to the bicipital groove for the GT fracture

and/or translation of the diaphysis, like in two-part (surgical neck) fractures. The GT is pulled posteromedially by the infraspinatus and teres minor muscles, while the lesser tuberosity (LT) is pulled anteromedially by the subscapularis muscle (Fig. 5.22).

In four-part proximal humerus fractures, it has been demonstrated that the main vertical fracture plane separating the tuberosities is located posterior to the bicipital groove, and that the principal displacement of the fractured tuberosities occurs in the transverse (horizontal) plane [34] (Fig. 5.23).

In fractures involving the greater tuberosity, loss of reduction and fixation of the greater tuberosity leads to definitive retraction and atrophy of the two single external rotator muscles of the shoulder (infraspinatus and teres minor), resulting in definitive pseudo-paralyzed and stiff shoulder for which surgical options are limited. By contrast, posttraumatic humeral head necrosis is well tolerated if the greater tuberosity has healed in an anatomical position and there is no screw penetration or glenoid erosion. Thus, all efforts of the surgeon should not be directed toward the humeral head, but to the greater

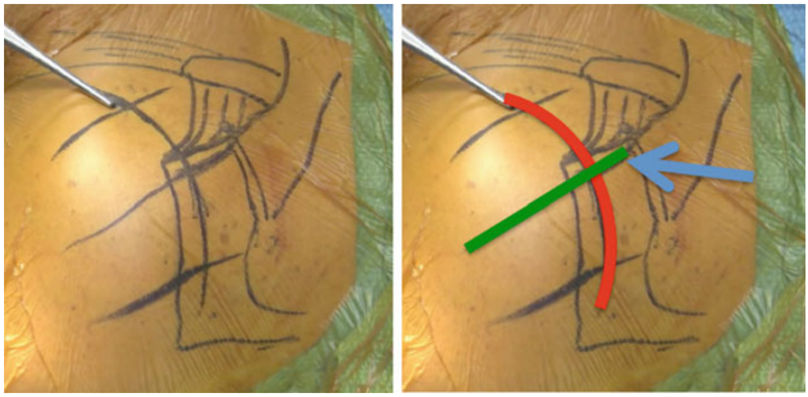

Fig. 5.24 Landmarks and skin incision for a superior transdeltoid approach have been drawn out. A saber incision in line with Langer's lines is made (*red arc*). It is centered over the division between the anterior and middle deltoid (*green line*). The *blue arrow* is the site of the acromial osteotomy, which facilitates the deltoid repair at the end of the case

tuberosity fixation and reduction. The humeral head becomes stable when both tuberosities are reduced and fixed. The Aequalis Locking IM nail has been designed specifically to optimize tuberosity-fragment fixation and provide stable support for the humeral head, improving proximal humerus reconstruction and fixation in osteopenic bone. The design of the nail and the specific technique have been created to avoid the common complications and problems related to previous IM nailing of proximal humeral fractures.

Superior Transdeltoid Approach

A saber cut incision in line with Langer's lines is planned and created to expose the division of the anterior and middle deltoid (Fig. 5.24).

This division is found just lateral to the anterior edge of the acromion. A split is made between the anterior and middle deltoid fibers with the arm in slight abduction to help relax the deltoid. The saw is used to create an osteotomy of the anterior acromion, which will allow exposure for nail entry and facilitate later repair. The osteotomy is completed with an osteotome. The deltoid is split no more than 4 cm from the acromion to avoid injury to the axillary nerve. The saber incision helps to avoid splitting the deltoid to distally to prevent this from happening. Gelpy self-retaining retractors help to facilitate the exposure (Fig. 5.25).

A curved Hohman retractor is placed over the coracoid to help gain exposure for bursal resection. The bursa is excised to expose the greater tuberosity (GT), lesser tuberosity (LT), and head fracture fragments. Great care is taken to stay below the deltoid fascia to avoid injury to any branches of the axillary nerve (Fig. 5.26).

The vertical fracture (separating the tuberosities) is identified and then the fibers of the rotator cuff can be incised longitudinally to expose the head fragment if needed (Fig. 5.27).

The biceps tendon is identified and tenodesed to the overlying soft tissue. The biceps tendon may be entrapped within the fracture fragments. Stay sutures help to facilitate retraction of the cuff split to permit exposure and reduction of the fracture (Fig. 5.28).

Alternatively, a "mini-open" transdeltoid approach (allowing for tuberosity and head reduction) can be combined with a small medial incision (in front of the AC joint) for nail insertion.

Reduction and Temporary Fixation of the Epiphyseal Fragments

The goal is to transform the four-part fracture into a two-part fracture: this means to first reduce the head fragment with the tuberosities, and second to reduce and fix the epiphysis with the diaphysis. The head fragment must be elevated out of valgus. This is accomplished by freeing up the fracture fragments with a Steinmann pin or

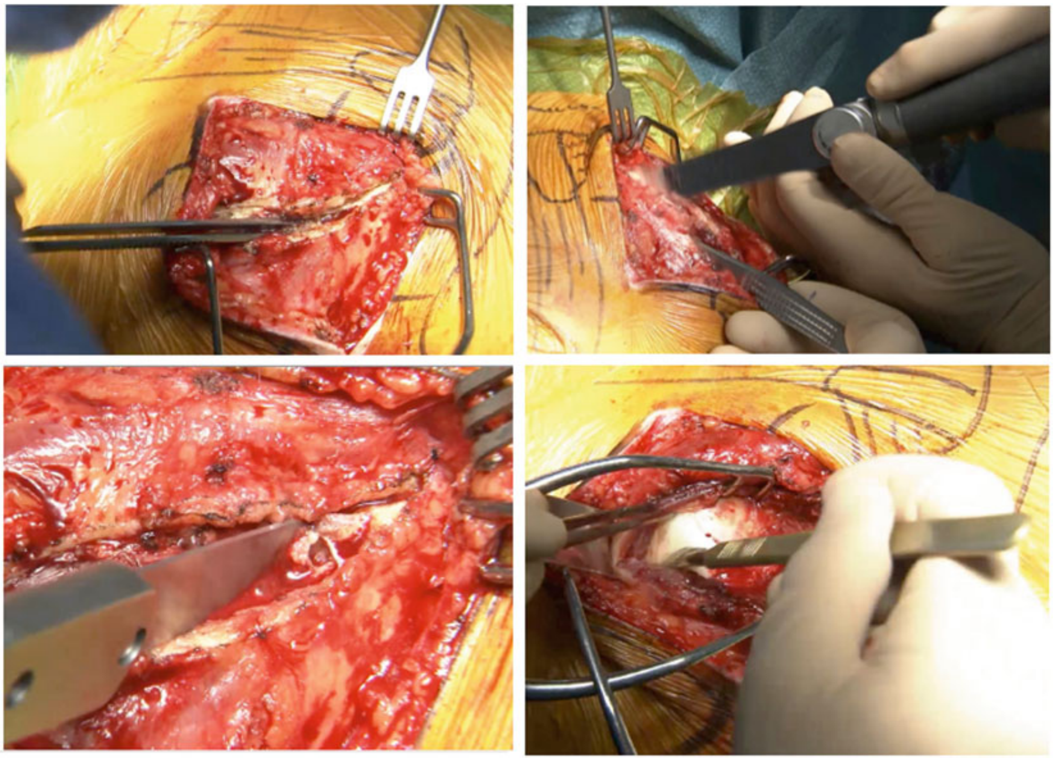

Fig. 5.25 A split is made between the anterior and middle deltoid fibers. A saw and then osteotome is used to osteotomize the anterior acromion to facilitate later repair. The deltoid is split no more than 4 cm from the acromion to avoid injury to the axillary nerve

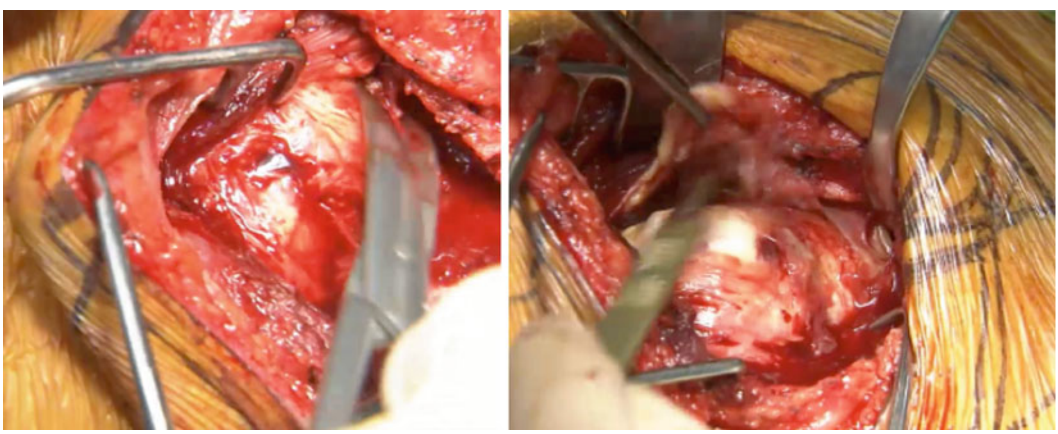

Fig. 5.26 Bursal adhesions are removed to facilitate exposure of the fracture. One must dissect below the deltoid fascia in order to avoid injury to branches of the axillary nerve

similar elevator. The humeral head can then be elevated out of its valgus position with an impactor (Fig. 5.29).

Next the "book" can be closed with the previous sutures placed through the Supraspinatus and Subscapularis, as the GT and LT are brought

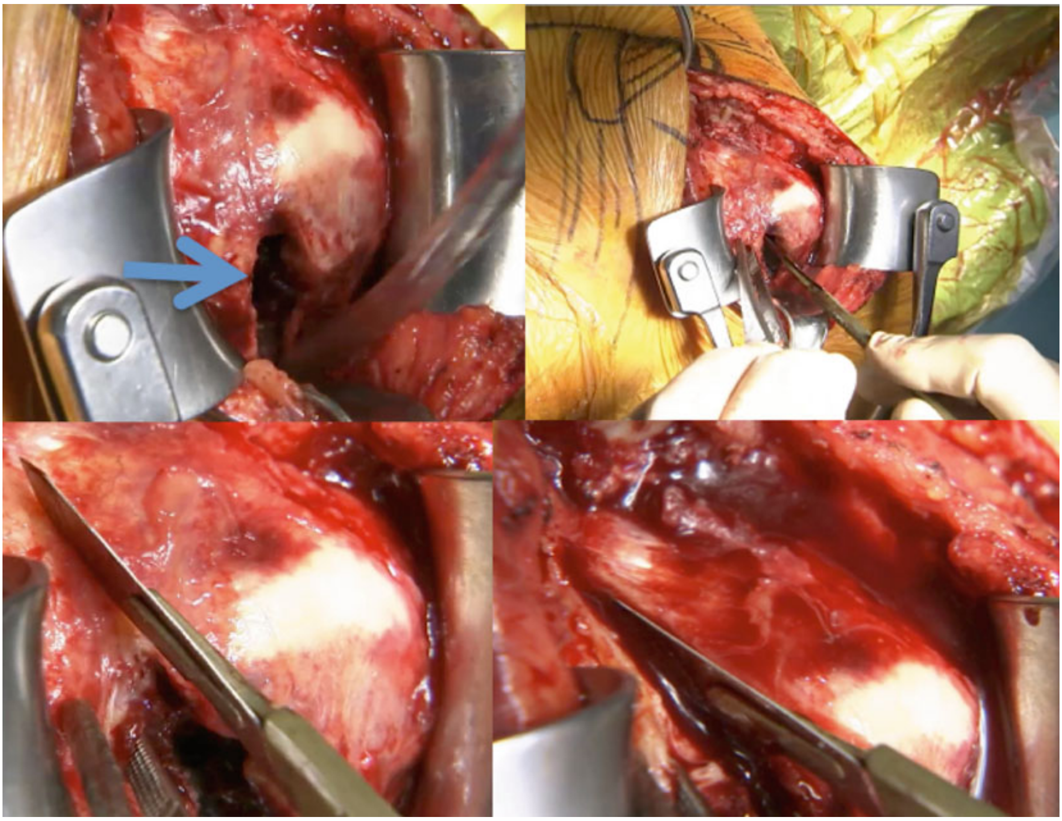

Fig. 5.27 The fracture is identified by the *blue arrow*, after bursa has been removed. The fibers of the RC are split longitudinally. Fracture hematoma is expressed from the joint upon entry

together supporting the humeral head reduction. The reduction of the fracture fragments is palpated with a forceps to confirm fracture lines have been opposed. The reduction is held with a pointed reduction forceps. Next, a small (2 mm) pin is introduced into the humeral head posterior to the eventual path of the nail, but allowing stabilization of the reduction of the head to the glenoid (Fig. 5.30).

Insertion of the IM Nail

The cannulated awl can then be introduced into the humeral head with a twisting motion straight in line with the humeral shaft. The entry point is just posterior to the bicipital groove and medial to the insertion of the rotator cuff. Again, about 5-mm of cartilage should be left lateral to the hole made for insertion of the nail. This hole in the cartilage does not articulate with the humeral head and allows preservation of the rotator cuff insertion. After the awl is introduced, the guidewire can be placed and correct positioning confirmed with fluoroscopy (Fig. 5.31). The awl is removed and the humeral head reamed to accept the nail. The reamer is only used to expand the proximal humerus for the proximal portion of the nail.

Control of Height and Rotation of the Nail

The nail is introduced with the jig and seated to the etch mark on the guide which will seat the nail slightly over the top of the humeral head. A pin is inserted into the lateral side of the jig to

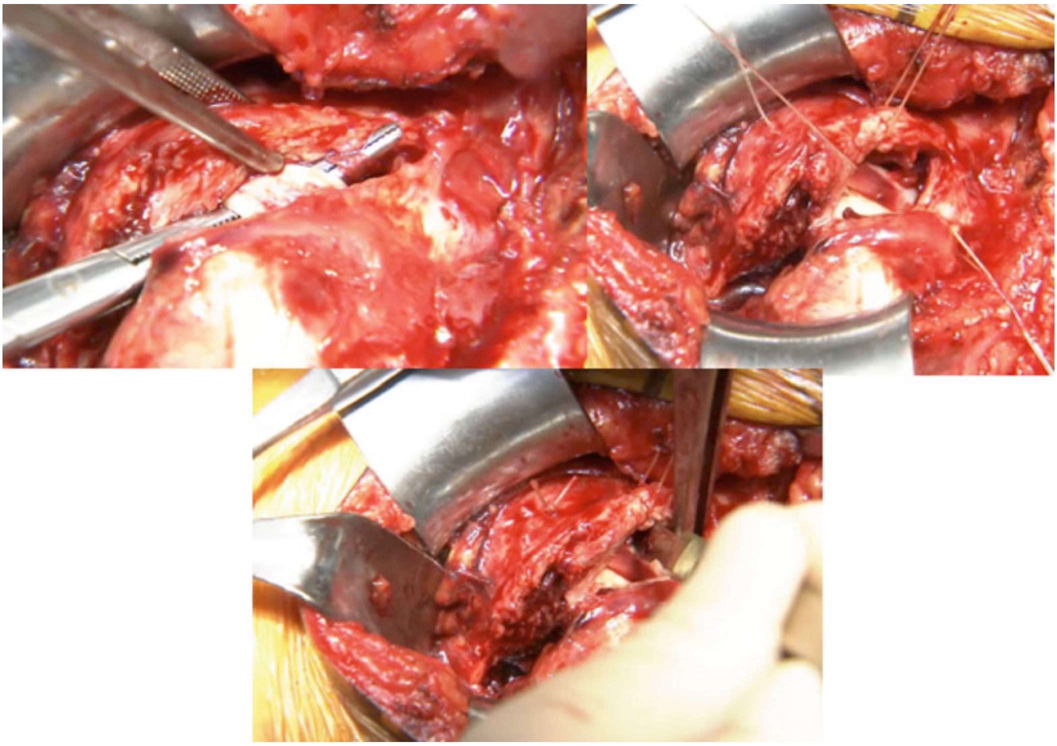

Fig. 5.28 The biceps tendon is identified and tenodesed to the overlying soft tissue. Stay sutures help to facilitate retraction of the cuff split to permit exposure and reduction of the fracture

ensure the proper depth of insertion, which is also confirmed under fluoroscopy (Fig. 5.32). The top of the nail is located below the articular cartilage. The version of the humeral head and its position relative to the tuberosities must be checked. This is uniquely accomplished with this particular system with an outrigger attachment that is aligned to the forearm. Thus, the arm must be placed in neutral rotation and the version rod aligned with the forearm.

Definitive Fixation of the Epiphyseal Fragments

With the version rod aligned with the forearm (Fig. 5.33), the proximal GT screws can be placed. Again the trocars are inserted through the guide-sleeves and advanced to the cortex. By applying pressure to the outermost trocar (the trocar nearest the guide) the inner trocars can be seen to "back out" as they are advanced against the cortex. This ensures the drill sleeve is directly against the bone. The outer cortex is then drilled. There is no need to drill the inner cortex as the screws are captured within the locking mechanism of the nail. This ensures that the screws will not penetrate the head errantly. When the drill is advanced past the nail it is replaced with the appropriate sized screw. As the screw is advanced through the nail, the polyethylene locking mechanism can be felt to engage the screw.

The two locking screws are placed in the GT. The LT locking screw is then placed proximally in a similar manner to complete the construct (Fig. 5.34). A fourth additional locking screw can be added at the calcar level to stabilize the humeral head medially if needed. We rarely use this fourth screw.

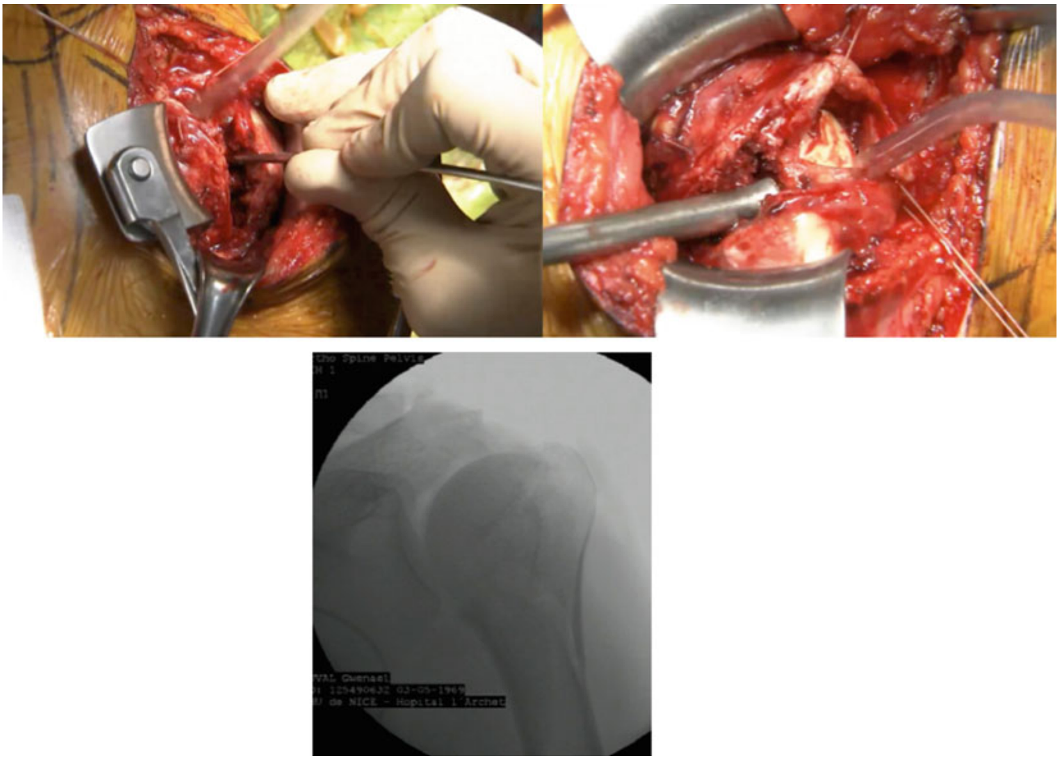

Fig. 5.29 A Steinmann pin is introduced through the fracture site to free up the fracture fragments and allow reduction of the humeral head. An impactor can be introduced into the fracture to further facilitate this reduction. Image intensification is used to confirm reduction

Reduction of the Epiphysis with the Diaphysis

At this point, the three proximal fragments are reduced and fixed to the nail with the locking screws, and the distal screws can be inserted to secure the nail within the intramedullary canal. This will lock the nail in its correct orientation within the medullary canal. A calibrated drill is inserted through trocars that are inserted into the guide, which ensures correct targeting and position of the screws and avoids injury to neurovascular structures. The near cortex is drilled and far cortex can be palpated by tapping the drill. The drill is measured after penetration of the lateral cortex. The correct length screw is then inserted through the trocar and screwed in place. The second distal (diaphyseal) screw is then placed in a similar manner, allowing for centering of the nail in the medullary canal (Fig. 5.35).

Final Control and Closure

The arm is internally and externally rotated and screw position is confirmed with fluoroscopy. During live fluoroscopy, the humeral head can be seen moving in rotation with the rest of the humerus despite the fact that there is no screw directed toward the head (Fig. 5.36). The humeral head fragment is stable because first, the nail acts as a strut, and second the reduced tuberosities provide a “seating surface” for the head. In addition, the reduced rotator cuff tendons and muscles entrap the head inside the glenohumeral joint.

Finally, the split in the rotator cuff is repaired with side-to-side sutures. The hole in the humeral head will be covered with fibrocartilage and will not articulate with the glenoid. The acromial osteotomy and deltoid split are then repaired and the skin closed routinely (Fig. 5.37).

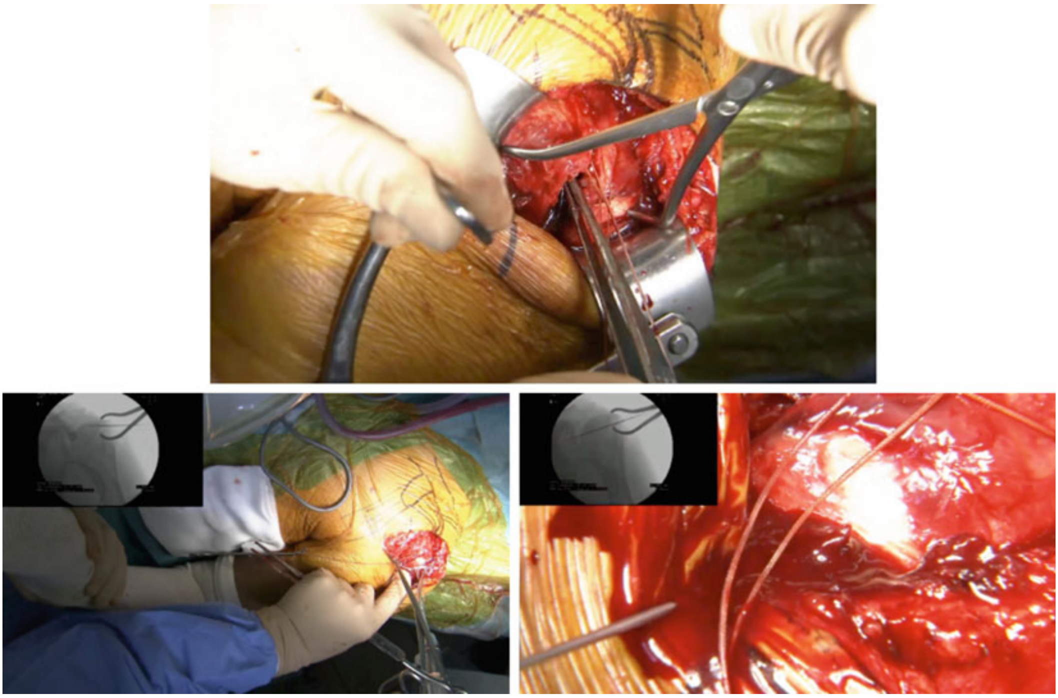

Fig. 5.30 The "book" of the GT and LT are closed over the humeral head with a pointed reduction forceps. The forceps is in line with the fracture fragments and confirms the fracture lines have been closed. A pin is introduced into the humeral head posterior to the path of the nail, but allowing stabilization of the reduction of the head to the glenoid

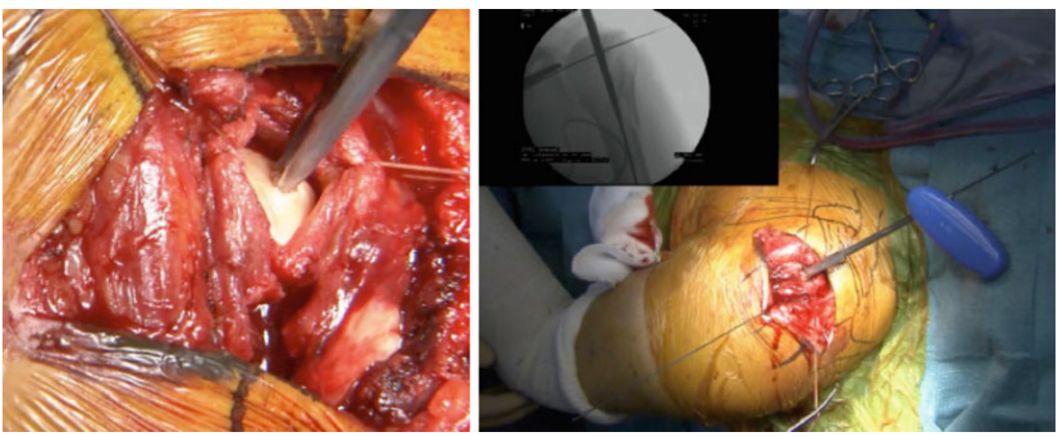

Fig. 5.31 The awl is introduced into the humeral head with a twisting motion straight in line with the humeral shaft and the guide wire introduced through the awl into the shaft. This is confirmed with fluoroscopy

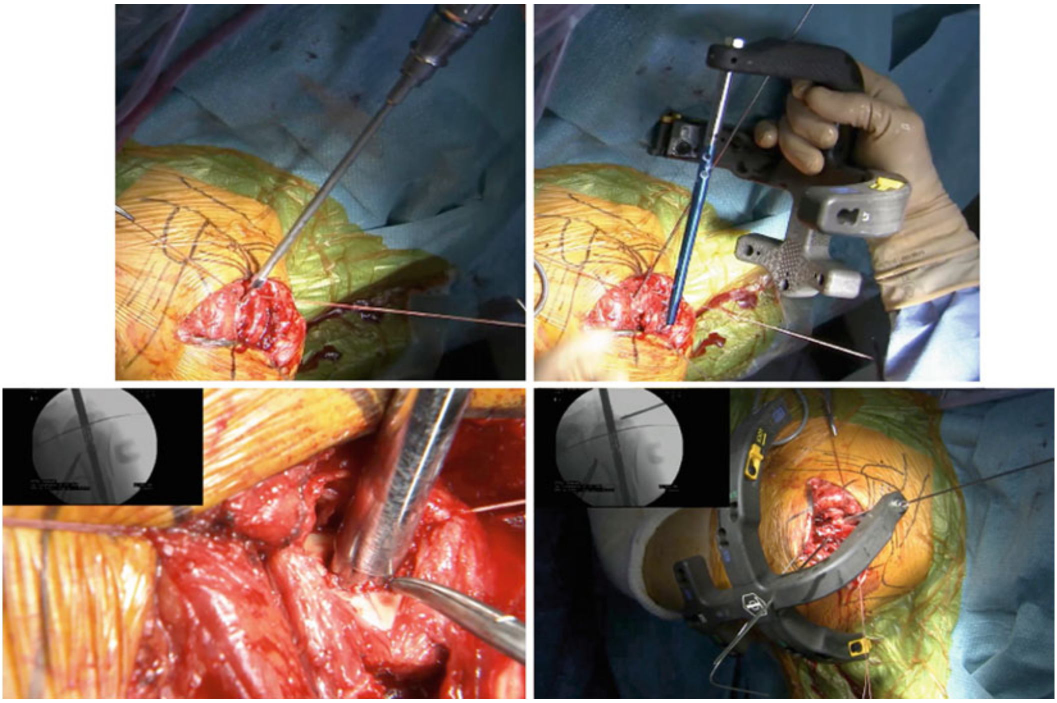

Fig. 5.32 The awl is removed and the humeral head reamed to accept the nail. The nail is introduced and seated to the etched mark on the guide which will seat the nail below the humeral head. A pin is inserted into the lateral side of the jig to ensure the proper depth of insertion which is confirmed under fluoroscopy

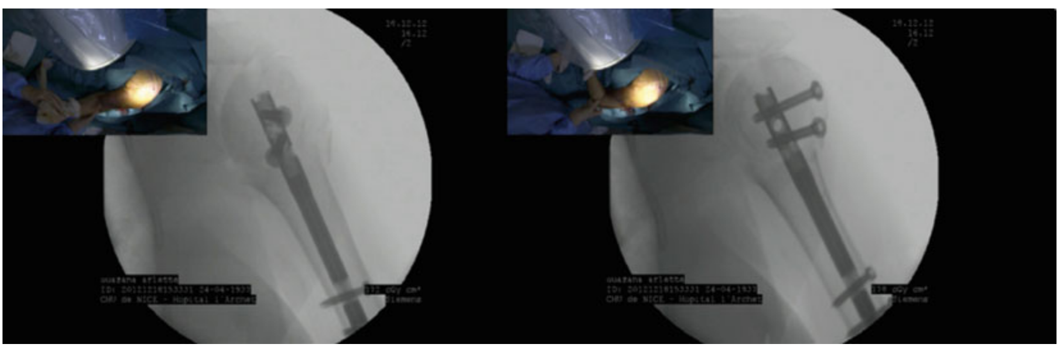

Fig. 5.33 The version of the humeral head is checked with the outrigger attachment which is placed parallel to the forearm. This will ensure correct version of the nail to the humeral head and tuberosities

Postoperative Care

Sling with abduction pillow that allows the proximal humerus to rest in neutral rotation and slight abduction (relax the rotator cuff and decrease tension on the greater tuberosity) and is worn for 3–4 weeks. Gentle pendulum shoulder exercises as well as mobilization of the elbow, wrist, and fingers are started immediately. External rotation of the shoulder with the arm at side and internal rotation with the hand in the back by a physiotherapist are prohibited for 6–8 weeks postoperatively.

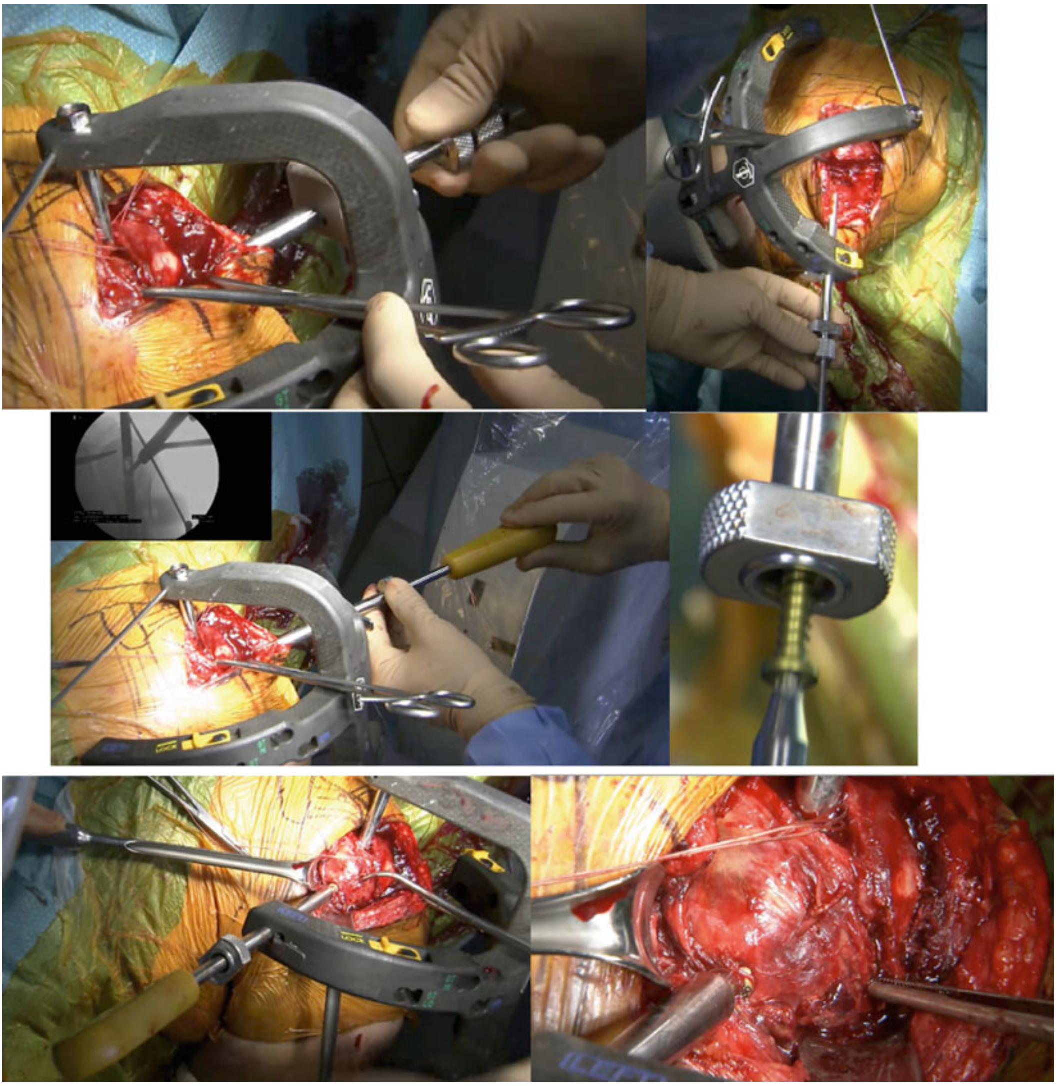

Fig. 5.34 The GT screws are then placed proximally. These are again advanced through the trocars. The skin incision can be retracted to avoid placing an additional incision on the skin. The anterior cortex is drilled and the screw inserted through the trocar. The LT screw is then placed proximally

Results of the Aequalis IM Locking Proximal Humerus Nail

Between 2008 and 2013, 94 patients with acute displaced Neer two-, three-, or four-part proximal humerus fractures were treated with the Aequalis IM locked nailing. Of these 94 patients, 90 patients were successfully prospectively followed for an average of 12 months (6–31 months) to obtain clinical and radiographic outcomes. Three patients had bilateral fractures, resulting in 97 proximal humeral fractures included in this analysis group. Fifty-two females and 38 males were included in the study, with a mean age of 58 years (17–86).

According to the Neer fracture classification criteria, 44 fractures were two-part surgical neck fractures, and 1 two-part fracture dislocation, 30 fractures were three-part fractures, 1 of which had a humeral head split, and 15 fractures were four-part, 3 of them were fracture-dislocations.

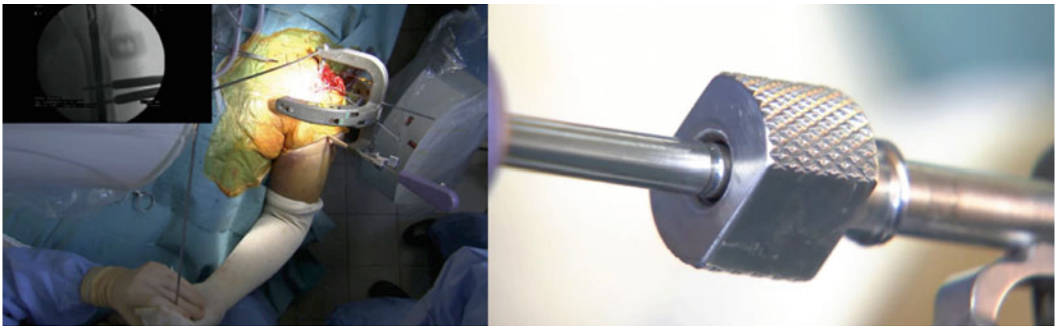

Fig. 5.35 The distal screws are inserted to secure the nail within the intramedullary canal. The calibrated drill is inserted through the guide and depth measured after penetration of the lateral cortex. The drill is advanced with a tapping motion to “feel” the opposite cortex prior to penetration to ensure accurate measurement. The correct length screw is then inserted through the trocar. Again there is an etch line to ensure the proper depth of insertion

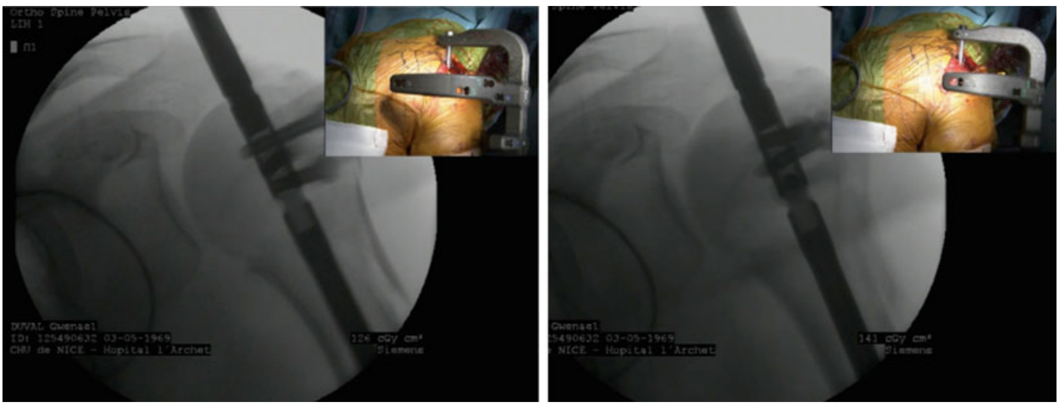

Fig. 5.36 The arm is internally and externally rotated and screw position is confirmed with fluoroscopy

The functional results for the 97 shoulders are summarized in Tables 5.2 and 5.3. The average Constant score was 67 points (range, 24–94) and the average age adjusted Constant score was 83 % (range, 26–117). The average pain score for the study group was 13, on a scale from 0 to 15. Average active forward flexion was 134° and average external rotation was 44°.

All patients had radiographic imaging available to assess fracture healing, osteonecrosis, and implant complications (Fig. 5.38). Ninety-six fractures showed radiographic healing, where one fracture (1 %) showed evidence of delayed union at 6 month, and two additional fractures (2 %) had a slight malunion of the greater tuberosity. No patients included in this evaluation had non-unions of the greater or lesser tuberosities.

Avascular necrosis (AVN) was noted in four shoulders (4 %), two of which required additional operative intervention. The two patients underwent shoulder replacement and had both a good functional result. Short and long-term complications included three incidences of prolonged stiffness, associated with symptomatic proximal screws. They underwent arthroscopic proximal screw removal with arthrolysis during the same operative intervention. One patient experienced postoperative bilateral posterior dislocation, due to seizure, leading to early revision.

The following perioperative complications were noted: one drill-bit was broken intraoperatively and retained, two nails were left slightly proud, one humeral head was placed in varus, one patient had calcific tendinopathy,

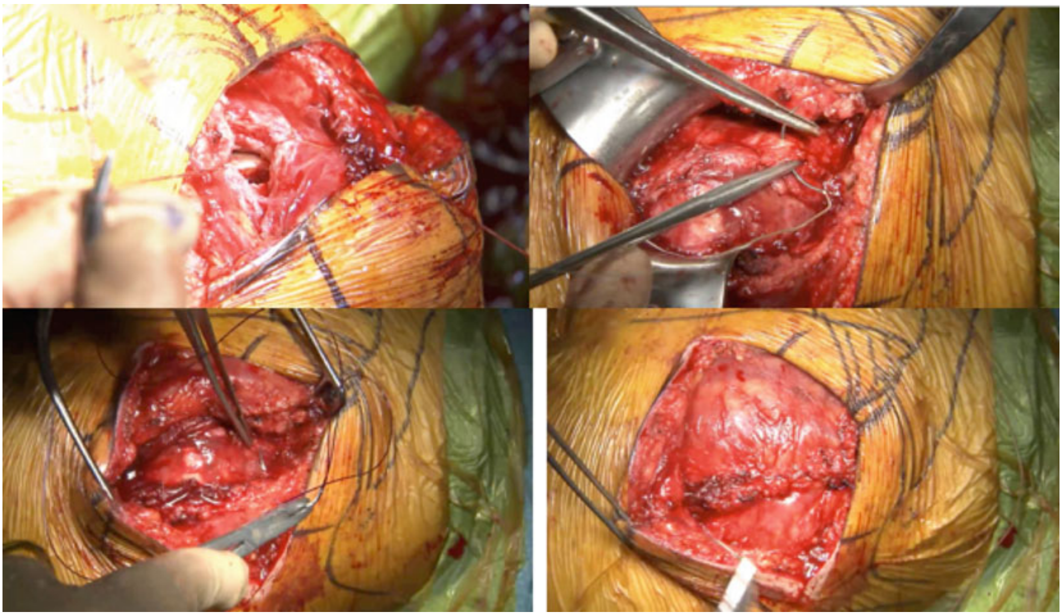

Fig. 5.37 The split in the rotator cuff is then repaired with side to side sutures. The hole in the humeral head is just visible below the split with the nail well below the surface. The acromial osteotomy and deltoid split are then repaired and the skin closed

Table 5.2 Clinical outcomes

	Two part	Three part	Four part
AAE (°)	146 [100–180]	129 [60–170]	127 [80–160]
ER1 (°)	45 [20–90]	40 [20–70]	41 [0–90]
IR1	L3 [but-T7]	L3 [but-T7]	L5 [GT-T12]

Table 5.3 Functional outcomes

	Two part	Three part	Four part
Pain	13.5 [8; 15]	12.2 [6; 15]	13 [10; 15]
Constant score	72 [47; 94]	63 [24; 87]	68 [42; 89]
Adjusted constant	86 [66; 104]	80 [26; 117]	55 [82; 111]
SSV (%)	80 [55; 100]	73 [40; 100]	66 [50; 85]

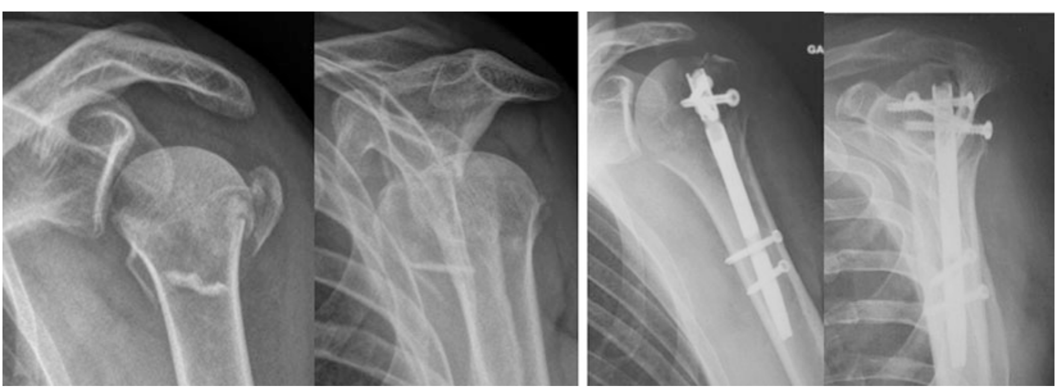

Fig. 5.38 Example of four-part fracture and the result at 6 months

and in two nails the distal screw did not pass through the distal locking nail hole.

Conclusion

The device and technique presented here represent a valuable treatment option for two-, three-, and four-part fractures of the proximal humerus. This is confirmed by our clinical experience. Our observations demonstrate favorable clinical, functional, and radiographic outcomes for treatment of patients with even the most technically challenging fracture patterns.

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6 Proximal Humeral Locking Plates for Displaced Fractures of the Proximal Humeral Humerus

Robert J. Neviaser

Fractures of the proximal humerus are the third most common fractures in older patients, following the hip and distal radius in incidence of occurrence, and are considered fragility fractures [1]. They are seen most commonly in white females between the ages of 75 and 84. Most of these injuries can and are treated without an operation with expected satisfactory results. As fixation techniques and devices have improved, there has been an increase in the tendency to treat these fractures operatively. Among the most common form of operative treatment is open reduction and internal fixation with proximal humeral locking plates. This technique is the focus of this chapter.

Indications

In this chapter, we refer to fracture patterns using the Neer classification system of two-, three-, and four-part fractures [2]. This system requires that, on order to be considered a part, a fragment must be displaced 1 cm or angulated at least 45°. Over time, these criteria have evolved to make a displacement of 5 mm or more an acceptable indication for fixation if the direction of displacement can create a functional limitation. An example of this is the superior displacement of the greater tuberosity, which has the potential of restricting abduction.

The types of proximal humeral fractures that are amenable to reduction and fixation with a locking plate include two-part surgical or anatomic neck fractures (but not isolated greater or lesser tuberosity fractures), three- and four-part fractures, and fracture dislocations with any of the previously mentioned displaced parts. The most common types treated with plating are the two-part surgical neck and the three-part involving the surgical neck and the greater tuberosity. While the fracture pattern has a significant role in the decision about whether the injury can be treated by this technique, age, bone quality, types of comorbidities, and functional status play a role in deciding whether to treat the patient operatively or not. Thus, a healthier, mentally competent, active, independent patient would be a good candidate for surgery, while a sick, infirm, house-bound person with dementia would not, even if the images of the injury appear to be suitable for fixation.

It is important to remember that the Neer classification was based on plain X-ray assessment. This may often be the only imaging necessary. If any doubt exists about the configuration or number of fragments, a CT scan may be used for clarification.

Surgical Technique

Two surgical approaches are available: the deltopectoral and the deltoid splitting. Each has

R.J. Neviaser (✉)
Department of Orthopaedic Surgery, George Washington University, 2150 Pennsylvania Ave NW, Washington, DC 20037, USA
e-mail: rneviaser@mfa.gwu.edu

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its advantages and disadvantages The deltopectoral has lower risk of injury to the axillary nerve or deltoid muscle damage, but reaching the displaced greater tuberosity fragment is more challenging. The deltoid splitting approach gives easier access to the displaced greater tuberosity but has a higher risk of axillary nerve and deltoid muscle injury. In one comparative study, the outcomes of the two approaches led to a lower Constant score for the deltoid splitting approach due to poorer motion [3].

The deltopectoral approach is done with the patient in the sitting position. The deltoid splitting approach is done with the patient in the lateral decubitus position, with the uninjured side down on the table.

In either case, the use of the C-arm or fluoroscopy is essential. It can be used in one plane and rotating the arm to obtain different views of the proximal humerus or in two planes by rotating the machine to obtain orthogonal views, i.e., an AP and an axillary. The C-arm should be positioned before the start of the procedure to confirm that the operative area can be viewed on the monitor adequately.

If the deltopectoral approach is used, an incision is made on the anterior surface of the shoulder from the lateral edge of the tip of the coracoid process paralleling the anterior border of the deltoid and ending near the deltoid insertion. The deltopectoral interval is identified and the cephalic vein is reflected medially. Subdeltoid dissection with an elevator and a finger will lead one to the fracture fragments.

If using the deltoid splitting approach, the incision is made approximately over the mid portion of the deltoid. The muscle is split starting at its acromial origin and bluntly divided distally until the first sign of some resistance. The axillary nerve is identified on the deep surface of the muscle by palpation or, if necessary, by dissecting it out. A suture can be placed at the lower portion of the split to minimize the possibility of inadvertent additional splitting from retraction during the case. Then similar subdeltoid dissection is done to identify the fracture.

For two-part surgical neck fractures (Fig. 6.1), the first step in reduction is to identify the greater tuberosity and pass a heavy non-absorbable suture through the rotator cuff where it attaches to the greater tuberosity (the tendon bone junction). Placing this suture is helpful in improving control of the head fragment. If the head is in varus, traction inferiorly on this suture will assist in bringing it into anatomic position. If the head is already in anatomic position, traction will keep it there while the shaft is reduced. The shaft is then mobilized so that it can be brought into alignment with the head fragment and the plate is slid along the anterolateral cortex of the proximal humerus with its proximal part against the greater tuberosity and the inferior portion against the shaft. A clamp is placed to hold the plate against the shaft after the fracture is reduced. A very useful clamp is a single-jawed Lowman clamp. The tip of the plate must be below the tip of the greater tuberosity to prevent the plate blocking elevation and abduction postoperatively. Proper positioning of the plate also enables correct placement of calcar screws. Repeated C-arm checking is mandatory to confirm appropriate fracture reduction and plate position.

Fig. 6.1 Two-part surgical neck fracture with medial calcar comminution and head in varus

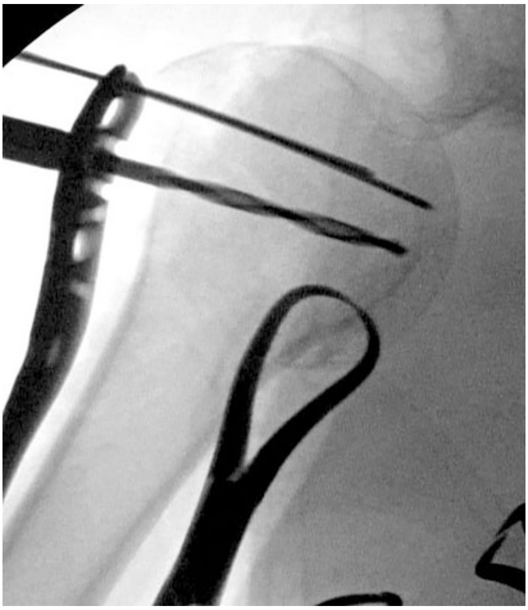

Fig. 6.2 Drill through the plate and the reduced tuberosity into the head to appropriate depth. Stabilizing wire for the plate is above the drill bit

The plate has small holes for temporary stabilizing wires to be placed through it into the head. Two of these are helpful in preventing the plate from small shifts in position while placing the screws. A drill is then placed through the plate into the head to a depth of approximately 8–10 mm (Fig. 6.2) from the articular surface. Confirmation of direction and depth is done with the C-arm. A locking screw of measured length is inserted into the head through the drilled track, and depth and direction are confirmed via C-arm. A second screw is placed along the calcar after drilling, and direction and depth are confirmed with several C-arm views in different planes.

Bicortical screws can then be placed through the plate and the shaft to secure the distal part of the plate and allow removal of the clamp. These screws need not be locking screws unless the bone appears to be of poor quality. After there are at least two screws in the head and two in the shaft, the clamp is removed. The rest of the screws are inserted into both areas. It is preferable to have at least five or six screws in the head with two or three of these along the calcar (Fig. 6.3).

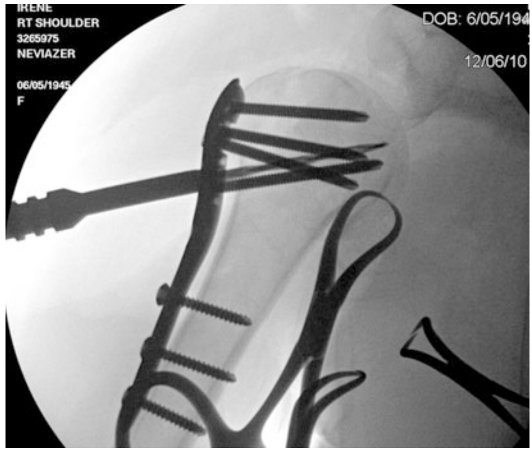

Fig. 6.3 Drill direction and depth for the second of two calcar screws

Fig. 6.4 Three-part fracture with valgus position of the head

Three-part fractures usually involve the surgical neck and greater tuberosity. There are two common types: those with the head in valgus (Fig. 6.4) and those with the head in varus (Fig. 6.5). The options for surgical approach are the same as described. Dissection for these fractures, like the two part, must be gentle with the careful use of an elevator or a finger. The long head of the biceps can often be a useful guide to

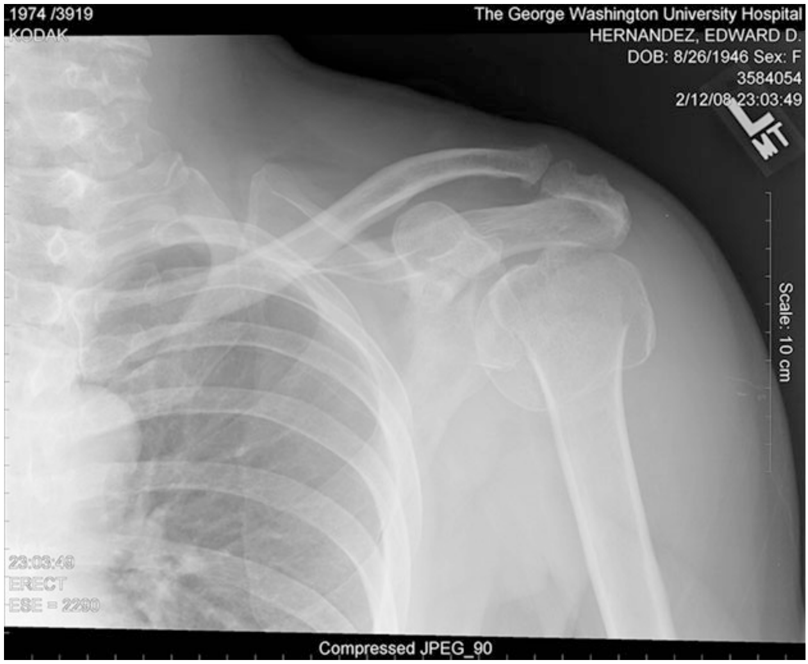

Fig. 6.5 Three-part fracture with the head in varus

the orientation and position of the fragments. Placement of the previously described traction suture through the tendon bone junction of the cuff and the greater tuberosity is important for control of this fragment. If the head is in valgus, it is very gently pried up to face the glenoid. This is done very carefully in order not to disrupt the stable medial periosteal cortical hinge of the head. Once this is done, there is a noticeable defect behind the head laterally into which the greater tuberosity usually fits quite nicely. If the head is in varus, it is a more difficult challenge. The head fragment must be tilted upward into its anatomic position, often by using a finger or elevator on its inferior aspect to lift it into the proper position. The greater tuberosity can then be placed behind the plate positioned as noted earlier, and temporarily stabilized through the tuberosity to the head with the stabilizing wires. The greater tuberosity position must be confirmed by C-arm. The tip of the greater tuberosity should be between 6 and 10 mm below the top of the reduced humeral head (Fig. 6.6a). If it is higher than the top of the head, it will restrict abduction. If the tuberosity is lower than described it will create a significant glenohumeral joint displacement upward and alter joint mechanics, potentially leading to degeneration [4]. Another C-arm shot is taken to ensure that not only is the tuberosity in the proper position but the tip of the plate is also below the tip of the greater tuberosity. The shaft is then reduced to the head/tuberosity fragments, aligning the medial cortex of the shaft with the medial inferior edge of the head and the lateral cortex of the shaft with the inferior edge of the greater tuberosity. The shaft is then clamped to the plate (Fig. 6.6a, b) and placement of the screws into the head through the plate and tuberosity, and subsequently into the shaft, is carried out as described above. Any tear in the rotator cuff is repaired. In treatment of the two- and three-part fractures, the biceps is tenodesed to the transverse humeral ligament or simply released by tenotomy.

If there is a displaced fracture of the lesser tuberosity, it cannot be incorporated directly under the plate. A heavy, non-absorbable suture is placed through the tendon bone junction of the subscapularis and the lesser tuberosity and then passed through the small stabilizing holes in the anterior portion of the plate to secure it in a reduced position.

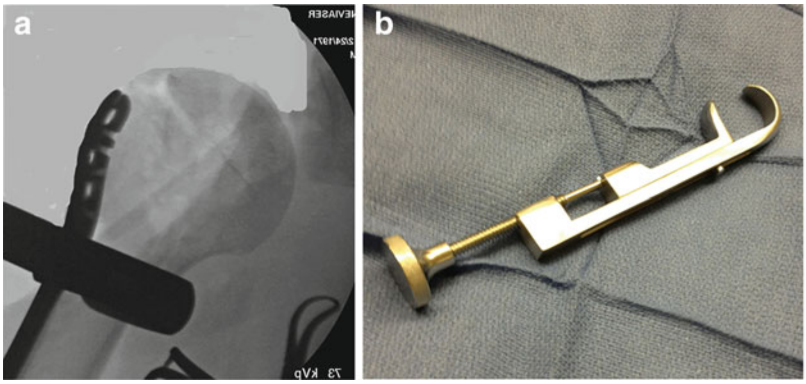

Fig. 6.6 (**a**) Reduced three-part fracture with head reduced anatomically, the greater tuberosity reduced in anatomic relationship to the head (its tip 6–10 mm below the top of the head), and the plate in proper location so that the top of the plate is below the tip of the greater tuberosity. The entire reduction is maintained with a Lowman clamp over the plate and shaft holding the reduction and plate position so that the initial screw placement can be carried out. (**b**) A single-jawed Lowman clamp which is a useful, strong, and secure clamp to hold the plate and fracture reduction

If there is concern about the stability of the construct to maintain the head in the anatomic position due to poor bone quality of the head or extensive comminution of the medial column support, some have advocated using an intramedullary fibular allograft into the head and shaft (Fig. 6.7) [5]. Incorporating a heavy, non-absorbable suture through the tendon bone junction of the cuff and the greater tuberosity and passing it through the small holes for the stabilizing wires in the upper part of the plate have also been used to add further security for keeping the head in its anatomic position.

It is critical that C-arm views in multiple planes be obtained to confirm the placement and depth of each drill and then each screw placement to avoid over or under, as well as misdirected, screw placement. A final C-arm assessment is always done before the routine closure (Fig. 6.8).

A few keys points about technique need emphasis. The head should be reduced anatomically, never left in varus. It has been shown that a final varus head position is associated with much higher rates of avascular necrosis, screw cutout, and other failures of the construct [6]. The tip of the greater tuberosity should be anatomic, i.e., a few millimeters below the top of the head. The tip of the plate, in turn, should be below the tip of the greater tuberosity (Fig. 6.6a) to avoid plate impingement and to enhance placement of calcar screws (Fig. 6.3). Screw depth and placement should come within 8–10 mm of the articular margin of the head and every attempt made to have the screws reach the

Fig. 6.7 A fibular allograft in the medullary cavity of the shaft and the head, used to support the reduction of the head, if the quality of the bone is considered to be poor or there is significant loss of head support due to medial calcar comminution

Fig. 6.8 Final C-arm picture to confirm reduction and plate and screw position prior to wound closure

areas of the head with the highest bone mineral density and resistance to pullout. These have been shown to be the central, posterior inferior, and posterior regions of the head [7]. Thus, the direction of the screws should be such that their tips are lodged in these areas (Fig. 6.8).

Postoperatively, the arm is placed in an immobilizer. Elbow, wrist, finger, and thumb motions are encouraged beginning in a few days after surgery. Shoulder motion, however, is delayed at least 2 and up to 4 weeks postoperatively. This is extremely important because it allows the body to provide early healing to supplement the stability provided by the anatomic reduction of the fracture and fixation by the plate. This further minimizes the risk of failure of the construct in the form of loss of reduction, screw penetration, and screw pullout.

Outcomes

We published our outcomes utilizing these principles and techniques in 2011 [8]. At that time we had 45 patients with 46 shoulders with a mean follow-up of 34 months, with a minimum of 24 months to a maximum of 88 months. Since that publication, we have more than 70 patients

Fig. 6.9 Healed three-part fracture with no loss of reduction, no screw penetration, no avascular necrosis, and no failure of fixation

with no change in outcomes. Not surprisingly, two-thirds were women and the mean age was 68 years, with an age range of 24–95. There were 19 two-part, 21 three-part, 3 four-part, and 1 head splitting fractures. Fifteen cases had significant medial metaphyseal comminution. All cases were done through a deltopectoral approach.

At final follow-up, the mean range of motion was as follows: elevation 140° (range 100°–175°), eternal rotation in the abducted position 77° (range 45°–95°), external rotation at the side (range 49°–85°), and internal rotation to T11 (range T5 to iliac crest).

The VAS pain score was <1, and there was no deltoid or axillary nerve damage. All fractures healed (Fig. 6.9), there was no loss of the reduction at final follow-up compared to that achieved in the operating room. There was no screw penetration or cutout, plate impingement, or avascular necrosis. No humeral head healed in varus. The mean score for the American Shoulder and Elbow Surgeons Outcome Assessment was 82 and for the Disabilities of Arm, Shoulder and Hand (DASH) was 11.

In summary, those steps associated with a successful outcome for treating proximal humeral fractures via open reduction and fixation with proximal humeral locking plates include using a deltopectoral approach, reducing the humeral head anatomically with every effort directed to avoiding head varus, placing the plate so that its tip is inferior to the tip of the greater tuberosity, having at least two calcar screws (Fig. 6.9) and directing all head screws into the central, posterior inferior, and posterior superior regions of the head to a depth of within 8–10 mm of the chondral surface, doing the entire operation using frequent, multiplanar C-arm control, and delaying any motion of the shoulder for at least 2 weeks longer for poorer quality bone, to permit the body to provide additional stability and strength to the fixation construct through early healing.

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7 Hemiarthroplasty for the Treatment of Proximal Humerus Fractures

Andrew S. Neviaser

In 1955, Neer introduced primary humeral head replacement for the treatment of displaced three- and four-part fractures [1]. This report contained 12 cases, 7 of which were acute fractures. Articular replacement was the next logical step following the disappointing results of open reduction and internal fixation or humeral head excision. In the decades following, hemiarthroplasty became the gold standard for treating the complex fractures of the proximal humerus. Neer reported a larger series in 1970 with promising results [2]. However, subsequent reports have been less favorable, and in recent years, the indications for hemiarthroplasty have become increasingly limited [3–5]. Several factors have contributed to the diminished role of humeral head replacement in the treatment of these fractures. Locking plate technology has improved our ability to maintain reduction in poor-quality bone and preserve the native joint. An improved understanding of humeral head perfusion and techniques which minimize soft tissue dissection has also significantly reduced postoperative osteonecrosis and rarely is the risk of osteonecrosis high enough to justify joint replacement [6]. Although some radiographic osteonecrosis may occur, clinically significant joint collapse is uncommon [7]. In younger patients, joint preservation should always be the primary goal and replacement is rarely indicated. In elderly patients, the results of hemiarthroplasty have been less predictable than in younger patients. The reverse total shoulder is now being increasingly used in this group and early reports suggest more consistent functional outcomes although complication rates are also higher [8].

Like any treatment of these difficult fractures, hemiarthroplasty is technically demanding. The most common complication is failure of tuberosity healing which leads to devastating consequences [9]. Each step in the reconstruction affects the position and tensioning of the tuberosity repair and is critical to the overall result. Functional outcomes can be optimized by anatomically replicating the native proximal humerus. The “jigsaw method” is a technique which provides a template of the patient’s native anatomy and can aid the surgeon in achieving appropriate head size, height, and humeral version. If these goals can be achieved and the tuberosities securely fixed, excellent functional outcomes often follow.

Indications

Absolute indications for hemiarthroplasty are difficult to define. Displaced fractures in which adequate reduction or fixation cannot be achieved are candidates for joint replacement. In patients younger than 60 years, joint replacement is almost never necessary and should be

A.S. Neviaser (✉)
Department of Orthopaedic Surgery, George Washington University, 2150 Pennsylvania Ave NW, Washington, DC 20037, USA
e-mail: aneviaser@gmail.com; aneviaser@mfa.gwu.edu

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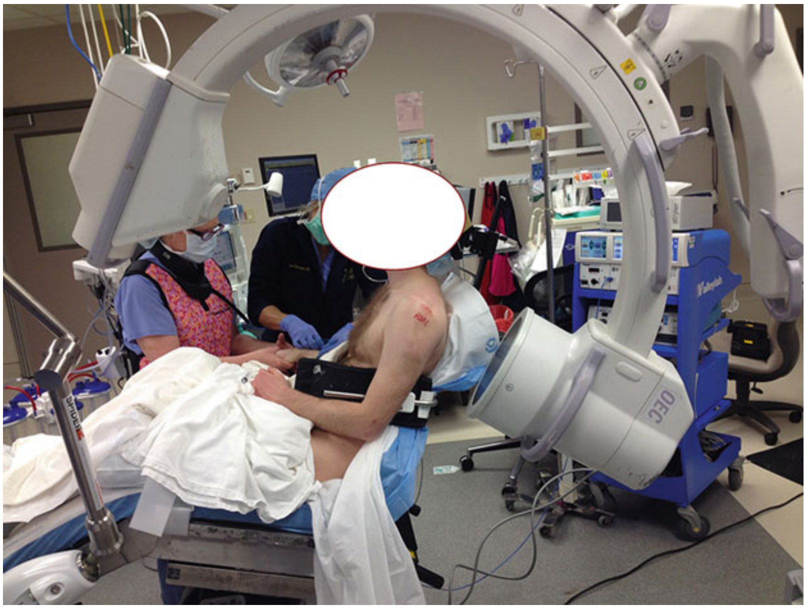

Fig. 7.1 When setting up the patient, the ability to obtain adequate images should be confirmed before draping. The position of the C-arm shown here permits easy images without significant movement of the patient's arm or encroachment on the field

avoided except in rare circumstances such as fractures with comminuted articular segments (i.e., greater than two pieces) or humeral head bone loss. In patients older than 70 years, reverse shoulder replacement produces more consistent functional outcomes and should be considered. The use of hemiarthroplasty is thus limited to middle-aged patients with fractures such as a head splitting fracture with more than two pieces or four-part fracture dislocations.

Surgical Technique

The beachchair position is familiar to most surgeons and is most commonly used. One should ensure that adequate X-rays can be taken intraoperatively before the case begins (Fig. 7.1). Positioning the C-arm at the head of the bed allows for images to be obtained without much movement of the arm and the C-arm does not encroach onto the surgical field.

A traditional deltopectoral approach is typically used and provides the greatest exposure of the shoulder. After incising the clavipectoral fascia, the tuberosities and rotator cuff are exposed. Minimal resection of bursa is required to identify fracture planes and the long head biceps tendon. The surgeon should not immediately split connections between the tuberosities to access the articular pieces. In some instances these connections can be preserved and may aid in tuberosity healing. The head can usually be pulled out from beneath the tuberosities and the tuberosities retracted medially during stem preparation. Later, the tuberosities can be pulled over the prosthesis like a hood to establish reduction [10]. If the head is difficult to remove and significant connections between the tuberosities and the head piece are present, joint replacement should be reconsidered because the head is likely viable. When the tuberosities are separate pieces, they can each be mobilized with releases similar to those used in rotator cuff surgery. The subscapularis and lesser tuberosity are mobilized as a unit with release of the rotator interval and anterior joint capsule. Bursal sided releases in the subacromial space are typically all that is required to mobilize the greater tuberosity and postero-superior cuff. Tagging sutures are placed at the tendon bone junction to establish control of each tuberosity.

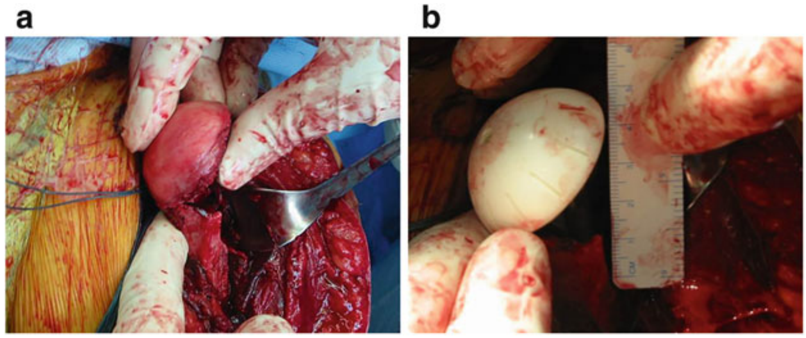

Fig. 7.2 (**a**) The native head is reduced to the neck in an anatomic position. (**b**) A trial prosthesis is placed in position to recreate the native head-neck alignment

Head Size

Failure of tuberosity healing is the most common cause of poor functional outcome following hemiarthroplasty and each step in the articular replacement should be executed to optimize the tuberosity repair. Prosthetic head size and version can significantly affect tuberosity tension and thus healing. Following mobilization of the tuberosities, a prosthetic head is selected. The humeral head represents a portion of sphere. The native articular piece should be matched to a prosthetic trial based on radius of curvature, depth, and width. If the native head size falls between two trial sizes, the smaller option is chosen. Excessive offset from a head that is too big increases tension on the repaired tuberosities leading to pull off and also overtensions the joint capsule restricting motion.

Head Height

The "jigsaw" method, described by Bigliani and Flatow, involves reconstructing the head–shaft relationship by reducing the native head anatomically on the shaft to create an intraoperative template for reconstruction [10] (Fig. 7.2a). It provides a reliable method for reproducing native head height. If the head piece is comminuted, it can be put together on the back table and held by K wires to produce the anatomic model. Calcar comminution can also be pieced together to recreate the native surgical neck. With the head anatomically reduced to the shaft, measurements of head height can be taken from fixed landmarks such as the pectoralis major tendon. Warner et al. established a distance of 5.6 cm from the top of the head to the upper border of the pectoralis major tendon as a reliable guideline [11]. The native head-neck reconstruction provides a more precise replication of native anatomy, although it should not deviate greatly from 5.6 cm. With the head-neck alignment defined, trials can be used to recreate this relationship (Fig. 7.2b). In situ measurements confirm proper height of the trail. If the prosthesis is placed too low, the rotator cuff and other portions of the myofascial sleeve will be too lax leading to inferior subluxation or dislocation. A prosthesis that is placed too high will lead to a painful overstuffed joint.

Prosthetic Version

The jigsaw method can also help to recreate appropriate prosthetic version which is also critical to tuberosity healing. If the prosthesis is placed in excessive retroversion, internal rotation of the shoulder will create tension on the greater tuberosity whereas too much anteversion will tension the lesser tuberosity when the shoulder is externally rotated. Native retroversion can vary from 0° to 50° [12]. By recreating the native proximal humerus, native version can be accurately reproduced. Average retroversion is usually between 20° and 30° and if the reconstruction model varies too much from this guideline, the model should be reassessed [12]. Once the head

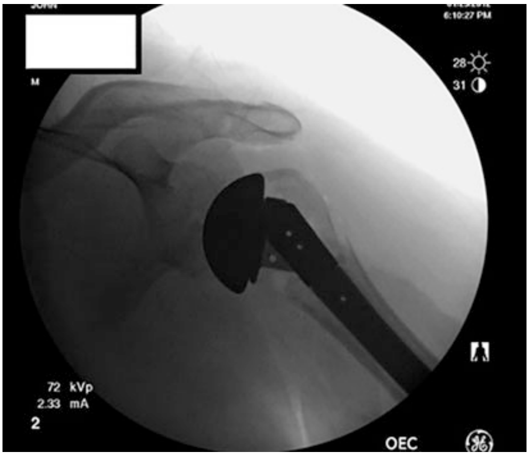

Fig. 7.3 Intraoperative images confirming that the reconstruction has adequately recreated the native alignment

height and version are established, a reduction with the trial prosthesis is performed. The tuberosities are provisionally reduced and fluoroscopic images taken (Fig. 7.3). The bone of the humeral shaft is typically osteoporotic and securing the stem with cement reduces the possibility of intraoperative fracture and later subsidence.

Tuberosity Fixation

Union must occur between the greater and lesser tuberosity as well as between the tuberosities and the shaft. Fixation must therefore be in both the coronal as well as the sagittal planes. Wire is more durable than suture fixation, produces less slippage, and yields greater rates of healing but is more difficult to use [13]. A hybrid construct of both sutures and wires provides the benefits of both. Frankle et al. have shown that a circumferential medial cerclage decreases intrafragmentary motion and strain, and increases union rates [14]. A wire can be used for this cerclage while suture fixation can be used to fix the tuberosities to the shaft. A running, locking stitch of heavy nonabsorbable suture should be placed through the subscapularis and a second through the supra and infraspinatus. These sutures are used to secure each tuberosity to the stem. Additional heavy sutures are passed through bone tunnels in the shaft and then through cuff tendons such that they secure the tuberosities in the axial plane. The medial to lateral sutures are tied first followed by the inferior to superior sutures. This prevents over-reduction of the greater tuberosity below its ideal position of approximately 8 mm below the head. A cerclage wire through the stem and around the tuberosities is passed before the sutures are placed but is the final piece that is tightened. Bone graft from the excised head should be used routinely and may also increase rates of tuberosity healing. Intraoperative imaging is then used to confirm acceptable reduction of the tuberosities.

Postoperative Rehabilitation

Patients can be placed in an immobilizer with a small abduction pillow. Surgeon-guided rehabilitation is critical to the procedure's ultimate success. Gentle passive motion can be introduced when the surgeon feels that adequate stability of the tuberosities has been achieved. In a patient with robust bone and sizable tuberosities, passive motion can begin within the first few (2–3) days postoperatively. However, in many cases, the tuberosity pieces are small shells of cancellous bone with thin cortices. Under these circumstances, stability is better achieved by the biologic bond of bone healing rather than by the repair construct and motion (even passive motion) of the shoulder should be delayed as much as 4 weeks if necessary. Early stiffness following such a delay will likely resolve and tuberosity pull off is prevented with this conservative approach. A sling is worn for 6 weeks regardless of when motion is initiated. The sling is discontinued and active motion can be initiated after 6 weeks. Strengthen exercises are rarely necessary and should not be introduced before 3 months postoperatively.

Results

Neer's report in 1970 included 32 patients who had undergone prosthetic replacement. Four patients achieved an excellent result and 27 were satisfactory [2]. Only one failure was reported. The same

Fig. 7.4 A patient 2 years following hemiarthroplasty for head splitting fracture

institution reported a subsequent series of 70 patients with 82 % achieving satisfactory results [10]. Ten patients had significant limitations of motion. Ninety-five percent of patients were pain free. Hertel and Bastian found that outcomes for hemiarthroplasty were similar to those following osteosynthesis with only small differences in strength between the groups [15]. Other authors have reported outcomes that are more inconsistent. Olerud et al. found that hemiarthroplasty produced superior pain relief but not improved motion compared to nonoperative treatment for four-part fractures in the elderly [4]. In a large systematic review, Kontakis found an average forward elevation of 106° with a range from 10° to 180° [5]. This review also found that most of these procedures are performed by surgeons who do less than one per year. This is likely a significant factor in the wide range of outcomes.

Attempts to improve tuberosity healing by improving prosthetic design have shown some promise. Lower profile fracture stems provide more room for tuberosity fixation and reduced tension on their repair. We have reported on the use of a fracture stem which incorporates tantalum into the proximal stem. Highly porous tantalum has a Young's modulus similar to that of bone. It has been used successfully in hip and knee reconstruction where it has shown reliable bony ingrowth. In 13 patients followed for a mean of 26 months, average forward elevation was 131° and the mean American Shoulder and Elbow Score was 81 (Fig. 7.4). All patients had minimal pain. Other fracture-specific designs include a metaphyseal window in the stem that allows for bone grafting and tuberosity contact. Comparison studies have found significantly higher rates of tuberosity healing when fracture-specific stems are used as compared to standard stems [16].

Conclusions

Hemiarthroplasty has a more limited role in the treatment of proximal humerus fractures than in previous decades. Pain relief has been shown to be a reliable outcome but return of function is inconsistent and may depend on surgeon experience. Exacting technique is required to recreate the native anatomy and ensure tuberosity healing. Establishing proper head size, height, and version sets a foundation for tension-free reduction of the tuberosities. The jigsaw puzzle method creates a template of native anatomy to help establish these relationships. Tuberosity fixation should be in multiple plans and include a cerclage around the stem and both tuberosities. Surgeon-directed rehabilitation is critical to optimize motion and avoid tuberosity pull off. Fracture-specific stems may aid in tuberosity healing. As indications become increasingly narrow, surgeons with little experience in hemiarthroplasty or proximal humeral fractures should consider referral of these difficult cases to tertiary care centers.

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8 Reverse Shoulder Arthroplasty for Proximal Humerus Fractures

Lynn A. Crosby and Toby Anderton

Introduction

Shoulder arthroplasty dates back to the late 1800s, when the French surgeon Jules-Émile Péan used a platinum-and-rubber prosthesis to replace a glenohumeral joint that had been destroyed by tuberculosis [1, 2]. Little progress in design or clinical outcome was made until the 1950s, when Neer developed an unconstrained prosthesis for the treatment of displaced proximal humerus fractures [3, 4]. Reverse Total Shoulder (RTSA) use in the 1970s was limited secondary to mainly failures of the glenoid component fixation. This limited the use in patients with rotator cuff deficiency until Grammont developed prosthesis with a medialized center of rotation and a decrease in the stress applied to the interface of the glenoid component [5–7]. More recently RTSA has become popular for primary replacement in complex proximal humerus fractures. Hemiarthroplasty and open reduction and internal fixation (ORIF) with locked plating were the treatment of choice but with variable functional outcomes and concerns of glenohumeral arthritis, rotator cuff problems, and tuberosity healing difficulties [8]. This is especially concerning in the older population that has a higher incidence of rotator cuff problems and poor bone quality. RTSA has resulted in excellent pain relief and seems to have a more consistent functional outcome in early reports when compared to hemiarthroplasty [8].

Proximal Humerus Fractures

Proximal humeral fractures account for nearly 10 % of all fractures in the elderly population [9, 10]. They cause substantial pain, loss of function, and loss of independence in performance of activities of daily living [11]. A wide variety of treatment options exist for these injuries demonstrating the difficulty in a standard treatment recommendation.

Proximal humeral fractures represent nearly 50 % of all shoulder girdle injuries. The most commonly used classification system (Neer) for proximal humerus fractures classified "parts" based off of 45° of angulation or rotation, and more than 1 cm of displacement of the greater tuberosity (1), lesser tuberosity (2), articular surface (3), and the shaft (4) [12, 13]. Four-part proximal humerus fractures represent between 2 and 10 % of all proximal humerus fractures. These fractures have a high potential for nonunion, malunion, and avascular necrosis. The articular component is generally devoid of blood supply secondary to its loss of soft tissue

L.A. Crosby (✉)
Department of Orthopaedic Surgery, Medical College of Georgia, Georgia Regent's University, Augusta, GA 30912, USA
e-mail: lycrosby@gru.edu

T. Anderton
Department of Orthopedic Surgery, Georgia Regents Medical Center, 1120 15th St, Augusta, GA 30912, USA
e-mail: adobetoby@gmail.com

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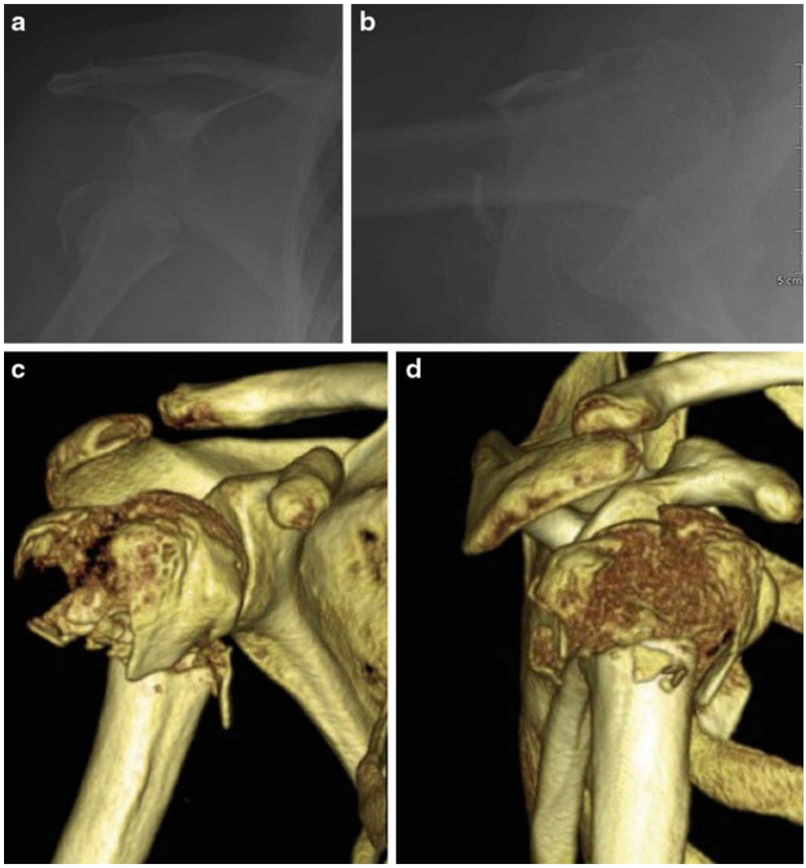

Fig. 8.1 (**a** and **b**) AP and lateral radiographs of a fracture dislocation in a 70-year-old male. (**c** and **d**) 3D reconstruction images of a four-part proximal humerus fracture demonstrating the severity of the damage to the bone

attachments, and a compromised blood supply (Fig. 8.1a–d). The incidence of proximal humerus fractures has been increasing due to the rise in the elderly population in recent decades. With the increasing number of elderly and high incidence of osteoporosis we can expect to see more proximal humerus fractures in the future. Controversies exist over operative vs. nonoperative management because of the lack of controlled outcome studies that are difficult to initiate.

The Incidence of Degenerative Rotator Cuff Tears in the Elderly

A cadaveric study demonstrated the incidence of full-thickness tears increased with increasing age. In cadavers less than 60 years of age the incidence of rotator cuff tears was 6 % compared to 30 % in over 60 years of age [14]. This study excluded all partial-thickness tears. The incidence of rotator cuff tears and the severity of these full-thickness tears are likely exacerbated with displaced proximal humerus fractures. This might explain some of the poor functional results with >60 year old patients with ORIF or Hemiarthroplasty after displaced proximal humerus fractures.

Prosthetic Replacements in Fractures

Prosthetic replacements with hemiarthroplasty and reverse total shoulder arthroplasty have consistently shown good results in pain relief [15]. Recent studies have shown that RTSAs have greater function in the >65 years age group than does Hemiarthroplasty or ORIF. In our experience even poor outcomes with RTSA generally do better than poor outcomes with hemi-arthroplasty. Reverse total shoulder arthroplasty outperformed hemiarthroplasty and ORIF with regard to forward flexion, American Shoulder and Elbow Society score, University of Pennsylvania shoulder score, and Single Assessment Numerical Evaluation score in proximal humeral fractures [15]. RTSA appears to provide superior range of motion early and more predictably when followed over time. Many authors have noted that cost is a reason for HA or ORIF over RTSA. However, the total or overall cost on the system with RTSA has significant cost saving to Medicare [8]. These studies bear out our clinical experience of primary reverse shoulder arthroplasty vs. hemiarthroplasty or ORIF for the elderly patient population with displaced proximal humerus fractures.

Indications for RTSA in Fractures

We recommend RTSA for acute elderly (physiologically >70 year old) patients with poor biologic potential for fracture healing, three or four-part proximal humerus fractures that have an articular head split, fracture dislocation, or comminution of the greater tuberosity. In addition to these criteria in the acute setting, deltoid function must be reasonably preserved. Glenoid bone stock and quality must be able to accept the implant and screws for secure fixation. The ease of postoperative care and the lack of need for formal rehabilitation may be of importance for the selection of RTSA to manage acute fractures in elderly patients with severe osteopenia [16] (Fig. 8.2a–d).

In addition these chronic criteria are also acceptable: tuberosity malunion in the elderly, tuberosity nonunion, proximal humerus malunion, proximal humerus nonunion, and fractures with a deficient rotator cuff.

Contraindications

Nonsurgical management is generally reserved for patients with significant medical comorbidities that would preclude them from undergoing a surgical procedure. Patients who refuse or are unable to follow postoperative protocols (dementia or ipsilateral lower extremity fracture) will likely have poor results and unsatisfactory outcomes. Complete axillary nerve palsy is a contraindication because of the very high probability of recurrent instability and the minimal potential gain in function [8]. Non-operative management should be considered in these situations. Infection, neuroarthropathy, and substantial glenoid bone loss (defects or severe erosion) are also contraindications.

Surgical Planning

Adequate X-rays of the fracture are essential to plan the procedure. Complete anterior/posterior, axillary Y, and axillary lateral views of the shoulder will aide in glenoid bone stock evaluation. If these films are unobtainable or poor quality a CT scan of the shoulder should be obtained to evaluate the glenoid and fracture pattern. A/P and lateral images of the humerus may reveal segmental humeral shaft injuries that could preclude the use of certain implants. Available OR staff that are knowledgeable of the implants and procedure decrease operative duration and likelihood of unexpected complications.

Hood Wear

We perform the majority of our RTSA in an academic setting, and as such we believe the hood is of benefit to avoid bacterial shedding during cases where discussion is necessary. The use of hoods may also protect the surgical team from potential contamination from the patient if they have Hepatitis or HIV. However, using a surgical hood is not required.

Patient Positioning

We prefer a modified beach chair position with the head of the table at 30° and the operative arm draped free, and mobile to full abduction in the extended position. This usually requires a surgical table with a removable side. This is critical to evaluate implant height and for glenoid

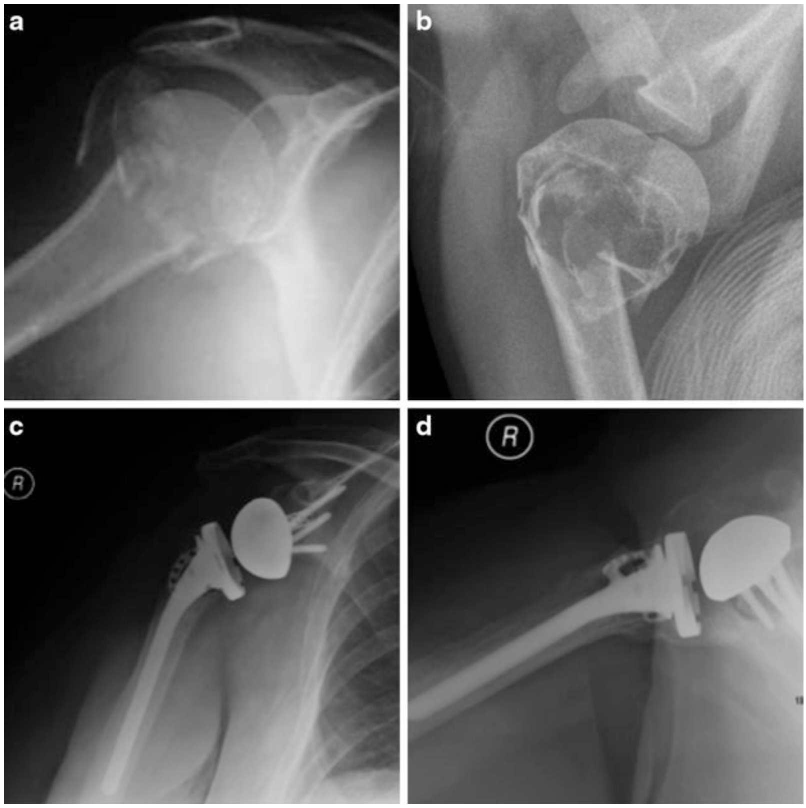

Fig. 8.2 (**a** and **b**) AP and lateral radiograph of a three-part proximal humerus fracture. (**c** and **d**) Reverse Total shoulder arthroplasty for three-part proximal humerus fracture in a 74-year-old male

exposure. We use a draped out Mayo stand to aid in arm control and placement to allow surgical assistants to be able to use their hands and not have to hold the extremity.

Skin Preparation

Infection after RTSA can be devastating, and with the increased dead space around the implant, secondary to its design, proper skin preparation to avoid infection is crucial. *Propionibacterium acnes* (*P. acnes*) has been shown to be an opportunistic aero-tolerant anaerobe of the normal skin flora about the shoulder that can cause infection if the skin is not appropriately prepped. We prefer to use hydrogen peroxide to cleanse the skin before surgical prep (*P. acnes* is sensitive to hydrogen peroxide) with clorihexdine and re-prep the skin edges before skin closure.

A number of delayed infections are caused by *P. acnes*. Antimicrobial susceptibility testing on 28 strains from the shoulder showed antibiotics with the lowest MIC values against *P. acnes* (MIC50 and MIC90) included penicillin G (0.006, 0.125), cephalothin (0.047 and 0.094), and ceftriaxone (0.016, 0.045), while others also showed activity. Strains resistant to clindamycin were also noted [17].

Preoperative Antibiotics

Because of the emergence of *P. acnes* we have included in our preoperative regiment Ancef and Vancomycin given 30 min before the skin incision is made. The Vancomycin is only given during the procedure and then discontinued. Ancef is given during the procedure and continue for three doses postoperatively as in most arthroplasty cases.

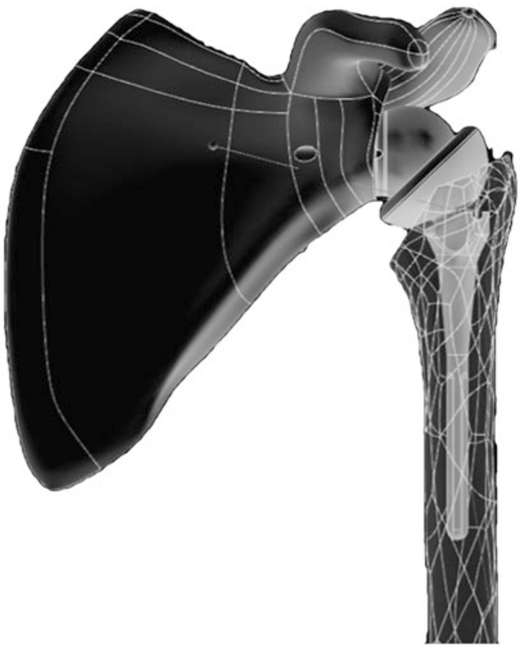

Fig. 8.3 Computer-generated example of the lateralized glenoid—Encore

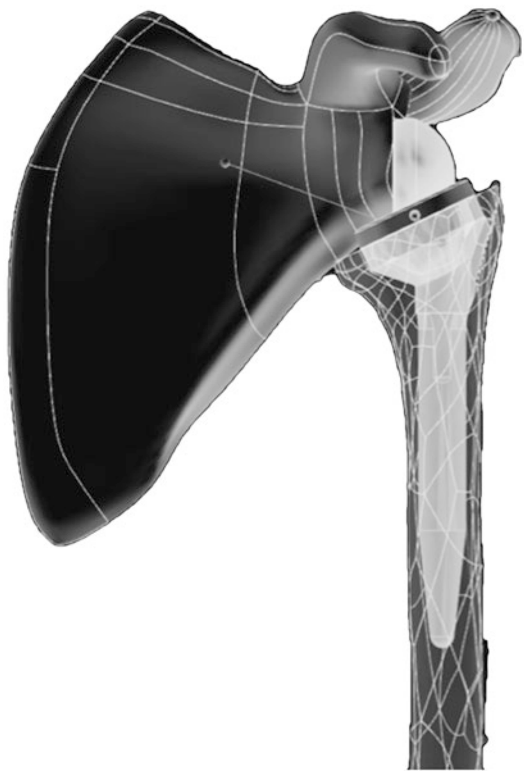

Fig. 8.4 Computer generated example of the medialized glenoid—Gramont (Tornier, Depuy) Zimmer, Biomet

Implant Selection

Understanding the mechanics of your RTSA implant is critical to understanding the best implant for your patient. Implant designs focus to medialize or lateralize the center of rotation. Each implant has benefits and potential complications. Many implants now have what has been termed a platform stem. Meaning that the humeral component creates a unified platform where either a reverse ball and socket or a hemiarthroplasty component can be placed depending on the circumstances. This also allows an exchange of the implants from a hemiarthroplasty to a reverse or vice versa in revision cases without removing the stem (Figs. 8.3, 8.4, and 8.5).

Fig. 8.5 Computer generated example of the inferior lateralized—Exactech

Surgical Techniques

Surgical intervention can be undertaken in the immediate postinjury period or delayed if other injuries or medical conditions need to take precedence.

Deltopectoral and superior-lateral approaches are used for a RTSA. A deltopectoral approach is the most widely used approach and it provides for a better visualization for the orientation of the glenoid component. This enables the surgeon to decrease glenoid mal-position and thus lowering the incidence of loosening and inferior scapular notching [18]. A superior lateral approach was found to be much better than deltopectoral approach in terms of postoperative instability (0 % vs. 5.1 %, respectively; $P < 0.05$) and was better in terms of preventing fractures of the scapular spine and the acromion ($P < 0.05$) [18].

Our preference is the deltopectoral approach. The deltopectoral approach facilitates excellent glenoid exposure, identification, and protection of the axillary nerve, and access to the humeral shaft.

A standard deltopectoral approach uses an 8–12 cm incision placed 1–2 cm lateral to the coracoid process. The incision is carried though the subcutaneous tissue with sharp dissection or electrocautery to the level of the cephalic vein. An attempt is made to protect the vein and mobilized it to the medial border of the deltoid. If it is violated it can be ligated without significant consequence. The interval between the deltoid and pectoralis major is identified and utilized for access to the subdeltoid/subacromial bursa. The bursa is excised, revealing the long head of the biceps tendon, and subscapularis tendon insertion on the lesser tuberosity. The subscapularis can be completely excised or tenotomized close to the musculotendinous insertion on the lesser tuberosity. It is up to the surgeon to decide to repair the subscapularis after the implants are positioned or remove it. There is no significant difference in outcomes in either case. The long head of the biceps tendon is tenodesed at the level of the pectoralis major tendon insertion and the proximal portion removed. After removal of the subscapularis and long head of the biceps tendon adequate visualization of the glenohumeral joint and fracture fragments can be accomplished.

The humeral head is removed and the bone is harvested for graft. The lesser tuberosity can be completely removed and used for graft as well. If the surgeon has chosen to repair the subscapularis the lesser tuberosity is preserved with the tendon. Heavy #5 nonabsorbable suture is placed through the boney tuberosity fragments. The glenoid is exposed; the labrum and biceps tendon stump is excised. The capsule is released circumferentially from the glenoid with electrocautery or sharp resection. Care is taken to locate and protect the axillary nerve with blunt retraction. We prefer to remove the glenoid cartilage with curettes to preserve as much of the subcondral bone as possible. The exact positioning and orientation of the base plate is crucial and should be placed as low as possible on the glenoid that still allows for good positioning of the screws. At least 2–3 mm of inferior overhang is needed to best prevent contact of the humeral component with the inferior scapulae [5, 6]. The metaglene is placed with 5° of inferior tilt. Preoperative planning/imaging must establish that the glenoid can be prepared without creating excessive anteversion, retroversion, or superior glenoid tilt. Augmented metaglenes are available in superior, posterior, and if needed anterior 8° build ups. After placement of the appropriate number of compression screws that are then converted to a locked construct with caps the glenosphere can be placed. We recommend utilizing the largest glenosphere that can easily be inserted. This aids in stability of the construct.

The humerus is then reamed and broached by hand and the humeral shaft prepared for cement. We utilize a cement restrictor to avoid cement extravasation distally and allow for compression of the cement mantel. Drill holes and sutures should be passed through the shaft to provide for tuberosity reduction and stability.

Cement is prepared and placed in the distal humeral shaft; care should be taken to avoid proximal migration of the cement as bone graft will be added proximally around the humeral stem to promote bone healing of the tuberosities to the humeral shaft.

It is important to recognize that external rotation of the arm relies on the infraspinatus and teres minor, which are attached to the greater tuberosity. Internal rotation is a combination of the subscapularis, pectoralis muscles, latissimus dorsi, and teres major muscles. In our experience repairing only the greater tuberosity and not the lesser improves external rotation. Intact Subscapularis muscle via replacement of the lesser tuberosity will force the deltoid to work harder to achieve abduction in the first 80°. The intact Subscapularis also forces the posterior cuff to work harder to avoid Horn-blower's deformity. These concepts are supported by Hansen et al. (2008) who published a study of the effect of subscapularis on loading of the glenohumeral joint with up to 460 % increase in posterior cuff load, and up to 130 % increase in deltoid load as compared with a released subscapularis [19]. We choose not to repair the lesser tuberosity or subscapularis tendon and have not experienced a problem with instability.

RTSA has shown reasonable functional improvement even without tuberosity healing. A recent study of the normal anatomy of the proximal humerus demonstrated that the greater tuberosity is on average 8 + 3.2 mm below the top of the articular segment [20]. Thus, even small amounts of proximal greater tuberosity displacement can be problematic [21, 22]. Working to place the greater tuberosity in a more anatomic position will improve external rotation [23].

Repairing the tuberosities with nonabsorbable #5 suture is recommended. We choose to use at least three sutures through the bone or preferably the bone–tendon junction. This technique is the same as used if hemiarthroplasty is used for the treatment of these fractures. The sutures are placed through holes provided in the implant and then placed back through the tuberosity or tendon–bone junction. The sutures that were placed through the humeral shaft are then placed through the bone–tendon junction. One suture is placed circumferentially around the entire construct to aid in decreasing the tension and help prevent tuberosity pull off. Bone graft is placed under the sutures before they are tied to help maintain the graft in place. The implant is reduced before the sutures are tied.

Postoperative Care

The RTSA leaves a large area of potential dead space. We recommend the use of postoperative drains to prevent hematoma formation. Anticoagulation regiment is a 5-day course of 325 mg of Aspirin. Use of a sling for comfort and early Codman exercises are utilized. Formal physical therapy is started at 4–6 weeks. When formal therapy is started we use a three-phase program similar to that used after large rotator cuff surgery: Passive range of motion, passive assistive range of motion and finally active resistive range of motion.

Results

Reverse total shoulder arthroplasty in its modern design with medialization and inferior placement of the center of rotation have alleviated many of the design complication with fixation and longevity of the RTSA. Studies regarding the reverse ball and socket design have shown maintenance of function and 89 % retention of implants at a 10-year follow-up [24]. Reverse total shoulder arthroplasty is a reliable method of treatment for acute proximal humerus fractures that are not amenable to closed treatment or reconstruction in the elderly patients.

The clinical relevance of scapular notching has not fully been understood, and future studies with adequate study power are necessary to examine its significance.

Summary

Proximal humerus fractures will continue to be a difficult problem to treat in the elderly population. Osteoporosis and poor bone healing potential continue to be challenging. In this population the reverse total shoulder arthroplasty appears to be an option that still needs to have longer-term follow-up to adequately determine the benefits. Currently, the research data available demonstrate a much improved quality of life with regard to pain resolution, and function in the short to mid-term range of follow-up for the use in proximal humeral fractures. There are, however, no long-term studies demonstrating the fracture reverse's longevity with the newest designs that improve tuberosity healing, less scapular notching, and improved range of motion.

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9 Complications of Treatment of Proximal Humerus Fractures

Julie Y. Bishop

Overview

As discussed elsewhere in this book, fractures of the proximal humerus are relatively common, accounting for 4–5 % of injuries to the appendicular skeleton [1–6]. Although 80–85 % are primarily minimally displaced osteoporotic fractures in the elderly, depending on the mechanism of injury and energy of the trauma, they can present in a wide range of ages [7, 8]. Most minimally displaced fractures can be successfully treated nonoperatively and relatively good results can be expected [8–10]. Only about 20 % of fractures require surgical intervention and perhaps only 1 % truly mandate surgical intervention (due to open fracture, associated vascular injury, head split fracture, pathologic fractures, fracture-dislocations) [8, 11]. In the remaining 19 % who proceed with surgery, it is generally undertaken with the aim of improving functional outcomes when compared to nonoperative treatment and reducing the risk of complications that are associated with nonoperative management. In general, the results of surgical treatment of proximal humerus fractures are good, with improved function and less pain than if those same fractures had been treated nonoperatively. However, many reconstructive options are available to treat these fractures and each comes with its own set of advantages, disadvantages and potential pitfalls. The true art of treating proximal humerus fractures lies in the hands of the treating physician, in understanding not only the fracture pattern but more importantly the underlying patient factors and patient expectations. A lower-demand patient with multiple medical comorbidities is more apt to accept a diminished functional outcome if this allowed him to avoid surgery. A physiologically younger and more active patient has greater expectations and is willing to risk more in an effort to obtain the best outcome. Thus, it is a balancing act in the decision making process between operative and nonoperative management and unfortunately, despite best intentions, complications of treatment do occur. Therefore, this chapter is aimed at reviewing the treatment complications of both nonoperative and operative management of proximal humerus fractures. The goal is to present the most common complications, while at the same time, providing tips and insights to avoid these complications.

Complications of Nonoperative Management of Proximal Humerus Fractures

The majority of nondisplaced proximal humerus fractures treated nonoperatively has good outcomes [12–14]. A recent systematic review looking at the nonoperative treatment of

J.Y. Bishop (✉)
Department of Orthopaedics, Wexner Medical Center, The Ohio State University, 2050 Kenny Road, Columbus, OH 43221, USA
e-mail: Julie.Bishop@osumc.edu

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proximal humerus fractures showed an overall high rate of radiographic healing and good functional outcomes [13]. Further, surprisingly the results of nonoperative treatment of many displaced proximal humerus fractures are acceptable as many of the patients that present with proximal humerus fractures are elderly, low demand, and may have many medical comorbidities [14]. These patients can often tolerate diminished function, and thus the true goal in this population is to avoid an outcome that not only limits function, but causes extreme pain as this is less tolerated. Typically the complications of nonoperative management that are less acceptable in this population are nonunion, symptomatic malunion and osteonecrosis [15, 16]. More active and younger patients typically expect good functional outcomes as well as no pain. In these patients, if nonoperative management is undertaken, it is because the treating surgeon believes the outcome will provide this for the patient. These patients are much more sensitive to diminished outcomes from not only the major complications listed above, but also, more subtle malunions affecting function and the development of any stiffness. In addition, missed pathology and the late onset of posttraumatic arthritis can be the source of a poor outcome after nonoperative management in any patient population. In general, secondary salvage surgeries to address complications are always more challenging and outcomes typically worse then what would be expected after primary operative treatment [17]. Of course, it is not possible to predict every outcome, and unfortunately complications occur despite proper treatment. This chapter will arm the treating surgeon with more insight to help avoid these costly complications.

Avascular Necrosis

The development of osteonecrosis after fracture of the proximal humerus is generally dependent on disruption of the vascular supply to the humeral head at the time of the original injury [18]. It has been shown that the predictors of humeral head ischemia are the length of the dorsomedial metaphyseal fracture extension and the integrity of the medial hinge [19, 20]. However, recent literature has shown that perhaps the initial acute ischemia can be overcome if adequate reduction and stable conditions for revascularization can be obtained [21]. In addition, there are clearly times when AVN does not develop despite a very devascularizing injury pattern and then instances in which it occurs after a minor injury. Thus, the absolute pathophysiology is not completely understood. In general, the overall risk of AVN has been reported to be between 1 and 34 % [22, 23]. One recent systematic review looking at the nonoperative management of proximal humerus fractures found only 13 reported cases out of a total of 650 patients [13]. Therefore, the reported rates in the literature are variable. In general, the rate is higher (26–75 %) in those with a four-part fracture, and the risk is two to three times higher in four-part versus three-part fractures [8, 24–26]. However, this complication is mostly avoided as the majority of those with a four-part tend to proceed with surgery, unless medical comorbidity precludes this [26–29]. Patients with more severe injuries that are treated nonoperatively are often easier to detect because the onset of AVN is not unexpected. Repetitive attempts at a closed reduction of an initially displaced fracture can predispose to this condition and should be avoided. Further, multiple attempts at a closed reduction may have no, if any, effect on the rates of malalignment; thus physicians should proceed with care when considering a closed reduction [12]. However, the reader should be aware that AVN can occur in the nondisplaced proximal humerus fracture, and thus an index of suspicion must remain. The diagnosis should be sought after when patients show evidence of fracture healing at the expected timelines, but persist with worsening pain and at times, stiffness. Function may or may not be affected in early cases of AVN, but the classic finding is persistent pain with no clear explanation. At this point, the surgeon should have a high rate of suspicion and seek further imaging. Often it is not immediately obvious from the radiographs, but an MRI will show early presentations, expose the extent and severity and help direct treatment algorithms (Fig. 9.1).

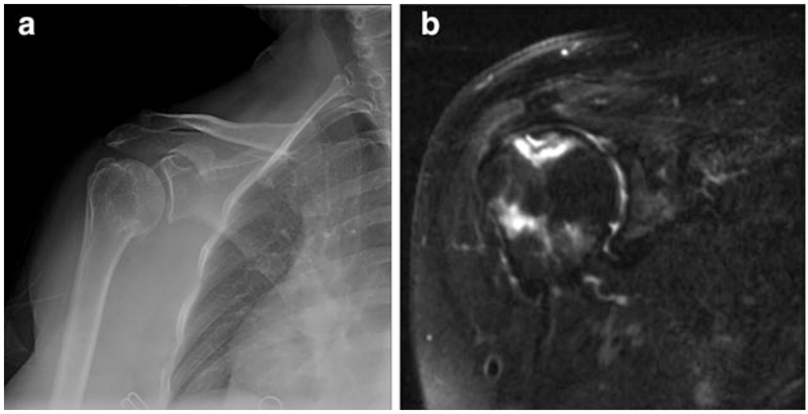

Fig. 9.1 (**a** and **b**) Radiograph 1 year (**a**) after a non-displaced proximal humerus fracture in an active 52-year-old female. Fracture appears healed on the film, but the patient complains of continued pain. MRI (**b**) of the same patient was obtained, which shows evidence of the prior fracture line at the surgical neck and the onset of avascular necrosis in the humeral head

Nonunion

Nonunions of the proximal humerus can be very debilitating to the patient, as often they present with a considerable amount of pain and varying degrees of functional loss. The rate of nonunion is reported to be approximately 1.1–10 % following closed treatment of proximal humeral fractures [12, 30–32]. A prospective study from Hanson et al. evaluated 124 proximal humerus fractures in an effort to study the outcomes of conservative management. When evaluating bony union they found 93 % of patients achieved a solid union after 1-year follow-up; however only 3 % required surgery for this. The median time to definite union was 14 weeks, and not surprisingly, they found smoking was a significant risk factor for nonunion. Smokers had a 5.5-time increased likelihood of developing a nonunion compared to nonsmokers [12]. Court-Brown and McQueen reported a 1.1 % nonunion rate in their prospective study of 1,027 consecutive proximal humerus fractures, but noted the rate to increase with higher degrees of metaphyseal comminution (8 %) and surgical neck displacement (10 %) [30]. In general, fracture patterns that disrupt the necessary blood supply for healing place patients at higher risk for nonunion and are commonly seen in two-part surgical neck fractures [33, 34]. Greater tuberosity nonunions are rare unless markedly displaced as they usually will heal and hence are more likely to develop a malunion. In addition, systemic diseases may compromise a patient's ability to heal a fracture, especially those with severe osteopenia, obesity, heavy smokers, nutritional deficiencies and/or metabolic bone diseases. These same systemic factors though, may also lead physicians to avoid surgery in patients with displaced fractures for fear of postoperative complications. Given the potential for significant morbidity associated with surgical management of this problem, nonoperative management is an option, if this is the nondominant arm in an elderly person and pain is not too severe (Fig. 9.2). Because although in theory, more than 1 cm of displacement of the surgical neck fractures deems a surgical neck fracture "displaced," many surgeons do accept a large degree of displacement in elderly, more sedentary patients, as long as there is some contact between the humeral head and the shaft. As long as these displaced fractures heal, the patient often will maintain some degree of function (although he may be stiff) and have minimal pain. However, if there truly is minimal to no contact between the shaft and the humeral head, surgery should be considered, because a nonunion can be very painful and function can be drastically impacted. If surgical intervention is still not deemed safe, a very detailed conversation about expectations should be had with the patient and family. A painful nonunion could take away the independence of an elderly patient who prior to the injury, was living alone and functioning well (Fig. 9.3).

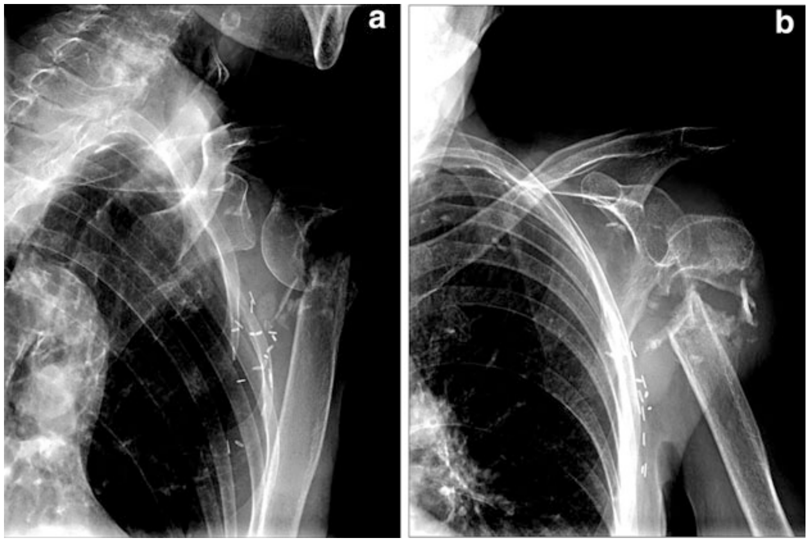

Fig. 9.2 (**a** and **b**) Radiographs taken 6 months after a surgical neck fracture which was sustained in a sedentary, 95-year-old patient. Despite the clear evidence of a nonunion, the patient has no pain, although does have decreased function

Fig. 9.3 AP X-ray of a completely displaced proximal humerus fracture in a healthy, independently living, 84-year-old female. The patient presented for a second opinion after the original physicians treatment plan was non-operative. The patient had lost the ability to care of herself due to a complete lack of function and significant pain

Upon presentation of a symptomatic nonunion, many patients have substantial dysfunction and are rarely able to perform ADLs. The pain can be severe and is worsened by any attempt to use the extremity. These symptoms are typically not tolerated well in any population. Physical examination typically reveals pain and stiffness, and often the patient is pseudoparalytic. Integrity of the axillary nerve must always be determined. The standard radiographic views are always obtained, including a true anteroposterior (AP) in the plane of the scapula (grashey) an outlet and an axillary view. Often a computed tomography (CT) scan is helpful in judging better the degree and extent of bone loss, which can be substantial. In particular, surgical neck fractures with a varus deformity are higher risk for a nonunion. While there is bone contact between the humeral head and the shaft, this fracture pattern tends to be unstable. The more cortical distal fragment has poorer healing qualities compared to the more cancellous proximal fragment. An already soft, cavitated humeral head becomes more cavitated by motion against the medial cortical bone of the humerus and this further compromises healing potential in this area (Fig. 9.4). A CT or magnetic resonance imaging (MRI) scan will clearly show the cavitation of the humeral head and will often guide the surgical treatment choices. Patients who present with this fracture pattern should be watched closely for the first 3 weeks with serial X-rays. If the humeral head continues to collapse into further varus deformity, the micromotion between the medial humeral head and the calcar can cause a substantial degree of bone loss as described (Fig. 9.5). These are better detected early, when perhaps a standard open reduction and internal fixation (ORIF) can be performed rather than an arthroplasty.

Fig. 9.4 An example of how a varus positioned humeral head can lead to cavitation of the humeral head as the osteoporotic head rubs against the medial cortical bone of the humerus

If possible, the surgeon should always try to avoid the development of a nonunion by careful assessment of the fracture pattern, weighing carefully also patient-specific risk factors. Patients should be warned about the risks of smoking and encouraged to quit smoking until fracture consolidation is obtained. The concern is that the treatment of proximal humeral nonunions, as compared with that of acute fractures, poses additional challenges due to bone loss, compromised bone quality, associated malunion, and soft-tissue contractures. The evidence indicates that the results of late arthroplasty placement are inferior to those of acute replacement/fixation for the treatment of proximal humerus fractures [17, 31, 35, 36]. The treating surgeon should also beware the patient with preexisting glenohumeral arthritis, as there is often joint contractures, and thus motion is shifted to the fracture site. Even nondisplaced proximal humerus fractures are higher risk for development of a nonunion, and these fractures should be given careful consideration (Fig. 9.6).

Malunion

The malunion rate after nonoperative treatment of proximal humerus fractures has been estimated to be 4–20 %, with a recent systematic review showing varus malunion as the most complication of nonoperative treatment [13, 37]. Some degree of malunion is almost inevitable with nonoperative treatment but when symptomatic, malunion is often associated with debilitating pain, limitation of range of motion, loss of function and subsequent significant disability. For the symptomatic patient, operative intervention is often required, but these surgeries prove especially challenging. Multiple factors contribute to the difficulty of malunion surgery, including disruption of the normal anatomy, substantial soft tissue scarring and contracture, especially of the rotator cuff, and osteoporosis. Several studies have clearly shown that the results of arthroplasty for secondary treatment of malunion are inferior to those of primary treatment, especially when a corrective osteotomy is necessary [35, 37–41]. Functional outcomes are lower and complications higher when arthroplasty is performed for the sequelae of proximal humerus fracture malunion [35, 37–44]. Truly, the better goal is to avoid the malunion if possible, as careful and close evaluation of initial fracture patterns and close patient follow-up can reduce the incidence of this devastating and technically challenging complication.

The main three types of malunions described by Beredjiklian et al. include: malposition of the tuberosities, incongruity of the articular surface, and malalignment of the tuberosities and humeral head relative to the shaft [43]. Upward pull of the greater tuberosity can lead to abutment against the acromion, limiting elevation. Posterior displacement can lead to abutment against the glenoid and can limit external rotation. Both positions can lead to a shortened and contracted rotator cuff. Varus or valgus deformities of the humeral head in the frontal plane can change the normal structural

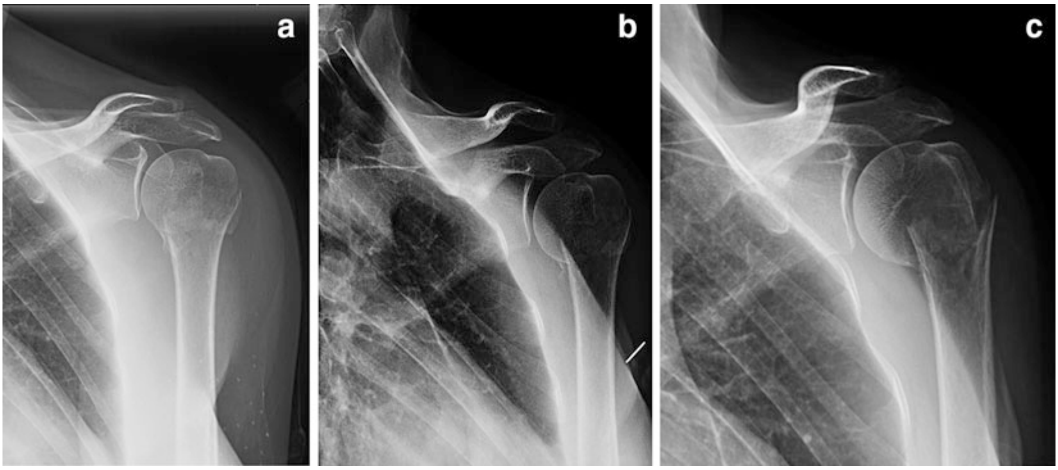

Fig. 9.5 (**a**–**c**) Example of an initially minimally displaced surgical neck proximal humerus fracture (**a**). Imaging 1.5 weeks after injury (**b**) shows that the humeral head is slipping into a varus position. Imaging 3 weeks after injury (**c**) shows and even more varus position of the humeral head

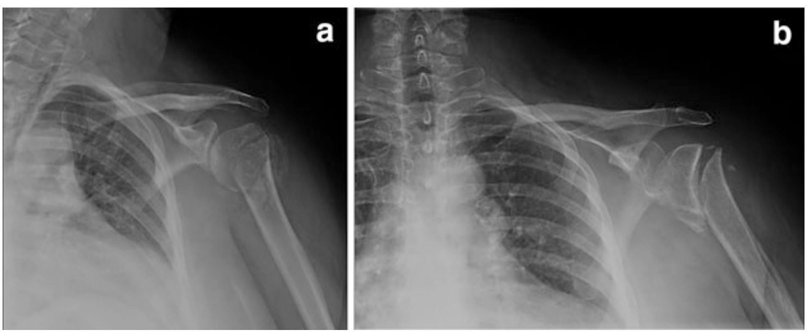

Fig. 9.6 (**a** and **b**) Radiograph (**a**) of a surgical neck fracture that is minimally displaced in a patient with preexisting glenohumeral arthritis, best seen on this AP image. Six months later, X-rays (**b**) show a clear nonunion has developed, as the glenohumeral joint is contracted due to the arthritis and motion was likely through the fracture site, predisposing it to nonunion

relationships within the glenohumeral joint. This can alter joint mechanics, increase contact forces within the joint, and result in areas of greater stress concentrations. Combined, these factors can lead to contractures, stiffness, and even predispose to head collapse [44]. Malunion due to a missed intra-articular fracture can lead to secondary arthritis within the glenohumeral joint.

Malunion is more commonly seen in two-part fractures, as displaced three- and four-part fractures are more likely to undergo early surgery. When a malunion of a three- or four-part does occur, it is often quite severe, with substantial distortion of anatomy, requiring quite complex surgery. In general, 10 mm of displacement is typically recognized as the threshold for acceptable displacement of a greater tuberosity fracture, although less displacement is accepted in more active patients. The deltoid force required for abduction is significantly higher when the greater tuberosity is displaced more than 5 mm and painful impingement and loss of function is less tolerated in the more active population [45]. Malunion between the humeral head and shaft is often tolerated well and can surprising lead to decent functional outcomes, especially in the elderly. If the passive range of motion can be maintained, the joint is congruent and the rotator cuff is intact, these can be tolerated well and function preserved. However, it has been shown that if the malalignment is more than 45° between the humeral shaft and

Fig. 9.7 (**a** and **b**) AP X-ray (**a**) of a 44-year-old male 3 years after a proximal humerus fracture that was treated nonoperatively due to his mild mental retardation. Unfortunately the AP view shows the humeral head healed in a varus position, allowing impingement of the greater tuberosity with attempted elevation. Axillary view (**b**) shows the posterior malunited position of the greater tuberosity

the articular segment, there could be an unacceptable loss of forward elevation and abduction [43, 46–48].

When patients present with a symptomatic malunion, pain and loss of motion are the primary complaints. A careful exam should be performed, with attention to impingement and biceps signs. If passive external rotation is very limited, often there is a bony block to mobility, such as a very posterior greater tuberosity impinging against the glenoid (Fig. 9.7). In the worst-case scenario, the posterior greater tuberosity can impinge on posterior glenoid with external rotation and almost lever the humeral head anteriorly, leading to anterior instability. Further, strength testing can show rotator cuff weakness as the external rotators have been placed in a position that shortens and contracts the muscle tendon unit, leading to decreased strength. Likewise, cuff pathology can develop due to superior displacement of the greater tuberosity attritionally breaking down the superior cuff. Painful biceps pathology may also occur due to malunion of the bicipital groove and can be a substantial pain generator.

The most common errors during diagnosis occur with improper evaluation of the fracture pattern. The AP view will allow determination of the neck-shaft angle and the degree of humeral head varus or valgus. The scapular lateral and AP view allow assessment of the height of the greater tuberosity, and the axillary view is instrumental in evaluating the posterior displacement of the greater tuberosity as well as position of the bicipital groove. A CT scan with three-dimensional (3D) reconstructions is the best option to understand the complex anatomy of the presenting fracture as well as a malunion [39, 49]. For the presenting malunion, this can be helpful in determining if the greater tuberosity is healed to the shaft (more manageable) or if it healed to the posterior humeral head or even posterior glenoid. In these cases it can be virtually impossible to restore normal anatomy because of the severe shortening of the cuff. Tuberosity osteotomy is a formidable undertaking and in general should be avoided at all costs. Even after proper technique, mobilization of the tuberosity and achievement of a successful union is exceptionally challenging [35, 50]. Prosthetic arthroplasty is the primary treatment when there is joint incongruity and secondary arthritic changes are present, preferably without an osteotomy. However, for symptoms due primarily to the malunion of the greater tuberosity, minimally invasive techniques represent a viable treatment option [51, 52].

Malunion of a proximal humerus fracture at times is anticipated if the patient was a poor surgical candidate. In these cases, if function is adequate and pain tolerable, the patient likely can avoid surgical intervention. However, many times development of a malunion is due to failure to appreciate the extent of displacement, lack of adequate radiographs, or lack of adequate follow-up radiographs to detect displacement of initially nondisplaced fractures. Overzealous or premature rehabilitation and range of motion of an initially nondisplaced fracture can also lead to malunion. Soft tissue interposition such as the long head of the biceps could also be a factor contributing to the malunion. In general, though, it is preventable with proper initial evaluation and follow-up as proper initial treatment has the best chance of achieving a successful outcome.

Posttraumatic Arthrofibrosis

Posttraumatic stiffness, especially after a minimally displaced fracture pattern and not actually loss of motion due to a malunion, is an avoidable complication. Of course, the lower demand the patient, the better tolerated the complication. However, as expected, it is not well tolerated in the young active patient. The most important factor is avoidance of prolonged immobilization, which has been shown to be of no value [10]. Functional recovery has been shown to be much better when a structured physical therapy program starts early [25, 53]. Especially in those with a stable fracture pattern, early protected mobilization is imperative and pendulums, hand, wrist and elbow motion can be started as soon as comfort allows. Passive mobilization of the shoulder can occur when the fracture is "sticky" and moves as a unit, typically by 3 weeks post injury. However, one should be sure that the loss of motion is not due to some other reason, such as missed greater tuberosity fracture blocking motion, and careful attention should be given to proper radiographs to assure this.

Missed Pathology

When a greater tuberosity fracture occurs, especially if isolated, the fragments are often small and comminuted and can deemed as unimportant to examiners who do not realize that these fragments contain the attachment of the rotator cuff. They can also be misinterpreted as calcium deposits (Fig. 9.8) [54]. Even if the fragment is not displaced, when small enough, joint fluid can intercede between the fragment and the cuff footprint and lead to nonunion and eventual resorption of the fragment. One should hold a high index of suspicion for these patients, especially if radiographs appear unchanged yet the patient continues to complain of pain and symptoms similar to rotator cuff pathology. MRI can be helpful in detecting these fragments initially or later showing the eventual cuff pathology so proper treatment can occur (often at this point, a formal cuff repair) (Fig. 9.9). Further, even if it is not small, the greater tuberosity fracture can be missed if the proper X-rays are not obtained. At times, the greater tuberosity can be pulled out of sight on the AP view. A critical eye can evaluate the AP film and notice that the greater tuberosity is not present, and then pick it up on an axillary and scapular lateral view. If it is missed, this can lead to a painful malunion as described above (Fig. 9.10).

Fig. 9.8 AP X-ray of a greater tuberosity fracture that was originally missed as the avulsed tuberosity was thought to be calcium deposits. Reprinted with permission from Warner JJ, Iannotti JP (eds.) *Complex and Revision Problems in Shoulder Surgery*. Philadelphia, PA: Lippincott Williams & Wilkins, 2005

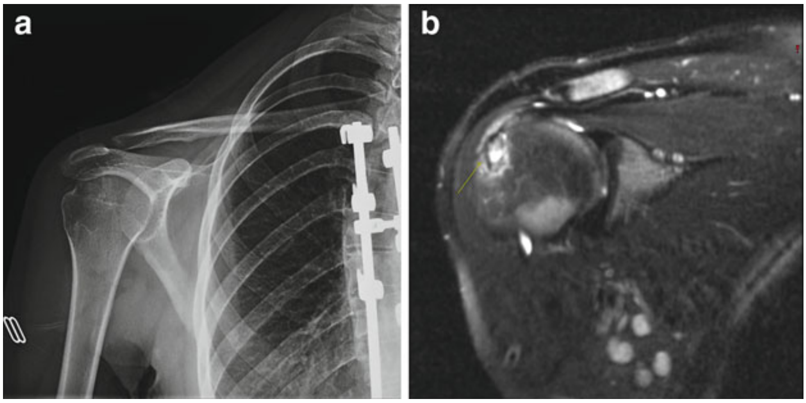

Fig. 9.9 (**a** and **b**) AP X-ray (**a**) of a 22-year-old female, 1 year after falling down the stairs and at that time, was diagnosed with a non-displaced greater tuberosity fracture. The patient was treated nonoperatively, but persisted with substantial pain consistent with rotator cuff pathology. MRI (**b**) confirmed the avulsion fracture of the greater tuberosity, but the small bone fragments had resorbed and essentially, the rotator cuff was no longer attached. This was confirmed at arthroscopy and repaired like a standard rotator cuff

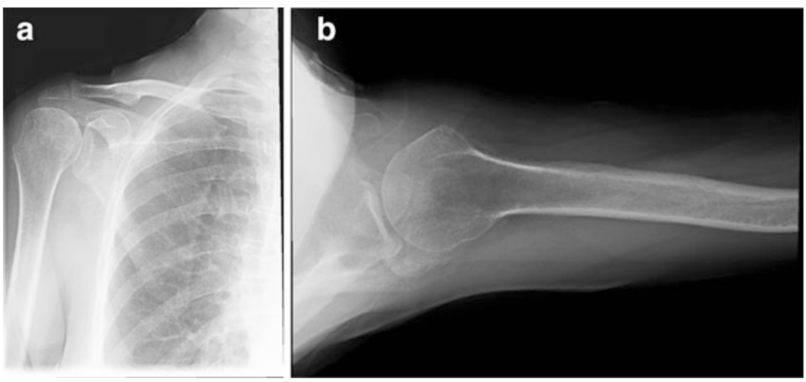

Fig. 9.10 (**a** and **b**) AP view (**a**) of a patient with a missed greater tuberosity fracture. Close evaluation will show though, that the normal outline of the supraspinatus facet is missing and the humeral head is sitting slightly high. Axillary view (**b**) shows the greater tuberosity fragment had malunited and healed to the posterior aspect of the glenoid

Posttraumatic Arthritis

Posttraumatic glenohumeral arthritis is most often related to missed intra-articular pathology, such as a humeral head split that subsequently healed in a malunited position. As above, it can also occur after a two-part malunion in which the joint contact forces are altered by a more varus positioned humeral head and arthrosis ensues (Fig. 9.11). Arthritic change typically takes much longer to progress, and patient symptoms may present many months to years down the road from the initial injury. At times, it presents subsequent to the actual traumatic impact itself. Except in the cases of joint incongruity and malunion, it truly is not preventable, and this should be explained to the patient initially as a possible long-term consequence of the initial fracture.

Complications of Operative Management of Proximal Humerus Fractures

As well stated by Murray et al., in their paper on proximal humerus fractures, "complications may occur as an inevitable consequence of the

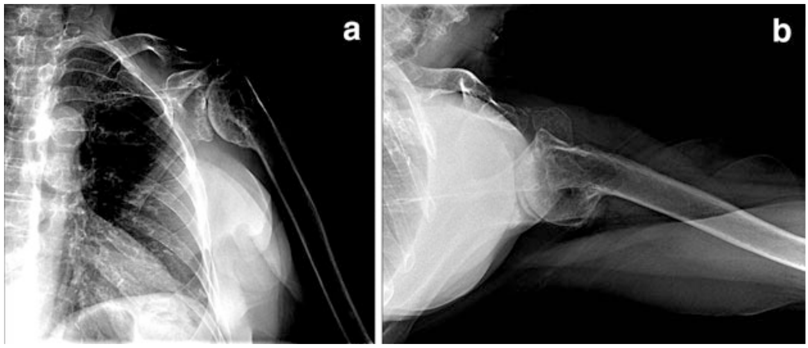

Fig. 9.11 (**a** and **b**) AP view (**a**) of a long-standing varus malunion of a proximal humerus fracture that has led to long-term glenohumeral arthritis. Axillary view (**b**)

original injury, or as a result of errors in treatment" [11, 46]. Unfortunately, more often than not, "errors in treatment" are the more prevalent reasons for operative complications. One must remember that at times, operative treatment of proximal humerus fractures is not any better than nonoperative treatment. There truly is not a consensus on best practices for treatment of proximal humerus fractures [55, 56]. Thus, one must take into account all patient factors and medical comorbidities when considering surgery. For instance, if a patient may not be able to participate in postoperative physical therapy, then operative management may be unwise. If the surgeon chooses to intervene surgically it should be because substantial enough improvement is expected that the risks of surgery are worthwhile, and risks should be minimized. Nonetheless, certain fracture patterns do require surgery, and unfortunately, complications and poor outcomes can occur even when surgery was well indicated.

Failure of Open Reduction and Internal Fixation (ORIF) Osteosynthesis

It has recently been shown that since the introduction of locking-plate technology for treatment of proximal humerus fractures, the relative rate of osteosynthesis in the United States has increased 25.6 % from 1999 to 2000 and 2004 to 2005. However, also significantly increased is the rate of revision surgical procedures to correct failure of osteosynthesis ($p = 0.043$) [55]. As locking-plate technology has really expanded the indications for ORIF in osteoporotic bone, there have been many reports on the outcomes and high complication rates [55–64]. Complication rates vary and are reported as high as 49 %, with the rate of revision surgery up to 25 % in some studies [55–70].

Most complications occur intraoperatively and have been reported to be present upon the treating surgeon leaving the operating room. One prospective, multicenter study evaluated 155 patients within the first postoperative year [64]. The authors reported a 34 % overall complication rate, and 40 % of these were present at the conclusion of the surgery, with the most common complication noted being screw perforation of the humeral head. These findings were supported by Zhu et al., who also noted screw perforation as the most prevalent complication leading to revision surgery [70]. Other complications include varus malunion, inadequate fixation, malreduction, loss of reduction/hardware failure, osteonecrosis, plate impingement, infection, and nonunion [59, 63]. Unfortunately, these complications can be quite devastating and many lead to subsequent surgeries. Jost et al. recently looked at a negatively selected population of 121 patients treated for complications after ORIF with locking plates [59]. They reported that the complications resulted in an 88 % revision rate, and secondary arthroplasties were placed in more than 50 % of the patients. A worrisome finding was the high rate of screw cut out, especially in the cases of avascular necrosis (AVN), which led to subsequent destruction of the glenoid (Fig. 9.12).

Many of the common complications are preventable problems, primarily rectified by

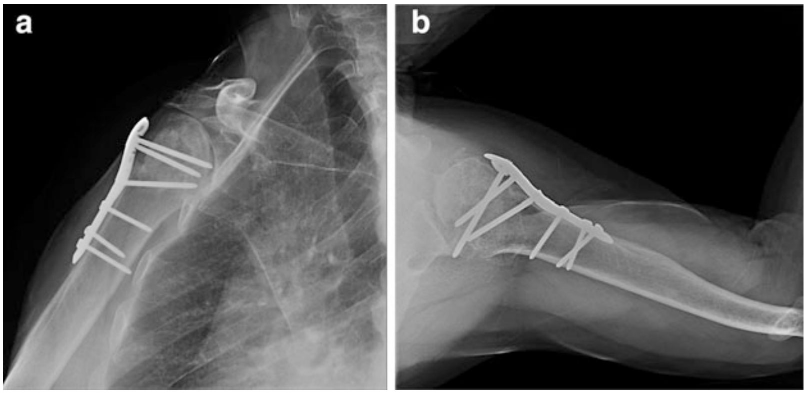

Fig. 9.12 (**a** and **b**) One year after a four-part proximal humerus fracture was treated with ORIF in a sedentary, 74-year-old male. AP view (**a**) shows the onset of AVN, collapse of the humeral head and resorption of the tuberosities. Axillary view (**b**) shows penetration of the humeral head with the screws and subsequent arthrosis of the glenoid

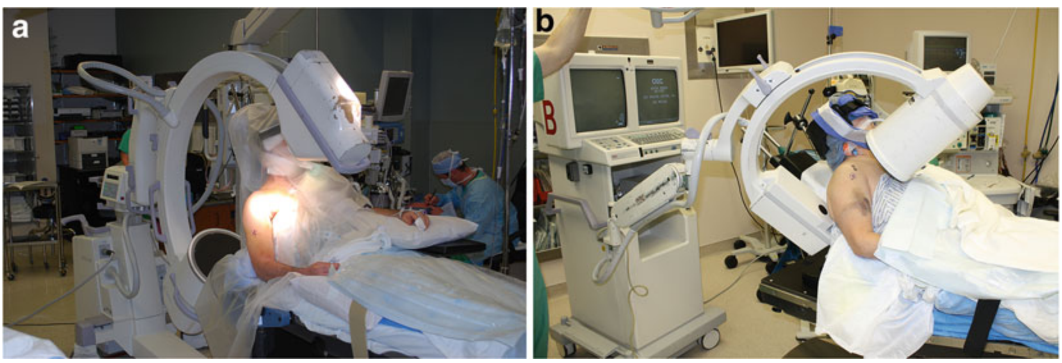

Fig. 9.13 (**a** and **b**) Appropriate intraoperative use of the C-arm is crucial to success of ORIF (**a**). Positioning of the C-arm is key, shown here is the large C-arm. Positioning when using the mini-c-arm (**b**). Reprinted with permission from Lee D, Nevasier RJ. *Operative Techniques: Shoulder and Elbow Surgery*. New York: Elsevier, 2010

understanding the anatomy and obtaining accurate imaging intraoperatively. Having an appropriate understanding of patient positioning and use of intraoperative C-arm image intensification can help avoid some of these issues (Fig. 9.13). Adequate intraoperative imaging will enable appropriate screw length and appropriate plate placement, such that it is just below the level of the supraspinatus facet of the greater tuberosity (Fig. 9.14). Hasty decision making and inadequate time spent gaining proper exposure can lead the surgeon to miss pathology, primarily not reducing or inadequately reducing the greater tuberosity, which in turn can lead to malunion or nonunion of the greater tuberosity and subsequently poor function (Fig. 9.15). Further,

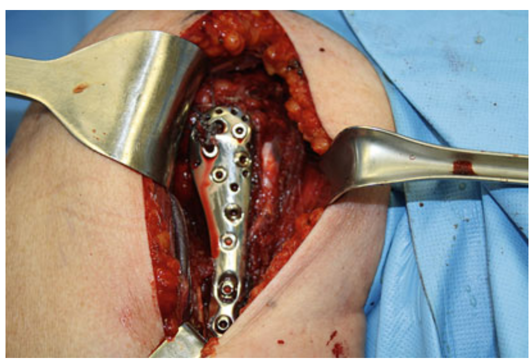

Fig. 9.14 Intraoperative view of appropriate plate positioning, which must account for the thickness of the rotator cuff when visualizing plate position and plate should be just below the supraspinatus facet. Reprinted with permission from Lee D, Nevasier RJ. *Operative Techniques: Shoulder and Elbow Surgery*. New York: Elsevier, 2010

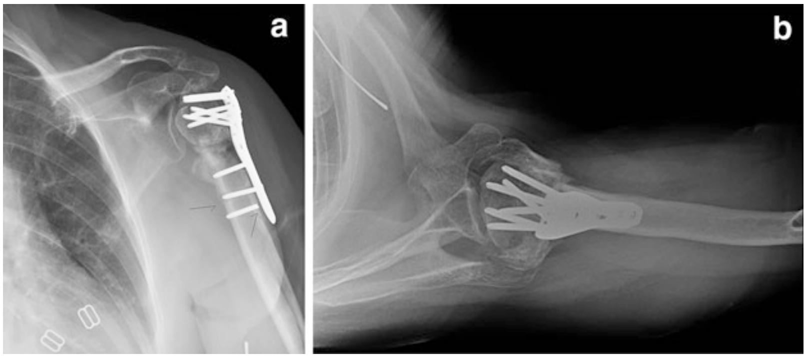

Fig. 9.15 (**a** and **b**) AP X-ray (**a**) of a painful nonunion in which the humeral head was plated in extreme varus and the motion at the fracture site led to hardware failure. Axillary view (**b**) shows malreduction of the tuberosities as well. Often, more than one area of failure exists with the complex complications of ORIF

underestimating the degree of displacement of the fracture pattern and the effect this can have on blood supply can contribute to failures. The reported rates of AVN for three- and four-part fractures, respectively, after ORIF are 12–25 % and 41–59 % [26–28]. Elderly, osteoporotic patients with a displaced four-part fracture are at high risk for failure of ORIF; thus, these patients may be better suited with arthroplasty initially. Secondary arthroplasty has been shown to yield inferior results to primary arthroplasty, thus a surgeon's first surgery is typically the best [65]. It is more appropriate to attempt ORIF in a younger patient in an attempt to save the native humeral head, although at times, this still may not be successful (Fig. 9.16).

Under-recognition of the degree of osteoporosis can also be associated with fixation failure [60]. Close evaluation of local bone density must be undertaken prior to embarking on plate fixation, especially appraising the degree of bone loss and comminution of the medial column. Medial bone loss has been well recognized in the literature to predispose to plate failure, especially in the patient with an initial varus fracture deformity [67–69]. In particular, if a patient undergoes surgery several weeks after injury, there is often an increased degree of calcar bone loss and cavitation of the humeral head, contributing more to potential fixation failure. In an effort to maintain a reduced position for the humeral head and prevent varus collapse, Gardner et al. have recommended meticulous placement of a superiorly directed oblique locking calcar screw (the so-called "home run" screw) and achieving an either anatomic or slightly impacted reduction [66]. Bone augmentation has been supported in the literature to help maintain medial cortical support, and early results are promising. Use of an endosteal strut allograft has been shown to reestablish medial support and allow a joint-preserving surgery even in comminuted and osteoporotic bone [71–73]. Autologous iliac bone impaction grafting has also been shown to yield excellent results in a small study of 21 patients but certainly larger future studies are needed (Fig. 9.17) [74].

Failure of Percutaneous Fixation Osteosynthesis

Minimally invasive treatment of proximal humerus fractures has become more prevalent in an effort to preserve the humeral head, but avoid the complications associated with ORIF. Advocates of this technique cite the main advantage is the preservation of blood supply due to decreased soft tissue stripping, in addition to a more cosmetic scar and decreased intraoperative blood loss. However, many view this as a technically demanding procedure, and care must be taken to have a thorough understanding of the fracture pattern [75–78]. Failure to recognize the true degree of displacement can lead to a higher rate of avascular necrosis and thus every effort should be made to achieve an anatomic reduction. Studies with shorter term follow-up report a

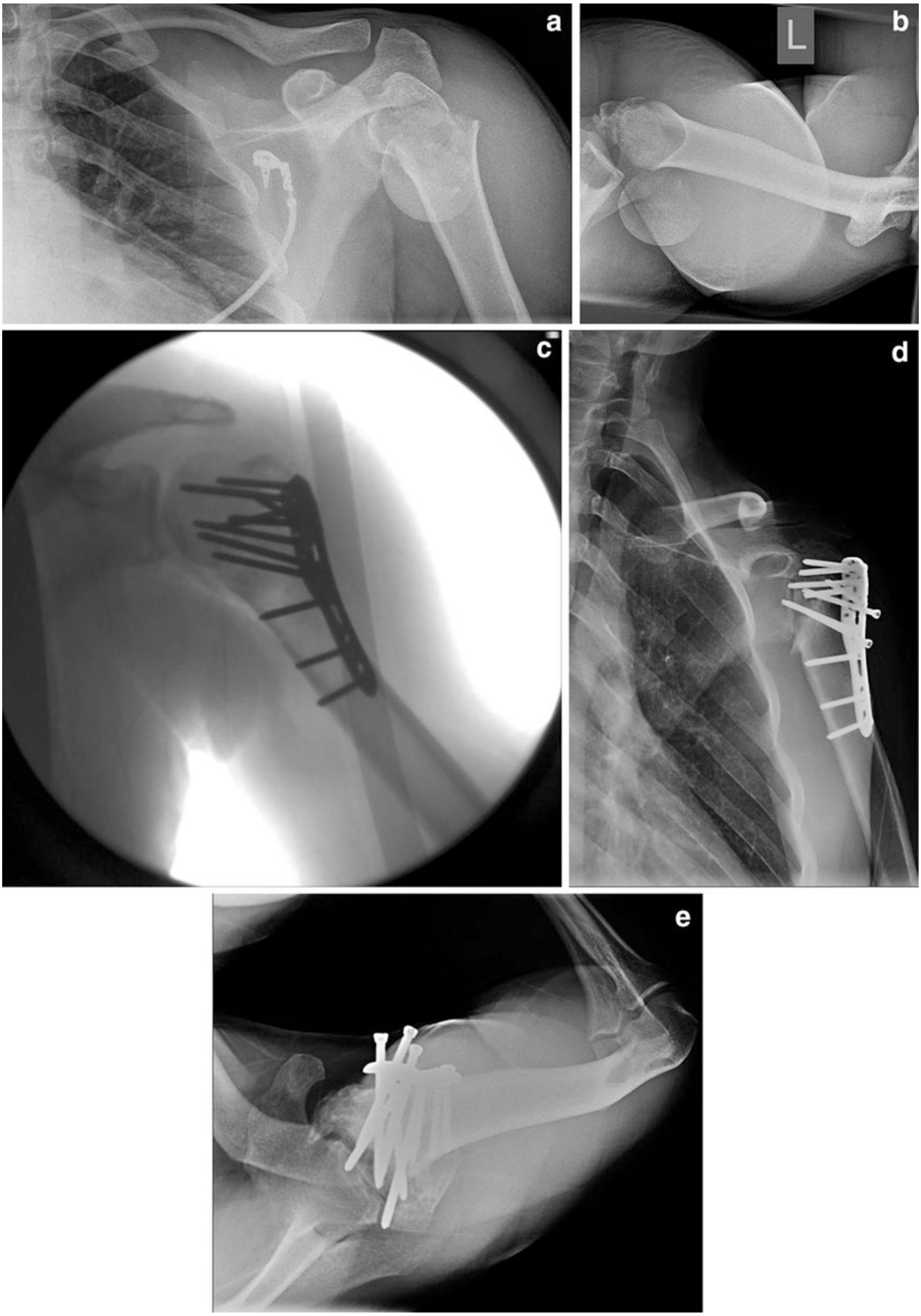

Fig. 9.16 (**a**–**e**) AP view (**a**) of a 32-year-old male, presented with a fracture-dislocation after a high speed motor vehicle accident. Axillary view (**b**). A valiant attempt was made to preserve the humeral head and proceed with reduction and ORIF (**c**). Unfortunately, the patient presented 5 years postoperatively with the complaint of extreme pain and poor function. The humeral head had completely collapsed as seen on this AP view (**d**). The screws had unfortunately at this point, caused substantial damage to the glenoid (**e**)

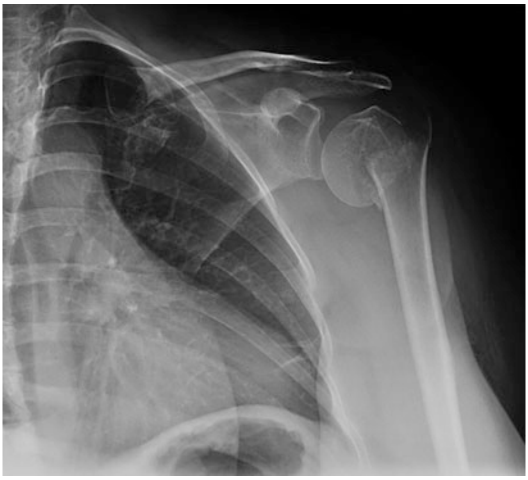

Fig. 9.17 AP radiograph of an acute fracture, in an active 58-year-old female, that presented in substantial varus with some medial comminution. This fracture pattern should be considered the at-risk pattern for failure of ORIF back into a varus position

lower rate of AVN, varying between 4 and 16 % [75, 78–82]. However, a more recent study evaluated the longer term outcomes and reported a 26 % AVN rate at a mean of 50 months after surgery, with 50 % of the valgus-impacted four-part fractures showing osteonecrosis. Posttraumatic arthritis was present on the radiographs of 37 % of the patients, with a higher prevalence in those who had four-part fractures [77]. However, they found that for many, the osteonecrosis was tolerated well and did not uniformly lead to revision surgery. Thus, although over time a higher rate of osteonecrosis presented, they found the functional outcomes remained stable. Other complications of percutaneous pining include failure of fixation, malunion, nonunion, pin migration, infection, and neurovascular injury [78]. Careful assessment of the fracture pattern, an appreciation of the degree of osteopenia, and a thorough understanding of intraoperative techniques to aid in reduction of the fracture will best prepare the treating surgeon to minimize avoidable complications.

Arthroplasty Complications

Traditionally, a humeral head replacement (HHR) with tuberosity reconstruction has been considered the gold standard when operative treatment is undertaken for complex fractures in which ORIF is not feasible. However, the literature has been wrought with poor outcomes, and the early reported results of Neer could not be replicated [83–86]. In recent years, more attention has been given to performing a reverse shoulder arthroplasty (RSA) for these complicated fractures, especially in older patients with preexisting rotator cuff deficiency or comminuted, osteoporotic tuberosities [87–90]. However, there is not yet a clear recommendation for one procedure over another, and complications are prevalent with both forms of treatment. Many of these complications can be avoided with meticulous attention to surgical detail.

When performed for a complex fracture, HHR is considered a technical challenge, even when performed by the most seasoned shoulder surgeon. The most common complications include tuberosity malunion/nonunion/pull-off, stiffness, rotator cuff dysfunction, instability, glenoid arthrosis, component malpositioning, heterotopic bone, and infection [83–86, 91]. Reasons for failure are often multifactorial, with both patient and surgeon based factors contributing. Patient-based factors include patient age (≥75 years), female gender, and osteoporotic tuberosities [86, 92]. Clinical outcomes ultimately depend on the function of the rotator cuff [86]. Therefore, appropriate tuberosity position, avoidance of subsequent displacement, and obtaining tuberosity healing is paramount. Anatomic positioning of the tuberosities first hinges on placing the prosthesis at the appropriate height. Careful preoperative planning and appropriate intraoperative landmarks should be sought when positioning the humeral stem [93–95]. The superior border of the pectoralis major tendon can be used as a guide, as the top of the humeral head has been shown to be approximately 5.6 cm above this [94]. When the stem is placed too proud, the tuberosities are at greater risk for detachment and then subsequent impingement of the migrated prosthesis against the acromion [85]. This impingement can be quite painful and is often not well tolerated, leading to revision surgery (Fig. 9.18). Even when the stem is placed anatomically, over-

Fig. 9.18 Proud cemented component, placed for a four-part proximal humerus fracture in an active 63-year-old female. Tuberosities are not visualized as they had pulled off and resorbed. The patient complained of pain and lack of function

reduction or under-reduction of the tuberosities can still occur. If the tuberosity is over-reduced in an effort to obtain bony overlap for healing, too much stress can be placed on the rotator cuff tendon and lead to dysfunction. However, if under-reduced and the tuberosities are proud, not only can they impinge against the acromion and limit motion, but also they are more apt to proceed to a nonunion due to lack of bony contact for healing. Tuberosity placement 10–16 mm distal to the superior margin of the prosthetic head has been shown to be the best position to obtain optimal elevation and rotation [96]. Recently, the use of a fracture specific stem has been shown to double the rate of tuberosity healing compared to a conventional stem [92, 97]. In addition, tuberosity fixation and healing can be augmented with cancellous bone from the humeral head, and the use of cable wire has been advocated as well [98]. Finally, many advocate delay of aggressive shoulder motion and rehabilitation until there is radiographic evidence of tuberosity healing [83].

Appropriate landmarks should also be obtained to aid in choosing the appropriate version for the prosthesis, as inaccurate version can contribute to tuberosity failure and instability. The bicipital groove is a consistent landmark, and it has been shown that 30° of retroversion can be reproducibly obtained when placing the lateral fin of the prosthesis 30° posterior to the groove [99]. When using the epicondylar axis to set humeral version, a prior elbow fracture malunion or a destructive arthritic condition, such as rheumatoid arthritis, can lead to a misjudgment of version. This should be evaluated prior to surgery. Often the humeral component is placed in excessive retroversion for fear of anterior instability. However, this overcompensation can cause the greater tuberosity to pull-off when the arm is internally rotated. Again due to the fear of instability, an oversized humeral head is utilized at times (Fig. 9.19). However, this will essentially "overstuff" the joint and place a strain on the rotator cuff and lead to tuberosity failure and rotator cuff dysfunction. Every effort should be made to re-create the most anatomic construct.

Given the uncertain outcomes when HHR is performed for fracture, especially the tuberosity related complications and associated rotator cuff dysfunction, RSA has recently become a more prevalent alternative [88, 100]. RSA does not rely on anatomic tuberosity healing for functional outcomes and in addition resurfaces both the humerus and glenoid, thus avoiding pain from glenoid arthrosis or proximal migration of the humerus. However, potential deterrents have been the perceived risk of increased complications [101, 102]. The risks associated with RSA in general are well known and documented, including instability, infection, scapular notching, hematomas, intraoperative fractures, component loosening, component disassembly, postoperative humeral fractures, acromion stress fractures, and neurologic injuries [103]. Of course, these RSA-specific complications can all potentially occur after a RSA is placed for a humeral fracture. A recent systematic review, evaluating HHR versus RSA

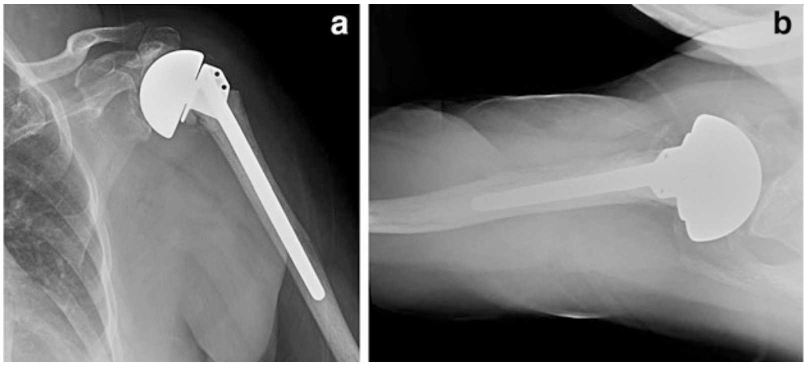

Fig. 9.19 (**a** and **b**) AP radiograph of an HHR that was placed for a four-part proximal humerus fracture. The humeral head is clearly too large, which led to tuberosity failure and poor function and pain

for fracture, reported that the complications were not substantially different between the two groups [90]. There were more dislocations in the RSA group, as well as scapular notching, but a 23 % incidence of tuberosity complications in the HHR group. This study only included data on HHR for fracture when it was compared directly to RSA, and no long-term data was available regarding the RSA group. Another recent systematic review did show a higher clinical complication rate in the RSA group [104]. However, this study did include data for case series in which HHR was performed alone for fracture.

There are a few key points though, that are more relevant to when a RSA is placed for fracture versus the traditional cuff arthropathy. Although it is clear, forward elevation after a RSA is not dependent on tuberosity healing or positioning, the ability to externally rotate is. Overall function and the ability to perform activities of daily living are considerably enhanced when external rotation is intact. The treating surgeon must make an attempt to securely fixate the greater tuberosity with the attached infraspinatus and teres minor to the humeral shaft. The positioning is not nearly as critical as when reattaching for an HHR, and the goal is to place it in a position that will allow healing. In addition, if no attempt is made to repair the tuberosities, this proximal bone loss places the prosthesis at higher risk for instability, one of the most common complications. Finally, the treating surgeon should be wary of the comminuted greater tuberosity that leaves many pieces of bone adherent to the posterior capsule. If large enough, these fragments can lead to instability as they impinge against the humeral prosthesis and lever it out anteriorly. Every attempt should be made to check for this and remove any significant fragments.

When considering the complications of RSA versus HHR, the reader should be aware that while tuberosity resorption is considered a complication when reviewing outcomes after HHR for fracture, the resultant poor function is often tolerated well in the low-demand elderly patient [105, 106], while a complication such as a dislocation after a RSA typically requires a return trip to the operating room, which is truly a more catastrophic complication, especially in an elderly patient with medical comorbidities. Thus, essentially, all complications are not equal, and this should be factored in to the risk–benefit analysis during treatment decision making for these types of fractures.

Infection

Thankfully, given the rich vascularity and muscle coverage of the proximal humerus, infection is relatively rare after fixation of shoulder fractures. When deep infections present early, invariably there are more classic signs that may involve wound breakdown, drainage, erythema, and at times, constitutional symptoms. If ORIF was performed or the implant is stable, often these can be treated with surgical debridement

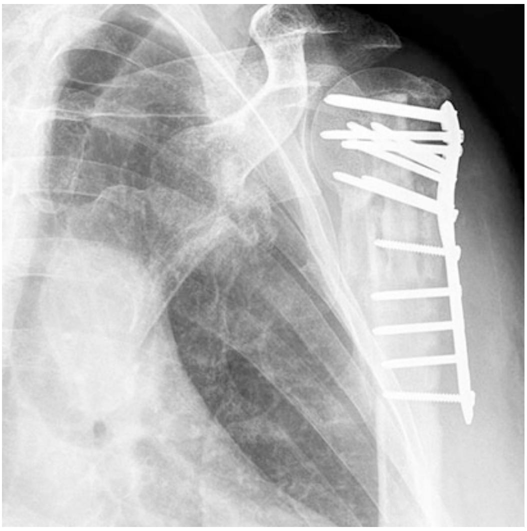

Fig. 9.20 AP radiograph of a revision ORIF, performed 2 weeks after the index procedure had failed catastrophically. When revised, a fibular allograft strut was utilized. Seven months later, the patient was complaining of worsening pain. Lab values were all elevated. X-ray shows bone resorption distally as the plate pulls away from the bone. Gross infection was found at the time of surgery with substantial bone loss

Fig. 9.21 A 64-year-old female presents 1 year after a HHR was placed for fracture. Tuberosities had clearly resorbed likely due to an oversized humeral head, and thus the patient had clear reasons for pain and dysfunction. However, lucency around the cement mantle raised the suspicion for a coinciding infection, which was proven at the time of surgery with frozen sections and positive cultures

and a prolonged course of antibiotic therapy [107]. For the more prolonged, indolent infections which do not present with the classic signs, an index of suspicion should always be maintained. When a patient presents with persistent pain of unclear etiology after any surgical intervention in the shoulder, infection should always be diligently ruled out. *Staphylococcus aureus*, *S. epidermidis*, and *Propionibacterium acnes* (*P. acnes*) are the most commonly isolated organisms from the cultures of postoperative shoulder infections [108, 109]. *P. acnes*, in particular, is a slow-growing pathogen with a particular propensity for the shoulder and is being reported with increasingly frequency as the cause of chronic, indolent shoulder infections. Unfortunately, the clinical symptoms are often subtle, and diagnosis is often based on presumption. Appropriate lab workup includes a white blood cell count (WBC), an erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). The WBC is rarely elevated and even in a chronic deep infection is often normal. The ESR and CRP are nonspecific markers of inflammation and can be unremarkable in cases of *P. acnes* infection. Joint aspiration is potentially helpful, however, the anaerobic cultures must be held for 10–14 days in order to potentially detect *P. acnes*. An indium-labeled WBC scan is utilized at times, although its variable sensitivity and specificity can make result interpretation difficult. Radiographs should be carefully evaluated for any signs of radiolucency or unexpected bone resorption (Fig. 9.20). However, even when clear reasons for persistent pain exist, such as implant failure or malposition, infection still must be considered, as often there are multiple issues contributing to the patients' pain and dysfunction (Fig. 9.21). When revising any prior shoulder surgery, intraoperative frozen section and cultures should always be obtained. However, one should note that in the case of *P. acnes*, the results of the frozen section are not always conclusive [110]. A recent study by Grosso et al. has shown that the sensitivity of frozen section histology is lower for *P. acnes* compared to other infection groups, although the specificity is 100 %. They recommend a threshold of a total of ten or more polymorphonuclear leukocytes in five high-power fields in an effort to increase the sensitivity of frozen section [110].

Conclusion

Complications after nonoperative and operative management of proximal humerus fractures unfortunately occur, although overall the incidence is low. The treatment of proximal humerus fractures can be considered an "art" as minimal Level 1 evidence exists to guide the treating surgeon not only in selecting patients for surgery, but the best technique to use when surgery is undertaken. Therefore, the treating surgeon should continually strive to hone his or her skills as the majority of complications are avoidable with diligent patient evaluation, close follow-up, thoughtful decision-making, and meticulous surgical techniques.

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Evaluation and Management of Proximal Humerus Nonunions and Malunions

10

Dale Nicholas Reed

Proximal Humerus Nonunions

The management of proximal humerus nonunions can be challenging for even the most experienced shoulder surgeon. To adequately diagnose and properly treat proximal humerus nonunions the surgeon must understand the potential causes of the nonunion, different types of nonunions, and available literature on the treatment to provide the best outcome for both patient and surgeon.

Weber and Cech published the first classification system for nonunions [1]. They classified nonunions into either hypertrophic or atrophic nonunions depending on vascularity of bone ends. Hypertrophic nonunions have adequate blood supply and nutrients to heal the fracture but no mechanical stability. Atrophic nonunions lack an adequate blood supply and therefore the nutrients for bony healing.

Clinically a nonunion is defined as the lack of bony healing based on both clinical exam and radiologic studies. The Federal Drug Administration (FDA) has defined a nonunion as a fracture that is greater than 9 months old and has not shown radiographic signs of progression toward healing for three consecutive months [2]. Proximal humerus nonunions have been defined in the literature as early as 6 months after injury and many support treatment as early as 3 months after the fracture if there is suspicion for nonunion to avoid poor clinical outcomes with delayed treatment [3].

Nonunions of the proximal humerus have been noted with both operative and nonoperative treatment of these fractures. The development of a proximal humerus nonunion can lead to persistent pain, limited mobility, and can affect the patient's quality of life. Most proximal humerus fractures are minimally displaced and heal uneventfully with nonoperative treatment [3, 4]. Nonunion rates with nonoperative treatment have been noted to be as low as 1.1–2 % in studies that included 1,027 and 650 patients treated nonoperatively [3, 4]. Nonunions of the proximal humerus after operative treatment have been shown to range between 0 and 7 % depending on type of fracture and fixation device utilized [5–9].

Pathoetiology

Nonunions typically do not occur because of only one variable, but are the result of multiple underlying factors. Specific fracture characteristics that may lead to nonunion are associated soft tissue injury, high energy fractures, soft tissue interposition, pathologic fractures, prior radiation to affected area, and fractures that were inadequately managed either operatively or nonoperatively. Patient factors may also contribute to the formation of a

D.N. Reed (✉)
Department of Orthopedics, Associates in Orthopedics and Sports Medicine, 1104 Professional Blvd, Dalton, GA 30720, USA
e-mail: NickReed15@yahoo.com

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nonunion. These include advanced age, malnutrition, diabetes mellitus, metabolic bone disease, smoking or nicotine use, anti-inflammatory medication use, corticosteroid use, systemic disease, and infection [10]. Healy et al. noted that in 64 % of proximal humerus nonunions that one or more medical comorbidities were present prior to treatment [11].

Additional specific factors that have been determined to increase the risk of nonunion in the proximal humerus include two part surgical neck fractures, inadequate immobilization, early aggressive physical therapy, osteoporosis, loss of motion of the glenohumeral joint, distraction at the fracture site secondary to the weight of the arm, muscular forces acting on the proximal humerus, and proximal biceps interposition in the fracture [12, 13]. Court-Brown et al. identified an increased risk for proximal humerus nonunion if metaphyseal comminution was present with up to 33 % displacement of the surgical neck [3]. Inappropriate management either operatively or nonoperatively can lead to nonunions of the proximal humerus.

Treatment

Nonoperative Treatment

Nonoperative treatment has a role in the management of nonunions of the proximal humerus especially in patients with multiple medical comorbidities and or low functional demands. Not all proximal humerus nonunions are painful and for those elderly or medically challenged patients we would recommend nonoperative treatment. However, for patients who have painful nonunions and rely on the affected upper extremity for activities of daily living, operative management is an appropriate treatment.

Operative Treatment

Preoperative Evaluation

Prior to proceeding with operative intervention multiple steps need to be taken to ensure that the appropriate outcome is achieved. The goal of surgery is to provide mechanical stability and create a biologic environment conducive for bony union. A thorough patient history and physical examination is required. The history should provide an insight into the details of the initial injury and the severity or amount of energy required to cause the fracture. What prior treatments have been attempted either surgical or nonsurgical? How much pain and/or disability are perceived by the patient as this may change treatment recommendations? All preoperative medical comorbidities that can be treated or improved prior to surgery should be taken care of.

The physical examination is important when managing nonunions of the upper extremity: Inspection of the overlying skin envelope looking for any possible signs of infection, prior incisions, or any evidence of asymmetry with contralateral limb. Patients typically have very little active range of motion when dealing with a proximal humerus nonunion. Passive range of motion is typically increased as the examiner is moving the upper extremity through the nonunion. The neurovascular exam of the upper extremity should include evaluation of the axillary and musculocutaneous nerves. Electrodiagnosic testing (EMG) may be required if there are questions regarding the nerve function of the proximal humerus. Vascularity of the upper extremity should be documented prior to proceeding to the operating room especially in posttraumatic cases where previous surgery has been performed.

Preoperative imaging should include a standard trauma series which includes a true AP of the shoulder, axillary lateral, and scapular Y view. The radiographs should be evaluated for evidence of nonunion, malunion, osteoarthritis, infection, and avascular necrosis of the humeral head. Any prior treatment in the form of hardware or arthroplasty should be carefully evaluated for signs of failure. Computed Tomography (CT) with three-dimensional reconstruction can provide further evaluation of bone loss and planning for reconstructive procedures. Magnetic Resonance Imaging may be needed to further evaluate the soft tissue around the shoulder and assist in identifying early avascular necrosis and possible infection not appreciated on plain films or CT scans.

Fig. 10.1 Proximal humerus nonunion with varus collapse noted after open reduction and internal fixation with screw penetrance into glenohumeral joint. Laboratory workup was equivalent and decision for two-stage procedure was made. Multiple cultures grew *P. acnes*

Suspicion for an infected nonunion must always be considered during preoperative evaluation. Infected nonunions are often missed preoperatively because they are often indolent in nature (Fig. 10.1). Appropriate laboratory workup should include a Complete Blood Count (CBC), Sedimentation Rate (ESR), and C-Reactive Protein (CRP). More advanced imaging can be ordered if the surgeon feels that it will be useful such as an MRI or Indium labeled white blood cell scan. The gold standard for diagnosing an infected nonunion is positive tissue or fluid cultures from a biopsy or aspiration of the nonunion site [14–16]. Always have the laboratory hold the cultures for a minimum of 2 weeks and specifically evaluate for *Propionibacterium acnes*. This organism lives in the sebaceous glands and hair follicles, and is a common pathogen in infections of the shoulder region.

Specific Proximal Humerus Nonunions

Tuberosity Nonunion

The literature on the management of tuberosity nonunions is small as the majority of tuberosity fractures heal, but often in a malunited position. However, when tuberosity nonunion does occur, pain and disability can be substantial. The primary difficulty in repairing tuberosity nonunions is the size and quality of the bony fragment that is remaining.

Greater tuberosity nonunions can lead to significant weakness, impingement, or both. The majority of the rotator cuff attaches to the greater tuberosity so a nonunion will render the rotator cuff incompetent and lead to a clinical situation that is similar to a large/massive rotator cuff tear [17]. The fragment is often displaced in a superior and posterior direction secondary to the pull of the rotator cuff. This superior displacement can lead to abutment with the overlying acromion and secondary impingement and pain.

Lesser tuberosity nonunions can also lead to significant pain and disability. The lesser tuberosity is the insertion site for the subscapularis and a nonunion can produce subscapularis insufficiency. The patient will often present with anterior shoulder pain and internal rotation weakness. The physical exam is similar to a subscapularis tear exam producing a positive belly press test and inability to do a lift-off test.

Repair of greater and lesser tuberosity nonunions can be surgically approached differently secondary to their respected location but the underlying principles remain the same. Greater tuberosity nonunions are approached from a lateral based deltoid splitting incision and lesser tuberosity nonunions are typically managed through a deltopectoral incision. The surgeon must be very careful in not causing any further damage to surrounding soft tissues that could lead to further devitalization of the fragment. If the nonunion is chronic the attached rotator cuff will often be scarred to adjacent tissue and must be released to allow adequate mobilization of the fragment and repair of the rotator cuff if required. The bone of the proximal humerus needs to be debrided to bleeding tissue to allow for healing of the tuberosity. If the fragment is of sufficient size and adequately mobilized, then either cannulated or non-cannulated screws with washers in a compression technique may be utilized. Care must be taken when performing the final tightening of the screws as the tuberosity fragment can be split or fragmented during fixation. If only one screw is possible then the repair can be augmented with suture fixation to surrounding rotator cuff or bony tunnels can be created in the proximal humerus for suture fixation. If the tuberosity fragment is of insufficient size to accept screw fixation an alternative is to excise the bony fragment and repair the rotator cuff to the proximal humerus using suture anchors or transosseous tunnels. The goal is to restore the rotator cuff to a bleeding bony bed for healing and restoration of rotator cuff function.

Fig. 10.2 Painful surgical neck nonunion in an 84-year-old female with cavitation of the humeral head and bone loss proximally

Surgical Neck Nonunion

Surgical neck nonunions are the most common nonunions of the proximal humerus and often accompanied by tuberosity malunion, avascular necrosis of the humeral head, and posttraumatic glenohumeral osteoarthritis increasing the difficulty of treatment [11, 12, 18–20] (Fig. 10.2). Treatment of surgical neck nonunions can be difficult secondary to poor bone quality, distorted or disrupted anatomy especially in cases with prior surgical treatment, extensive soft tissue scarring, and cavitation of the humeral head. Most patients present with pain and loss of function. Treatment options must include stabilizing the nonunion to allow boney healing by the use of intramedullary devices, plating systems, or arthroplasty.

Intramedullary devices have been and continue to be used to treat surgical neck nonunions. The initial reports showed favorable results in achieving union. Neer reported results using an intramedullary device and tension band construct with bone grafting and noted union in 12 of 13 patients [12]. Nayak et al. and Norris et al. used a similar technique and noted very favorable results with union rates of 80 % [21, 22]. However, the initial success was complicated by the mechanical impingement from these devices and secondary rotator cuff dysfunction. This led to the need for secondary surgical procedures to remove hardware and perform soft tissue releases in an attempt to restore function. Revision procedures have been noted to be as high as 80 %. This high revision rate has led many surgeons to discontinue the use of these early intramedullary devices in the treatment of proximal humerus nonunions. Newer intramedullary devices have been designed to minimize secondary surgical procedures and rotator cuff dysfunction. Yamane et al. followed 14 consecutive patients treated with interlocking intramedullary nailing and bone grafting for proximal humerus nonunion and noted 100 % union rate and improvement in clinical outcomes [23]. Overall, history has not favored the use of intramedullary nails and other fixation devices may provide better stability to promote bone healing.

Plate Fixation

Successful surgical treatment of proximal humerus nonunions has been well documented using plate fixation. Adequate bone stock to place the hardware, a viable humeral head, and the absence of glenohumeral arthritis are required. T plates were originally utilized with some difficulty in obtaining adequate stability in the remaining bone. This prompted the use of blade plates which required less bone for fixation proximally and the plate acting as a tension band construct that counteracts the force of the rotator cuff reducing the forces on the repair and helped to promote bony union. Recently, the use of locking plates has been recommended in bone of poor quality to give added stability to promote healing.

Galatz et al. evaluated 13 patients with surgical neck nonunions treated with either a T plate or blade plate with autogenous bone grafting and reported union in 12 of 13 patients with excellent clinical results 11 of 13 patients. Patients with avascular necrosis, arthritis, humeral head bone loss, or nonunion of the tuberosities were excluded from the study [24]. Allende prospectively evaluated seven patients with documented atrophic nonunions of the proximal humerus treated with a blade plate and reported union in all seven patients [25]. Tauber et al. treated 45 patients with established surgical neck nonunions with blade plate fixation with no bone grafting and reported union in greater than 90 % of patients [26]. Ring et al. used blade plate and autogenous bone graft in 25 patients with proximal humerus nonunion and reported union in 23 of 25 patients [27]. Badman et al. evaluated 18 patients with symptomatic proximal humerus nonunions and treated them using a fixed-angle locked plate and also bone grafted by using an intramedullary strut allograft and reported union in 94 % of patients [28].

Regardless of the treatment plan chosen the surgeon needs to provide a biologic environment conducive to bony union and provide mechanical stability to support healing while minimizing trauma to surrounding structures. The approach can either be a deltopectoral approach or a lateral approach depending on surgeon preference. The surgeon must be aware of the distortion of the anatomy which commonly occurs with proximal humeral nonunions. Caution should be exercised during dissection as to not injure the axillary or musculocutaneous nerves. We recommend finding the biceps tendon and corresponding intertuberculous sulcus, this will aid in identification of anatomy. The biceps should either be tenotomized or tenodesed depending on surgeon preference. All interposing tissue at the nonunion site should be removed and bleeding bone both proximally and distally needs to be achieved. Once the bone has been prepared and ready for fixation the use of K-wires or Steinman pins can be a useful aid to assist in controlling the bony fragments. No matter what type of fixation is chosen the surgeon should have orthogonal views to ensure adequate reduction and avoidance of malunion and to ensure that hardware has not penetrated the glenohumeral joint. We recommend the use of intraoperative C-arm in all cases. After appropriate reduction and fixation the nonunion site should be inspected for bone loss and recommend bone grafting of some nature in all cases. After fixation stability and range of motion of the shoulder joint should be tested and if there are contractures of the capsule or surrounding soft tissue a release may be performed. This will aid in rehabilitation postoperatively and limit force transmission to the nonunion site [11].

Prosthetic Replacement

There is little literature that specifically addresses arthroplasty as a treatment for proximal humeral nonunions. More commonly arthroplasty is discussed in the setting of reconstructive salvage procedures for proximal humerus fractures. However, arthroplasty may be the only option especially when the patient with a proximal humerus nonunion presenting with avascular necrosis of the humeral head, inadequate bone stock, articular defects, and posttraumatic osteoarthritis. Boileau et al. evaluated hemiarthroplasty in six surgical neck nonunions and all required an osteotomy of the greater or lesser tuberosity for anatomic positioning of the implant. All six patients were reported to have poor or fair results [29]. An additional study in 2006 evaluated 22 nonunions of the surgical neck treated with nonconstrained shoulder arthroplasty (hemiarthroplasty or total shoulder arthroplasty) and reported very poor results secondary to the need for greater tuberosity osteotomy and recommended that all attempts should be made to perform open reduction and internal fixation over nonconstrained shoulder arthroplasty in the management of proximal humerus nonunions [30]. Mansat et al. reported when dealing with late sequelae of proximal humerus fractures that performing a greater tuberosity osteotomy worsened the final results [31]. Duquin et al. performed hemiarthroplasty in 54 patients and total shoulder arthroplasty in 13 patients with a proximal humeral nonunion and noted inconsistent tuberosity healing with less than 50 % of patients having a satisfactory outcome at final follow-up [32]. Dines et al. so reported poor results and cautioned to avoid a tuberosity osteotomy during treatment of proximal humerus nonunions with arthroplasty [33]. Other studies have also evaluated hemiarthroplasty and total shoulder arthroplasty in proximal humerus nonunions and have noted that they appear to have poor results and higher complication rates when used in posttraumatic sequelae or if the nonunion was noted after a prior failed ORIF [34, 35]. Therefore, based on the literature our recommendations for hemiarthroplasty or total shoulder arthroplasty in the setting of a proximal humerus nonunion the surgeon should try to restore the normal anatomical alignment with the prosthesis while avoiding tuberosity osteotomy.

Another intriguing option in the management of proximal humerus nonunions is the reverse total shoulder arthroplasty. The reverse total shoulder arthroplasty does not depend on an intact rotator cuff to function properly and therefore is not as dependent on exact anatomic tuberosity positioning as hemiarthroplasty or total shoulder arthroplasty (Fig. 10.3). Martinez et al. specifically looked at treating proximal humerus nonunions with a reverse total shoulder in 18 patients [36]. Fourteen of 18 patients were satisfied with the result of surgery, but they did report 2 postoperative dislocations out of the 18 initially treated. Their conclusion was that the reverse total shoulder provided improved pain relief and motion, but with an apparent higher risk of dislocation [36]. Boileau et al. evaluated the Grammont reverse total shoulder for proximal humerus fracture sequelae in five patients and noted improved active elevation and Constant Scores, with no change in external rotation or internal rotation [37]. The reverse total shoulder may be a viable option in proximal humerus nonunions but should be considered only in older patients or younger patients who are physiologically older with low demands. The surgeon will have to be cautious in considering a reverse arthroplasty in a younger patient when no other viable option exists. The patient must fully understand the risks, benefits, and limited long-term clinic outcomes for the reverse total shoulder.

Fig. 10.3 Reverse total shoulder arthroplasty used to treat patient from Fig. 10.2. Patient noted significant pain relief postoperatively

Three- and Four-Part Proximal Humerus Nonunions

Three- and four-part proximal humerus nonunions are not very common because the tuberosities typically heal but are often in a malunited position. However, if a three- or four-part proximal humerus fracture does occur then the treatment recommendations are the same as outlined for surgical neck nonunions and isolated tuberosity nonunions. If adequate bone stock exists then open reduction and internal fixation with bone grafting would be the treatment of choice. If there is inadequate bone stock, avascular necrosis of the humeral head, or osteoarthritis, then hemiarthroplasty or total shoulder arthroplasty may be the best option. Hemiarthroplasty has been reported not to do as well in three- and four-part nonunions when compared to surgical neck nonunions [38]. In older patients with three- and four-part proximal humerus fractures we would recommend reverse total shoulder arthroplasty.

Conclusion

Proximal humerus nonunions are uncommon in comparison to the total number of proximal humerus fractures that occur. However, when encountered an appropriate preoperative evaluation must be undertaken in order to maximize treatment. Conservative treatment should be performed in patients who have minimal pain and minimal disability. Patients with significant pain and disability should undergo operative reconstruction. Currently no gold standard for treatment of proximal humerus nonunions exist. We recommend open reduction and internal fixation with bone grafting when possible and hemiarthroplasty or total shoulder arthroplasty for patients when there is inadequate bone stock, avascular necrosis of the humeral head, and underlying posttraumatic osteoarthritis. We recommend reverse total shoulder arthroplasty for elderly patients or those with very low physiologic demands.

Proximal Humerus Malunion

Proximal humerus malunions can be extremely difficult to manage even for experienced orthopedic shoulder surgeons. To adequately manage proximal humerus malunions the surgeon must understand the potential causes of malunion, appropriate preoperative evaluation, and available literature on the treatment of proximal humerus malunions.

A universally accepted classification system for proximal humerus malunions does not exist. The lack of a well defined classification system leads to difficulty when evaluating published patient outcomes and treatment recommendations. Several authors have created classification systems including Beredjiklian et al. who took into account both osseous and soft tissue abnormalities to make the surgeon aware that both are important in treatment and the final outcome [39]. Boileau et al. developed a posttraumatic sequelae classification system for proximal humerus fractures that included proximal humerus malunions, but this system relates to arthroplasty treatment [29] The most used classification is a descriptive classification that is a modification of Neer's classification of acute proximal humerus fractures [40].

Fractures of the proximal humerus are relatively common and have been noted to represent 5–9 % of all fractures [21, 41, 42]. Proximal humerus malunions have been reported after both operative and nonoperative treatment of proximal humerus fractures. Proximal humerus malunion can lead to persistent pain, disability that affects the activities of daily living, and affect the quality of life of the patient.

Pathoetiology

The etiology of proximal humerus malunions is not complicated. Malunions arise from non-anatomic healing of the tuberosities, surgical or anatomical neck, or a combination. Malunions have been noted after both nonoperative and operative intervention. Lyengar et al. performed a systematic review of outcomes after nonoperative treatment of proximal humerus fractures and noted that varus malunion was the most common complication of nonoperative treatment [4]. The soft tissue attachments to the proximal humerus including the rotator cuff, pectoralis major, and deltoid account for the displacement of the fragments after acute fracture. The reason for proximal humerus malunion with nonoperative treatment is likely multifactorial including failure of the surgeon to recognize displacement of fracture fragments on initial films, inadequate follow-up of the fracture, patients to unhealthy to undergo surgery and early aggressive postoperative rehabilitation are a few possible reasons. Malunions have been documented to occur between 0 and 22 % after percutaneous pinning, open reduction and internal fixation, intramedullary nailing, and hemiarthroplasty in the treatment of proximal humerus fractures [5, 9, 23, 43, 44]. The causes of malunion after operative intervention include loss of fixation or inadequate initial reduction.

Fig. 10.4 Thirty-year-old patient who had anterior glenohumeral joint dislocation and was treated nonoperatively for his greater tuberosity fracture. Note the posterior/superior malunited position of the greater tuberosity

Treatment

Nonoperative Treatment

Nonoperative treatment has a role in malunions of the proximal humerus especially in patients with multiple medical comorbidities and those with very low functional demand. Not all proximal humerus malunions are painful enough or limit activities enough to prompt the patient to undergo surgery and for those patients we would recommend continued nonoperative treatment. However, patients who have a painful malunion with limited function we recommend operative management.

Operative Treatment

Tuberosity Malunion

Greater tuberosity malunion is the most common malunion of the proximal humerus (Fig. 10.4). The difficulty in treatment is related to the size of the remaining tuberosity, amount of displacement and any underlying soft tissue contractures. Greater tuberosity malunions are typically displaced in a superior and posterior direction secondary to the pull of the attached rotator cuff. The superior malposition can lead to contact of the greater tuberosity with the overlying acromion and can limit both abduction and forward flexion. The posterior displacement can lead to contact with the posterior glenoid and can lead to loss of external rotation. Significant weakness can be associated with greater tuberosity malunion related to rotator cuff dysfunction as seen in a massive rotator cuff tear [17].

Lesser tuberosity malunions are not seen as commonly as greater tuberosity malunions, but can lead to significant pain and disability when present. The pull of the subscapularis typically causes the lesser tuberosity to be pulled into a medial malunited position. This displacement can lead to both a decrease in internal and external rotation secondary to insufficiency and contracture of the subscapularis and impingement on the coracoid process. The patient will often complain of anterior shoulder pain and will have an exam that is consistent with a full thickness subscapularis tear.

The decision to operate on an isolated tuberosity malunion is continued pain and disability. Biomechanical studies have shown that minimal displacement of the greater tuberosity can lead to significant alterations in the motion of the glenohumeral joint [45]. Neer's original description considered 1 cm to be amount of displacement that warranted surgery. Recent recommendation suggest as little as 5 mm of displacement of the greater tuberosity may causes pain and disability [40].

Open treatment of either greater or lesser tuberosity malunion is similar. The approach used can either be a lateral based approach or a deltopectoral approach. The surgeon should be prepared for distorted anatomy that will be encountered during the approach and great care should be taken to protect both the axillary and musculocutaneous nerves. The bicipital groove can be a readily identifiable landmark that can assist in dissection. An adequate subacromial and subdeltoid release should be performed to remove all adhesions. Often the identification of the tuberosity fragment can be difficult to define and we would recommend fluoroscopic assistance if there is any question about the position. Once the fragment is identified an osteotomy is performed using fluoroscopy to determine position of osteotome and tuberosity fragment. Extensive rotator cuff releases both subacromial and within the glenohumeral joint should be performed. A release of the rotator interval and capsular release both anterior and posterior to assist in mobilization of fragment and glenohumeral joint is usually needed. Traction sutures can be placed in the rotator cuff attached to the tuberosity and to assist the surgeon when performing the soft tissue releases. If an internal rotation contracture is noted then we suggest anterior, posterior, and superior release of the subscapularis. After osteotomy and preparation of soft tissues are complete the bony bed for repair must be prepared by removing all scarred and devitalized tissue down to a healthy bleeding bony bed. The tuberosity fragment should be able to be placed in the anatomic site for repair. If this is not possible then the tuberosity should be advanced as close as possible and kept below the humeral head. Fluoroscopy can be used to assist in tuberosity reduction if the anatomy is distorted. If the fragment is large enough we recommend fixation with compression screw and washer construct. This may be backed up with nonabsorbable suture because hardware loosening has been reported [46]. If the fragment is of insufficient size for screw fixation then we recommend suture fixation using either anchors or transosseous tunnels with multiple passes through the rotator cuff and proximal humerus. After repair the arm should be taken through a range of motion to identify quality of repair and to set limits on postoperative rehabilitation. Early passive and active assisted range of motion is encouraged if repair is sufficient. No resistive strengthening therapy should be instigated until bony fragment or soft tissue has incorporated.

There are only a few studies that specifically address osteotomies for proximal humerus malunions and there are small numbers specifically addressing isolated tuberosity malunions. Morris et al. evaluated three greater tuberosity malunions that underwent corrective osteotomy and fixation. All patients united and were reported to have improved pain relief and range of motion [47]. Beredjiklian et al. evaluated multiple different types of proximal humerus malunions treated with corrective osteotomy and reported eight patients that were specifically treated with isolated tuberosity osteotomy and soft tissue reconstruction. Overall, 88 % had no or minimal pain and the best results in the proximal humerus were noted in those patients with isolated tuberosity malunions [39]. Russo et al. evaluated humeral osteotomies for posttraumatic malunions of the proximal humerus in 19 patients with different types of malunions including tuberosity malunions. The average age was 46 and they reported union in all 19 patients with excellent results in 14 and satisfactory results in 5 with significant pain relief and improved range of motion in both groups [48].

Arthroscopic treatment of malunions of the greater tuberosity has recently been evaluated and has proven to be successful in a few case reports and case series of patients [49, 50]. The technique involves addressing both soft tissue and bony abnormalities arthroscopically. The greater tuberosity is marked using fluoroscopic assistance and the rotator cuff is detached from the tuberosity. The tuberosity is then taken down with an arthroscopic burr. The rotator cuff is then released arthroscopically and advanced to the anatomic footprint and repaired using standard rotator cuff repair techniques. The biceps is either tenotomized or tenodesed. An arthroscopic capsular release is also performed addressing both the anterior and posterior capsule. An arthroscopic acromioplasty is performed to increase the working space between the proximal humerus and acromion. Martinez et al. evaluated eight patients with malunion of the greater tuberosity. They reported seven excellent or good results and one poor result. All patients documented postoperative pain relief. Seven patients reported normal or near normal function and returned to previous occupation [49]. Ladermann et al. evaluated four patients with isolated greater tuberosity malunions that underwent arthroscopy with tuberoplasty and rotator cuff advancement [50]. The average ages of the patients were 49 and the average follow-up was 50 months. They reported improved function and decreased pain in all patients. Three patients rated their result as excellent, three as good and three as fair. Eighty-nine percent of the patients were able to return to their previous sport or activity postoperatively [50]. The results from these two studies suggest that this is a reasonable option in a younger patient with a proximal humerus tuberosity malunion; the procedure however is technically demanding.

Therefore, tuberosity malunions may be treated with an open or arthroscopic procedure with both reporting overall improved function and decreased pain. Markedly displaced tuberosity fragments would most likely be best treated with an open procedure, but there is no literature comparing open versus arthroscopic treatment of proximal humerus malunions.

Surgical Neck Malunion

Surgical neck malunions can lead to pain and deformity of the upper extremity that can limit range of motion and disability. The malunion is typically an apex anterior and varus deformity secondary to pull of the rotator cuff, deltoid, and pectoralis major. This deformity can lead to significant loss of forward flexion and abduction secondary to impingement [19]. Internal and external rotation is typically preserved unless posttraumatic soft tissue contractures have occurred. The difficulty with treatment is secondary to poor bone quality, abnormal anatomy, prior treatment, soft tissue contractures, rotator cuff pathology, and avascular necrosis of the humeral head. The indication to operate on a surgical neck malunion is pain and limited function that affects the patient's quality of life. Operative techniques for surgical neck malunions primarily consist of open procedures with a few recent articles discussing arthroscopic management. If there are no signs of osteoarthritis or avascular necrosis of the humeral head then osteotomy with fixation is warranted. If there are signs of osteoarthritis or avascular necrosis arthroplasty should be considered (Fig. 10.5).

Fig. 10.5 Proximal humerus malunion that has resulted in severe glenohumeral joint osteoarthritis leading to severe pain and disability

Open treatment of a surgical neck malunion requires an extended approach and secondary to possible neurologic injury from distorted anatomy a deltopectoral approach is supported. The bicipital groove and coracoid process provide bony landmarks. Care should be taken to protect both the axillary and musculocutaneous nerves. Adequate subacromial and subdeltoid release should be performed to allow appropriate exposure of the proximal humerus. Once the malunion site is identified the rotator cuff should be inspected to ensure no tears are present and if so then cuff repair should follow fixation of surgical neck. Using fluoroscopy for assistance the osteotomy is carefully created using either an oscillating saw or osteotome. After the osteotomy is completed then correction can be performed using direct visualization or fluoroscopic aid. Steinman pins can be used to control the fragments and traction sutures can be placed in the rotator cuff to assist in soft tissue release. A complete release of any adhesions to the proximal fragment should be performed to allow adequate mobilization. The proximal and distal fragments can be fixated with a proximal humerus plate of the surgeon's choice. Fluoroscopy should be used in both the AP and lateral planes to ensure appropriate inclination and rotation of the humeral head. If there are any areas that lack bony contact bone grafting is recommended.

There are limited studies that specifically address osteotomies for proximal humerus malunions. Solonen et al. evaluated seven patients who underwent corrective osteotomy of surgical neck malunions with plate fixation and reported five excellent results and two poor results. They reported union in all patients and felt that the two patients who had poor results were secondary to soft tissue pathology not addressed at the time of surgery and rather than from the corrective osteotomy [51]. Beredjiklian et al. treated patients with proximal humerus malunions which included surgical neck malunions and reported a satisfactory outcome in 69 % of patients in the study. The authors concluded that osteotomy of proximal humerus malunions are only successful if both osseous and soft tissue abnormalities are managed appropriately at time of surgery [39]. Russo et al. performed corrective osteotomies in 19 patients and reported pain relief and satisfactory results in all patients [48].

Current recommendations for patients with surgical neck malunion with a preserved glenohumeral joint and viable humeral head include open osteotomy, reduction and fixation with correction of underlying soft tissue abnormalities. In patients who do not have a viable humeral head or extensive osteoarthritis then arthroplasty is recommended.

Three- and Four-Part Malunions

Three- and four-part malunions of the proximal humerus can be very challenging to treat and typically lead to continued pain, loss of motion, and severely limited function. When encountered these malunions are associated with significant soft tissue injuries, soft tissue contractures, joint incongruity, and increased incidence of both glenohumeral osteoarthritis and avascular necrosis of the humeral head [52]. Osteotomy of three- and four-part proximal humerus malunions is typically not recommended but if the patient is young with large viable fragments and no osteoarthritis of the glenohumeral joint then osteotomy can be considered.

An extended deltopectoral approach is warranted in the management of three- and four-part proximal humerus malunions. Extensive soft tissue releases should be performed to free up the subacromial and subdeltoid spaces. The anatomy will typically be distorted and the surgeon should use any remaining landmarks such as the bicipital groove, coracoid process, and rotator cuff attachments. Fluoroscopy can always be used to assist in identification. The location of the tuberosities especially the greater tuberosity will dictate treatment and outcomes. Once the subscapularis is identified a tenotomy, subscapularis peel, or osteotomy of the lesser tuberosity can be performed to gain access to the glenohumeral joint. The subscapularis should be adequately released while protecting the axillary nerve. The capsule including posterior capsule, rotator interval, and rotator cuff should be released at this time especially if contractures are present. The glenoid can now be inspected and the determination of hemi versus total arthroplasty decision is made based on the amount of osteoarthritis noted. If the proximal humerus malunion is severe and implantation is impossible in face of the malunion then osteotomy may be required to accommodate implants. With the use of modular implants an osteotomy especially of the greater tuberosity can usually be avoided. Current modular implants may allow the surgeon to accommodate a wide variety of proximal humerus bony deformities while recreating appropriate soft tissue tension. During implantation of the humeral prosthesis multiple decisions such as height, version, and inclination must be addressed to adequately restore the anatomy. Boileau et al. reported by lengthening the humerus by 1 cm or more led to a proud prosthesis and was associated with proximal migration, tuberosity failure and limited function. Shortening of the humerus was better tolerated and adverse effects were not reported until >15 mm of shortening [53]. Judging the appropriate height can be difficult in these cases and the surgeon can use guides to assist in height, use the tuberosities intraoperatively if not severely malpositioned, or use the superior border of the pectoralis major which has been found to be 5.6 cm below the top of the humeral head [54]. The most common error is placing the component in excessive retroversion which can also lead to failure of tuberosities and subsequently component failure [55]. The component should typically be placed around 20° of retroversion and the transepicondylar axis and bicipital groove can assist the surgeon in determining this version. The prosthesis can either be cemented into position or press-fit depending on quality of bone and quality of stem fit. After implantation of components is completed and subscapularis repair has been performed the surgeon should ensure that the soft tissues have been adequately released and balanced prior to closure. In the cases where the proximal humerus malunion is to severe for implantation of components an osteotomy is required. The malunited fragments when osteotomized should be of sufficient size for fixation and care should be taken not to violate the rotator cuff. The tuberosities should be fixated below the humeral head and typically require suture fixation to the prosthesis and proximal humerus through bony tunnels. Bone grafting is also recommended and can be obtained from the humeral head.

The results of arthroplasty of three- and four-part proximal humerus malunions can be expected to provide pain relief but improved range of motion and strength are not consistently obtained and should be discussed preoperatively with the patient. The literature is not specific in reporting on the results of arthroplasty in the treatment of malunions of the proximal humerus.

Boileau et al. treated a total of 71 patients with posttraumatic sequelae from proximal humerus fractures and 16 patients were noted to have severe malunions involving the tuberosities. The patients were treated with unconstrained arthroplasty and osteotomies if needed. The results were favorable in 81 % of the 71 patients treated. However, all patients who underwent a tuberosity osteotomy had poor or fair results and all had less than 90° of forward flexion postoperatively. The conclusion from the study was that osteotomy of the greater tuberosity leads to poor and unpredictable results and should be avoided by using modular prosthesis if possible [29]. Dines et al. treated 20 shoulders with posttraumatic sequelae with arthroplasty and noted preoperative malunion in 8 of the 20 shoulders. Their results mirror Boileau in the fact that patients who underwent an osteotomy of the tuberosity had lower clinical outcome scores and range of motion when compared to patients who did not undergo osteotomy. They also advised to avoid osteotomy by using modular implants to restore anatomy and soft tissue tensioning [33].

Antuna et al. performed total or hemiarthroplasty on 50 patients after proximal humerus fractures reporting on 37 three- and four-part malunions. The conclusion was that most patients had pain relief but 50 % had unsatisfactory results and patients who had prior surgery or required an osteotomy at the time of arthroplasty had the poorer outcomes [38]. Mansat et al. treated eight patients with proximal humerus malunions and osteotomy was performed in three of these patients. All three patients who underwent osteotomy had poor results. Their conclusion was that osteotomy should be avoided [31].

Norris et al. treated 17 three- and four-part proximal humerus malunions with arthroplasty. Tuberosity osteotomy was required in 57 % of cases, but they reported pain relief in 95 % of patients treated and minimal improvement in range of motion [35]. Tanner et al., Frich et al., and Bosch et al. performed arthroplasty in the treatment of patients with three- and four-part proximal humerus malunions and reported the outcomes were inferior to treatment of acute fractures [56–58]. The studies also reported inferior results with delayed treatment, tuberosity osteotomy, and extensive soft tissue scarring [56–58].

Recent advancements in reverse total shoulder arthroplasty make this a very attractive procedure in the treatment of proximal humerus malunions especially three- and four-part malunions in the elderly population. Willis et al. used the reverse shoulder arthroplasty in the treatment of 16 patients with proximal humerus malunions. They reported a statistically significant improvement in the American Shoulder and Elbow Score, Pain score, and the Simple Shoulder Test. Forward flexion, abduction, internal rotation, and external rotation were all significantly improved postoperatively. They noted no major complications. Two patients demonstrated scapular notching at latest follow-up and one patient was noted to have proximal humeral bone resorption [59]. Werner et al. have shown that patients who undergo a reverse total shoulder arthroplasty as a secondary procedure are at a higher risk for postoperative complications than patients undergoing a primary procedure (39 % versus 18 %) [60]. Despite possible higher complication rates reverse total shoulder arthroplasty may be the most viable option in elderly patients with posttraumatic proximal humerus malunions.

Conclusion

Proximal humerus malunions are best treated by avoidance with recognition and treatment of displaced proximal humerus fractures early especially in younger patients. Potential outcomes and patient goals should be discussed prior to the procedure. Currently there is no agreed upon treatment for proximal humerus malunions, but based on the literature younger patients with viable humeral heads and no glenohumeral osteoarthritis should be treated with an open osteotomy or possible arthroscopic procedure. Patients who have an avasular humeral head and or posttraumatic osteoarthritis are best treated with arthroplasty; tuberosity osteotomy may be avoided by the use of modular implants. Reverse total shoulder arthroplasty seems the most logical treatment in the elderly patients with pain and disability from proximal humerus malunions.

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