Shoulder Arthroplasty

The Shoulder Club Guide

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Preface

> *When it is obvious that the goals cannot be reached, don't adjust the goals, adjust the action steps.*—Confucius

Dear Colleagues,

Shoulder Club International (SCI, www.shoulderclub.com) is an international group focused on education in shoulder and sports. It includes several shoulder experts from around the world, such as the United States, United Kingdom, Korea, Italy, France, and Turkey. The group is open to novice and experienced shoulder surgeons alike. The goal of SCI is to organize annual educational activities such as symposiums and cadaver labs with high scientific-level collaboration together with European School for Training in Orthopaedics (ESTRO). In recognition of these efforts, the organization has received recognition of the quality and depth of the educational programs from the European Orthopaedics and Traumatology Education Platform (EOTEP) of EFORT in the form of accreditation.

Advances in shoulder replacement surgery have allowed for the successful treatment of various shoulder conditions. As the elderly population increases and the surgical indications for shoulder replacement surgery continue to expand, the number of shoulder replacements performed annually will continue to increase. Accordingly, the number of complications also will be expected to increase. Successful shoulder replacement outcomes require surgeons to have a thorough understanding of the surgical indications, surgical technique, and potential complications of the procedure. The basis for this book originally stemmed from my passion for disseminating the philosophy and developing better knowledge of shoulder arthroplasty.

In truth, I could not have achieved my current level of success without a strong support group. First of all, I thank my spouse Pınar and daughter Alin Defne, who supported me with love and understanding. And secondly, my co-editors, committee members, and contributors, each of whom has provided patient advice and guidance throughout the research process. Thank you all for your unwavering support.

Ankara, Turkey
Gazi Huri

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I would like to express my special thanks of gratitude to my students Aylin Ceren Güven and Pelin Bölükbaşı from Ankara University Biomedical Engineering who provided valuable support to do this wonderful book project and also helped me in doing a lot of research.

Contents

Shoulder Anatomy

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Sümeyye Yılmaz, Tuğberk Vayısoğlu,
and Muhammed Ali Çolak

The shoulder is a complex structure which is comprised of various bones, joints, muscles, nerves, and vessels. It has the importance of being the only true connection between the axial skeleton and the upper extremity, and it plays the key role for upper extremity movements. In order to make the positioning of the upper extremity properly, all structures forming the shoulder must be intact and interoperate. Knowing the anatomy of the shoulder is essential for surgeons who want to evaluate the pathologies correctly and avoid the possible complications while performing surgical procedures. In this chapter, we will review the basic anatomy of the shoulder.

1.1 Bones and Joints

The skeleton of the shoulder is composed of four bones: the sternum, the clavicle, the scapula, and the humerus. These bones, by making several articulations, form the shoulder girdle. The sternoclavicular (SC) joint, the acromioclavicular (AC) joint, and the glenohumeral joint are the three main joints; there are also the scapulothoracic joint and the subacromial space which, technically, are not real joints but are considered as articulations in this chapter.

1.1.1 Sternum

The sternum, commonly known as the breastbone, is a centrally located flat bone which integrates the two sides of the ribcage. It lies on the midline of the chest and measures 15–17 cm in an average adult [1]. The sternum draws the front border of the superior and the anterior mediastinum and consists of three parts: the manubrium, the body, and the xiphoid process [2]. The sternum receives the arterial supply from branches of the internal thoracic artery, which originates from the subclavian artery, or sometimes from the thyrocervical trunk, and proceeds caudally inside the ribcage on both sides [3, 4].

The sternum originates from a pair of longitudinal mesenchymal structures, also called the sternal bars, on both side of the anterior chest wall. Around the 6th week of fetal life, the components that contribute to organize ventral thoracic region are developing ribs and the sternal anlage. Those precursors are completely separated from each other until 7th week. After that, once the developing ribs make contact with the sternal anlage at ventrolateral chest region, the cartilaginous sternal plates grow medially and fuse at midline approximately at the beginning of the 9th week. The main effect of developing ribs on sternum is to transform early stage non-segmented sternum into more developed segmented sternum [5, 6]. Ossification starts after chondrification stage and proceeds in a craniocaudal direction which is a general acceptance

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nearly for all parts of the body during development. Each part of the sternum has its own ossification centers categorized as major and minor ones. The manubrium has one, the body (mesosternum) has four (each called sternebrae), and the xiphoid process has one major ossification center [5, 7].

As mentioned before, the sternum consists of three parts. All three parts should be delicately examined from morphological perspective, due to their close relations with significant structures. The manubrium is a quadrangular-shaped, broad bone which forms the upper part of the sternum. Its superior surface has a palpable indentation called the jugular notch (suprasternal notch) in the midline. There are usually two types of variations which affect the superior margin of the manubrium: episternal ossicle and suprasternal tubercle. Those variations occur in the presence of supernumerary ossification centers [8]. In clinical practice, the jugular notch is important to evaluate the aorta, thereby, variations should be considered during examination. Just inferior to the jugular notch, the lateral surfaces of the manubrium have articular sites for the clavicles, attachment sites for the first rib cartilages, and articular demifacets for the second rib cartilages from superior to inferior, respectively. The body is the longest part of the sternum and is thinner than the manubrium. The first seven true ribs, except the first one, have cartilaginous connections on both sides of the body. In addition, the pectoralis major muscle originates from this part [1, 3].

The body has an articulation with the manubrium called manubriosternal joint, and this joint remains cartilaginous in 90% of adults. At this junction, an angle known as the sternal angle is formed. This angle is an important anatomical landmark and is located between the 4th and the 5th thoracic vertebrae. The xiphoid process forms the inferior part of the sternum and is the smallest part of the sternum. Due to its developmental characteristic, it frequently remains cartilaginous for a long time, but eventually it ossifies and transforms into a bony structure. The xiphoid process provides attachment sites for major abdominal muscles' aponeurosis such as the rectus abdominis and the transverse abdominis muscle [3, 7].

The sternum and the clavicle are connected to each other via the sternoclavicular joint at the manubrium of the sternum, and, therefore, the articular site on the manubrium is the starting point of the appendicular skeleton. This origin links the appendicular skeleton to the axial skeleton and allows the upper limb to carry out complex movements [9].

1.1.2 Clavicle

The clavicle, also known as the collarbone (Latin, little key), is a long, s-shaped bone which is located at the superior-anterior part of the thoracic region, on the first rib. It lies horizontally across the shoulder and possesses a double curvature. The turning point of the curvatures separate clavicle into medial two-thirds and lateral one-third. The medial two-thirds, the sternal part, is convex forward, and the lateral one-third, the acromial part, is concave forward [10, 11].

The superior surface of the clavicle is smoother than the inferior surface and is home to several muscle attachments on the medial and the lateral site. Medially, there are attachments for sternocleidomastoid muscle (SCM) and pectoralis major muscle. Laterally, deltoid and trapezius muscles' impressions can be seen [12]. The inferior surface has impressions for muscles too, and it also has attachment sites for clinically important ligaments. On the medial side, costoclavicular ligament lies between the clavicle and the end of the first rib including the first costal cartilage. Moving laterally, the subclavius muscle has large insertion area on the clavicle called the subclavian groove. Near the acromioclavicular (AC) joint, there are impressions for two ligaments: trapezoid line for trapezoid ligament and conoid tubercle for conoid ligament. Together they form the coracoclavicular (CC) ligament. The coracoclavicular ligaments prevent superior displacement of the distal clavicle [13, 14] (Fig. 1.1).

As it can be seen, medial and lateral parts of the clavicle are strengthened by many factors on both surfaces, but the middle part is vulnerable due to lack of supporting factors. This is the reason why clavicle fractures most commonly occur

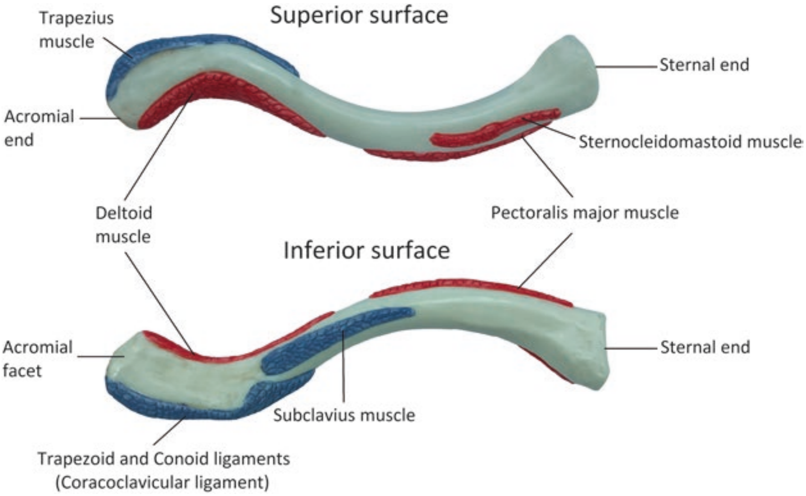


Fig. 1.1 Superior and inferior surfaces of the clavicle. The origins of the muscles are shown with red color, and the insertions of the muscles and the tendons are shown in blue

in the middle part (80%) [12]. The clavicle has the highest rate of fractures among other bones in the skeletal system, statistically [15]. The diagnosis of the clavicle fractures can be done by examining the AC and CC ligaments [16].

The arterial supply of the clavicle is provided by three varied arteries. The first one is a branch of the thyrocervical trunk: the suprascapular artery. The second one is the thoracoacromial artery, which is the first artery that originates from the second part of the axillary artery. The last one is the internal thoracic artery, and it originates from the subclavian artery [17].

From embryological aspect, the clavicle has notable importance. It is the first bone to ossify in the early human embryo, between the 5th and the 7th weeks. However, the medial epiphysis of the clavicle is one of the last ossification centers in body to close at early 20s [18]. The clavicle is formed via intramembranous ossification, which is one of two mechanisms that the body uses for ossification process and does not need a cartilage model [19]. Besides, the clavicle does not have a medullary cavity. Still, it is classified as a long bone [12].

The clavicle articulates with acromion of the scapula at the lateral end and with the manubrium of the sternum at the medial end. At the medial end, also called the sternal end, the manubrium of the sternum and the clavicle are connected to each other via the SC joint. This joint is surrounded by a fibrous capsule and interacts with some anatomical structures such as costoclavicular and interclavicular ligaments. At the lateral end, the clavicle and the scapula are connected to each other via the AC joint, and they form a plane type of synovial joint. Together, they make up the shoulder girdle which is a complex of anatomical and physiological joints. Movements of the shoulder girdle are restricted mostly by the clavicle in all directions, specifically in forward direction [20].

1.1.3 Scapula

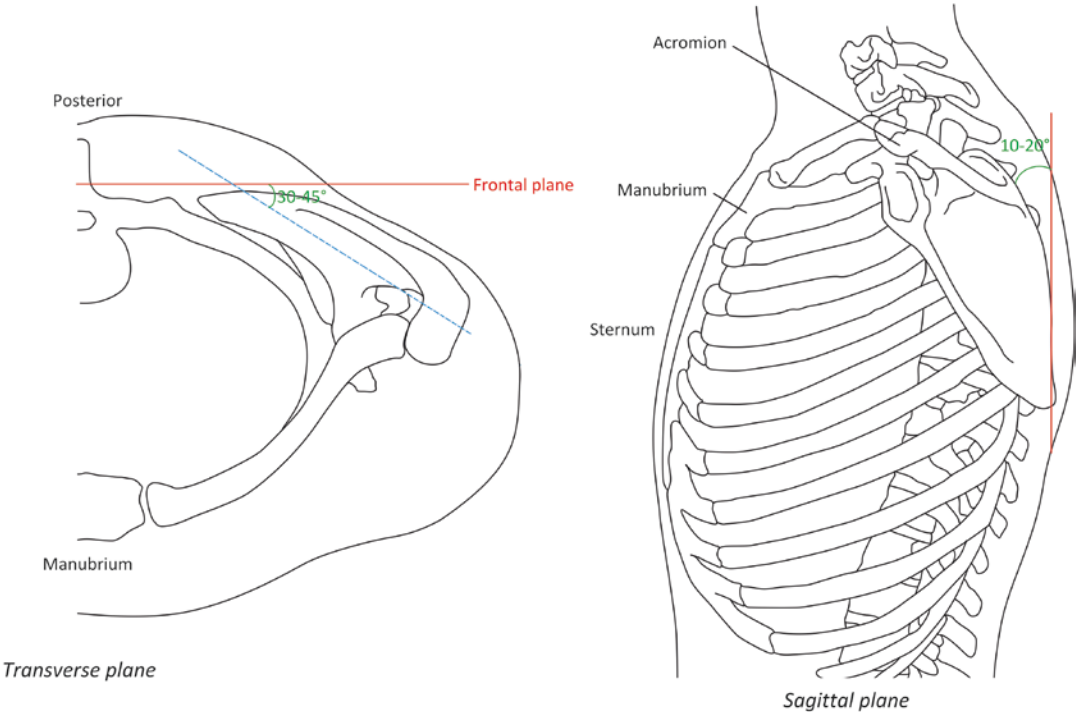
The scapula is a thin triangular bone which is one of the main components of the shoulder joint. Consisting of three borders (medial, lateral, and superior), three angles (inferior, superior, and lateral), and two surfaces (anterior and posterior), it is located posterolaterally behind the ribcage and extends between the 2nd and 7th ribs. Due to its thinness, the body of scapula is translucent [21, 22].

Embryologically, the scapula starts developing at the C4–C5 level and later descends into its position; its failure to descend results in Sprengel’s deformity [23]. It contains seven or more ossification centers with one in the body, two in the coracoid process, two in the acromion, one in the vertebral border, and one in the inferior angle. The scapula starts ossifying at several of these centers during the second month of fetal life. However, the ossification of the glenoid cavity, the coracoid process, the acromion, and the lateral border are not complete until late into puberty. Failure of the numerous ossification centers to fuse may result in anatomical variances such as the formation of os acromiale [24, 25].

The scapula has a distinct location in the human body. Viewed transversally, it creates a 30–45° angle with the frontal plane as the lateral border protrudes anteriorly. Additionally, the scapula also creates a near 10° angle with the frontal plane in a sagittal cross-section as the superior scapula rotates anteriorly [26] (Fig. 1.2).

The concave posterior surface of the scapula is divided at the upper one-third by the spine of scapula into the supraspinous and infraspinous fossae which provide origin regions for the muscles of the same name. Running superolaterally, the spine forms the acromion process, which is palpable at the superior shoulder region, and articulates with the lateral head of the clavicle. The spine also contains an origin for the deltoid muscle at the deltoid tubercle as well as an attachment to the trapezius muscle [21, 22] (Fig. 1.3).

The acromion process shows some anatomic variation. First described by Bigliani et al. [27], the acromion was classified into three different types based on its morphology: Type I—flat, Type II—curved, Type III—hooked (Fig. 1.4). In 1993, a Type IV acromion—where the undersurface of the acromion process is convex—was defined by Gagey et al. [28] (Fig. 1.5). According to Bigliani's research, Type II acromion was the most common acromion type, and following research supported this notion [29]. Furthermore, Bigliani concluded that Type III hooked acromion processes were more prone to subacromial impingement due to a decreased acromiohumeral distance (AHD). Following research conducted by Epstein et al. [30] showed that Type III acromions were observed twice as much in patients with rotator cuff impingement syndrome. Although conflicting results are found, some



Transverse plane

Sagittal plane

Fig. 1.2 The scapula creates a 30–45° angle with the frontal plane in transverse cross-section and 10–20° angle with the frontal plane in sagittal cross-section

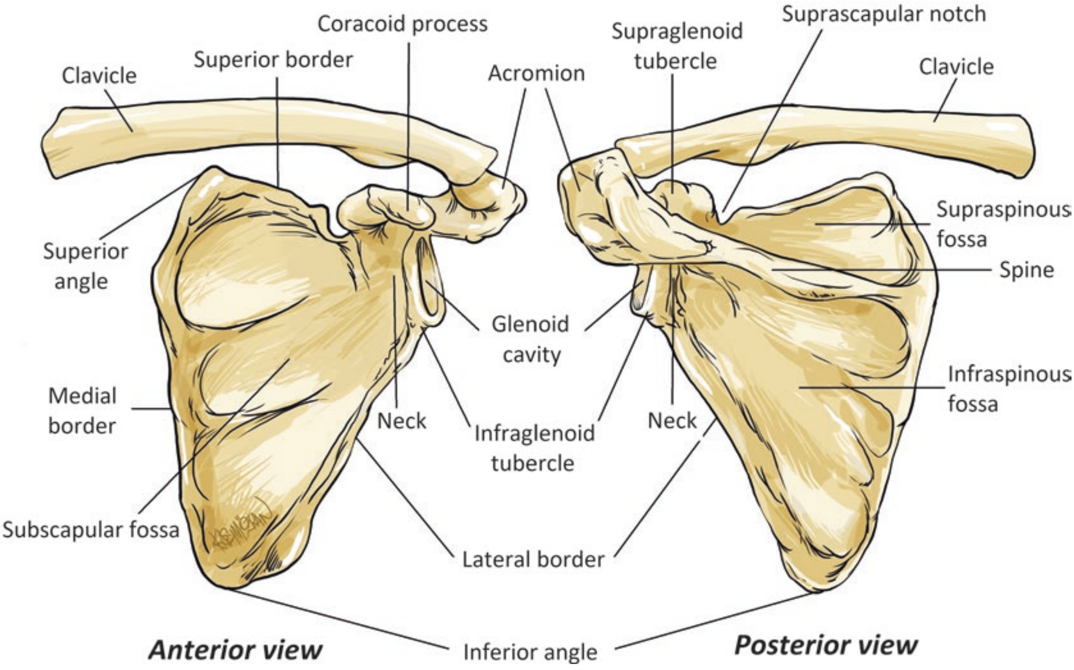


Fig. 1.3 The anterior and posterior views of the scapula

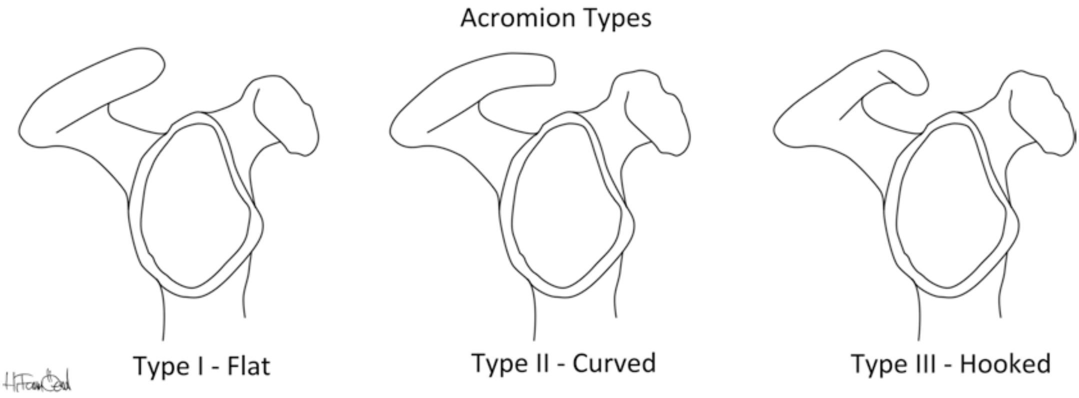


Fig. 1.4 The drawings of the types of acromion (described by Bigliani et al.)

researches have concluded that Type III acromion processes are significantly associated with rotator cuff tears as well [24, 31].

Inferomedial to the acromion, the lateral border of the scapula forms the glenoid cavity. Facing anterolaterally and slightly superiorly, the glenoid cavity is surrounded by the glenoid labrum. Together, these structures form a concave fossa which articulates with the head of humerus [21, 22].

The anterosuperior portion of the glenoid cavity is indented by a notch which provides it a specific shape. According to the prominence of this notch, glenoid cavity shape variations occur. In general, there are three types of glenoid cavities: oval, pear, and inverted comma. If the glenoid notch is absent, the cavity obtains an oval shape. If the notch is present but not distinct, the cavity is pear shaped. And if the notch is distinct, the cavity forms an inverted comma shape. Although

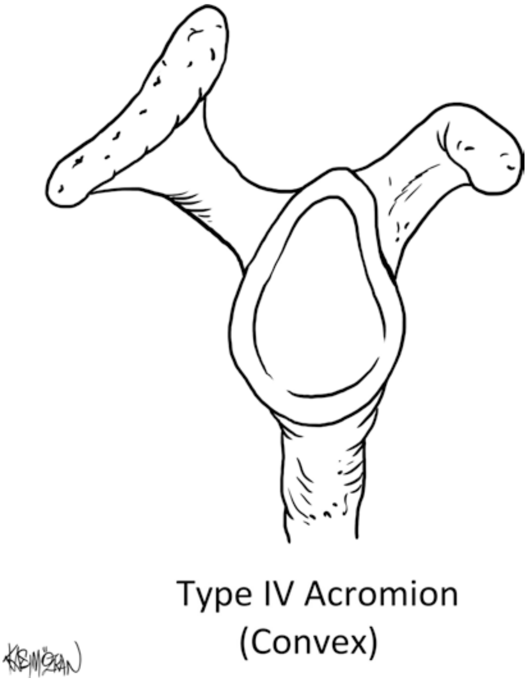


Fig. 1.5 The drawing of the type IV acromion (described by Gagey et al. in 1993)

the percentages vary depending on the research conducted, the pear-shaped glenoid cavity is the most common [32, 33].

In addition to the specific orientation of the scapula in the human body, the glenoid cavity has a specific orientation in regard to the scapula itself. According to a study carried out among 344 human scapulae, the glenoid cavity has, on average, 1.23° of retroversion (angled posteriorly) and 4.2° of superior inclination. Although no significant size difference was measured between races, the study showed significant racial difference in the measurement of glenoid version; white adults had an average of 2.66° of retroversion, while black adults had 0.20. The orientation of the scapula, especially the glenoid cavity, and the angular differences between races have extreme importance in glenoid surfacing for asymmetric glenoid bone loss; surgeons may consider these data while planning certain operations [34].

Additionally, there are important muscular attachment sites inferior and superior to the glenoid cavity. The infraglenoid tubercle provides attachment for the long head of triceps muscle. Similarly, the long head of biceps muscle attaches to the supraglenoid tubercle [21, 22].

Superior to the glenoid cavity is another process called the coracoid. Running superiorly, anteriorly, and then laterally, the coracoid process does not form any articulations but serves as an important attachment site for various muscles and ligaments. The short head of the biceps brachii, coracobrachialis, and pectoralis minor muscles attach to the coracoid process. Additionally, the coracoclavicular, acromioclavicular, and coracohumeral ligaments are attached to the coracoid process [21, 22].

At the base of the coracoid process, there is a small notch on the superior border of the scapula called the suprascapular notch (Fig. 1.9). Converted into a foramen by the transverse scapular ligament, the suprascapular notch forms a pathway for the suprascapular nerve. Although variations of suprascapular notch shape occur (u- and v shaped), there has been no correlation discovered between the variations in shape and suprascapular impingement/entrapment [21, 22, 35].

1.1.4 Humerus

The humerus, the bone which forms the skeleton of the arm itself, establishes the ball-and-socket-type shoulder joint and hinge-type elbow joint by articulating proximally with the glenoid cavity of the scapula and distally with the radius and ulna, respectively [36, 37]. It is the bone that helps us to position our upper extremity in space [38, 39].

Embryologically, the humerus is first visible as mesenchymal humerus at Carnegie stage 16, and the cartilaginous humerus begins to form during stages 16–17. The ossification of the humerus starts from the midshaft. The primary ossification center can be seen histologically by week 7 and the first bony collar appears at stage 21 (week 8) in the middle of the bone. By the 6th month, it extends proximally to the anatomical neck and distally to the olecranon fossa and the epicondyles. The secondary ossification centers are seen on the proximal and distal epiphyses. Both the proximal and the distal epiphyses also develop from separate ossification centers, and each of those ossification centers starts to be seen at different times in utero. These proximal and distal epiphyses become the future sides for the proximal and distal ends of the humerus. They complete their formation in the early childhood [40].

Based on our knowledge of embryology and anatomy, we can divide and study the humerus in three parts. These are the proximal end, the shaft, and the distal end of the humerus.

1.1.4.1 The Proximal Humerus

The proximal end of the humerus (also called the proximal humerus) is the part of the humerus which articulates with the small, shallow glenoid cavity of the scapula, and together they create the shoulder joint. The important anatomical landmarks on the proximal end of the humerus are the head, the anatomical neck, the greater and lesser tubercles, the intertubercular sulcus, and the surgical neck [36–38] (Fig. 1.6).

The head forms one-third of a sphere [40], and it projects medially, posteriorly, and superiorly [38, 40] to articulate with the glenoid cavity of the scapula. Covered by a hyaline cartilage, the head is the main part of the humerus that contributes to the formation of the shoulder joint. In a study made by Boileau and Walch, the diameter of the articular surface of the humeral head has been reported as 43.3 mm [41].

The anatomical neck is the obliquely directed, shallow, and constricted region between the head and the greater and lesser tubercles laterally and between the head and the shaft medially [38]. It represents the closed epiphyseal plate [37]. It provides attachment to the capsule of the glenohumeral joint, except in the superior part where there's an area without capsular ligament for the passage of the long head of the biceps brachii muscle [36].

The greater and lesser tubercles are the two prominences found on the lateral side of the proximal humerus. The greater tubercle is located superiorly, and it provides attachments to the supraspinatus, the infraspinatus, and the teres minor muscles. The lesser tubercle is located

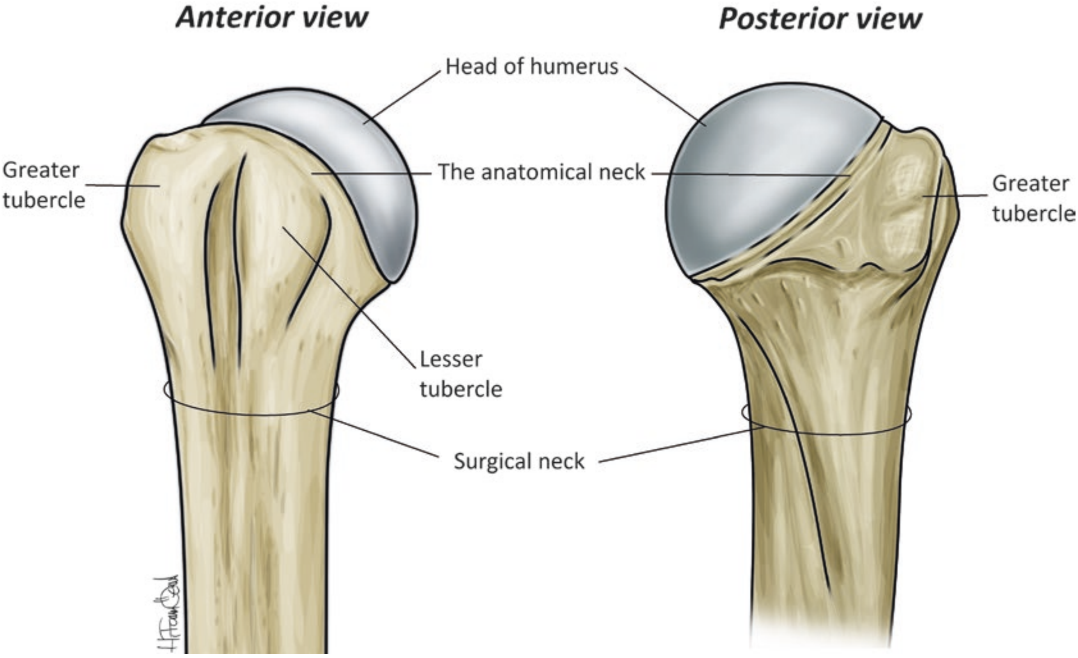


Fig. 1.6 The picture showing the anterior and posterior surfaces of the proximal humerus

more anteriorly and inferiorly, and it provides attachment to the subscapularis muscle. These four muscles form the “rotator cuff” muscles, which help to position the arm, and they are also the main providers of the stability and the integrity of the shoulder joint [38, 40]. In 1928, Meyer described the supratubercular ridge found on 17.5% of humeri and stated that it may help to prevent the medial displacement of the tendon of the long head of biceps brachii muscle by forcing it laterally [42]. Separating the greater and lesser tubercles, there is the intertubercular sulcus (bicipital groove) through which the long head of the biceps brachii muscle passes. The intertubercular sulcus continues distally to the shaft of humerus; the lateral lip, the medial lip, and the floor of it provide attachments to the pectoralis major, the teres major, and the latissimus dorsi muscles, respectively [36, 38, 40].

The surgical neck is the weak, horizontally oriented [38] region of the proximal humerus which is inferior to the greater and lesser tubercles and superior to the shaft of the humerus. The anterior circumflex humeral artery passes anteriorly, and the posterior circumflex humeral artery and the axillary nerve pass posteriorly to the surgical neck.

The proximal humerus is the third most commonly fractured bone in the body following distal radius and the proximal femur fractures. They are especially seen in elderly women as osteoporotic fractures following low-energy traumas [43]. They can also be seen in younger patients, but in those cases, it’s most commonly associated with high-energy traumas or sports injuries [44].

To understand the importance of the proximal humeral fractures, to decide the treatment options, and to predict the possible complications (such as avascular necrosis of the humeral head) and outcomes of the patients, scientists tried to define several types of classification systems. Those classifications were usually based on the levels of the fractures, the mechanisms of injuries, etc. In 1970, Charles Neer defined his own four-segment classification system based on the fractured segments of the proximal humerus and whether they are displaced or not [45]. He thought that the existing classifications were inadequate in evaluating the proximal humeral fractures. It has been more than 40 years, but surgeons still use Neer’s classification system widely because it is useful in understanding the pathological features of the fractures, deciding the possible outcomes and treatment options, and grouping for research purposes.

According to his classification system, Group 1 includes the fractures with displacements of less than 1.0 cm or angulations of less than 45°. This group constitutes more than 85% of all proximal humeral fractures, and they usually do not require surgery. Group 2 includes the fractures with pure displacement at the anatomical neck. Malunion or avascular necrosis can be seen in this type of fractures. Group 3 includes the fractures with displacement at the surgical neck. They can be either angulated, separated, or comminuted fractures. The fractures of the surgical neck are important because they may result in axillary nerve injury and they may also damage the arterial structures. These complications are especially seen in separated type of Group 3 fractures. Group 4 includes the greater tuberosity displacements and is pathognomonic for longitudinal rotator cuff tears. They can be either two-, three-, or four-part fractures. The prognosis gets worse when the displaced parts increase in number. Group 5 includes the lesser tuberosity displacements and can also be in the form of two-, three-, or four-part fractures. Finally, Group 6 includes the fractures with dislocations. In two- and three-part dislocations, the blood supply is usually maintained. In four-part fracture dislocations, the head is detached, and neurovascular symptoms are seen more commonly.

In 2004, Hertel et al. defined the binary description system by slightly modifying the Codman’s classification for proximal humeral fractures [46]. They stated that Neer’s classification system was unclear because there were several types of fracture planes that are not considered and there were some overlappings of the defined subgroups. Their aim was to assess the predictors of ischemia of the humeral head after fractures. They defined 12 fracture types based on 5 fracture planes. Those five fractures planes were between the head and the greater

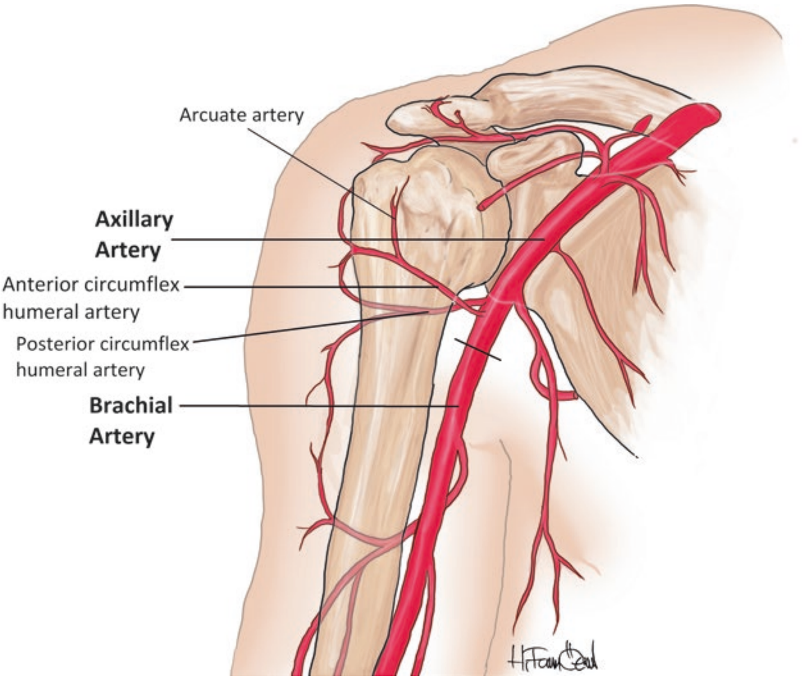


Fig. 1.7 Anterior view of the vessels that supply blood to the proximal humerus

tuberosity, the greater tuberosity and the shaft, the greater tuberosity and the lesser tuberosity, the lesser tuberosity and the head, and the lesser tuberosity and the shaft. They also added criteria related to medial metaphyseal head extension and the integrity of the medial hinge. They stated that humeral head perfusion is important to decide the treatment options, and the most important predictors of this are the fracture types and the two additional criteria.

The arterial blood supply of the proximal humerus is mainly derived from the anterior circumflex humeral artery. The anterolateral ascending branch of the anterior circumflex humeral artery (also called the arcuate artery) enters the head through the foramina found in the area of the upper end of the intertubercular sulcus, or sometimes it enters the bone by giving branches to the lesser and the greater tubercles [47] (Fig. 1.7). The posterior circumflex humeral artery also contributes to the blood supply of the humeral head by giving branches to the posterior portion of the greater tubercle and a small posteroinferior portion of the head [48]. Although the anterior circumflex humeral artery seems to be damaged more than 80% in proximal humeral fractures, osteonecrosis of the humeral head is not seen that common [49]. So, there are some new studies which state that actually posterior circumflex humeral artery is more important in the blood supply of the humerus than we know [49, 50]. Knowing the anatomy of the arteries that supply the humeral head is not only helpful to predict the outcome of the fractured fragments and whether they will undergo ischemia or not, but it is also really important in planning the surgeries that involve the shoulder in order to prevent damage and protect the vascularization [46, 51].

1.1.4.2 The Shaft of the Humerus

The shaft is the twisted portion of the humerus between the proximal and distal ends. It's cylindrical in shape in the cross-sections of the upper half, whereas it's triangular in the cross-sections of the lower half [40]. It has two important features: the deltoid tuberosity on the lateral side for the attachment of the deltoid muscle and the radial (spiral) groove that goes diagonally on the posterior side through which the radial nerve and the profunda brachii vessels pass [36, 52]. The fractures of the shaft in this area can damage these structures. Injury to the radial nerve may result in paralysis of the supinators of the forearm as well as the extensors of the wrist and the metacarpophalangeal joints. In this situation, the patient cannot extend the wrist and the fingers of the injured side, and with the unopposed force of the flexors, the wrist stays slightly in flexed position. This condition is called as "wrist drop," or sometimes it's called as "drop hand" [52].

The main nutrient foramen is the opening that is usually located on the anteromedial side of the midshaft, and it's directed toward the distal end [53, 54]. It becomes apparent approximately at 9th to 10th weeks of embryological life [40]. The major blood supply to the humerus is via the nutrient artery that arises from the brachial artery [36], and it passes through this foramen into the medullary cavity of the humerus. There may also be some accessory foramina, but those foramina are usually located on the posterior aspect of the humeral shaft [54, 55]. The nutrient artery is particularly important during the active growth of the bone, the early phases of ossification [55], and during fracture healing [54]. The anatomy of the nutrient artery should be known and taken into consideration while performing the orthopaedical procedures like fracture reductions, bone microsurgery, bone grafting, etc.

At the lower part, the shaft widens, as the medial and lateral supracondylar ridges form on each side. The brachialis muscle attaches anteriorly, and the medial head of the triceps muscle attaches posteriorly to the distal part of the shaft [36, 52].

1.1.4.3 The Distal End of the Humerus

The distal end of the humerus is triangular in shape. It has two projections on either side called the medial and lateral epicondyles from which the flexor and extensor muscles of the forearm originate, respectively. The ulnar nerve passes posterior to the medial epicondyle and can be damaged in the fractures of the medial epicondyle. The articular surfaces of the distal humerus includes the capitulum laterally and trochlea medially to make articulations with the head of the radius and the proximal part of the ulna, respectively. Superior to them, there is the radial fossa laterally and coronoid fossa medially. The radial fossa accommodates the head of radius while the coronoid fossa accepts the coronoid process of the ulna during flexion of the elbow. On the posterior side, there is the olecranon fossa which accepts the olecranon process of the ulna during extension of the elbow [36, 40].

The blood supply of the distal humerus mainly relies on the descending branch of the main nutrient artery [47]. It gives branches to the supracondylar regions. However, the epicondylar regions are supplied mainly by the posterior ulnar recurrent artery, the recurrent interosseous artery, and the radial recurrent artery [56].

1.1.5 Sternoclavicular Joint

Sternoclavicular (SC) joint, or sternoclavicular articulation, is the connection between the manubrium of the sternum and the medial end of the clavicle. The SC joint is biaxial and classified as a saddle type of synovial joint, but despite its structural materials, it has the ability to act like a ball-and-socket type of joint functionally. Theoretically, the SC joint allows movement in three planes, as a triaxial joint. The reason it is not classified as triaxial joint is because rotation movements cannot be isolated from the body [9]. There is a fibrous joint capsule which surrounds the SC joint, and the capsule attaches to the articular disk. The articular disk lies between articular faces superiorly and inferiorly and separates the synovial cavity into two compartments [57]. The SC joint is the only true connection between the trunk and the upper limb structurally. Therefore, most shoulder movements originate from this articulation. Moreover, SC and acromioclavicular (AC) joints determine the position of the scapula; therefore, the position of the arm is strictly related to interwork of joints [9].

In the body, musculoskeletal movements are always restrained by limitative factors, specifically, by ligaments. The SC joint contains four major ligaments: anterior sternoclavicular ligament, posterior sternoclavicular ligament, interclavicular ligament, and costoclavicular ligament.

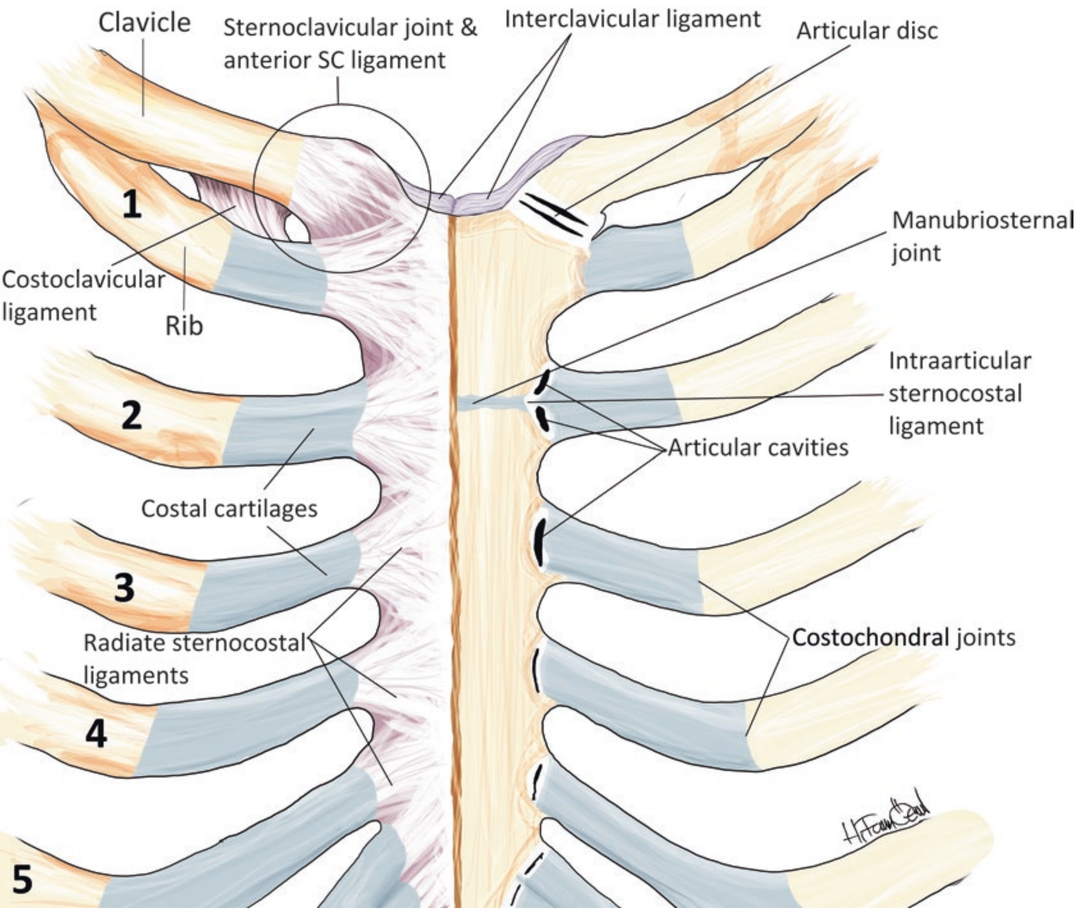


Fig. 1.8 The sternoclavicular joint and associated structures, seen from anterior

Anterior and posterior SC ligaments attach both front and back parts of the medial end of the clavicle and the manubrium of the sternum [57]. The posterior SC ligament is the primary restraint factor for the posterior dislocations. Posterior dislocation of the medial end of the clavicle my harm the vessels in the superior mediastinum [58]. It can also cause difficulty in breathing or dysphagia [13, 16]. The interclavicular ligament lies horizontally on the jugular notch and is a linkage between the medial surfaces of the clavicles. It stabilizes the articulation and restricts elevation of the sternum when the clavicle's lateral end is depressed. The costoclavicular ligament, which is the most important restraining ligament of the SC joint, lengthens between the first rib and the inferior aspect of the clavicle. It restricts the elevation of the pectoral girdle [57]. The costoclavicular ligament limits protraction, but it does not restrain the depression of the clavicle [9] (Fig. 1.8).

As can be seen, the sternoclavicular joint performs movements under strong restraining factors. However, due to its synovial materials, it has a wide variety of motion abilities, such as protraction (30°), retraction (30°), elevation (45°), and depression (10°). In addition to these, when the arm is elevated via flexion, the clavicle rotates around its longitudinal axis [9, 57].

1.1.6 Acromioclavicular Joint

The acromioclavicular (AC) joint is a plane-type of synovial joint which connects the lateral end of the clavicle and the acromion of the scapula. It is surrounded by a thin, loose fibrous capsule, and the capsule is supported by AC ligament, superiorly. The lateral face of the clavicle and the medial face of the acromion are covered with fibrous cartilage, and between two articular faces, there is a meniscoid intraarticular disk [57]. Due to the structure of the joint, it gives rise to nonaxial gliding motions [59].

The blood supply of the AC joint is provided by suprascapular and thoracoacromial arteries which are the branches of the thyrocervical trunk and the axillary artery, respectively [57].

The AC joint increases the range of motion of the scapula and implicitly of the arm. It allows extra rotation of the scapula on the scapulothoracic joint and contributes to raise the arm above the head [59].

The AC joint consists of three clinically important ligaments which are positioned at different locations. The two ligaments attached to the lateral one-third of the clavicle are the AC and the coracoclavicular (CC) ligaments. The AC ligament basically consists of two parts. The superior part is the main supporting factor for the joint capsule and also helps maintaining the horizontal plane. It receives fibers from trapezoid and deltoid muscles. The inferior part is thinner and covers the inferior part. On the other hand, the CC ligament is the most restrictive ligament of the clavicle and carries nearly all weight of the upper limb. It is made up of two separate ligaments: anteroposteriorly, the trapezoid ligament and posteromedially, the conoid ligament. Although it is not directly related to the AC joint, it prevents superior dislocations. The CC ligament provides the most powerful support for maintaining the horizontal plane of the clavicle [13, 16, 58]. The third one is an extrinsic ligament and has close relations with the AC joint. The coracoacromial ligament originates from medial border of acromion and attaches to the coracoid process of the scapula. Its main function is to protect the most functional joint of the upper extremity, the glenohumeral joint. The coracoacromial ligament covers the glenohumeral joint, superiorly. Without coracoacromial ligament, the humeral head can easily be traumatized and gets injured [57] (Fig. 1.9).

There are some conditions which can cause injury to the AC joint. Several of those conditions are AC joint dislocations, AC arthritis, and distal

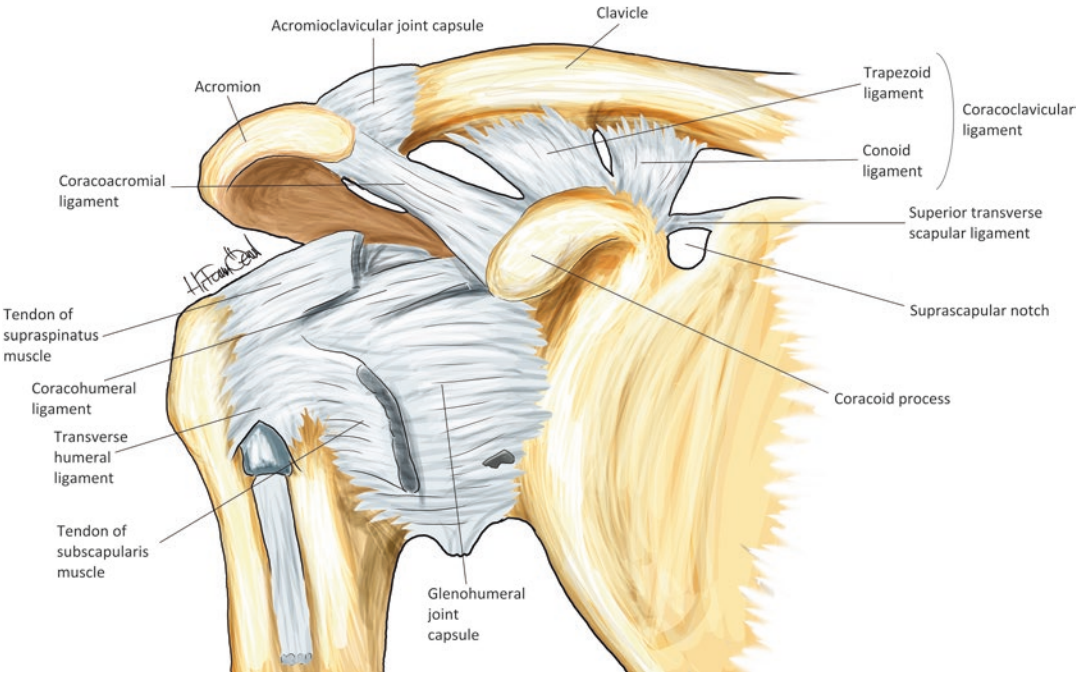


Fig. 1.9 The acromioclavicular joint, the glenohumeral joint, and associated structures seen from anterior

clavicle osteolysis [13, 16]. The AC joint dislocation, also called shoulder separation, is a condition when someone has a hard fall on his shoulder or has stretched his arm over limits [57]. The classification of AC joint dislocations can be done by checking the AC ligament and CC ligament. CC ligament ruptures indicate severe injuries and result with elevation of the clavicle [15].

1.1.7 Glenohumeral Joint

The glenohumeral joint, also called the shoulder joint, is the ball-and-socket type of synovial joint between the head of the humerus and the glenoid cavity of the scapula. The glenoid cavity of the scapula, in comparison to the humeral head, is so small and shallow that it only accepts little more than a third of it [60]. This articulation allows the glenohumeral joint to have greater range of motion than any other joint in the body [15, 61]. The glenohumeral joint can perform movements around the three axes so that the arm can perform flexion-extension, abduction-adduction, medial and lateral rotation, and circumduction [60].

Being the most mobile joint of the body [15] makes the glenohumeral joint very unstable. So there are several static and dynamic restraints of the shoulder joint to provide the stability. The static restraints of the glenohumeral joint are composed of the bony, capsular, cartilaginous, ligamentous structures. Among them, the negative intraarticular pressure has the greatest importance. The dynamic restraints are composed of the muscular structures around the shoulder [62, 63]. The list of the restraints is given in Table 1.1.

Table 1.1 Restraints of glenohumeral joint

Static restraints	Dynamic restraints
Glenoid labrum	Rotator cuff muscles
The capsule of the glenohumeral joint and glenohumeral ligaments	The long head of biceps brachii muscle
The negative intraarticular pressure	
Articular conformity	
Articular version	

The articular surfaces of the humeral head and the glenoid cavity are covered by a hyaline cartilage [60, 64]. Around the glenoid cavity, there is a fibrocartilaginous, ringlike structure called the glenoid labrum (Figs. 1.10 and 1.11). With the help of the labrum, the depth of the glenoid cavity is increased by approximately 50% [62, 63]. Superiorly, it's continuous with the tendon of the long head of the biceps brachii muscle that serves as one of the dynamic restraints of the glenohumeral joint by changing the orientation according to the rotational movements of the upper extremity. During internal rotation of the arm, the biceps tendon slides anteriorly and prevents the anterior translation of the humeral head whereas during external rotation, it slides posteriorly to prevent the posterior translation of the humeral head [63].

The fibrous membrane of the joint capsule attaches medially to the margin of the glenoid cavity and laterally to the anatomical neck of the humerus. On the medial side of the humerus, it extends below the anatomical neck. This inferior portion of the joint capsule is loose in structure so that it contributes to the abduction of the arm, and it's the only part of the joint capsule which is not supported by the rotator cuff muscles, which is why the dislocations of the shoulder joint are mostly toward the inferior direction [60, 63, 64]. Underlying the capsule, there is the synovial membrane, and it protrudes through the opening on the anteroinferior part of the joint capsule to form the subtendinous bursa of subscapularis. It also forms the synovial sheath for the tendon of the long head of the biceps brachii muscle [60, 64].

The fibrous membrane of the joint capsule thickens and forms the glenohumeral ligaments, the coracohumeral ligament, and the transverse humeral ligament. The glenohumeral ligaments support the anterior aspect of the joint capsule. The superior and middle glenohumeral ligaments originate from the anterosuperior glenoid labrum and insert to the lesser tuberosity. The inferior glenohumeral complex originates from the inferior glenoid labrum and inserts to the anatomical neck [60, 64]. The inferior ligament is composed of three parts: the anterior part, the

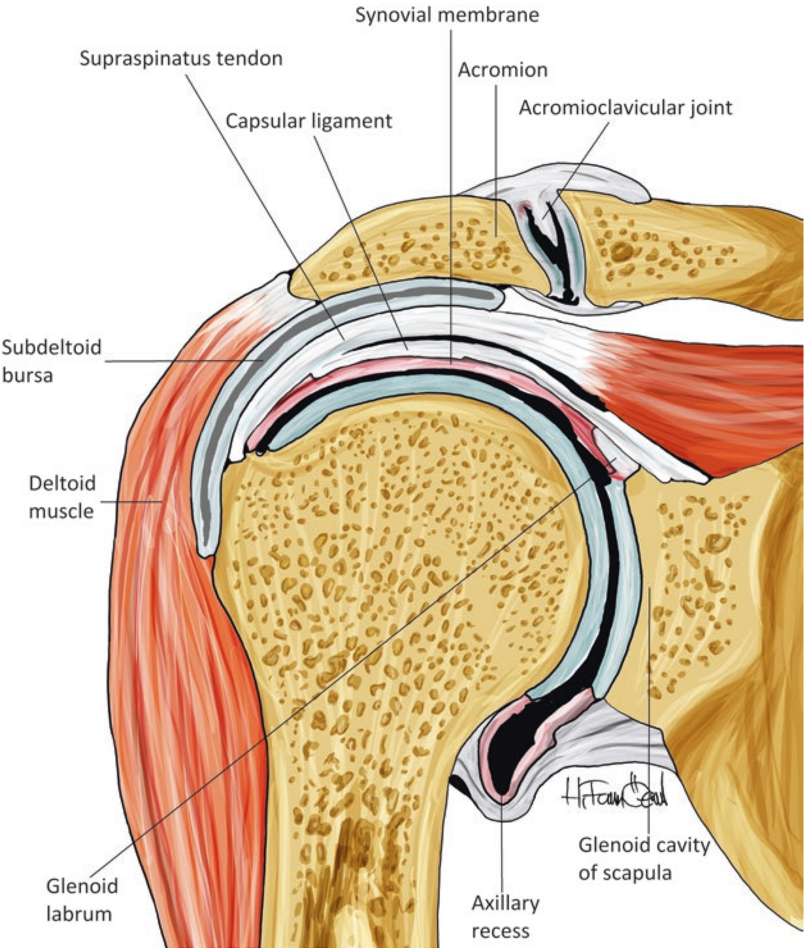


Fig. 1.10 The glenohumeral joint seen in coronal section, showing the cartilaginous structures, bursae, and the musculotendinous structures related to the joint

posterior part, and the axillary pouch in between [65]. They get tense with the motions of the humerus to hold the humeral head across the glenoid cavity [66]. The coracohumeral ligament originates from the base of the coracoid process of the scapula and inserts to the greater tubercle. The transverse humeral ligament is a fibrous band in between the greater and the lesser tubercles. It overlies the intertubercular sulcus and turns it into a canal which holds the synovial sheath and the long head of the biceps brachii muscle [60, 64].

There is the subacromial (subdeltoid) bursa which is related with the shoulder but not connected to the synovial cavity. Located below the acromion and the deltoid muscle and above the tendon of the supraspinatus muscle, the subacromial bursa facilitates the movement of the supraspinatus tendon [60] (Figs. 1.10 and 1.11).

There are plenty of muscles around the glenohumeral joint which serve either as to restrain the joint or to produce the movements. They are listed in Table 1.2.

1.1.8 Scapulothoracic Joint

As we discussed earlier, the anterior surface of the scapula is in relation with the posterior thoracic cage. Due to the scapula's ability to move around, this specific relation is also named the scapulothoracic joint. Defining the range of motion of the

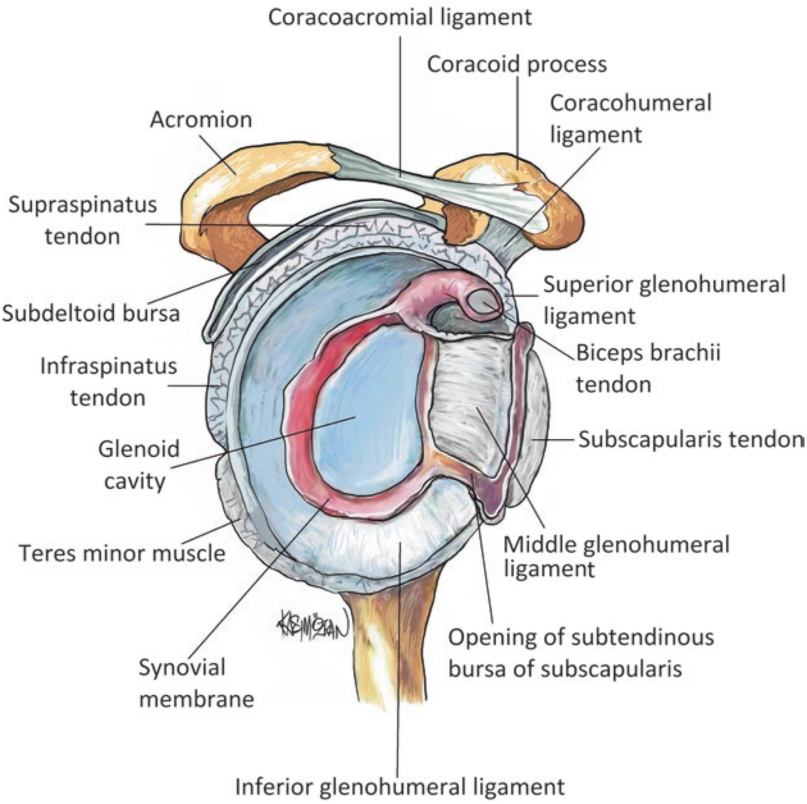


Fig. 1.11 The lateral view of the glenohumeral joint opened

scapula in regard to the thoracic wall, the scapulothoracic joint mainly amplifies the motion of the glenohumeral joint and augments its range of motion. Furthermore, this joint functions as an important shock absorber to protect the shoulder during outstretched arm falls. With the assistance of two major (scapulothoracic and subscapularis) and four minor bursae, the scapulothoracic joint allows the following movements: elevation/depression, abduction/adduction, downward/upward rotation, and scapular tilt. Elevation and depression of the scapula occur simultaneously with anterior and posterior scapular tilt, respectively; this is mainly due to the convex curvature of the thoracic cage. Similarly, the scapula tilts medially and laterally as the scapula abducts and adducts, respectively. The motions of the scapula alongside this joint are mainly accompanied and restricted by the acromioclavicular and sternoclavicular joints [67, 68].

1.1.9 Subacromial Space

The subacromial space is a functional interval which extends vertically between the humeral head and the acromion of scapula. In radiographic examinations, the height of the acromiohumeral distance (AHD) varies from 1.0 to 1.5 cm. Its inferior surface is defined by the rotator cuff tendons (supraspinatus and anterior part of infraspinatus) and superiorly by the acromion of scapula, coracoacromial ligament, and acromioclavicular joint. The subacromial space is occupied by the subacromial bursa, and the subacromial bursa is fused with subdeltoid bursa under the deltoid muscle. The bursa is essential to ease the movements of rotator cuff without injuring tendons. If any structure in the acromiohumeral distance is damaged, it may proceed to the pathology called "impingement syndrome" [69–72].

Table 1.2 Muscles associated with glenohumeral joint

Muscle	Origin	Insertion	Innervation	Function
Pectoralis major	Clavicle, sternum, first six costal cartilages	Lateral lip of the bicipital groove	Medial (C8, T1) and lateral (C5, C6, C7) pectoral nerves	Adducts and internally rotates the humerus
Pectoralis minor	3rd–5th ribs	Medial aspect of the coracoid process	Medial pectoral nerve (C8–T1)	Protracts scapula
Subclavius	First rib	Inferior surface of the clavicle	Nerve to subclavius (C5, C6)	Moves clavicle inferiorly
Serratus anterior	1st–8th ribs	Anterior medial surface of scapula	Long thoracic nerve (C5, C6, C7)	Hold scapula against chest wall
Trapezius	External occipital protuberance, nuchal ligament, spinous processes of C7–T12	Lateral third of the clavicle, acromion, scapular spine	Spinal accessory nerve (CN XI)	Elevates, depresses, and retracts scapula; rotates glenoid cavity superiorly
Latissimus dorsi	Spinous processes of T6–T12, thoracolumbar fascia, iliac crest	Medial lip of the bicipital groove	Dorsal scapular nerve (C5)	Extends, adducts, and internally rotates the humerus and raises the body during climbing
Levator scapulae	Transverse processes of C1–C4	Medial border of scapula (superior to spine of scapula)	C3 and C4 nerves	Moves scapula superiorly and rotates the glenoid cavity inferiorly
Rhomboid major	Spinous processes of T2–T5	Medial border of scapula (from spine to inferior angle)	Dorsal scapular nerve (C5)	Retracts and elevates scapula
Rhomboid minor	Spinous processes of C7–T1	Medial aspect of scapular spine	Dorsal scapular nerve (C5)	Retracts and elevates scapula
Deltoid	Lateral aspect of clavicle, acromion, and scapular spine	Deltoid tuberosity of humerus	Axillary nerve (C5, C6)	Abducts arm
Teres major	Inferior angle of scapula	Medial lip of bicipital groove	Lower subscapular nerve (C5, C6)	Adducts and internally rotates the arm
Biceps brachii	Supraglenoid tubercle and coracoid	Radial tuberosity	Musculocutaneous nerve (C5, C6, C7)	Flex and supinate the elbow

1.2 Muscles

There are several muscles around the shoulder joint to provide the high mobility of the shoulder, and some of these muscles also serve to restrain the shoulder joint.

The muscles of the shoulder region, except the rotator cuff muscles, are listed in Table 1.2 [73–75]. The first four muscles (pectoralis major, pectoralis minor, subclavius, and serratus anterior) are the anterior axio-appendicular muscles. Following five muscles (trapezius, latissimus dorsi, levator scapulae, rhomboid major, and rhomboid minor) are the posterior axio-appendicular muscles. Deltoid, teres major, and rotator cuff muscles are the intrinsic shoulder muscles. And finally, the biceps brachii muscle doesn't belong to these groups but it is related to the shoulder.

The rotator cuff muscles are not discussed in Table 1.2, but they will be discussed in this chapter later in detail.

1.2.1 Deltoid

The deltoid is the muscle that covers the shoulder and gives its rounded shape. It is one of the intrinsic shoulder muscles, and it has anterior, middle, and posterior parts. These parts can contract independently or as a whole. When contracted independently, the anterior part helps the pectoralis major muscle for flexion and medial rotation of the arm and the posterior part helps the latissimus dorsi muscle for extension and lateral rotation of the arm. With the simultaneous contraction of all the three parts, the arm is abducted. During the abduction, the main working part is the middle part; the anterior and posterior parts function as stabilizers [73, 76].

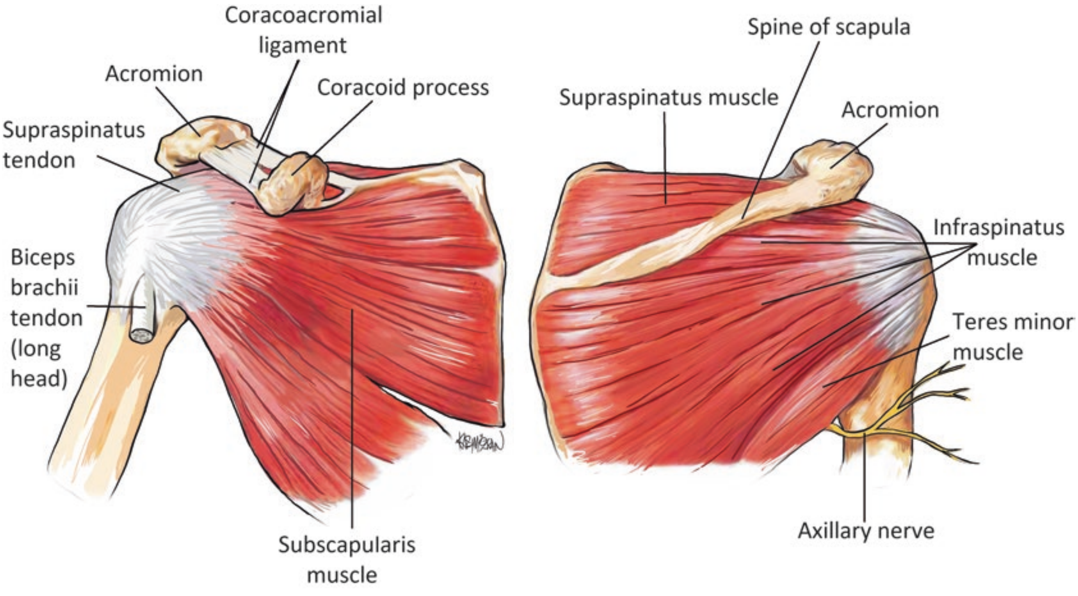
The deltoid muscle is effective after 15° of abduction. First 15° of abduction is initiated by the supraspinatus muscle, or by leaning to side and using gravity. It is hinged at its origin, and by this hinge effect, the deltoid muscle also prevents the inferior displacement of the humeral head from the glenoid cavity in fully adducted position, especially when lifting or carrying heavy objects [77].

The deltoid muscle is innervated by the axillary nerve (C5–C6), and its blood supply comes mainly from the posterior circumflex humeral artery. The axillary nerve and posterior circumflex humeral artery give branches to the deltoid muscle after passing posteriorly around the surgical neck [78].

1.2.2 Rotator Cuff Muscles

The "rotator cuff" describes a musculotendinous cuff that contributes to the stabilization and mobility of the shoulder joint. It is composed of the supraspinatus, the infraspinatus, the teres minor, and the subscapularis muscles. As these muscles approach to the glenohumeral joint, their tendons blend with each other and with the joint capsule. This way, they reinforce the joint capsule. At the same time, via contraction of these muscles, the humeral head is held in the glenoid cavity during the movements of the arm [73] (Figs. 1.12 and 1.13).

All the rotator cuff muscles play a role in the rotational movements of the arm. The supraspinatus, the infraspinatus, and the teres minor muscles are involved in the medial rotation of the arm, whereas the subscapularis muscle is involved in the lateral rotation of the arm. The supraspinatus muscle is also important from



Anterior view

Posterior view

Fig. 1.12 The rotator cuff muscles seen from anterior and posterior

Fig. 1.13 The rotator cuff muscles seen from above

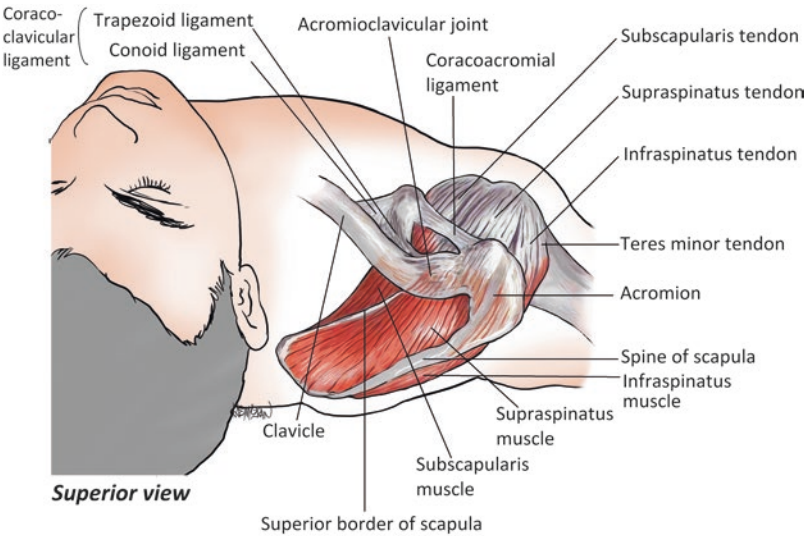


Table 1.3 Rotator cuff muscles

Muscle	Origin	Insertion	Innervation	Function
Supraspinatus	Supraspinous fossa	Greater tuberosity	Suprascapular nerve	Abducts (first 15°) and internally rotates the arm
Infraspinatus	Infraspinous fossa	Greater tuberosity	Suprascapular nerve	Externally rotates the arm
Teres minor	Dorsolateral scapula	Greater tuberosity	Axillary nerve	Externally rotates the arm
Subscapularis	Ventral scapula	Lesser Tuberosity	Upper and lower subscapular nerves	Internally rotates the arm

fully adducted position to the first 15° of abduction of the arm. The detailed information about the origins, insertions, innervations, and functions of the rotator cuff muscles can be found in Table 1.3 [74].

As mentioned before, there is very narrow space called the subacromial space in which the subacromial bursa and the tendon of supraspinatus muscle are located. Any pathology that causes further narrowing of this space can cause shoulder impingement syndrome, and usually the supraspinatus muscle is impinged [70].

There is the rotator interval which is an anatomical space bounded by the superior margin of the subscapularis tendon, anterior margin of the supraspinatus tendon, and the coracoid process of the scapula. The contents of this space are the coracohumeral ligament, the superior glenohumeral ligament, the tendon of the long head of the biceps brachii muscle, and the anterior joint capsule [79]. It has a complex anatomy, and it is hard to see the structures with imaging modalities or arthroscopy. Because of this, it is challenging to make the proper diagnosis of the rotator interval anomalies [80]. Besides, the role of the rotator interval is still not exactly understood; it is under discussion [81]. Some studies suggest that the structures in the rotator interval help to maintain the negative intraarticular pressure in the glenohumeral joint [82]. Some studies claim that it resists the inferior and posterior translation of the glenohumeral joint [83]. There are also some other studies suggesting that the rotator interval is an area of tissue deficiency, and injuries of the rotator cuff lead to some chronic symptoms [81] (Fig. 1.14).

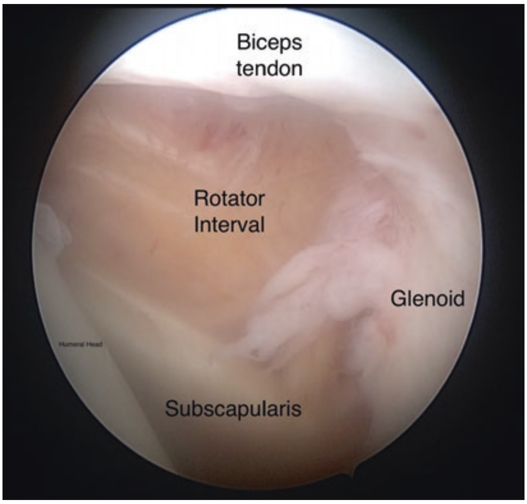


Fig. 1.14 The arthroscopic view of the rotator interval (reprinted with permission from Dr. Huri)

There are some anatomical spaces between some of the muscles of the shoulder region and the humerus [78]. Each of these spaces acts like a passageway for some anatomically important structures coursing from anterior to the posterior scapular regions (Fig. 1.15). These spaces are

- The quadrangular space: The borders of this space are the inferior border of the teres minor muscle, the surgical neck of the humerus, the superior border of the teres major muscle, and the lateral border of the long head of the triceps brachii muscle. The posterior circumflex humeral artery and vein and the axillary nerve pass through this space. Hypertrophy of any muscles, or fibrosis of any muscle ridges constituting this space, can cause impingement of the axillary nerve, and this situation is commonly known as "the quadrangular space

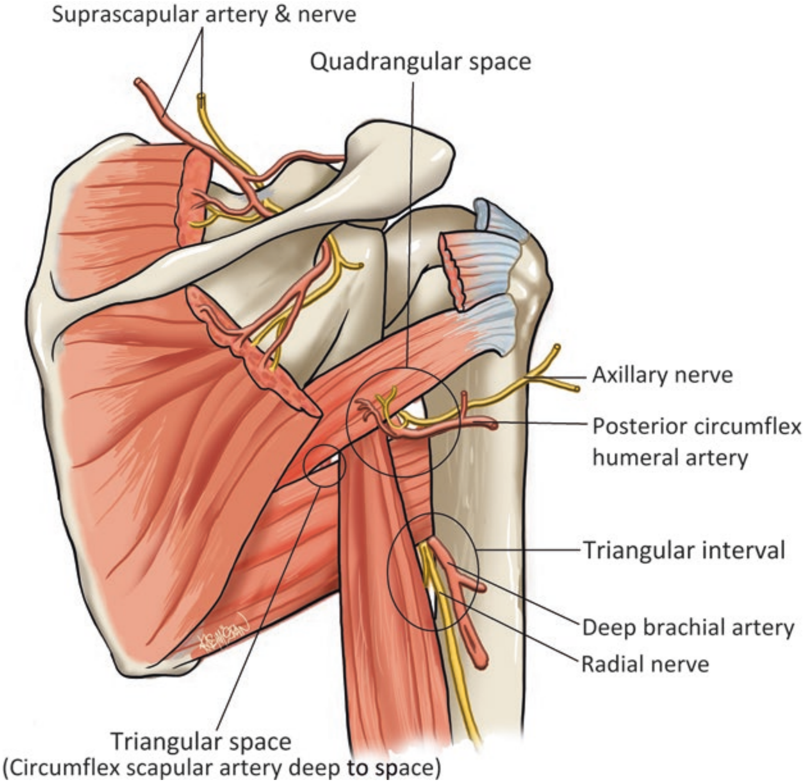


Fig. 1.15 The picture showing the quadrangular and triangular spaces and the triangular interval with associated structures

syndrome." The quadrangular space syndrome will be discussed in detail in Chap. 2.
- The triangular space: The borders of this space are the medial border of the long head of the triceps brachii muscle, the superior margin of the teres major muscle, and the inferior margin of the teres minor muscle. The circumflex scapular artery and vein pass through this space.
- The triangular interval: The borders of this space are the lateral border of the long head of the triceps brachii muscle, the shaft of the humerus, and the inferior margin of the teres major muscle. The radial nerve and the deep brachial artery and associated vessels pass through this space.

1.3 Neurovascular Anatomy

The neurovascular anatomy of the shoulder mainly refers to the brachial plexus and the axillary artery and its branches [84].

1.3.1 Brachial Plexus

The brachial plexus is the main nerve network that supplies motor, sensory, and sympathetic fibers to the upper extremity, and it extends from the neck to the axilla [85]. It is consisted of roots, trunks, divisions, cords, and terminal branches. The ventral rami of C5–T1 nerves form the roots of the plexus. The roots pass between the anterior and middle scalene muscles with the subclavian artery anterior to them and as the plexus descends the roots of C5 and C6 unite to form the anterior trunk, C7 continues as the posterior trunk, and C8 and T1 unite to form the inferior trunk. Each trunk then divides into anterior and posterior divisions as the plexus passes from the cervico-axillary canal behind the clavicle. As a general rule, the anterior divisions supply the flexor compartments of the upper extremity, while the posterior divisions supply the extensor compartments. The posterior divisions of all trunks unite and form the posterior cord. The anterior divisions of the superior and middle trunks unite to form the lateral cord, and the anterior division of the inferior trunk continues as the medial cord. The cords are named according to their relative positions to the second part of the axillary artery. Finally, at the axilla, each cord divides into two, and then they reunite and form the terminal branches: the musculocutaneous nerve (C5, C6, C7) that takes fibers from the lateral cord, the axillary nerve (C5, C6) and the radial nerve (C5, C6, C7, C8, T1) from the posterior cord, the median nerve (C5, C6, C7, C8, T1) from lateral and medial cords, and the ulnar nerve (C7, C8, T1) from the medial cord [75, 85, 86].

There are also some nerves which arise before the plexus gives the terminal branches. From the roots, the dorsal scapular nerve (C5) and the long thoracic nerve (C5, C6, C7) arise. Also, the root C5 contributes to the phrenic nerve. From the trunks, the suprascapular nerve (C5, C6) and the subclavius nerve (C5, C6) arise. Finally, the lateral pectoral nerve (C5, C6, C7), the upper and lower subscapular nerves (C5, C6), the thoracodorsal nerve (C6, C7, C8), the medial brachial cutaneous nerve (T1), and the medial antebrachial cutaneous nerve (C8, T1) arise from the cords [75] (Fig. 1.16).

Its long course in close proximity to the operation field, the limited maneuverability, and its close relation to the bony structures against which it may be compressed make the brachial plexus very vulnerable to injuries during shoulder surgery [87]. After shoulder arthroplasty, the incidence of neurological complications ranges from 0.6% to 4.3%, and majority are the neuropraxic injuries to the brachial plexus [88]. Because of the anatomic distribution of the nerve fibers, injuries to the brachial plexus typically present with characteristic patterns of sensory and/or motor deficits.

1.3.2 Vascular Anatomy

The blood supply of the shoulder mainly comes from the axillary artery which is the continuation

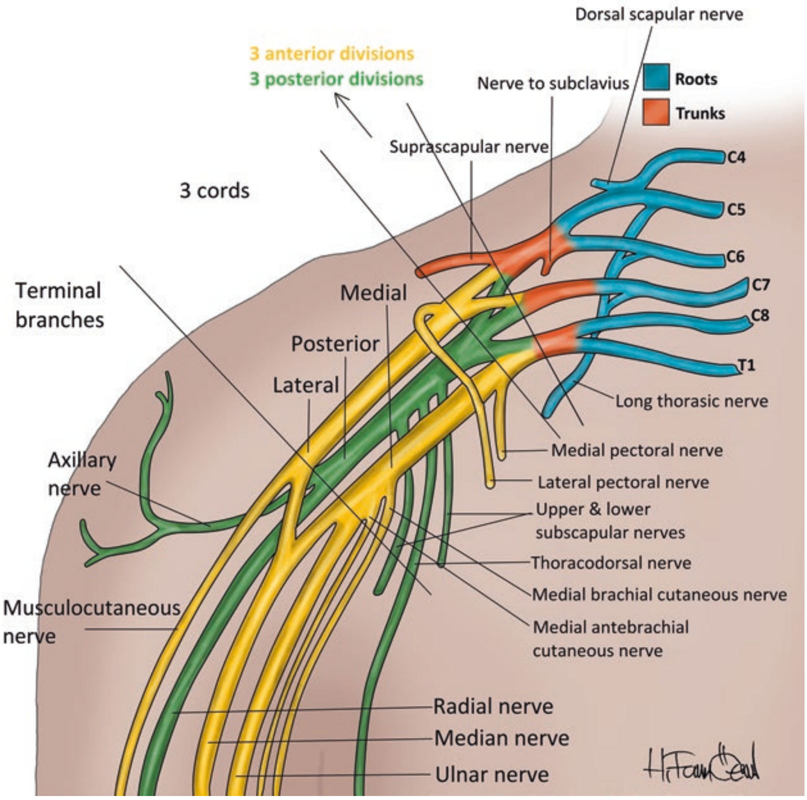


Fig. 1.16 The drawing of the brachial plexus

of the subclavian artery starting from the lateral border of the first rib. It continues as the brachial artery at the inferior border of the teres major muscle [84].

The axillary artery is divided into three parts according to the pectoralis minor muscle. The first part is lateral to the first rib and medial to the pectoralis minor muscle. It gives the superior thoracic artery just inferior to the subclavius muscle. The second part of the axillary artery is posterior to the pectoralis minor muscle, and it has two branches: the thoracoacromial artery and the lateral thoracic artery. The thoracoacromial artery then divides and gives off the clavicular, acromial, deltoid, and pectoral branches. The lateral thoracic artery may also originate from the thoracoacromial, suprascapular, or subscapular arteries. The third part of the axillary artery is distal to the pectoralis minor muscle, and it has three branches: the subscapular artery, the anterior and posterior circumflex humeral arteries. The subscapular artery is the largest branch of the axillary artery. It ends by dividing into the circumflex scapular and the thoracodorsal arteries. The circumflex humeral arteries anastomose with each other and encircle the surgical neck of the humerus [89, 90].

There is also the suprascapular artery which arises from the thyrocervical trunk which is a branch of the subclavian artery. It may also originate directly from the 3rd part of the subclavian artery. It courses inferolaterally and then to the posterior, entering the posterior scapular region by passing over the superior transverse scapular ligament. The suprascapular artery gives branches to several structures during its course. Its relation to the shoulder is that it supplies the structures in the posterior scapular region [91, 92] (Fig. 1.17).

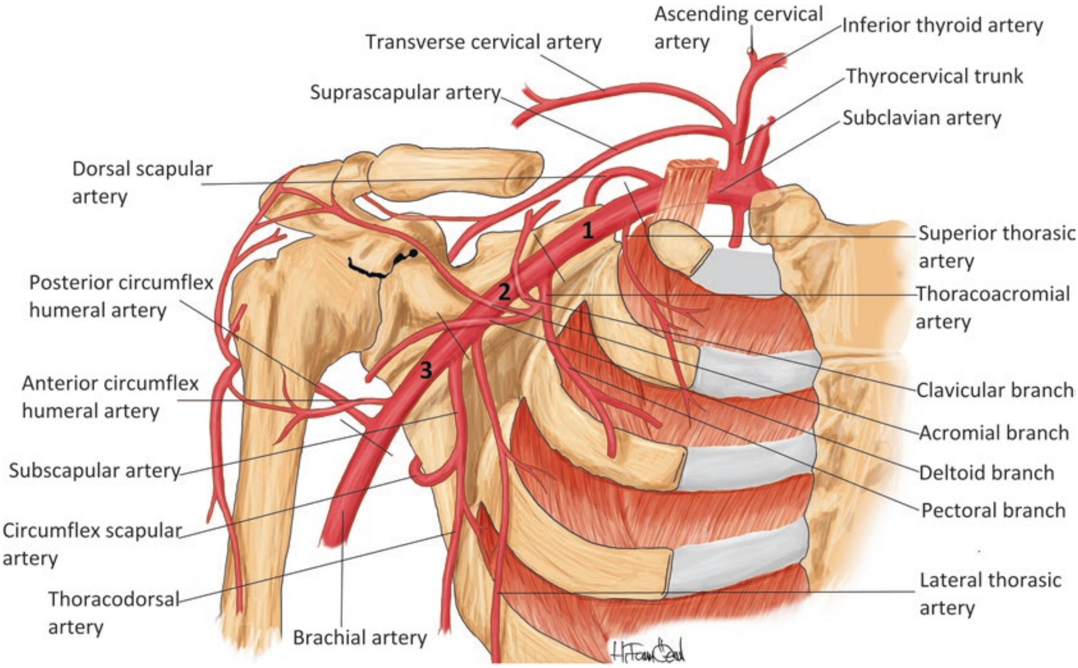


Fig. 1.17 The picture showing the axillary artery and its branches

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2

Axillary Nerve Palsy

Naime Dilara Özkan and Sena Gül Çakır

The axillary nerve is one of the main nerves of the shoulder with motor and sensory function. Due to its anatomical course, axillary nerve is quite vulnerable to injuries, and therefore, its injury is commonly seen in clinics. Clinical presentation is generally typical, and good results can be achieved with proper medical management. In this chapter, we will review the anatomy of axillary nerve as well as the diagnosis and management of axillary nerve injury.

2.1 Anatomy of the Axillary Nerve

Axillary nerve originates from the brachial plexus.

The brachial plexus consists of roots, trunks, divisions, cords, and branches. The ventral rami of the spinal nerves C5–T1 (and in some variations T2) form five roots. The roots merge to form the superior, inferior, and middle trunks. Each of these trunks divide into anterior and posterior divisions. The posterior divisions then merge to form the posterior cord, which branches to form the radial and axillary nerves [1–3].

The axillary nerve generally carries fibers from C5 and C6. Occasionally, C7 may also contribute to the axillary nerve [4].

The axillary nerve may also give rise to the inferior subscapular nerve, which innervates the subscapularis and the teres major [4].

2.1.1 The Course of the Axillary Nerve

After its formation, the axillary nerve travels posteriorly through the quadrangular space with posterior circumflex humeral artery and vein [2, 3].

The borders of the quadrangular space consist of the following anatomical structures: the subscapularis, the head of humerus, and the teres minor at the superior; the teres major at the inferior; the coracobrachialis muscle, and the surgical neck of the humerus at the lateral; and the long head of triceps at the medial [5].

After passing through, the axillary nerve gives rise to two motor branches that innervate the deltoid and the teres minor muscles, and a sensory branch called the superior lateral cutaneous nerve of arm, which innervates the skin above the inferior deltoid region [3]. The deltoid branch of this nerve travels posteriorly around the surgical neck of the humerus alongside the posterior circumflex humeral artery and vein to innervate the deltoid muscle [2].

While passing through the quadrangular space, axillary nerve gives branch to teres minor

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[6]. After passing, axillary nerve is coursed just anterior and inferior to the glenohumeral joint [7], and then it divides into two branches: anterior and posterior. The anterior branch gives rise to the motor branches that innervate the deltoid muscle, and the posterior branch forms the superior lateral cutaneous nerve of arm which innervates the skin above the inferior deltoid region.

However, in some studies some variations regarding the course of axillary nerve are shown. Steinmann et al. [4]. have shown in their study that when the axillary nerve exits the quadrangular space, it continues posteriorly to the humeral neck and divides into anterior and posterior branches. The anterior branch travels around the surgical neck of the humerus alongside the posterior circumflex humeral artery and vein and innervates the anterior part of deltoid muscle. Along the way, the nerve sends branches to innervate the middle and anterior portions of the deltoid. The posterior branch innervates the teres minor and the posterior portion of the deltoid. The branch to the teres minor arises within or distal to the quadrangular space and enters the muscle at its inferior border. The posterior branch gives rise to the superior lateral cutaneous nerve of arm terminally, coursed inferiorly, deep to the posterior aspect of the deltoid [8] and innervates the skin above the deltoid [4, 8–12].

2.2 Axillary Nerve Injury

The axillary nerve injury will be discussed under the following titles:

- Definition
- Etiology
- Clinical Presentation
- Diagnosis
- Prognosis
- Differential Diagnosis
- Medical Management

2.2.1 Definition

Axillary nerve injury is characterized by trauma to the axillary nerve and thus the dysfunction of the muscles innervated and lack of sensation of the skin above the deltoid. It is seen most often due to closed trauma involving traction on the shoulder [13].

The axillary nerve injury is usually present with other brachial plexus injuries. In reported studies, infraclavicular isolated axillary nerve injury occurred only 0.3–6% of brachial plexus injuries [4, 13].

2.2.2 Etiology

2.2.2.1 Glenohumeral Dislocation

Axillary nerve injury most commonly occurs after a traction type injury usually associated with anterior glenohumeral dislocation or proximal humerus fracture.

The incidence of axillary nerve injury due to anterior glenohumeral dislocation is 13.5–48%. The majority of the injuries are neuropraxias and typically resolve in 6–12 months [14].

When the humeral head is anteroinferiorly dislocated, it stretches the axillary nerve. The injury occurs commonly before the nerve is entering the quadrilateral space and proximal to the branching point of anterior and posterior divisions. Therefore, the anterior and posterior branches are both affected which results in deltoid and teres minor dysfunction as well as lack of sensory function of the skin above deltoid [14, 15].

Some patients have subclinical axillary nerve lesion. Since they have discomfort due to the injury, the nerve lesion may not be apparent clinically, but it can be detected by Electromyogram Test & Nerve Conduction Study (EMG/NCS) [13].

2.2.2.2 Proximal Humerus Fracture

Proximal humeral fractures represent about 4% of all fractures seen in an average orthopedic clinic and 2–3% of upper extremity fractures. Therefore, it is relatively very common [16]. The prevalence increases with the advancing age [17]. The demographic shifting of the population age-sex dependent characteristics is yet to be determined [17].

In adolescence and early adulthood, the cause of fracture is generally high-energy traumas. However, the high-energy traumas are less often than the low-energy traumas and osteoporotic fractures that are seen in elderly people [17].

In proximal humerus fractures, the most frequently involved nerves are axillary nerve and the subscapular nerve [10]. Axillary nerve injury is even more common since it is coursed just anterior and inferior to the glenohumeral joint and runs posteriorly to the surgical neck of humerus accompanied by the posterior circumflex humeral artery [4]. The surgical neck is weaker than the proximal regions of the bone; it is one of the sites where the humerus commonly fractures. Thus, the axillary nerve is quite vulnerable to both traumatic and iatrogenic injuries [7, 18].

2.2.2.3 Blunt Trauma

Direct blow to the lateral shoulder or the deltoid muscle causes a compressive force to the axillary nerve as it travels on the deep subfascial surface within the deltoid.

This type of injuries generally occurs during collision in contact sports such as hockey or American football.

No axillary nerve ruptures have been reported to occur by this type of injury until 1998 [9, 19].

There was a case report regarding axillary nerve rupture due to blunt trauma [20].

2.2.2.4 Quadrilateral Space Syndrome (QSS)

Axillary nerve and posterior humeral circumflex artery pass through the quadrilateral space below the shoulder capsule. This syndrome is caused by compression force on axillary nerve and posterior humeral circumflex artery or traction force on axillary nerve. It generally occurs in the dominant arm.

Axillary nerve compression within the quadrilateral space is usually secondary to abnormal fibrous bands and hypertrophy of the muscular boundaries of the space [9, 19].

2.2.2.5 Compression Without Trauma

Compression of the axillary nerve due to enlarging mass or aneurism may cause injury. This type of injury is not very common [4].

2.2.2.6 Brachial Neuritis

Another atraumatic injury of axillary nerve is brachial neuritis. It is a multifocal, immune-mediated inflammatory process that involves the peripheral nerves. It was first reported by Parsonage and Turner in 1948 in a case report. Brachial neuritis is also called neuralgic amyotrophy or Parsonage-Turner Syndrome. It affects long thoracic, suprascapular, axillary, musculocutaneous, anterior interosseous and posterior interosseous nerves most commonly.

Motor axons are mostly affected. Therefore, the nerves that carry mostly motor fibers are affected to a larger degree and more commonly than mixed nerves and pure sensory nerves [4, 21, 22].

2.2.2.7 Iatrogenic

Open reconstructive surgery and some newer arthroscopic techniques can put the axillary nerve at risk [13].

- Capsular shrinkage: These procedures may increase the local temperature in the inferior capsule and lead to nerve injury. Injury has been reported in 1 or 2% of thermal capsular shrinkage procedures [13].
- Capsular resection for adhesive capsulitis: Nerve is in close proximity to the anteroinferior capsule; resection should be done carefully [13].
- Shoulder instability surgery: The axillary nerve travels on the anterior and inferior shoulder capsule, so procedures that involve this area such as Bankart procedure and inferior capsular shift procedure may put axillary nerve at risk [9, 19].
- Rotator cuff surgery: Axillary nerve travels horizontally within the deltoid muscle 5 cm inferior to the acromion. Incisions that split the deltoid muscle are often used in the treatment of rotator cuff disorders; however, overzealous muscle splitting will put axillary nerve at risk [9, 19].
- Shoulder arthroscopy: Posterior shoulder arthroscopic portal usually is located 2–3 cm inferior and 1 cm medial to the posterolateral corner of the acromion. Thus, the portals must be placed carefully because the axillary nerve might be at risk since it is close to that area [9].
- Shoulder arthroplasty: Implantation of the humeral and glenosphere components may

endanger the integrity of the axillary nerve due to its proximity to the humeral metaphysis and the lower glenoid rim [23].

- Thoracic surgery: Position of the patient during the surgery may cause traction type injury to the axillary nerve.

  There's a case report about a 21-year-old male who underwent a video-assisted thoracic surgery for a left-sided pneumothorax. In this case the body position during the operation, the right decubitus position with the left arm abducted 90° and flexion, caused compression or traction on the axillary nerve. After the surgery the patient had difficulties in left arm abduction and had paresthesia of the skin over deltoid. Deltoid muscle atrophy and tenderness over the quadrilateral space were also observed [24].

2.2.3 Clinical Presentation

Depending on the damaged portion, paralysis can occur in the muscles that axillary nerve is innervating (teres minor and deltoid), and since the axillary nerve has a sensory branch called superior lateral cutaneous nerve of arm, lack of sensation of the skin above deltoid could be observed. Due to the lack of innervation, atrophy of the muscles is also probable in chronic cases [4]. In many cases the nerve injury could go undetermined because of the pain and discomfort of the fracture or dislocation [9].

Initial presentation is generally the weakness with abduction, flexion, and external rotation accompanied by lack of sensation of the skin above deltoid [9]. The deltoid muscle's loss of function is more apparent since the rotator cuff nearly compensates all the function of teres minor.

The deltoid muscle provides 50% of the torque about the shoulder. Although active abduction may be limited after acute injury, many patients are able to compensate for the loss of deltoid muscle function with time [9]. Duchenne discussed deltoid muscle paralysis in 1867 and concluded that the supraspinatus muscle alone can fully abduct the arm [25]. In 1903, Bunts reported on ten patients with axillary nerve palsy, several of whom recovered full shoulder function despite complete paralysis of their deltoid muscles [9, 19, 26].

Concomitant injuries to the joints, bones, and other muscles, namely the rotator cuff, may compromise shoulder motion, and in these instances, shoulder function may be less predictable [9].

In some cases incomplete paralyses could be seen sparing the anterior or posterior portion of the deltoid. Deltoid muscle atrophy may not be too obvious. If rotator cuff function is preserved, the shoulder range of motion could be normal. However, their abduction strength is less than normal, and the patients tend to fatigue easily [4].

2.2.4 Diagnosis

Physical examination and electromyographic findings are helpful for diagnosing the axillary nerve injury. Clinical presentation is explained in detail in Sect. 2.2.3.

As mentioned before, some patients may not present the clinical symptoms of nerve injury due to the discomfort of the related injury. For these subclinical cases, nerve injury detection is possible using EMG/NCS.

2.2.5 Prognosis

The prognosis, hence the treatment plan, of the axillary nerve injury is closely related to the degree of nerve damage [19].

Degree of nerve damage is classified by Seddon in 1943 with his experience in World War II [27]. According to his classification, there are three degrees of nerve damage: neurapraxia, axonotmesis, and neurotmesis (praxis: to do, tmesis: to cut).

Seddon's classification considers the four components of a neuron: axon and three layers of connective tissue—endoneurium, perineurium, and epineurium.

Neuropraxia is the mildest form. In neuropraxia, the conduction velocity decreases without any damage to the axon or connective tissues. It usually occurs from mild injury, compression, or traction of the nerve and recovers without any intervention. Depending on the severity of demyelination, the effects can range from asynchronous conduction to conduction block, causing muscle weakness [28]. The prognosis of the neuropraxia is excellent. Recovery is spontaneous, and time range for recovery changes between hours and months [29].

Axonotmesis is the loss of axonal continuity with intact endoneurium. It usually occurs from stretch and crush injuries. Wallerian degeneration is seen secondary to axonal disruption. The endoneurium guides for axonal regeneration and surgical intervention are not necessary. The degree of axonal damage determines the regeneration process. The prognosis of axonotmesis is not as good as in neuropraxia, and the recovery of the structure and function of the injured nerve may be incomplete [19, 28].

Neurotmesis is the most severe form. In neurotmesis, there is complete disruption of axon and distortion of connective tissue. Wallerian degeneration is seen here too, but axonal guidance to regeneration is disrupted due to axonal misdirection, loss of blood-nerve barrier, and intraneural scarring. It usually occurs from sharp injury. Disruption of perineurium and epineurium requires surgical intervention [28], and the prognosis is poor [19].

In 1951, Sunderland expanded Seddon's classification into five categories to distinguish the severity of connective tissue damage [30, 31].

- Grade I is the mildest form and corresponds to neurapraxia. It is represented as segmented demyelination at injury site.
- Grade II corresponds to axonotmesis, and it is represented as disrupted axon with intact endoneurium.
- Grade III corresponds to axonotmesis/neurotmesis, and it is represented as disrupted axon and endoneurium with intact perineurium.
- Grade IV corresponds to axonotmesis/neurotmesis, and it is represented as disrupted axon, endoneurium, and perineurium with intact epineurium.
- Grade V corresponds to neurotmesis. It is represented as complete disruption of nerve.

MacKinnon and Dellon added one more grade, Grade VI, which represents a combination of different levels of damage.

2.2.6 Differential Diagnosis

All patients with axillary nerve injury should have radiographs performed of the shoulder and cervical spine to rule out associated bony and ligamentous injuries [9].

Unhappy triad is a condition with shoulder dislocation, rotator cuff tear, and axillary nerve injury.

QSS is a rare cause of axillary neuropathy by compression of the axillary nerve and posterior humeral artery within the quadrilateral space [32].

Posterior cord of the brachial plexus injury is a rare condition presented by palsy of deltoid, triceps brachii, and extensor muscles of the wrist, thumb, and fingers [33].

C5–C6 cervical radiculopathy causes weakness and pain in the shoulder, arm, and hand.

Parsonage-Turner syndrome is an idiopathic condition with abrupt onset of shoulder pain followed by motor and sensory neural deficits [34].

2.2.7 Medical Management

The axillary nerve has monofascicular composition, and the distance between injury zone and motor end plate is short, so the treatment results are better compared to other peripheral nerve lesion treatments [4].

The initial management during the acute phase of injury includes symptomatic management with rest and treatment of bony or ligamentous injury as indicated. If glenohumeral joint is dislocated, it should be reduced as early as possible to decrease the risk of complications, such as degeneration or neuromuscular insult [35].

After the reduction, the use of NSAIDs, ice, transcutaneous electrical nerve stimulation (TENS), and interferential therapy is recommended to reduce the inflammation and pain [36, 37].

Nonsurgical reduction has a high risk of recurrence, and the risk is higher in younger patients. So reduction should be followed by immobilization which restricts the abduction or external rotation of the arm and lowers the risk of recurrence [38].

Immobilization is usually recommended for 3 weeks in young individuals and up to 3 months in athletes [35]. During this period, controlled manner of exercises within pain and tolerance limits are recommended to prevent adverse effects of the immobilization, such as stiffness.

In older adults, the risk of recurrence is low, and the risk of stiffness during immobilization is high. So the period of immobilization is shorter than younger people, possibly as long as pain persists [37, 38].

Physical therapy is important to maintain the shoulder's active and passive range of motion, to strengthen the rotator cuff, deltoid, and periscapular musculature and to prevent muscle atrophy [14]. Joint contracture should be avoided while waiting for return of the function [13].

Nonoperative treatment of axillary nerve injury has good results in general. Majority of the patients have full recovery [13].

If axillary nerve recovery is not observed clinically or with EMG/NCS studies by 3–6 months after injury, surgery is indicated [32]. If the injury is caused by a sharp penetrating wound or surgery, surgical exploration should be performed earlier.

In order to get a good prognosis and recovery of function, surgery should be done within 6 months after the injury, but functional improvement may occur if surgery is done within 12 months. If the time between injury and surgery is more than 12 months, recovery of function is generally poor [4, 35].

2.2.7.1 Surgical Approaches

New technologies in nerve injury treatment have multidiscipline approach including biomedical engineering, neurosurgery, plastic surgery, and orthopedic surgery. Many techniques under the titles of neurolysis, neurorrhaphy, nerve grafting, neurotization, and nerve transfer have been used in order to provide nerve regeneration. Nerve autografts are the gold standard among the treatment options, especially for large nerve gaps [39].

Treatment should be planned with a good understanding of the injury in all aspects. Decision is determined at surgical exploration [4].

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3

Deltopectoral Approach

Bujar Shabani, Dafina Bytyqi, and Rosa Ballis

As the most commonly used approach in the shoulder, deltopectoral approach is used for reduction and internal fixation of proximal humerus fractures, to treat bony glenoid injuries, shoulder arthroplasty, inferior capsular shift, biceps tenodesis, or rotator cuff repair if the procedure cannot be accomplished arthroscopically.

In order to have good exposure and atraumatic dissection of the shoulder region, the surgeon needs to know anatomic planes and layers that separate these planes. This is described perfectly by Cooper et al., who described four layers based on a series of more than 100 open shoulder dissections [1]:

1. Muscular envelope composed of the deltoid and pectoralis major muscle bellies with their overlying fascia
2. Clavipectoral fascia surrounding the pectoralis minor and conjoint tendon then joining the superficial layer of the subdeltoid bursa and the deep face of the coracoacromial ligament
3. Musculotendinous layer composed of the deep layer of the subdeltoid bursa and the underlying musculotendinous units of the rotator cuff
4. Capsule of the glenohumeral joint and including the glenohumeral and coracohumeral ligaments

Patient positioning, Prepping, and Draping

Patient positioning is determined by two imperatives:

- Humerus exposure, requiring retropulsion, adduction, and external position
- Exposure of the glenoid which must face the operator as far as possible [2]

The patient is placed in the beach chair position (Fig. 3.1).

The head is secured in a Mayfield headrest or any commercial beach chair attachment and the back elevated at 40 to horizontal.

The opposite arm, legs, and other prominences are padded and secured.

The knees should be slightly bent (30°) in order to prevent neuropraxia by stretching the sciatic nerve.

Any available arm holders may be helpful.

Staphylococcus aureus, *S. epidermidis*, and *Propionibacterium acnes* are the bacterial species most implicated in infection after shoulder arthroplasty [3]. These germs are present in hair follicles; consequently the focus in draping is to exclude the axilla and the upper part of the shoulder [4].

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Fig. 3.1 Beach chair position

Chlorhexidine solution is thought to be the best antiseptic agent for preoperative skin preparation [5].

The deltopectoral incision begins inferior to the clavicle and lateral to coracoid tip, toward deltoid insertion (Fig. 3.2). The incision should be done enough large in order to reduce retraction force, thereby decreasing the incidence of tension neuropraxia [6].

Then, the cephalic vein is exposed (Fig. 3.3) and it can be retracted laterally or medially.

In most cases, the vein is retracted laterally because it is usually more adherent to the deltoid, and in this way the deltoid's venous drainage is preserved. If medially, the tributary vessels of the cephalic vein are ligated and coagulated as needed [7]. If the cephalic vein is not visible, look for a fat strip which may overlie the vein.

Together with the cephalic vein, the deltoid muscle is retracted laterally, while the pectoralis major medially (Fig. 3.4).

Superior part (1–3 cm) of the pectoralis major tendon may be released to achieve better exposure of the inferior portion of the subscapularis tendon and better mobility of the humerus. It

Fig. 3.2 Deltopectoral incision: inferior to the clavicle and lateral to coracoid tip, toward deltoid insertion

Fig. 3.3 Exposure of the cephalic vein

Fig. 3.4 Deltoid muscle is retracted laterally, while the pectoralis major medially

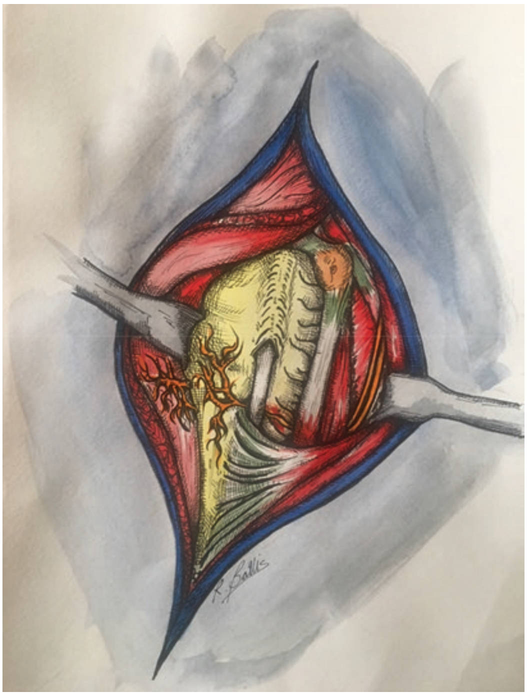

Fig. 3.5 Identification of musculocutaneous nerve and circumflex nerve

should be very careful in positioning of the retractors, because putting them inside the deltoid risk the axillary nerve lesion.

The clavipectoral fascia should be incised lateral to the conjoint tendon, start proximal to the coracoacromial ligament, and continue distally to the inferior aspect of the subscapularis tendon. The coracoacromial ligament does not need to be excised, and its preservation prevents anterosuperior humeral subluxation of the humeral head [8]. At this point it is important to identify the musculocutaneous nerve, which is localized deep to the conjoint tendon. It enters posterior to coracobrachialis, but the distance from the coracoid can vary from 1 to 5 cm (Fig. 3.5).

The next step is the identification of the long head of the biceps, which will help in locating the insertion of the subscapularis. The long biceps tendon is located immediately above the insertion of the pectoralis major, which joins the lateral lip of the intertubercular groove [2]. The biceps tendon is tenotomized (Fig. 3.6) below the subscapularis, tagged with a stay stitch, and

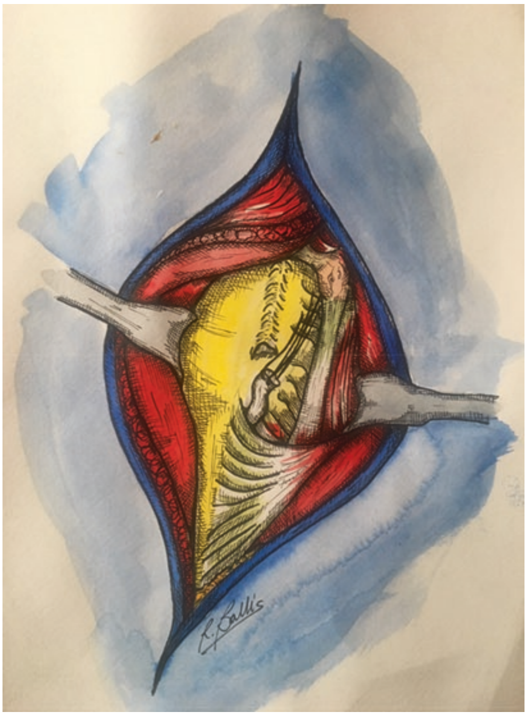

Fig. 3.6 Identification of the long head of biceps and tenotomy

Fig. 3.7 Soft tissues subscapularis release

left for the subsequent tenodesis to the superior border of the pectoralis major tendon at the end of the procedure [7]. Anterior humeral circumflex vessels along the inferior third of the subscapularis tendon are ligated or coagulated.

As the largest of the rotator cuff muscles, the function of the subscapularis is critical for stability following shoulder arthroplasty.

Release of the subscapularis tendon is essential to gain surgical access to the glenohumeral joint for total shoulder replacement. The two main techniques for releasing the subscapularis that have been described are

- Soft tissue subscapularis release either directly from the bone or through the tendon substance (Fig. 3.7)
- Lesser tuberosity osteotomy (Fig. 3.8)

This is an important decision because subscapularis dysfunction has been found to be associated with inferior clinical results following total shoulder arthroplasty [9, 10].

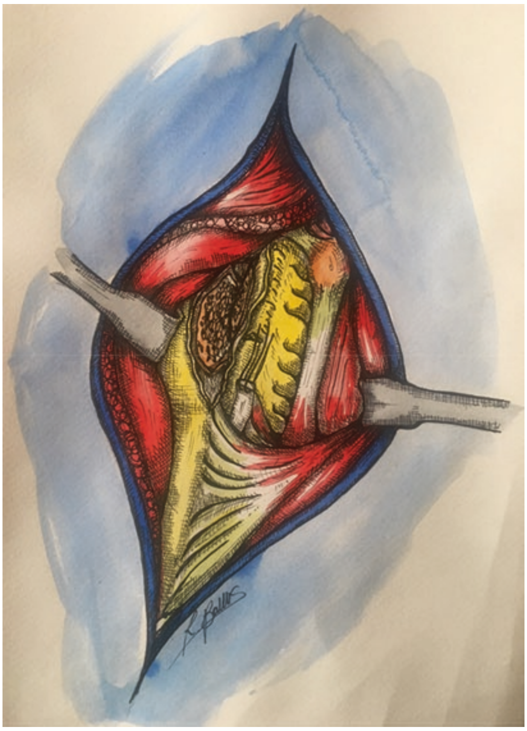

Fig. 3.8 Lesser tuberosity osteotomy

3.1 Which One to Choose?

Most of the studies are in the favor of the osteotomy [11–13]. The goal of the lesser tuberosity osteotomy is to maximize the strength of the subscapularis repair without violating the subscapularis tendon [12]. The contractile force of the subscapularis is equal to that of the other three rotator cuff muscles combined [14]. The other advantage of the osteotomy is bone-to-bone healing, which provide a stronger repair.

While, intraoperative fragmentation, nonunion, and fatty degeneration could be some possible complications of this technique [11].

On the other hand, loss of active terminal internal rotation [15], rupture of the subscapularis, and anterior instability are the main disadvantages of the routine division and repair of the tendon [16].

As conclusion about the releasing of the subscapularis tendon, it is valuable to note three important criteria according to Gerber et al. [17] for an ideal tendon repair:

- It should have a high initial fixation strength.
- It should allow minimal gap formation at the interface.
- It should maintain mechanical stability until healing of the tendon to bone is complete.

Adduction, gentle progressive external rotation, and extension of the arm at the side of the operating table allow for sharp release of the capsule from the anterior, inferior, and posterior humeral neck under direct vision. The axillary nerve should be identified and protected with inferior dissection.

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Biomechanics of rTSA

4

Dafina Bytyqi, Musa Kafeloff, and Bujar Shabani

4.1 Biomechanics of Rotator Cuff-Deficient Shoulder

The glenohumeral joint is the most mobile joint in the human body. The stability of the joint is provided by a combination of both static and dynamic factors. The bones, the ligaments, and the capsule represent the static stabilizers. The ligamento-capsular complex is crucial to the end range of motion when they are stretched [1]. The rotator cuff muscles are m. supraspinatus, m. infraspinatus, m. teres minor, and m. subscapularis and are the dynamic stabilizers. They provide "contraction-compression" model of stability [2]. The contraction both centers the head and compresses it against the glenoid fossa. They are most effective in the mid- and end-range of motion. Their action is best described as stability by balancing the force couples. Infraspinatus, teres minor, and subscapularis provide a net inferiorly directed force; deltoid muscle provides a net superiorly directed force resulting in net force balance in coronal plane. In the analogous manner, subscapularis is balancing infraspinatus and teres minor muscles in sagittal plane [3]. The rotator cuff actively stabilizes and opposes upward motion of the humeral head during contraction of the deltoid muscle.

Loss of the normal force couples about the shoulder with massive rotator cuff tears leads to an alteration of the compressive forces and consequently to deterioration of the concentric arc of motion. Without the force provided by the inferior rotator cuff, the humeral head starts to migrate superiorly resulting from the unopposed contraction of the deltoid muscle. So instead of an arm elevation with muscle contraction, it becomes more of a translational movement [4].

4.2 The History of the Concept of rTSA

The usage of reverse total shoulder arthroplasty (rTSA) has gained significant popularity, and instead of being a procedure of desperation, it is a procedure of choice for the management of the cuff-deficient arthritic shoulders.

However, attempts to compensate for rotator deficiency with the idea of fixed fulcrum with a ball in the proximal humerus and a socket in the glenoid date back to the 1970s when a number of reversed implants were designed. It was Neer that designed the reverse prosthesis with the hope that

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the given stability might compensate the rotator deficiency. He designed three consequent versions of fixed fulcrum rTSAs between 1970 and 1973: Mark I, Mark II, and Mark III. The first, Mark I, included a large ball for more motion and a glenoid implant fixed with acrylic cement, but because of the size of the ball, the rotator cuff cannot be attached. Mark II was different by smaller ball to allow rotator cuff repair, but this led to limited range of motion. Mark III design kept the smaller ball and added an axial rotation feature between the humeral stem and diaphysis to allow more motion. Unfortunately, this prosthesis was also unsuccessful due to dislodgement of the scapula in one patient. So there was a consensus that the scapula was not adequate to handle the forces transferred to it; with these constrained designs, the reversed arthroplasty was abandoned [5, 6].

It was Paul Grammont in 1985 that designed the first reverse shoulder prosthesis that worked. The first prosthesis designed in 1985 included two pieces, one metallic glenoid or "glenosphere," which represented two-thirds of a sphere, which was cemented, and the other humeral, polyethylene, which represented one-third of a sphere and was also cemented. The results of eight cases were published in 1987 [7]. The center of this prosthesis was still too lateral, which led Grammont to evolve his prosthesis to a half-sphere.

The second prosthesis, designed in 1989, is the prosthesis "Delta™ III," whose name recalls that it is only animated by the deltoid muscle alone. The first implantation dates back to 1991. The prosthesis, modular, contains four original pieces: glenoid baseplate (without cement), glenosphere (third of sphere and not two-thirds), humeral stem, and humeral cup. The glenoid baseplate is fixed using a central peg and four screws including two, upper and lower, divergent, which are essential to neutralize the shear forces. Osteointegration of glenoid baseplate is favored by a hydroxyapatite coating [8, 9].

His idea was to medialize the center of rotation by eliminating the neck of the glenoid implant. Thus, forces of the deltoid acting on the fixed fulcrum can convert the upward pull force of the deltoid into rotatory movement capable of elevating the arm. New center of rotation can recruit more of the deltoid fibers, minimize the shearing forces, and turn them into compressive. The glenoid component is one-third of a sphere with a large diameter allowing greater range of movement before impingement occurs.

When Paul Grammont presented his concept of rTSA, it has two main differences from previous designs: (1) a large glenoid hemisphere with no neck, fixed directly to the glenoid, and (2) a small humeral cup oriented with a nonanatomic inclination of 155 covering less than half of the glenosphere [10]. The result was stable prosthesis with medialized and lowered center of rotation, minimized shearing forces acting on the glenoid, increased deltoid lever arm, and lowered humerus [8, 10, 11].

4.2.1 Center of Rotation and Glenoid Positioning

Since the rTSA glenosphere is fixed to the native glenoid surface, the distance from the glenoid surface to the center of rotation is directly proportional to the mechanical torque about the component and the shear forces at the glenoid bone prosthesis interface.

The concept of the rTSA with a fixed fulcrum for rotation was originally adapted from the total hip arthroplasty designs. These original designs maintained the center of rotation of a normal shoulder joint. Unfortunately, fixation of the glenoid component could not withstand the shear forces created at the bone prosthesis interface and resulted in unacceptably high rates of early mechanical failures.

In order to address this issue, Grammont eliminated the neck of the previous implant designs by utilizing one-third of a sphere that was fixed directly onto the glenoid. This change medialized the center of rotation to the glenoid surface, effectively minimizing the shear forces across the glenoid bone prosthesis interface [10, 12].

Medialization of the center of rotation thus effectively converts the mechanical torque at the glenosphere into more compressive forces across the prosthesis–bone interface.

Also, another beneficial outcome is that medicalization of the center of rotation by 10 mm increased the deltoid moment by 20% and that distalization of the center of rotation by 10 mm increased the efficacy of the deltoid by another 30%.

Positioning of the glenoid component is currently an area of active research; the study of glenoid position may have important consequences for maximizing the impingement-free arc of motion.

In a cadaveric biomechanical study conducted by Nyffeler et al., four different positions of glenosphere were tested: glenosphere centered on the glenoid, leaving the inferior glenoid rim uncovered; glenosphere flush with the inferior glenoid rim; glenosphere extending beyond the inferior glenoid rim; and glenosphere tilted downward 15°. The relation between different glenoid component positions and glenohumeral range of motion was examined. They concluded that placing the glenosphere distally significantly improved adduction and abduction angles compared with all other test configurations [13].

Gutiérrez et al. in an in vitro study analyzed abduction/adduction motion and its dependence on five surgical (location of the glenosphere on the glenoid and tilt angle of the glenosphere on the glenoid) and implant-related factors (implant size, center-of-rotation offset, and humeral neck-shaft angle) on impingement-free abduction motion. They concluded that largest average increase in the range of impingement-free abduction motion resulted from a more lateral center-of-rotation offset. The position of the glenosphere on the glenoid was associated with the second largest average increase in abduction motion (when the glenosphere position was changed from superior to inferior). The largest effect in terms of avoiding an adduction deficit was provided by a humeral neck-shaft angle of 130, followed by an inferior glenosphere position on the glenoid, a 10-mm lateral offset of the center of rotation, inferior tilt of the glenosphere, and a 42-mm-diameter prosthetic size [14].

4.2.2 Stability

Although improving glenohumeral stability is the ultimate aim of RSA, subluxation and dislocation of RSA devices still occur. Dislocation rates have been shown in the range of 2.4, 6.3, 8.6, 16.7, and 31% [15–17].

Glenosphere-humerosocket stability is an important variable in selecting an appropriate RSA and is closely correlated to compressive force, socket depth, and to a lesser extent on implant size. Since the dynamic stabilization normally provided by the rotator cuff muscles is absent in the patient undergoing a rTSA, in order to maintain the relative position of the humerus against the glenoid, the rTSA design places the convex surface on the glenoid and the concave surface on the humerus. This effectively “constrains” the joint and prevents the humerus from translating superiorly against glenoid even during deltoid contraction.

The radii of curvature of the humerus and the glenoid are identical, imposing concentric motion.

Increased constraint secondary to the deeper and more conforming concavity of the humeral articular surface prevents glenohumeral translation while providing sufficient stability for functional range of motion. This high degree of intrinsic stability frees the reverse total shoulder prosthesis from dependence on active stabilization by concentric compression and provides a stable fulcrum for the remaining musculature.

The angle that the total joint force vector can subtend without risk of dislocation with the center line is thereby increased to ≥45°.

In a study evaluating the hierarchy of stability factors in the reverse shoulder, Gutierrez et al. found that the net compressive force acting on the glenohumeral articulation is the most significant element of stability [18].

Clinically, the compressive force is largely generated by active and passive structures of soft tissue together with the negative pressure within the glenohumeral joint. To date, techniques described to enhance RSA stability through soft tissue tension have focused on tensioning of the deltoid. This may be accomplished by lowering the humerus relative to the glenoid, by lengthening the humerus by inserting a thicker polyethylene humeral component and retaining as much proximal humerus as possible, or by lateralizing the humerus.

Stability also depends on glenoid component positioning. Glenosphere retroversion >20 has been shown to reduce anterior stability while the arm is in the resting position. In addition, placing the glenosphere in a position of inferior offset has been shown to increase stability by approximately 17%. Humeral component version has little effect on stability.

4.2.3 Role of Deltoid in rTSA

The rTSA was developed to optimize functional outcome by making better use of the patient's remaining musculature. The system is designed both to re-tension and to reposition the deltoid in relation to the joint's center of rotation. The lever arm of the deltoid muscle is almost doubled with a reverse TSA prosthesis; thus, the efficacy of the deltoid for abduction is also approximately doubled.

A medialized center of rotation increases the deltoid's moment arm by 20–42% and recruits additional fibers of the anterior and posterior deltoid to serve as abductors.

The fibers that are medial to the center of rotation in a normal shoulder come to lie lateral to the center of rotation and thereby become abductors and/or elevators. Thus, it is presumed that the longer lever arm resulting from the reverse prosthesis allows the recruitment of more deltoid fibers for elevation and abduction. Conversely, the anterior and posterior deltoid fibers lose their external and internal rotator moment. Thus, active external rotation in particular is often further compromised after rTSA [19, 20].

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5

Anatatomic Shoulder Arthroplasty: Causes and Indications to Surgery

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5.1 Introduction

An anatomic shoulder prosthesis should be implanted with the aim of increasing shoulder functionality and reducing pain. These two results are linked to both technical and psychological conditions, which can influence the successful outcome of the prosthetic restoration [2]. The first necessary condition for an excellent result is a good bone quality of both humerus and glenoid, corroborated by a good functionality of the rotator cuff and an adequate muscle strength [3].

The deficit of one of these two elements can easily compromise the success of the operation.

Glenohumeral articulation is naturally shallow, depending on soft tissues around it (the capsule, tendons and muscles) and on coordination of one to each other [4]. Therefore, success of any treatment mostly depends on the rehabilitation and recreation of this soft tissue balance [5].

On the other hand, the psychological aspect of the procedure is equally important. The patient should be motivated to carry out the operation and should focus his energies on postoperative rehabilitation, which plays a vital role in ensuring optimal functional outcome. It is important that the patient knows exactly how the prosthesis works, the expected outcome after surgery, details of the rehabilitation that will be performed after the intervention, and limitations that will eventually persist after the procedure [2].

5.2 Patient Recent History and Physical Evaluation

Evaluation of patient's recent history is essential to obtain a good operative result. The intervention cannot be performed before evaluation of an eventual fracture and/or chronic patient's diseases [6].

When a patient is examined following a fracture, a radiographic evaluation is necessary to plan the operation. In case of chronic diseases, assessment of contraindications needs to performed. For example, metabolic and cardiac diseases must be considered in order to obtain an optimal recovery. The patient must be informed and aware, given that there is no urgent condition, of surgical risks and of functional outcome that will be presumably obtained at the end of the procedure.

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In this assessment it is essential to consider patient's working condition, the dominant limb, family situation, and usual daily activities.

Awareness of metabolic or rheumatological diseases, such as rheumatoid arthritis, is important, especially if the patient is under a steroid treatment. The evaluation of any pre-existing neurological or neuromuscular pathologies must be performed, even with EMG if necessary. Any previous interventions or infections must be documented.

A productive approach is to administer a questionnaire to the patient in which he indicates the pain he is currently experiencing by means of a visual analog scale (VAS) [7], to assess the autonomy he has in the activities of daily living (ADL) [8], and to state the objectives he aims to achieve.

The clinical evaluation must be performed bilaterally and comparatively, including the elbow and wrist. A polyarticular arthritic or rheumatic involvement of the upper limb may influence postoperative rehabilitation after shoulder arthroplasty [6].

Evaluation of muscle status, especially rotator cuff and deltoid muscle, is essential. Likewise, the preventive assessment of the patient's nerve and vascular status and of the active and passive movement of the upper limb cannot be disregarded [9].

An accurate anamnestic and clinical evaluation allows to carry out surgery with the best guarantees of a satisfying result for the patient and must be systematically performed before each shoulder arthroplasty.

5.3 Primary Osteoarthritis

Several factors can contribute to the loss of regularity and congruence of bone and cartilage structures of the shoulder. After those degenerative processes, an erosion of the cartilage is created with consequent damage to the underlying bone structures and the surrounding soft tissues. This involves a loss of congruence of the bony heads with consequent progressive limitation of the articulation associated with pain [10].

Joint degenerative pathology of glenohumeral joint can be concentric or eccentric. The first form is generally idiopathic, due to an early wear of the cartilaginous structures caused by age or presence of associated pathologies, such as systemic arthritic forms (e.g., rheumatoid arthritis) or vascular-nervous pathologies (e.g., diabetes, peripheral nervous disorders, outcomes of chronic therapies with cortisones). The eccentric degenerative form, on the other hand, is generally secondary to an altered joint mechanics, with consequent pathological wear of the articular structures and tendency to the rise of the humeral head toward the acromial vault. Massive rotator cuff injuries, trauma outcomes, fractures, or previous surgery is usually the basis of this type of arthrosis [11].

The arthrosic degenerative pathology arises and evolves insidiously with an inevitable but slow progression. The patient generally complains of a progressive limitation of the function of the shoulder, associated with pain in extreme degrees of movement and joints that over time becomes increasingly important. The patient develops over time a considerable functional shoulder impairment with difficulty in performing the most common movements of daily life, such as lifting a weight, combing, wearing a jacket, or fastening a bra. Over time, pain may also be present during the night.

The conservative treatment aims at alleviating the painful symptomatology and the loss of articularity that characterize this pathology. The administration of oral anti-inflammatory drugs (NSAIDs) and infiltrations with cortisones (only in selected cases and usually not exceeding three injections per infiltration cycle) are medical devices that can help the patient overcome the most severe periods of the disease [12]. In addition, active and assisted kinesiotherapy cycles can be helpful to keep the joint capsule as elastic as possible, to avoid adhesions and to maintain adequate muscle tone, thus preserving existing functional abilities by trying to delay the worsening of disorders [13]. In most cases, this therapy is effective in improving quality of life, even if it is not able to limit the inevitable progression of the arthritic pathology.

Surgical treatment is necessary when medical therapy and kinesiotherapy are not able to provide effective relief to the patient.

5.4 Inflammatory Arthritis

The most frequent inflammatory arthritis is rheumatoid arthritis, but other arthritic inflammatory forms such as psoriatic arthritis must be taken into account.

The rheumatoid cloth, expression of the disease, causes an important inflammatory reaction around the joint, creating a soft tissue dysfunction that, at the shoulder level, largely contributes to correct articular movement. Usually the finding is a damage of the rotator cuff which is broken or dysfunctional. Rotator cuff tears can lead to instability and abnormal biomechanics because of loss of the normal downward and medializing force exerted on the humeral head by the rotator cuff. A massive rotator cuff tear is defined as a complete tear of two or more tendons. Massive rotator cuff tears are further subdivided into posterosuperior tears (involving the supraspinatus, infraspinatus, and, eventually minor tendons) and anterosuperior tears (involving the subscapularis and supraspinatus tendons) [14].

Patients with severe rheumatoid arthritis are younger than the population affected by primary osteoarthritis. Usually radiographic studies show erosions, osteopenia and subchondral cystic lesions. A characteristic picture is the symmetrical and central wear of the glenoid. Treatment usually performed with corticosteroids may result in a further worsening of osteopenia [15].

5.5 Avascular Necrosis

About 3–4% of shoulder arthroplasty are caused by this uncommon etiology [16]. The humeral head is the second most common site of avascular necrosis, after the femoral head.

The artery that primarily serves the humeral head is the anterior circumflex artery, a branch of the axillary artery that joins the surgical neck of the humerus at the level of the subscapularis muscle tendon. The anterolateral branch of the artery enters the head of the humerus at the level of the upper bicipital sulcus and subsequently subdivides into arterioles which nourish the humeral head.

The causes most commonly associated with this condition are post-traumatic (fractures/dislocations), prolonged corticosteroid therapy, hemoglobinopathy, sickle cell disease, decompression sickness for divers, alcohol and smoking abuse, sepsis, Gaucher disease, hypercoagulability, chemotherapy, diseases peripheral vascular disease, chronic dialysis, hyperlipidemia, connective disorders, Cushing’s syndrome, hyperuricemia, pregnancy, pancreatitis, myxedema, radiation therapy, or idiopathic [6].

It usually comes with pain and radiographic changes. The currently most reliable classification is the Cruess (a modification of the Ficat-Arlet) that at stage I shows only MRI and no radiographic changes; stage II in which sclerosis is seen; stage III with crescent sign, sphericity maintained, and collapse of the subchondral bone; stage IV with collapse of the articular surface and flattening; and stage V with glenoid involvement [17].

Conservative treatment includes joint load prohibition, articular range maintenance, and pain management, associated with treatment of the underlying cause if possible. Before performing an arthroplasty, it is possible to perform a core decompression [18] or a vascularized strut graft, the latter being a procedure that seems to stimulate neoangiogenesis in pre-collapse situations [19].

5.6 Post-traumatic Arthritis

Following fracture, especially in complex three- and four-part fragments fractures, patients sometimes develop alterations that prevent the correct function of the shoulder. Those include malunion, shoulder dislocation, and post-capsular shift. The imbalance of soft tissues created causes an eccentric rather than concentric glide of the humeral head on the glenoid, therefore eccentric consumption [20].

In these patients a conservative treatment can be used consisting of simple stretching of the anterior capsule to maintain a satisfactory range of motion (ROM).

Although shoulder hemiarthroplasty is technically challenging in the presence of fracture, it has traditionally been regarded as the "gold standard" for the treatment of those fractures in which satisfactory open reduction and internal fixation (ORIF) could not be achieved.

Hemiarthroplasty is particularly indicated in cases of avascular necrosis high-risk fractures of the humeral head. As indicated by Hertel et al., the main factors that influence osteonecrosis of the head are integrity of the medial hinge, length of the dorsomedial metaphyseal expansion of the fracture of the head, and the type of fracture.

In the elderly, hemiarthroplasty should be considered in the case of non-reconstructable head splits or humeral head impression fractures [21].

Also, when in the young ORIF cannot guarantee stability in reduction of the fracture, the surgeon should think of substitution of the humeral head since the correct healing of the large and small tuberosity is the factor that has the greatest influence in the success of hemiarthroplasty of the shoulder [6].

On the other hand, in cases of malunion or pseudarthrosis, shoulder disfunctions often cause disability in the patient. These can be either caused by deformities of the humeral head that create a mechanical impossibility of normal movement or by muscular atrophy resulting from the long joint immobilization.

The treatment of this situation is extremely difficult due to deformity, the possible pseudoarthrosis, and the frequent massive rupture of the rotator cuff.

In a multicenter study, Boileau et al. concluded that if prosthetic replacement is possible without performing tuberosity osteotomy, the surgeon should perform the intervention without taking care of the humeral deformity, adapting the prosthesis [22].

Jacobson et al., in the follow-up of anatomic prostheses, showed a good survival of 90.1% at 10 and 15 years (mean age 65, range 34–83 years). In these cases, anatomical prosthesis has in any case increased both pain and mobility, requiring a complex assessment by the surgeon.

The main complication is the postoperative instability of the shoulder, usually associated with rupture of the rotator cuff and capsule [23].

In these cases of post-traumatic sequelae with injured rotator cuff, the reverse shoulder prosthesis has been used more and more frequently, according to the literature that indicates this procedure as the most successful one. Reverse prosthesis usually requires a stem because of the loss of substance at the level of the humeral surgical neck. The surgeon should do everything possible to reconnect the tuberosity and the rotator cuff to allow an effective range of movement and function [24].

In conclusion, it is clear that the shoulder fracture remains a challenge for the surgeon, needing a careful evaluation to choose the best solution considering both the patient's age and the best result obtainable with each technique.

5.7 Indications to Surgery

The main reason for the surgeon to consider shoulder arthroprosthesis is a persisting pain and disability of the glenohumeral articulation after failure of appropriate conservative measures. In young and active patients, treatment with microfractures in arthroscopy and debridement should be performed in early cases [25].

In cases of rotator cuff tears, it is essential to perform a rehabilitation protocol in order to strengthen the deltoid muscle [26]. In association to this, an attempt to repair the rupture should be made, also considering augmentation with synthetic graft or allograft. Shoulder instability should be surgically treated if there is not an established arthropathy.

An unrepairable shoulder tendons rupture is a contraindication to anatomical prosthetics due to the anterior migration of the humeral component that presses on the proximal part of the glenoid component causing a rocking movement ("rocking horse") and subsequent dislocation.

Table 5.1 Indications for surgery

INDICATIONS FOR SURGERY
Primary osteoarthritis
Inflammatory arthritis
Avascular necrosis
Post-traumatic arthritis

It will be up to the surgeon to consider the quality of the glenoid bone and eventually to proceed with the insertion of a bone graft. All indications for surgery are summarized in the table below [3] (Table 5.1).

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6

Total Shoulder Arthroplasty: Principles and Biomechanics

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6.1 Introduction

Total shoulder arthroplasty (TSA) is a common treatment for patients with a deteriorated glenohumeral joint, often a result of rheumatoid arthritis or osteoarthritis. The main objective of this treatment is pain relief, which is achieved in most cases.

Shoulder arthroplasty remains the standard treatment to restore shoulder function and improve patient's quality of life in severe glenohumeral arthritis. The modern prosthetic system takes advantage from modularity and the availability of additional sizes of the prosthetic components.

Total shoulder arthroplasty requires release of contracted tissues, repair of rotator cuff defects, and reconstruction of normal skeletal anatomy with proper sizing and positioning of components.

Arthroplasty of the shoulder is different from hinge joint arthroplasty where collateral ligaments provide a high degree of stability with a large bony conformity and less range of motion. Normal shoulder kinematics can only be achieved when normal articular anatomy is reestablished and the passive and active stabilizers are balanced.

6.2 Shoulder Biomechanics

The complex biomechanics of the shoulder girdle encompasses the motion of 3 bones, 4 joints, and 16 muscles. The glenohumeral joint has the greatest range of motion of any diarthrodial joint in the body.

Understanding shoulder biomechanics in both the native shoulder and the prosthetic shoulder is essential for achieving a well-functioning, mobile, and stable anatomic shoulder arthroplasty.

When viewed from a biomechanical perspective, the anatomic elements of importance in shoulder arthroplasty are the proximal humerus, the glenoid, the capsuloligamentous structures, and the rotator cuff. The surgeon must evaluate the rotator cuff, as well as other structures, to perform a biomechanically good shoulder arthroplasty.

Meticulous analysis of the humeral and glenoid anatomy has been made with the purpose of producing components that will achieve normal shoulder kinematics. The humeral head is defined by its size and shape. Articular surface size can be defined by its radius of curvature and its thickness [1].

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These parameters are also compared with the center of rotation and to adjacent bony structures, having special implications in the final outcome of arthroplasty. The typical angle of the humeral axis to the center of the humeral head is 135°.

The humeral head offset refers to the position of the center of rotation of the humeral head from the axis of the humeral shaft in both the transverse and coronal planes. Several studies have shown that the humeral head center of rotation is offset from the humeral shaft axis, in both the transverse and coronal planes. In the transverse plane, the center of rotation is offset an average of 3 mm (range 2–4 mm) posteriorly. In the coronal plane, the center of rotation is offset an average of 7.5 mm (range 6–9 mm) medially. Therefore, these offsets both combine creating a center of rotation that is posteromedially offset [2].

The humeral head center line usually makes a retroversion angle of about 10–30° from the axis of elbow flexion.

The glenoid is pear shaped, with the superior anterior-posterior dimension being smaller than the inferior anterior-posterior radius. The glenoid center line, a line perpendicular to the planar surface of the glenoid, is usually neutral plus or minus a few degrees from the plane of the scapula. This relationship is altered in glenohumeral arthritis in which posterior wear of the glenoid results in glenoid retroversion, making arthroplasty more technically difficult [3] (Fig. 6.1).

The distance from the base of the coracoid to the greater tuberosity is called "lateral humeral offset" and generally measures about 57 mm. This reflects the size of the humeral head and the location of the joint line (the surface of the glenoid). The lateral humeral offset usually decreases in glenohumeral arthritis due to cartilage and bone loss on both sides of the joint. Shortening of the lateral humeral offset causes a decreased deltoid lever arm and a shortening of the resting length of the rotator cuff [4].

The physiological plane of elevation of the upper limb is situated on the plane of the scapula (anterior elevation) and not in the frontal plane (abduction) or in sagittal plane (flexion).

The biomechanics of the shoulder involves a complex variety of synchronous movements of the sternoclavicular, scapula-thoracic, and glenohumeral joints.

Anterior elevation of the glenohumeral joint is about 120°, combined with humerus lateral rotation.

In order to allow the arm to achieve full elevation (180°), a supplementary curve of 60° is needed and is possible because of scapula rotation.

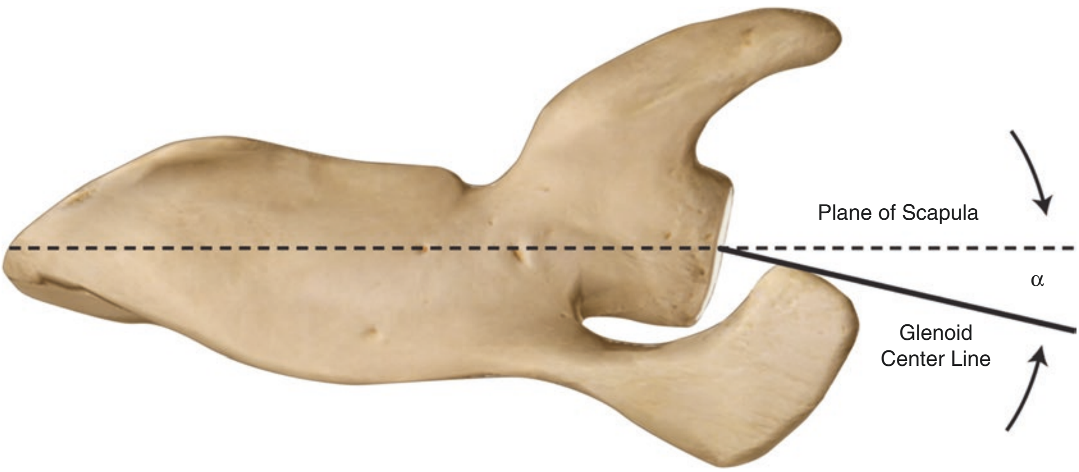


Fig. 6.1 The glenoid center line

6.3 Shoulder Stabilizers

The primary muscles and dynamic stabilizers of the shoulder can be divided into three primary groups. The scapulohumeral group includes the deltoid and rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis). The axioscapular group comprises muscles that act on the scapula and includes the rhomboids, trapezius, serratus anterior, and levator scapulae. The axiohumeral group includes the muscles that originate on the thorax and insert on the humerus and includes the latissimus dorsi and pectoralis major muscles.

Trapezius, rhomboids, serratus anterior, and levator scapulae are scapular rotators muscles. Scapula-thoracic joint is constituted by a sliding surface between anterior face of the scapula and thoracic cage. The coordinated movement between the scapula-thoracic joint and the glenohumeral joint has been defined by Codman as *scapula-thoracic rhythm*. The term scapula-humeral rhythm refers to the 2:1 ratio of glenohumeral to scapulothoracic motion. Full 180° elevation of the humerus cannot be achieved without 60° of upward rotation by the scapula on the thoracic spine [5].

The scapula-thoracic muscles transfer the potential energy of the trunk to kinetic energy in the shoulder. The kinetic train is a concept describing the transfer of energy from the trunk to the shoulder and arm. The scapula is a key link in the kinetic chain between the trunk and the shoulder. Any alteration in scapula-thoracic rhythm could predispose to shoulder joint modification. During an abduction movement of the arm, in the shoulder the glenoid (concave) is stable while the humerus (convex) abducts resulting in a sliding down or glide of the convex humerus on the concave glenoid surface.

The deltoid muscle is the primary abductor of the arm with supraspinatus contributing in the initiation of movement.

Biomechanically, during abduction of the arm at the shoulder, the supraspinatus muscle raises the arm during the first 15° of shoulder abduction. Then, from 15° to 90° of shoulder abduction, the medial deltoid assists to raise the arm biomechanically.

The rotator cuff muscles are important stabilizers of the glenohumeral joint during shoulder motion. They work in concert to elevate and rotate the arm, to compress and center the humeral head within the glenoid fossa, and to counteract antagonist moments from the three prime shoulder movers (deltoid, pectoralis major, and latissimus dorsi) at multiple shoulder angles.

Multiple muscles are activated synchronously to move the clavicle, scapula, and humerus to generate smooth movement of the arm.

The supraspinatus compresses, abducts, and generates a small external rotation torque peaking between 30° and 60° of elevation. In the absence of this check, the humeral head translates superiorly during humeral elevation resulting in subacromial impingement.

The infraspinatus and teres minor muscles provide glenohumeral compression, external rotation, and abduction. They also resist superior and anterior humeral head translation by exerting a posteroinferior force to the humeral head.

The subscapularis acts to produce glenohumeral compression, internal rotation, and abduction. Similar to infraspinatus, its muscle bellies generate their peak torque with the arm at 0° of abduction.

With rotator cuff pathology, altered kinematics and muscle activity are present, and superior humeral head translation increases and subacromial space decreases. In conditions such as osteoarthritis, cartilage degeneration and a collapsed head further alter the joint kinematics.

Retraction of the scapula is accomplished by the joint action of the trapezius and rhomboids. Upward rotation of the scapula is achieved by a force coupling of the upper trapezius, lower trapezius, and serratus anterior muscles. Scapular elevation is achieved through a force coupled action of the upper trapezius, elevator scapulae, and rhomboids. These force couples work together to rotate the scapula upward and contribute to the elevation of the arm.

The goal of conventional TSA is to restore stability, motion, strength, and smoothness—critical characteristics of a healthy shoulder joint. This is accomplished by replacing the humeral head and glenoid with prosthetic implants that are designed

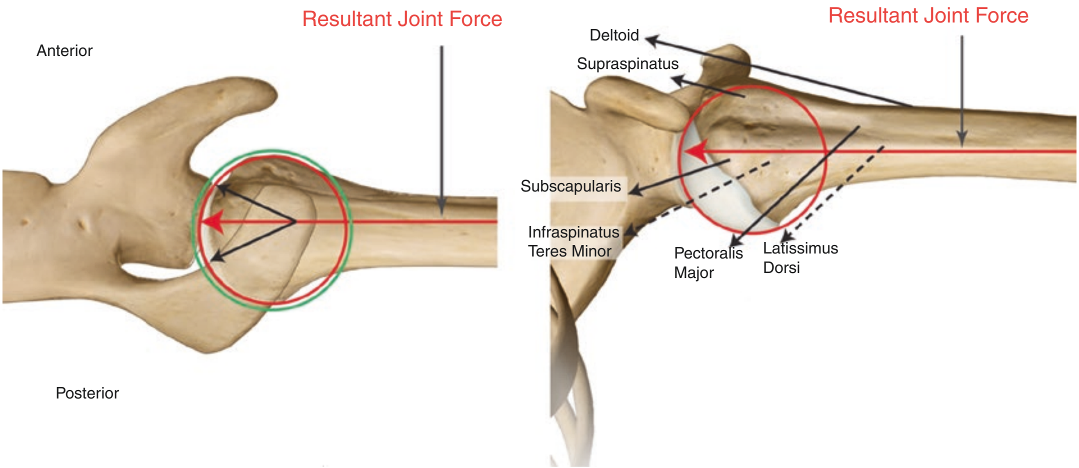


Fig. 6.2 Anatomic resultant joint force

to recreate the original anatomy. In the presence of intact rotator cuff and extrinsic shoulder muscles, a TSA is successful in restoring motion and improving function (Fig. 6.2).

6.4 Prostheses Biomechanics

Conformity is the interrelationship of the articular surface of the glenoid to the humeral head (Fig. 6.3). Glenohumeral conformity has been reported to be one of the most critical implant-related features that may affect the occurrence of glenoid loosening.

Perfect conformity would mean identical radii of curvature between the glenoid articulating surface and the humeral head. Studies that report conspicuous different radii of curvature, even in normal shoulders, may be defected because they fail due to the increased articular thickness at the level of the glenoid. Glenohumeral conformity in TSA influences humeral head translations to the glenoid component, contact stresses on the glenoid component and accompanying component wear, which may finally lead to glenoid-component radiolucency.

With perfectly conforming components, humeral head translations in any direction will result in edge loading. On the other hand, when there is a higher degree of component radial mismatch, contact stress rises due to the decreased contact area. There is therefore a balance between radial mismatch, which permits translation and conformity, and a minimized contact stress.

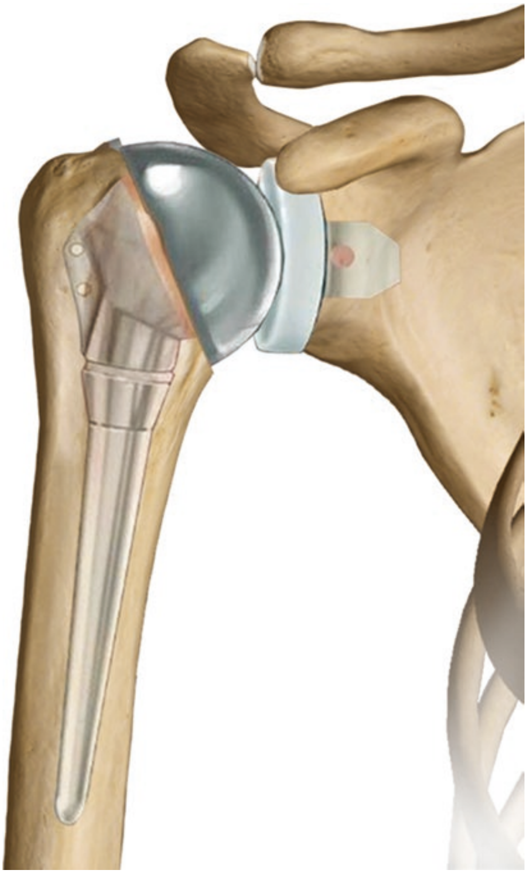


Fig. 6.3 Anatomic shoulder arthroplasty

In the normal shoulder, sufficient capsular laxity allows a large range of motion [6].

Tension of the capsuloligamentous structures varies depending on arm position, and the preservation of the length-tension relationship is critical for stability.

Deltoid is the most important muscle in shoulder arthroplasty. Surgeon's goal must be the preservation of its origin, insertion, and nerve supply. In addition, cuff tendons are at risk when humeral head osteotomy is performed. If the humeral cut is too low, the supraspinatus insertion may be detached, whereas an excessively retroverted cut could damage the cuff posteriorly. It is well accepted that the rotator cuff must be undamaged for successful total shoulder arthroplasty and the normal tension of the cuff must be preserved to restore the glenohumeral joint forces. Overstuffing shoulder joint disposes to excessive tension on soft tissues, limits tendon excursion, decreases range of motion, and predisposes to cuff tendons rupture [7].

The goal of arthroplasty surgery is to restore or alter shoulder biomechanics and joint kinematics in the affected shoulder in an effort to decrease pain and improve function.

Satisfactory results of replacement depend on

1. Prosthetic reproduction of a physiological bone conformity (shape of the humeral epiphysis and the glenoid silhouette corresponding to the normal structures in size, orientation, centers of rotation, and lever arm of the cuff tendons and deltoid muscle).
2. Optimum restoration of capsular tension to remove the asymmetric restraint caused by changes in capsule volume.
3. Restoration of the motor function and muscle balance.

The most important geometric parameters of a total shoulder arthroplasty include essentially humeral head diameter and thickness, neck inclination, humeral head height, humeral head retroversion, acromion-humeral distance, and medial and posterior head offsets. The cervico-diaphyseal angle is most often 135° + 5°. Prostheses are usually designed with a fixed angle of 130–135°, and the instrumentations perform head osteotomy at that angle.

Humeral head is extremely variable in shape and size: it is retroverted on average 19° (range 9–31°) and is proportional to the angle of retroversion of the scapula which instead is widely variable (0–60°). The humeral head is also inclined on average 41° (range 34–47°); head radius measures 23 mm (range 17–28 mm), and medial and posterior head center offset are on average 7 mm (range 4–12 mm) and 2 mm (range 1–8 mm), respectively [8].

Whereas degenerative diseases alter the spherical shape, the prosthetic head diameter often cannot be determined. The component's diameter is therefore chosen at the time in base of a trial reduction established on other parameters with special attention to the height of the hemisphere that seems to have a clear relationship with the head diameter.

Inaccurate anatomic recreation of the size of the humeral head may cause biomechanical consequences through malpositioning of the joint line or displacing the center of rotation [9].

Fischer has shown that displacing the center of rotation by 20% of its radius (5 mm for an average radius of curvature of 25 mm) changes the lever arm of the rotator cuff by 20% [10].

In all humerus the superior edge of the head protrudes 2–5 mm up to the superior edge of the greater tuberosity. If the head component is positioned under the edge of the greater tuberosity, joint's center of rotations drops causing a lowering of the humeral head and an increased tension in adduction, with a premature painful subacromial impingement.

On the other hand, a head protruding excessively above the greater tuberosity induces an increased tension on the cuff ("overstuffing") that leads to an increased risk of secondary rotator cuff tears.

It is important to note that alterations in neck-shaft angle may alter the tension on the rotator cuff and deltoid tendons potentially leading to rotator cuff and/or deltoid dysfunction. This variability can be approached in one of these two ways: using an adaptable implant with a variable neck-shaft angle or if using an implant with a fixed neck-shaft angle, plan the osteotomy and insertion depth to achieve an appropriate articular surface arc for the humerus. These two options can be summarized as adapting the prosthesis to the patient's anatomy or adapting the patient's anatomy to the prosthesis (Figs. 6.4 and 6.5).

Small errors in head retroversion do not strongly influence capsulo-ligamentous system tension nor the instantaneous center of rotation; an

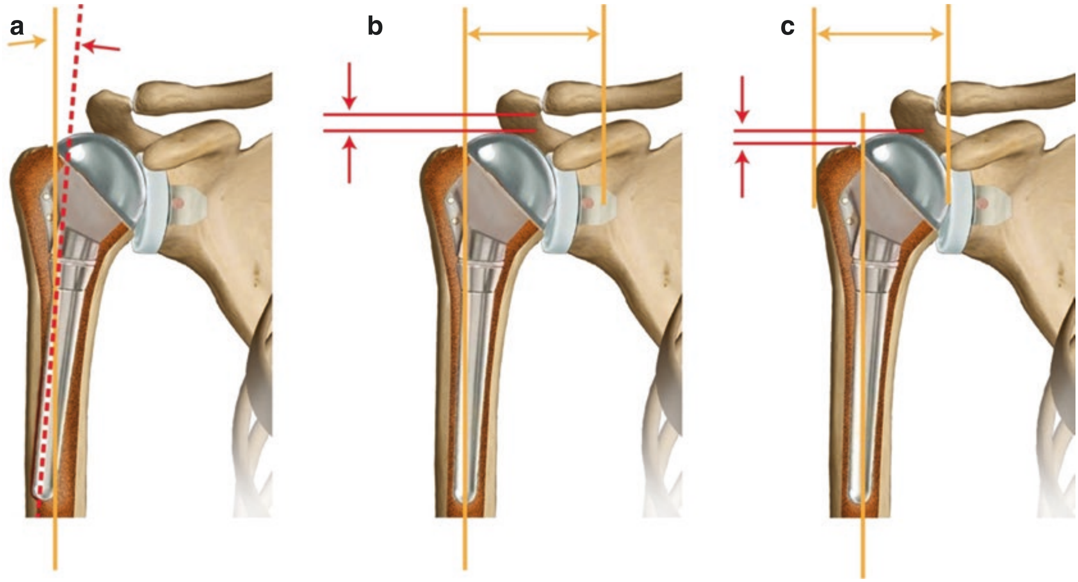


Fig. 6.4 Prosthetic components orientation

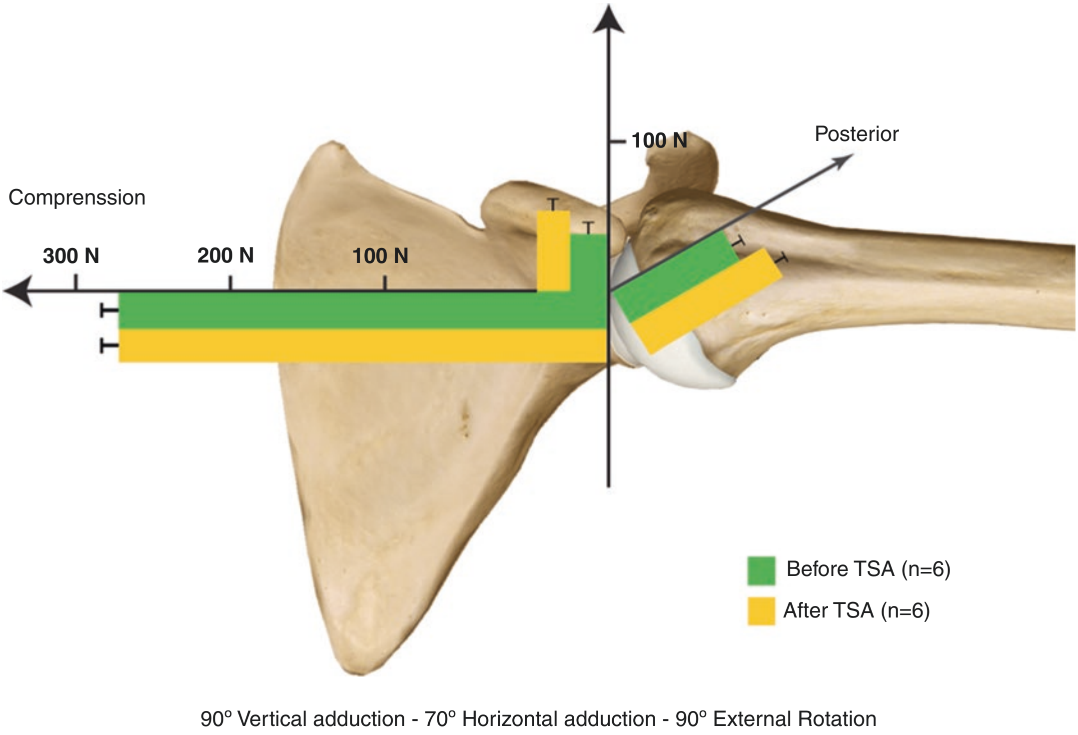
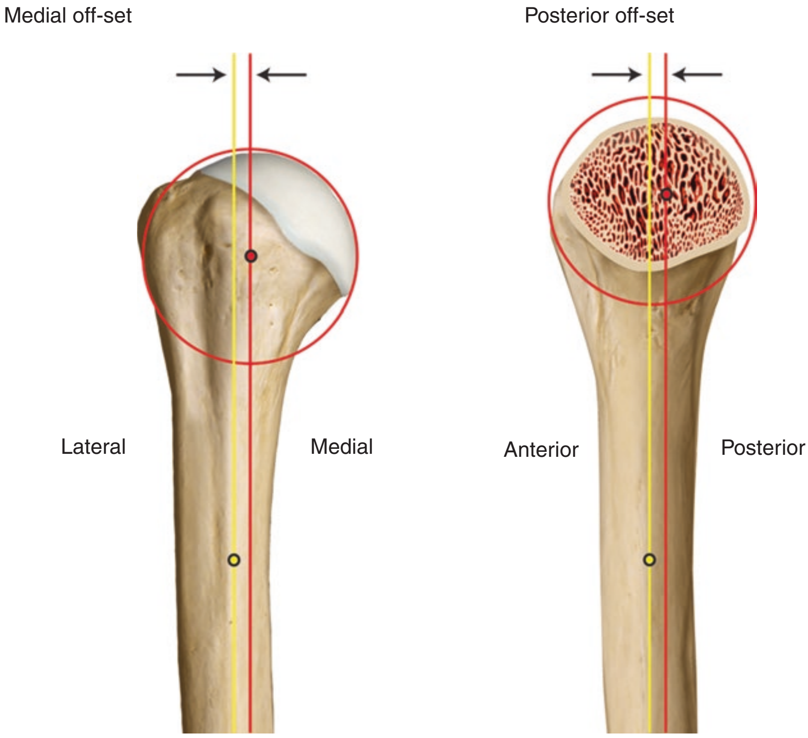


Fig. 6.5 Glenohumeral joint forces before (green) and after (yellow) shoulder arthroplasty

Fig. 6.6 Medial and posterior offset



Representation of the medial and posterior humeral head offsets

excessive retroversion, on the other hand, may induce posterior head subluxation in case of a posterior cuff tear, whereas an insufficient retroversion may cause subscapularis impingement [6].

The center of the head is not in line with the diaphyseal humeral axis but is displaced both in the coronal and the sagittal planes. In the coronal axis, the medial and lateral translation of the humeral component is measured as the distance between a line through the center of the humeral stem and a tangent to the lateral margin of the acromion that is parallel to the first line. It is called medial or lateral offset and ranges from 2 to 12 mm (median 7 mm).

An excessive amount of lateral or medial intramedullary bone may result in an excessively lateralized or medialized humeral component, altering load distribution and eventually cortical bone reabsorption. Also the change of the fulcrum of rotation may lead to rotator cuff and deltoid insufficiency [2].

The center of the head lies 0–10 mm (median 5 mm) posteriorly to the diaphyseal axis (posterior humeral head offset); if this point, and therefore the new center of rotation moves anteriorly, can induce an abnormal contact with the glenoid and abnormal pressure on the subscapularis (anterior offset). The acromion-humeral distance indicates the free space of the rotator cuff between the head component and the inferior face of the acromion and measures about 2 cm. A wider space reduces muscle tension and produces a loss of strength in elevation while a narrower spacer results in a stiffer joint and a possible subacromial impingement (Fig. 6.6).

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7

Unstable Reverse Total Shoulder Arthroplasty: How to Avoid and Manage

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The Grammont reverse total shoulder arthroplasty (RTSA), which is first used in patients with pseudo-paralysis, is started to be used in a wider indication spectrum in time, such as proximal humerus fracture sequela, failed total shoulder arthroplasty, and rheumatoid arthritis, by virtue of improvements in implant design in parallel with the technological innovation [1–4]. Although the implementation of these implants gained a wider interest in the world, the complication rates in the literature still reach as high as 68% [5–7]. The instability is a frequently experienced and a challenging complication [8]. Zumstein et al. in a systemic review reported the instability following the RTSA as the most frequent complication with an incidence of 4.7% [8], which is given in the literature between 2.4 and 31% [6–8]. Boileau pronounced the instability as the most frequent cause of RTSA revision [9]. Today, it is still one of the prominent complications despite the reduced risk by virtue of improved surgical technique and implant designs. Instability following the RTSA is the most frequent cause of revision surgery and the most difficult complication to cure and has the highest rate of recurrence [8, 10]. Approximately, one-half of this complication develops in the first 3 months after the surgery [11]. Bacle et al. reported the first 2-year dislocation in the initial 2 years in 15 of 84 patients (17.8%) who underwent RTSA with a mean follow-up duration of 150 months and added that there was no new dislocation after 2 years [12].

A complete medical history should be provided in the examination of the patients. Not just the instability but also the pain, the range of motion deficiency, decrease in strength, and trauma history should be queried. The duration and causes of symptoms should be recorded in detail. Component malposition should be the first issue to be considered in early-onset instability following the surgery. Findings of infection, joint range of motion, deltoid muscle integrity, strength, and atrophy, and especially the direction of the instability should be examined. The position and size of the components, bone defects, and instability direction can be examined radiologically with direct roentgenograms (anterior-posterior view, scapular Y view, axillary view). The bone stock should be carefully examined with computerized tomography, especially if a component revision procedure is planned. The direction of the dislocation, which may be anterior (most frequent), posterior, or inferior, can be examined by inspecting the position of the humeral component in relation with glenosphere.

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7.1 Causes of the Instability and How to Avoid

The compressive forces affecting the shoulder and constituted by the muscles around the shoulder are crucial elements for the joint stability. The instability caused by the deterioration of the stabilizing factors in patients with rotator cuff insufficiency can be restored by changing the shoulder biomechanics with RTSA [13]. Gutierrez et al. reported the factors affecting the RTSA stability as compressive forces, humerosocket depth, and glenosphere size, respectively [14]. RTSA has superior biomechanical composition when compared to a normal shoulder joint and a replaced one, and the compressive forces constituted by the soft tissue around a shoulder joint are the main elements of the stability.

The most efficient method protecting the joint from the dislocation is the appropriate patient selection. The compliance of the patient, bone stock, and the condition of the soft tissue should be examined carefully. The deltoid muscle should be examined repeatedly, and electromyographic studies should be applied when the integrity is doubtful. RTSA should be avoided in patients with deltoid muscle disfunction.

The instability following the RTSA mostly develops secondary to the multifactorial determinants [15–18]. The risk factors of instability can be divided into two as those related to patient characteristics and those related to surgery. The risk factors related to patient characteristics are body mass index (BMI) over 30 kg/m^2, male gender, previous surgery history of the affected shoulder, and subscapularis deficiency or atrophy [5, 11]. Those related to surgery are component malposition, insufficient soft tissue tension and coverage, deltopectoral approach, and subscapularis deficiency [19–23]. Besides these factors, impingement, heterotopic ossification, axillary nerve palsy, and asymmetrical polyethylene wear may also be the cause of an instability.

7.1.1 Malposition of the Components

Once the trial components are placed properly, the arm of the patient should be easily abducted over the head without any impingement and restriction. Following the placement of the components, the insert size should be adjusted to provide appropriate soft tissue tension during the examination of the joint range of motion and the stability.

Gutierrez et al. pronounced the important points of the correct positioning of the components to provide maximum range of motion without impingement as following: up to 10 mm lateralization of the joint center of rotation, tilting the glenosphere inferiorly, placing the glenoid component inferiorly, and changing the size of the components and the neck-shaft angle of the humerus [24]. In spite of the fact that the inferiorly placed metaglene averts the notching, the insufficiency caused by decreased bone-implant interface area and increased stress per unit area should be kept in mind [25]. Removing the scar tissue and bone fragments around the glenoid clearly also contributes to the avoidance of the instability secondary to impingement. Increasing the glenosphere size increases the stability by decreasing the impingement risk, especially in adduction; however, the surgeon should pay maximum attention to adjusting the soft tissue tension while doing that. In the case of glenoid bone defect, a larger-sized glenosphere may provide better coverage of the glenoid. Replacing the glenosphere tilted 15° inferiorly contributes to the stability by enhancing the compressive forces [26].

The stability in RTSA procedures should be provided without deeper, more constrained polyethylene inserts. These inserts pave the way for the range-of-motion restriction and early-onset instability secondary to the polyethylene wear [27]. Nevertheless, the shallower inserts bring out the instability while improving the range of motion. Larger range of motion increases the risk for the instability especially in patients with impingement risk.

7.1.2 Insufficient Soft Tissue Tension

The insufficient deltoid tension following RTSA is first described by Grammont. The insufficient deltoid tension causing redundant space between the components is called *global decoaptation* [1, 28]. Providing appropriate compressive forces essential for joint stability requires an optimal soft tissue tension (Fig. 7.1). Replacing the humerus during the surgery more laterally and inferiorly may constitute the compressive forces by increasing the soft tissue tension. The soft tissue tension can be calibrated in accordance with the conjoint tendon and the deltoid muscle tension. Taking the conjoint tendon as a reference for adjusting the soft tissue tension is described by Boileau et al., and they reported that surgical experience is needed for this evaluation [28]. The learning curve of the RTSA is thought to be lasting for initial 20 cases [29]. Lädermann et al. recommended to take the length of the uninvolved shoulder as a reference to adjust the deltoid muscle tension [30]. A stable shoulder joint is aimed with appropriate soft tissue tension and without any range of motion restriction. The polyethylene size should be chosen properly not to cause dislocation with full range of motion as the soft tissue tension is appropriate. Once the appropriate soft tissue tension is provided, there should be no space between the glenosphere and insert under longitudinal traction of the humerus.

Fig. 7.1 Constituting the soft tissue tension and balancing the global decoaptation by using a larger-sized insert

Preoperatively, in patients with external rotation deficiency or weakness, latissimus dorsi tendon transfer can be added to the RTSA to reconstitute the force couple of the shoulder. Gerber et al. reported significant improvement in the active external rotation and functional outcomes with RTSA when combined with latissimus dorsi tendon transfer [31].

7.1.3 Subscapularis Insufficiency

The basic subscapularis muscle contribution to the stability is by balancing the posterior force vectors and enhancing the compressive forces. Additionally, it prevents anterior subluxation of the humeral head by constituting an anterior barrier. This effect becomes more significant in lower abduction angles of the shoulder [32]. The etiology of the subscapularis deficiency are as follows: (1) inadequate repair during the surgery, (2) history of more than one surgery, (3) joint contracture or excessively tense subscapularis tendon owing to the component size, (4) subscapularis atrophy and weakness (Goutallier grade 3 or 4), and (5) early aggressive physical therapy. The instability rate following the RTSA is reported to be 1% after subscapularis repair and 9.5% with no repair [33]. The paramount reasons for early-onset instability in consequence of subscapularis insufficiency after RTSA with subscapularis repair are too much lateral offset and overstuffing on the ground of large-sized components. The most significant indicator of the subscapularis over-tensioning is the restriction in external rotation of the shoulder. In these patients, medialized tenodesis of the subscapularis can prevent over-tensioning and external rotation restriction, and by this means instability risk caused by subscapularis insufficiency.

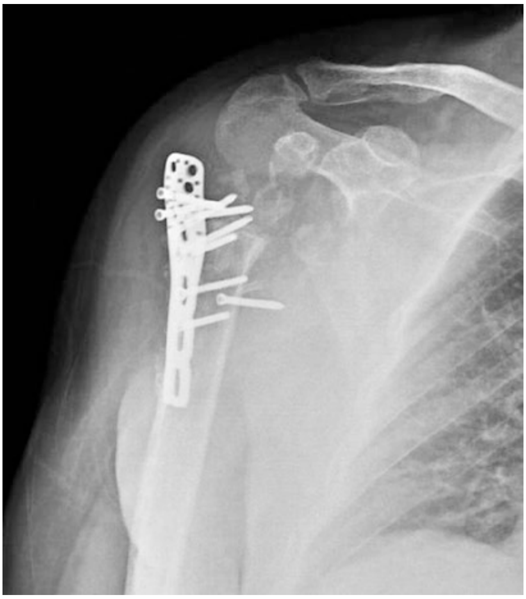

Fig. 7.2 Deterioration in the anatomy of the proximal humerus in a patient who developed implant insufficiency following the osteosynthesis for right proximal humerus fracture

Edwards et al. reported higher rates of dislocation risk in patients with no subscapularis repair in a study including prospective follow-up of RTSA procedures with and without subscapularis repair. However, they also pronounced that this group also had more complicated pathologies regarding the bone tissue besides the soft tissue deficiency [21]. Clark et al. in their retrospective study with similar patient characteristics reported no significant difference between the groups [7].

The repair of the subscapularis may not be feasible in patients with massive rotator cuff rupture including the subscapularis tendon and those with tuberculum minus pathology based on a previous fracture sequela (Fig. 7.2). The humeral component can be replaced in minimally retroverted position to decrease anterior dislocation risk when the subscapularis repair is not feasible.

7.1.4 Prior Surgery

The main causes of increased instability in revision cases are as follows: poor bone stock, insufficient soft tissue coverage, and destroyed anatomic landmarks. Trappey et al. reported the instability risk as 5.2% for primary RTSA and 8.3% for revision RTSA [34]. Wall et al. reported those risks as 13 and 37%, respectively [35]. Walch et al., in a multicenter study, reported the instability after RTSA performed in patients with failed anatomical arthroplasty as 11%, in post-trauma cases as 9%, and in primary rotator cuff arthropathy cases as 4% [10]. Padegimas et al. reported the prior surgery history as 66.7% in patients with instability following RTSA and 21.6% in those without instability [36]. Glenoid bone defects may develop after revision cases. These defects should be restored by glenoid component augmentation or bone grafts. As for humeral bone defects, preference of longer humeral stems will decrease the instability risk.

7.1.5 Deltopectoral Approach

This approach is a frequently preferred technique in shoulder arthroplasty because of providing a wider view and movement area. However, the subscapularis muscle is under risk with this approach which gives birth to instability related to the soft tissue damage. Although the superolateral approach offers a minimal soft tissue dissection without any subscapularis damage, the risks for axillary nerve injury and component notching because of the difficulty in reaching to the inferior aspect of the glenoid made the surgeons keep away from this approach [37–39]. Simovitch et al. reported that the notching can be prevented by optimal positioning of the glenoid component [38]. However, the notching risk increases because of the difficulty in inferiorly replacing the glenoid component. Furthermore, the deltoid muscle detachment may also lead to a functional deficit. The deltopectoral approach is especially advantageous in revision cases. Walch et al. reported the instability risk as 5.8% in 363 patients performed RTSA with a deltopectoral approach and as 1% in 94 patients with a superolateral approach [10]. Werner et al. reported the instability risk with deltopectoral approach as 6.3% after primary shoulder arthroplasty and as 9.8% after revision arthroplasty [40].

7.1.6 Body Mass Index

Chalmers et al. reported the mean BMI of the patients with early instability (first 3 months) following the RTSA as 32.2 kg/m^2 and added that the 82% of the patients had BMI over 30 kg/m^2 [5]. Padegimas et al. reported the mean BMI of the patients with instability following the RTSA as 33.2 kg/m^2 and that of those with no instability as 29.5 kg/m^2 [36]. The increase in the instability risk based on the obesity may be due to inappropriately adjusted soft tissue tension during the surgery, inappropriately positioned components, and adduction of the shoulder by the lever arm effect of the excessive soft tissue around the arm. Furthermore, excessive soft tissue may predispose to decoaptation during the movement.

7.1.7 Sex

Chalmers et al. reported that the 82% of the patients who developed early (first 3 months) instability following RTSA were male [5]. Padegimas et al. reported that the 60% of the patients with instability after RTSA were male [36]. Teusink et al. gave the ratio of previous surgery history in females who developed instability following RTSA as 75% and in males as 22% [11]. The increased risk for instability in male patients may be related to higher level of activity.

With the increase in experience of the surgeons and new prosthesis designs in time, the complication rates decreased. Ekelung reported the instability rate in 236 RTSA procedure between 1995 and 2002 as 6.7% and in 457 procedures after 2006 as 0.7% [27]. The key points to avoid instability following the RTSA are appropriate deltoid tension adjustment and replacing the humeral component in neutral or minimally anteverted position [27]. Adjusting the humeral height and offset by taking the contralateral upper extremity as a reference will decrease the instability risk, especially in patients with aforementioned risk factors (Fig. 7.3). Pastor et al., in their biomechanical study, reported that the integrity of the subscapularis muscle, larger-sized glenosphere replacement, and deep humeral cup replacement are essential factors for intact anterior stability in RTSA procedures [41].

Fig. 7.3 Constituting the appropriate humeral height during the RTSA procedure in a patient with right proximal humerus fracture sequela

It is recommended that an abduction orthosis of 3–6 weeks postoperatively should be prescribed to patients with aforementioned risk factors. The immobilization of the shoulder joint in abduction leads to deltoid muscle shortening and in this way increases the coaptation between the components.

7.2 Management of the Instability

In the general medical notion, the best treatment option is said to be the protection from the diseases. The surgical approach and postoperative follow-up should be planned carefully considering the potential causes of instability. A widely accepted treatment protocol has not been developed yet because of the inexactly known risk factors and etiology of the instability following the

RTSA [42]. The first step of the management is to find an underlying reason for instability. The mechanism of the instability is evaluated by patient history and radiographic examination. The shoulder joint infection is sought, and if doubted, then a synovial fluid aspiration is performed for microbiological culture. The soft tissue condition, positioning of the components, and neurological condition are evaluated when the instability develops.

The time for instability following the surgery is important. Walch et al. reported that the instability following the RTSA developed in the first 3 months after the surgery in 16 of 22 (72.7%) patients [10]. Teusink et al. reported that the 62% of the instability following the surgery developed in the first 3 months [11]. The dislocation following the RTSA usually does not generate significant pain; therefore, any restriction in the range of motion must alert the surgeon and make him/her doubt of joint dislocation which should be evaluated immediately with the radiographs. The diagnosis of the subluxation is easier than the dislocation because patients can usually describe this pathology in their own words. There is no described optimal management for this pathology yet.

The deltoid muscle and axillary nerve function, glenoid and humeral component position, and bone defects are evaluated when the instability develops. If they are all normal, the closed reduction under general anesthesia or sedation is tried first (Fig. 7.4). If the joint reduces, the stability is evaluated by moving the arm through full range of motion. The deltoid muscle and axillary nerve function, glenoid and humeral component position, and bone defects are reevaluated following the reduction. The instability usually occurs in adduction, internal rotation, and extension of the shoulder; therefore, an abduction-external rotation orthosis is prescribed which prevents those unintended movements of the shoulder. Functional rehabilitation is initiated following the 6-week immobilization. Teusink et al. reported the success rate of the closed reduction with 28-month follow-up as 62% in 21 patients with instability following the RTSA and also stated that 9% of those were suffering from persistent instability symptoms. There was no significant difference in outcomes after closed reduction between the early- and late-onset instability [11]. Gerber et al. stated that the early-onset dislocations were mostly secondary to poor surgical technique and had worse outcomes following closed reduction when compared to late-onset dislocations [22].

In our practice, all of the patients with dislocation following the RTSA undergo closed reduction, immobilization, and rehabilitation as the initial steps of management. Surgeons should keep in their mind that the conservative management of the instability following the RTSA is satisfactory in more than a half of the patients [43]. If the closed reduction fails, the open reduction should be performed, and the implants for any potential necessity of revision arthroplasty should be ready for this procedure. The glenoid and humeral components, polyethylene insert wear, bone defects, and soft tissue tension should be evaluated repeatedly during the surgery if the open reduction is initiated. Following the reduction, the full range of motion of the shoulder should be forced to exclude any potential mechanical impingement of residual bone or soft tissue. The residual bone and soft tissue are removed thoroughly taking care not to injure axillary nerve at the inferior aspect of the shoulder. If the stability cannot be provided, the scar tissue at the inferior aspect of the glenoid is debrided again, and then the stability is reevaluated following the soft tissue tension is enhanced (by increasing the polyethylene or humeral spacer thickness). If the stability still not provided, the components are revised. We must never forget that the outcomes of the revision cases for instability are directly related to the causes of the instability.

According to the instability direction, humeral osteotomy level is changed, and the anatomical offset is strived to regain. The version of the humeral component is adjusted [22, 23]. The glenoid bone graft can be used to enhance the lateral offset [19]. Humeral height can be increased with allografts [44]. Surely, the soft tissue tension should not be ignored to prevent any potential recurrence while making the

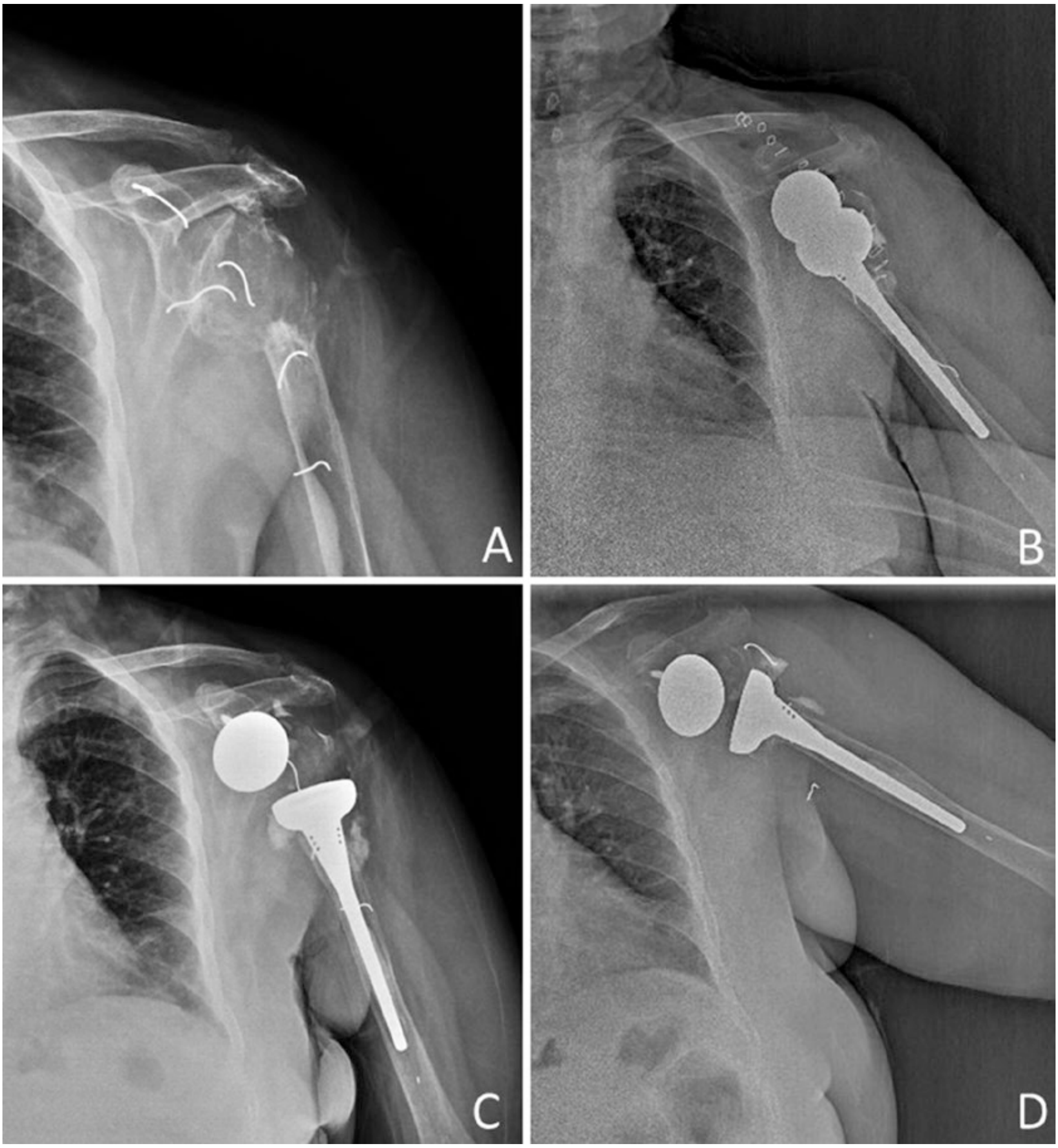

Fig. 7.4 Radiographs of a patient with a history of repeated right shoulder surgery; (**a**) anterior-posterior radiograph before RTSA, (**b**) postoperative anterior-posterior radiograph, (**c**) postoperative first-month anterior-posterior radiograph manifesting anterior dislocation, (**d**) and anterior-posterior radiograph following the closed reduction

aforementioned interventions. The humeral component aligns more medially and inferiorly with a higher neck-shaft angle (valgus) and more laterally and superiorly with a lower neck-shaft angle (varus). The anatomical neck-shaft angle is of importance to prevent the range of motion restriction on the ground of inferior impingement.

7.2.1 Restoration of the Soft Tissue Tension

The instability as a result of soft tissue looseness is managed by regaining the appropriate soft tissue tension, lengthening of the humerus, or lateralization of the joint center of rotation offset. To lengthen the humerus, (1) the neck-shaft angle can be increased (replacing the humeral component in valgus), (2) a larger humeral component size can be chosen, (3) a larger or eccentric glenosphere can be chosen, (4) the glenosphere can be replaced more inferiorly or tilted inferiorly, and (5) a thicker polyethylene insert can be chosen. To lateralize the joint center of rotation offset, the humeral component can be positioned in varus (lower neck-shaft angle), or a glenosphere with lateral offset can be chosen. To increase the offset, before a complicated intervention, like the revision of the components, simpler interventions should be made first, such as replacing with a larger-sized polyethylene insert and glenosphere.

The damaged soft tissue at the anterior aspect of the shoulder should be repaired in the case of anterior instability. If the soft tissue support is still insufficient, reinforcement with the pectoralis major tendon can be added. The force vector of the pectoralis major muscle, which is very powerful, is similar with that of the subscapularis muscle. The transfer of the pectoralis major tendon can be also considered in subscapularis insufficiency; however, its efficiency is under debate. Elhassan et al. reported the rate of the failure of pectoralis major transfer as seven in eight patients with subscapularis insufficiency following the shoulder arthroplasty [45].

The excessive soft tissue tension also should be avoided, which may result in a restricted range of motion, acromial fracture, and brachial plexus neuropraxia [46]. The factors affecting soft tissue tension are summarized in Table 7.1. The soft tissue tension should be considered before the determination of the component size. While the larger-sized components creating excessive soft tissue tension may develop early-onset soft tissue insufficiency, and so instability, small components result in soft tissue looseness leading to early-onset instability.

Table 7.1 The factors affecting the soft tissue tension

Level of humeral osteotomy
Neck-shaft angle of the humerus
Position, size, and offset of the glenosphere
Offset of the humeral component
Thickness of the humeral insert

7.2.2 Positioning of Components

Favre et al. evaluated the effect of the component version to the anterior instability. They pronounced that the version of the humeral component is a critical factor for stability and although the glenoid component version is not so crucial as the humeral component, the surgeon should pay attention not to replace the glenoid component retroverted more than 10° [47]. They stated that the humeral component anteversion increases the stability while the glenoid component retroversion decreases. The surgeon should keep in mind that increasing the humeral component anteversion may result in external rotation loss in the shoulder. The anatomical version should be preserved while the humeral component is being replaced according to the anatomical landmarks. It can be challenging to ensure that the arthroplasty is replaced in anatomical version when the anatomical landmarks are missing because of a previous surgery or fracture sequela. According to our measurements, replacing the humeral component in a position that the lateral protuberance of the component is located 10 (9–12) mm posteriorly from the base of the bicipital groove provided the anatomical version (Fig. 7.5). This technique especially is of benefit in patients with damaged proximal humerus anatomy.

Randelli et al., in a study evaluating the effect of glenoid component inclination to the stability, stated that the position of the glenosphere was tilted 10.2° inferiorly in patients with no instability, 8.3° inferiorly in those with traumatic instability, and 2.2° superiorly in those with atraumatic instability [48]. Another reason for the increased risk for instability as the 10° of inferior tilt of the glenosphere decreased is the risk for impingement developed in the adduction.

Kohan et al. reported 32% of recurrence following the surgery for instability following the RTSA [42]. They thought that the high rate of the recurrence depended on not including the patients managed with only closed reduction. Similarly, in two different case series including also the patients who underwent open reduction, the recurrence rates of instability were given as 18 [5] and 38% [11] in patients with instability follow-

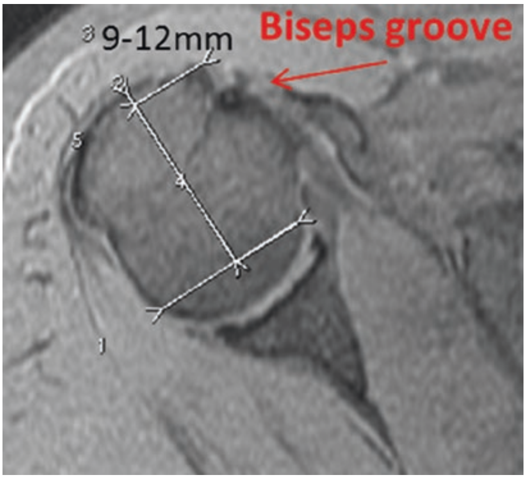

Fig. 7.5 The distance between the bicipital groove and the line bisecting perpendicularly the line drawn from anterior articular edge to posterior articular edge of the humeral head in the transverse plane of the shoulder magnetic resonance imaging that the humeral head is observed in greatest dimensions shows the appropriate localization of the prosthesis lateral corner to constitute the anatomic version

ing the RTSA. Chalmers et al. reported 2 recurrences in 11 patients with 2.5-year follow-up (18%) who developed instability following the RTSA in first 3 months [5]. They also reported that no recurrence was developed after the closed reduction in four of nine patients (44%) during the follow-up. Boileau et al. reported that the instability persisted in six of ten patients who underwent closed reduction for instability following the RTSA and in four of five patients who underwent open reduction [49]. They stated that the humeral shortening and excessive glenoid medialization were the main drawbacks in patients with persisted instability. Choosing the humeral component size and replacing in anatomical position by taking the uninvolved humerus as a reference and appropriate deltoid tension have critical roles in preventing the recurrence. In patients with humeral shortening but no excessive glenoid medialization, if a larger-sized polyethylene insert and a metal heightener (spacer) considering the prosthesis design do not help in adjusting the deltoid tension, longer cemented humeral stems can be chosen for revision and are replaced in a position restoring the humeral height. In patients with more than 5 cm humeral shortness, a structural humeral bone graft can be used. The stability is reevaluated with an eccentric or a larger-sized glenosphere if the instability persists despite the lengthening of the humeral component. The stability is strived to regain by replacing with a larger-sized glenosphere in patients with excessive glenoid medialization. If this does not work, lateralized glenosphere or bone grafts for glenoid defects are used to increase the lateral offset. The inferiorly tilted positioning of the glenoid component may increase the tension of the deltoid muscle and have a positive effect on coaptation between the components.

The posterior instability usually occurring due to the posteriorly tilted glenoid component because of a posterior bone loss of the glenoid can be managed by bone grafting or eccentric rimerization of the glenoid (Fig. 7.6). The surgeon should be careful while replacing the metaglene central peg process not in the graft but in the glenoid bone defect procedures because of the risk for implant insufficiency (Fig. 7.6).

The instability secondary to the humeral and glenoid component loosening is very rare. Walch et al. reported as 2% [10]. The management requires the revision of the humeral or the glenoid component and restoring the stability by appropriate soft tissue tension.

The resection arthroplasty technique can also be considered as an option in patients with persistent instability despite the recurrent procedures if there is no sufficient bone reserve or soft tissue support, if there are additional medical disorders, and if the patient is very old to endure the surgery.

When all these aforementioned issues are taken into account, one can easily deduce that there is not only one ideal decision in the following issues: surgical approach, component size and position, soft tissue tension, and prosthesis design. It is necessary to evaluate each patient one by one. The risk for instability can be decreased by replacing the components in anatomical version and height, considering the surgical technique and implant design, taking care not to give rise to impingement, and protecting the soft tissue from excessive damage during the approach.

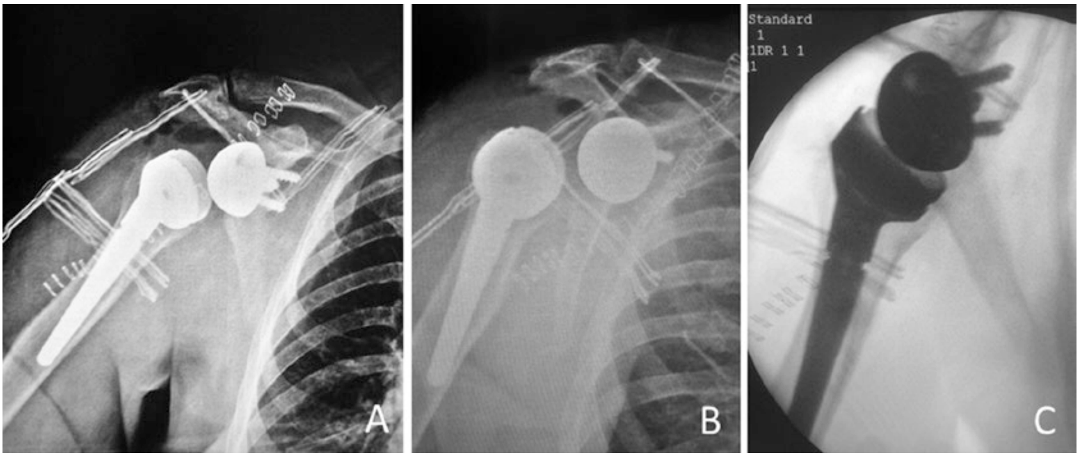

Fig. 7.6 Early-onset posterior shoulder dislocation secondary to glenoid component retroversion following the RTSA (**a**, **b**); a stable RTSA is succeeded by correcting the version of the glenoid component with a revision surgery (**c**)

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8

Keeled or Pegged Polyethylene Glenoid Components

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and Ulunay Kanatlı

The glenoid baseplate survival is of paramount importance for the outcome of anatomical and reverse total shoulder arthroplasty procedures. Various prosthetic designs have been described and experienced to decrease the failure rates and improve patients' satisfaction. Most of the orthopaedic surgeons have a great eagerness to implant and advocate the success of uncemented prosthetic components in arthroplasty procedures to avoid complications of cementing and troubles during the revisions. However, higher rates of failure were almost always reported for metal-backed glenoid components in the literature (Fig. 8.1). According to the Australian Orthopaedic Association National Joint Replacement Registry, the overall revision rates for total shoulder arthroplasties with cementless glenoids were four times greater than those for total shoulder arthroplasties with cemented glenoids [1]. This fact is thought to be due to better stress contribution under non-axial loading to the glenoid surface with the glenoid components fabricated wholly from polyethylene and placed with cement [2]. Studies in the literature have consistently reported unsatisfactory results following implantation of uncemented metal-backed glenoid components associated with high rates of polyethylene wear and glenoid version [3–6].

Fig. 8.1 Metal-backed glenoid component

The most common complication of TSA is the failure of the polyethylene glenoid component which accounts for the majority of the deleterious outcomes and manifests clinically by pain, loss of function, and presence of a clunking noise [7–10]. While many factors have been described as possible contributors to glenoid component

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Fig. 8.2 The bone-cement interface dissociation

failure, a systematic understanding of these factors is lacking. The main problem seems to be the loosening and the following revision which is troublesome for surgeons because of the restricted amount of bone reserve of glenoid. High rates of radiolucency at the bone-cement interface were previously reported numbers of times in the literature (Fig. 8.2). However, this fact does not always show up clinically as symptomatic loosening during the postoperative follow-ups. Nevertheless, with the better radiological and clinical survival periods in years, radiolucency may become a more important radiological finding of impending glenoid component failures than it is today.

The bone-cement interface dissociation (Fig. 8.2) is the major problem encountered at follow-ups which can also be more frequent by the admixture of antibiotics and by preparation methods that introduce porosity into cement. The interposing cement in the bone-cement interface brings out the risk for dissociation because of a thin layer of cement which is brittle and highly susceptible to fatigue, fracture, and displacement [11]. Additionally, an inadequate interposition of the cement results in loss of seating and loss of grouting effect of the cement which causes poor support for the component [12]. The mechanism of glenoid loosening is thought to be repetitive and eccentric loading of the humeral head on the glenoid, the so-called “the rocking horse” phenomenon. This eccentric or edge loading condition produces a torque on the fixation surface that induces a tensile stress at the bone-implant or bone-cement-implant interface, potentially causing interfacial failure and glenoid dissociation [13]. Actually, physiologic bone-cement interface stress can easily exceed the stress needed to initiate cement mantle cracks. A widely accepted common value for crack initiation in polymethyl methacrylate (PMMA) is about 5–7 MPa, and finite element models report this value with a lowest maximum principal stress (tensile) of approximately 6 MPa for the keeled design and unloaded arm [14, 15]. Therefore, it is obvious that there is an unavoidable risk for bone-cement interface dissociation. This prediction of failure risk is even more likely to be true when one considers that the glenohumeral loading used in the aforementioned study was in an unloaded and soft tissue-free arm [15].

The incidence of glenoid loosening was reported previously by a number of studies as low as 0% to as high as 96%, assuming the radiolucent lines as indicators of early loosening [7, 16–21]. These rates are unacceptable for the survival of a prosthesis to lead revision procedures. The authors dedicated in shoulder surgery investigated broadly the mechanisms of loosening to find a solution. Previously, Karduna et al. have found that the humeral head translates 1.5 mm in the anterior-posterior (AP) direction and 1.1 mm in the superior-inferior (SI) direction during the active glenohumeral motion including rotation and translation [22]. Similarly, McPherson et al. reported 4 mm translation of humeral head during the active motion of the glenohumeral joint in healthy individuals which they measured from the radiographs [23]. This physiologic motion is thought to be resulting from the bony incongruence of the glenoid and the humeral head and the congruence of the surrounding soft tissue, the articular cartilage, and the labrum. However, when the glenoid is resurfaced with a human-made implant, physiologic translation of the humeral head turns into eccentric loading of the bone-cement or bone-metal backed component because of the inadequacy of UHMWPE to mimic the viscoelastic properties of the articular cartilage and labrum [13]. This eccentric loading leads to rocking forces at the glenoid component which is shown to be increasing with the early radiolucencies at the subchondral bone-cement interface caused by incomplete glenoid component seating [17, 24]. Therefore, recent biomechanical, animal, and retrospective studies have involved mostly the glenoid design, rather than traditionally accepted cementing technique or thermal necrosis, in the development of the glenoid lucency [16, 25, 26].

So many methods have been advocated to improve fixation and long-term stability of the glenoid component previously. These include preservation of the subchondral plate, concentric spherical reaming of the glenoid cavity, enhanced biomaterials, mismatching of the diameters of the glenoid and humeral head, patient-specific components, cementing techniques, and new glenoid designs [27–32]. In this chapter, the review of the literature will be over the pegged and keeled glenoid components (Fig. 8.3).

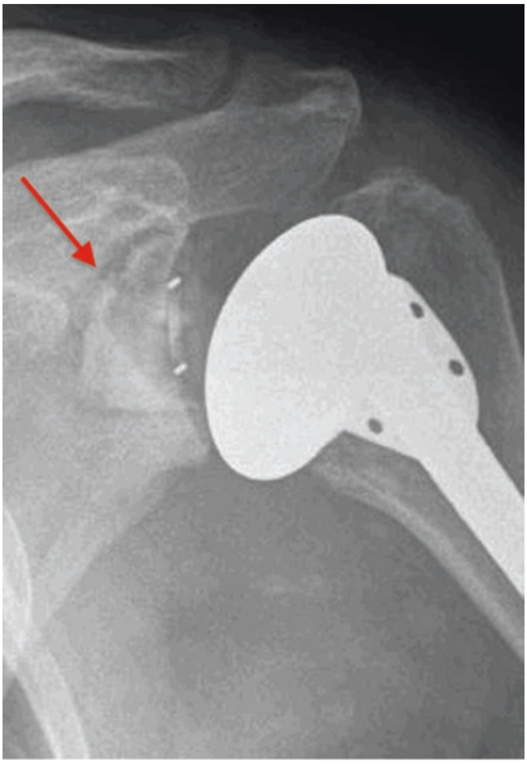

Fig. 8.3 Pegged and keeled glenoid component designs of total shoulder arthroplasty

With the presentation of a comparison between cemented pegged glenoid component and conventional keeled components in a well-designed finite element model by Lacroix et al. in 2000, the glenoid component-glenoid bone interface stresses were better understood and the hope for better longevity in TSA was raised again [15]. In that study, the authors used an advanced finite element model prepared wisely with quantitative computerised tomography (CT) of a normal scapula to investigate the stress of cemented glenoid component fixation and to quantify the probability of cement failure and found that keeled designs were more preferable over pegged designs in patients with rheumatoid arthritis while vice versa was valid for the normal bone. Actually, their study was planned and carried out comprehensively. The twisting of the components, which is described as the moment about the centre anchorage system of the component, was better resisted by the keeled designs than the pegged ones. However, the cement stress was 10% at the cement mantle above 5 MPa with the keeled design, compared to less than 1% with the pegged design, which was reversing in rheumatoid arthritic bone. Therefore, the twisting forces seem to be not playing a crucial role in loosening.

In 2002, Lazarus et al. reviewed retrospectively the postoperative radiographs of 39 patients with keeled glenoid component and 289 with pegged glenoid components. They used the Franklin method (Table 8.1) to grade the degree of radiolucency around the keeled glenoid components and modified Franklin method (Table 8.2) for the pegged glenoid components [33]. They found that the pegged components had better cementing than keeled components. They also

Table 8.1 Franklin method of grading scale for radiolucencies about keeled glenoid components

Grade	Finding
0	No radiolucency
1	Radiolucency at superior and/or inferior flange
2	Incomplete radiolucency at keel
3	Complete radiolucency (≤2 mm wide) around keel
4	Complete radiolucency (>2 mm wide) around keel
5	Gross loosening

Table 8.2 Modified Franklin method for grading scale for radiolucencies about pegged glenoid components

Grade	Finding
0	No radiolucency
1	Incomplete radiolucency around one or two pegs
2	Complete radiolucency (≤2 mm wide) around one peg only, with or without incomplete radiolucency around one other peg
3	Complete radiolucency (≤2 mm wide) around two or more pegs
4	Complete radiolucency (>2 mm wide) around two or more pegs
5	Gross loosening

Table 8.3 Grading scale for completeness of glenoid component seating

Grade	Finding
A	Complete component seating
B	<25% incomplete contact, single radiograph
C	25–50% incomplete contact, single radiograph
D	<50% incomplete contact, both radiographs
E	>50% incomplete contact, single radiograph

assessed the seating profiles with a new scale described firstly in their paper reflecting the amount of host subchondral bone directly in contact with the back of the glenoid component (Table 8.3) and found that incomplete seating was more common with the keeled components. The patients were part of a multicentre study in which 17 surgeons from 17 different centres participated. The trademark for the prosthesis was same in all patients (Global Total Shoulder System, DePuy Orthopaedics, Incorporated, Warsaw, Indiana), but that of the methyl methacrylate is not mentioned in the study.

Trail and Nuttall compared patients with pegged and keeled components in their study with a mean follow-up of 5.7 years and found that 90% of keeled components had a radiolucent line of more than 1 mm in at least one zone while 36% of pegged components had that. The incidence of radiological evidence of loosening was 53% although none required revision, and it was significantly less in the pegged designs [34].

Gartsman et al. compared 23 patients with keeled components and 20 with pegged components by scaling the radiolucencies on the early postoperative radiographs obtained within 6 weeks of surgery which were evaluated by three raters. The rate of lucency was 39% in the keeled components, which was significantly higher than the rate of 5% observed in the pegged components [35].

Roche et al. reported in 2006 that the keeled and pegged designs revealed no significant difference in edge displacement occurred before or after cyclic and eccentric loading [36]. They also added that each keeled and pegged designs remained fixed firmly following the tests showing the trustable resistance to edge displacement.

Nuttall et al. presented the results of their study in 2007 analysing the radiostereometric properties of the total shoulder arthroplasty patients, 10 with keeled and 10 with pegged glenoid components. In that study, the relative movement of the glenoid component with respect to the scapula was measured over a 24-month period, and the highest maximum total point movement was found to be 2.57 mm for keeled and 1.64 for pegged eroded components [37]. Whereas all components had moved at last follow-up, keeled components revealed significantly greater migration than the pegged ones. There was no significant difference between the designs in terms of pain relief and functional improvement at the end of the 24-month follow-up in that study; however, this finding does not change the fact that it can develop in a long-term follow-up. Rahme et al. presented in 2009 their findings which revealed no significant difference at the end of 24-month follow-up between keeled and in-line pegged glenoid components in terms of Constant-Murley score improvement, average micro-migration, and translation or rotation of the glenoid components with radiostereometric analyses [38].

In a study made by Edwards et al. in 2010, whether the difference between keeled and pegged glenoids in terms of postoperative radiolucent lines were decreased with the modern cementing techniques including the systematically and step-by-step application of saline solution lavage, sponge drying, and cementing under pressure using catheter tip syringe with no cement at the back of the glenoid component-glenoid bone interface was investigated [39]. The rate of glenoid lucency between pegged (0%) and keeled (15%) components did not differ significantly on immediate radiographs. However, after an average of a 26-month period, the higher risk in keeled components was obvious (15% versus 46%).

Throckmorton et al. also pronounced the similar outcomes with pegged and keeled designs in terms of pain relief, functional improvement, and risk for loosening at the end of a mean follow-up of 51.3 months for the keeled group and 45.7 months for the pegged group [12]. They reported early radiolucency on radiographs taken immediately after operation only in 4 of 50 pegged components and 1 of 50 keeled components. The decrease in radiolucent lines on early postoperative radiographs might be due to the modern cementing techniques which achieve a low incidence of early radiolucent lines at both the bone-cement (fixation) interface and the subchondral bone-component (seating) interface [40].

Raiss et al. reported in 2011 the outcomes of their fresh frozen cadaver study with ten pairs of scapulas [41]. There was a strong negative correlation with the bone mineral density (BMD) and the cement penetration in both type of designs, and the penetration amount was significantly higher in pegged components. However, the mean pull-out strength was significantly higher in the keeled group (1093 N) than the pegged group (884 N). Since the loosening of the glenoid components is thought to be secondary to the eccentric loads and rocking effect of the humeral head over the glenoid surface [13], the high pull-out strength did not affect the clinical and radiographic outcomes.

There are also different types of keeled glenoid components such as with anterior offset or inferior offset presented in the literature aiming to provide decreased stresses at the bone-cement interface and similar outcomes with pegged components. Murphy et al. investigated the anteriorly offset keel which preserved a greater amount of the more dense bone, which is mostly placed at posterior glenoid, and associated with lower stress because of the more directly aligned with the applied force [42]. Similarly, Orr et al. reported the inferiorly offset keel and pronounced that better replication of normal stresses of the glenoid can be achieved when compared to centrally located keels [43]. However, these two finite element models do not include comparison with pegged components. The main designs of the pegged glenoid components are as follows: the in-line pegged design in which three pegs of the component are arranged in a row and the outline design in which the pegs are dispersed behind the polyethylene back (Fig. 8.4). The advantage of the in-line peg (Fig. 8.5) design is to occupy less cavity of the glenoid bone than the outline design, thus preventing posterior penetration which simulates the keeled design preponderating in defective glenoids.

Pegged components have also made some progress over time. The most featured design developed by the implant manufacturers is the anchor peg glenoid which is minimally cemented design with a central uncemented finned peg (Fig. 8.6) holding on to the glenoid cancellous bone in a press-fit manner allowing bone growth between fins, thus, in theory, imparting long-term stability to the implant [44]. Wirth et al. reported improved stability and demonstrated the bone formation between uncemented central peg fins of the anchor peg very well in a canine study [45]. In a study reporting the outcomes of patients with minimum 5-year follow-up, bone formation between central peg fins was 85%, loosening was 0%, and lucent line formation was 25% [46]. This report had obviously better outcomes than the previous conventional pegged designs [12, 24, 34, 35, 39]. One important advantage of this

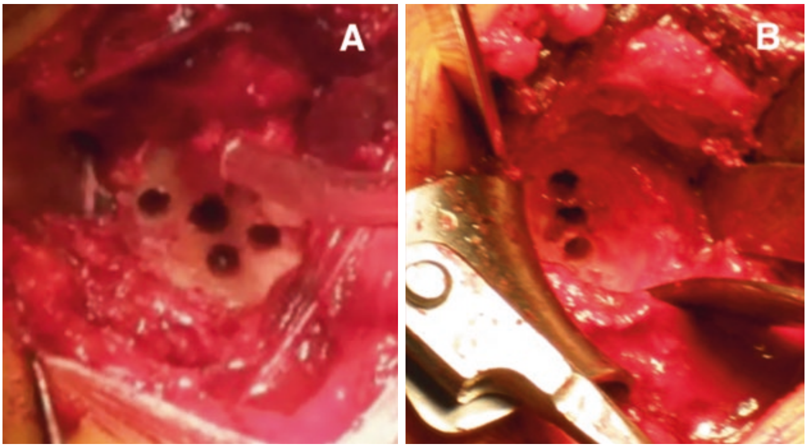

Fig. 8.4 (**a**) Prepared glenoid base for outline pegged glenoid component. (**b**) Prepared glenoid base for in-line pegged glenoid component

Fig. 8.5 In-line pegged glenoid component

Fig. 8.6 Minimally cemented design with a central uncemented finned peg

hybrid glenoid component with three cemented peripheral pegs and a central peg can be the feasibility in biologic fixation with use of native humeral head autograft for glenoid defects [47].

Gartsman et al. reported that the patient age, gender, and glenoid components' size did not significantly affect the postoperative lucency [35]. Edwards et al. reported that there was no higher risk for glenoid component radiolucencies with gender, age, shoulder dominance, glenoid morphology, humeral head size, glenoid component size, and glenohumeral mismatch [39]. However, in a study by Fox et al. in 2009, the male gender was significantly associated with high risk of revision [6]. Patients of that study aged 65 or younger at the time of surgery showed a trend towards higher rates of revision, but this was not significant statistically. In the same study, posttraumatic arthritis and avascular necrosis were found to be associated with the risk of revision. McLendon et al. reported high risk for failure rates of pegged components with age <65 years and preoperative glenoid erosion [48]. There is no data in the literature that these parameters come into prominence when comparing the glenoid component designs.

The first systematic review of the published evidence on glenoid component failure was reported by Papadonikolakis et al. in 2013 [49]. They presented the outcomes of 3853 TSA performed from 1976 to 2007 published in the English-language literature between 2006 and 2012. The rate of radiolucent lines occurred per year was 7.3%, symptomatic glenoid loosening per year was 1.2%, and surgical revision per year was 0.8%. Keeled components had greater rates of asymptomatic radiolucent lines than the pegged components; however, glenoid component failure was only associated with sex, Walch glenoid erosion classification [50], and diagnosis. The most interesting finding of this study was the absence of significant evidence supporting a decrease in the rate of symptomatic loosening over time. The study of Vavken et al. reviewing the literature to compare the pegged and keeled components also found a very small difference and added that this difference will, therefore, be most meaningful to high-volume shoulder arthroplasty centres [51].

The orthopaedic surgeons should keep in their mind that the radiographs can mislead them, and the various rates of radiographic lucency findings may be due to the various methods of taking the radiographs. As Havig et al. previously reported, even though the glenoid component is placed properly in neutral rotation and the radiograph could be taken in standard position, individual variation in the glenoid version of patients may lead to a potential error of as much as 15° [52]. Therefore the measured width of radiolucency can be smaller than the actual gap. Fluoroscopy and CT are shown to improve the accuracy of bone-cement interface width measurement [53].

In conclusion, the design of logical choice and gold standard for glenoid surface replacement in total shoulder arthroplasty (TSA) seems to be cemented pegged polyethylene components. New modern cementing techniques have also reduced the postoperative radiolucent lines which extended the glenoid implant longevity [54]. However, the efforts to develop the survival rates of the prosthetic materials have not resulted in an obvious difference between the pegged and keeled glenoid component in terms of clinical outcomes. Moreover, as Papadonikolakis et al. mentioned, even the rate of symptomatic loosening has not been decreased yet [49].

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9

The General Principles of Rehabilitation Following Shoulder Surgery

Irem Duzgun

Arthroplasty is a commonly used approach in cases of advanced shoulder pathologies. Depending on the severity of the pathology in the shoulder joint, the most suitable arthroplasty method is determined. Hemiarthroplasty, total shoulder arthroplasty, and reverse shoulder arthroplasty are the most frequently used surgical procedures. The primary goal of these surgeries is to reduce the level of pain in the preoperative period and to increase the patient's level of functional activity. Physiotherapy and rehabilitation applications are needed to reduce postoperative symptoms, to increase range of motion of the joint, to raise the strength of the shoulder girdle muscles to the highest possible level, and to improve the functional activity level of the shoulder.

In order to prepare a precise rehabilitation program, the physiotherapist should be familiar with the underlying pathology and the type of implant used. Furthermore, it is very important for the orthopedic surgeons and physiotherapists to work together to achieve satisfying results. Clinical experience is considered to play an important role in planning and applying a successful rehabilitation program following shoulder arthroplasty [1, 2].

The most important factors affecting rehabilitation are [1]:

1. Preoperative health status of the shoulder: The strength of the shoulder girdle and scapular muscles is very important in the postoperative recovery. Especially rotator cuff muscles, deltoid, and muscles around the scapula are key points in rehabilitation. The presence of external rotation lag sign provides an idea regarding the patient's postoperative recovery. A negative external rotation lag sign indicates a better postoperative progression in terms of regaining strength and wider range of motion.
2. Type of the implant used: Rehabilitation approaches vary depending on which of the hemiarthroplasty, total shoulder arthroplasty, or reverse shoulder arthroplasty approaches is applied.
3. Quality of glenoid and humeral bone: Bone quality is an important parameter influencing rehabilitation. The presence of osteoporosis, for instance, requires a reduction in the rate and intensity of rehabilitation.
4. Rotator cuff integrity: The integrity of the rotator cuff muscles plays an important role in selecting the type of the implant that will be used. In addition, the health status of rotator cuff muscles gives an idea regarding joint range of motion that can be achieved postoperatively.
5. Concomitant RC repair or tendon transfer: Any concomitant muscle repair or transfer will result in a prolonged rehabilitation period. In this case, active movements are postponed 6–8 weeks after the surgery.

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The predicted range of motion and functional activity level should be explained to the patient before the arthroplasty procedures. The underlying pathology, health status of the rotator cuff muscles, and strength of deltoid and periscapular muscles are the most important parameters in regaining joint range of motion and functional activity level following the surgery.

Arthroplasty is most commonly indicated in osteoarthritis, rheumatoid arthritis, osteonecrosis, rotator cuff deficiency/cuff tear arthropathy, and proximal humerus fractures [1].

As long as the rotator cuff is intact, total shoulder arthroplasty is often preferred in patients with osteoarthritis. It is particularly shown in the studies that reducing pain is effective in increasing joint range of motion and functional activity level [1, 3, 4]. For the first 4 weeks of rehabilitation, it is recommended to start with passive joint movements and to proceed to active-assisted and active movements [1].

The same rehabilitation protocol is applied in patients with rheumatoid arthritis, yet there is a slight difference in the anticipated active overhead movements after the surgery. Patients with rheumatoid arthritis may have difficulties in overhead activities due to their adversely affected bone and soft tissue quality. Strengthening exercises, especially below 90°, are recommended in these patients [1, 5, 6].

Since total shoulder arthroplasty has low success rate in patients with rotator cuff deficiency/cuff tear arthropathy [1], reverse shoulder arthroplasty is preferred [2]. With reverse shoulder arthroplasty, the center of the joint is placed more medially and inferiorly, allowing the deltoid muscle to function as the primary muscle for shoulder flexion and external rotation [2]. While placing the center of the joint inferiorly enhances shoulder elevation, placing it medially facilitates external rotation. There are differences between protocols of total shoulder arthroplasty and reverse shoulder arthroplasty.

Osteonecrosis is common in conditions such as caisson disease, Cushing's syndrome, and systemic lupus erythematosus and in patients using corticosteroid. Total shoulder arthroplasty is applied in these cases [1]. ROM has a better progression in osteonecrosis due to corticosteroid use [1].

9.1 Rehabilitation

Objectives of rehabilitation after arthroplasty are [1, 2]:

- Protecting the joint
- Ensuring that the deltoid or rotator cuff muscles are as active as possible
- Regaining joint range of motion and its function

It is recommended to use a shoulder sling for 4 weeks after all shoulder arthroplasties [1, 2].

In the early period of rehabilitation, it is very important to protect the joint. After total shoulder arthroplasty, excessive shoulder movements should be avoided. Excessive internal rotation such as placing back of the hand over the lower back, as well as sudden and extreme external rotation and abduction along with stretching in the direction of ER, may cause dislocation in these implants [1]. Similarly, shoulder adduction, extension, and internal rotation are prohibited after reverse shoulder arthroplasty. For this reason, the patients are required to see their elbow during the protection phase. Furthermore, movements that cause both adduction and internal rotation, such as touching the counter side of the body (counter shoulder, counter pelvis, etc.), are associated with high risk of dislocation [2].

Pain and inflammation must be addressed in the early postoperative period. It has been shown in a study that cryotherapy is an effective way in reducing symptoms after shoulder surgery [7]. These patients are recommended to use cold packs for 12–15 min at 2-h intervals to control pain, edema, and muscle spasms and to suppress inflammation.

To avoid negative effects of immobilization after arthroplasty, it is suggested to start passive joint movement in the early period. While passive shoulder flexion in supine within the pain-free range is applied on the first postoperative day following total shoulder arthroplasty [1], passive

Fig. 9.1 (**a**) Shoulder flexion exercises near the table—beginning position, (**b**) ending position

joint movement exercises start on the third week after reverse shoulder arthroplasty [2] (Fig. 9.1a, b). The time to start passive joint movement varies depending on the surgical approach applied in reverse shoulder arthroplasty. Considering bone healing in deltopectoral approach, it is suggested to start passive joint motion at the third week. However, passive movements start at the fourth week post-op, allocating enough time for healing of the deltoid [2]. In case of total shoulder arthroplasty, comparing the patients who started passive movements on the first post-op day to those who started on the fourth week after surgery shows that there is no difference in joint range of motion and functional activity level at the third month following the operation [8].

After both arthroplasty types, isolated abduction movement in the frontal plane is avoided to prevent increased load on the posterior capsule. Initially, it is recommended to start flexion in scapular plane in supine position and continue to move in frontal plane in the following weeks [1, 2]. Particularly, it is known that performing isolated abduction increases the risk of dislocation in reverse shoulder arthroplasty with deltopectoral approach [2]. After both surgeries, while 90° of elevation is targeted for the first 4 weeks, it is aimed to reach 120° of elevation by the sixth week (Fig. 9.2a–c).

Deltoid isometric exercises at the fourth week, active joint motion at the sixth week, and IR-ER isometric exercises at the eighth week are recommended for superior approach in reverse shoulder arthroplasty [2].

If subscapularis repair is performed during shoulder arthroplasty, passive ER movement should start gradually and progress under control in 30° and 45° of abduction. IR is recommended to be initiated at the scapular plane at the sixth week after the surgery [1, 2].

Fig. 9.2 (**a**) Shoulder flexion exercises with ball—beginning position, (**b**) ending position

Following shoulder arthroplasty, NMES can be applied to the posterior shoulder muscles and deltoid.

Six to 12 weeks after the surgery is considered as early strengthening phase. At the sixth week, active-assisted range of motion exercises start and active movements gradually replace them. Wand exercises are the most common active-assisted exercises (Fig. 9.3a–c). When it is difficult for the patient to proceed from active-assisted exercises to active movements, muscle activation needs to be increased by holding the arm independently at different angles. It is aimed to gain nearly similar active and passive range of motion by the 12th week.

In the reverse shoulder arthroplasty, the primary muscle is the deltoid [2]. Depending on the design of the implant, the center of the joint is placed either inferiorly to enhance arm elevation by extending the length of deltoid or medially to facilitate external rotation. However, external rotation is limited in these patients. According to the results of a study, along with an increase in the activity level of anterior and lateral deltoid muscles, the activity of upper trapezius muscle also increases in

Fig. 9.3 **(a)** Shoulder flexion exercises with a stick in supine—beginning position, **(b)** ending position, **(c)** shoulder flexion exercises with a stick in standing

patients with reverse shoulder arthroplasty [9]. In total shoulder arthroplasty, rotator cuff is considered as the primary muscle. One study reported that external rotation is better after total shoulder arthroplasty, and the deltoid and RC are the primary muscles in RSA and TSA, respectively [10].

In this phase, it is crucially important to increase the activation of the scapular muscles. A study comparing TSA and RSA reported that TSA results in more motion and consequently more scapulothoracic movements [11]. In RSA, however, more scapular motility is reported during arm elevation due to the increased upper trapezoidal activity [12]. Increased scapular activity has been shown to be a compensatory strategy during daily living activities. Particularly, the increased upper trapezium activity causes anterior tilting, internal rotation, and elevation of the scapula, which, in return, reduce the risk of squeezing in the scapular notch [13]. Hence, this scapular compensator movement of the patients is not attempted to be corrected. Originating from this compensational movement, clinical symptoms such as periscapular regional pain, subscapular bursitis, acromioclavicular joint problems, and scapular spine stress fractures are common among patients [13]. For these reasons, it is important to strengthen the muscles around the scapula within the rehabilitation program. Scapula retraction exercises are performed with the arms close to the trunk at sixth week (Fig. 9.4a, b). In the later phases of rehabilitation, it is important to further strengthen the muscles around the scapula.

From the 12th week onward is the moderate strengthening phase of the rehabilitation. The aim of this phase is to improve muscular endurance by high repetitive exercises with low weights. Shouder kinematics unchanged during resistive exercises depending on the type of the prosthesis used. It is also stated that both elastic band and weight can be used safely as there is no difference between the two in terms of outcomes [14].

Fig. 9.4 (**a**) Scapular retraction exercises with band—beginning position, (**b**) ending position

After the 16th week, the patients are allowed to perform mild housework and leisure-time activities.

Comparing TSA and RSA results shows that a wider range of active internal rotation is present after TSA [15]. When the kinematic analysis of the reaching activities is examined, it is noted that there is no difference between the two arthroplasties; however, it is more smooth and quick after TSA [10].

It is known that, after RSA, while daily living activities cause an increase in flexion, abduction, and adduction, these activities have no impact on ER and IR movements [16].

It is also demonstrated that 6 weeks after shoulder arthroplasty, patients are able to drive a car similarly to their preoperative period, and at the 12th week they can drive in a much better way [17].

It is stated that the vast majority of patients who used to do sports prior to the operation can return to their sport after the surgery. Some of the examples of most useful sports for these patients include swimming, cycling, jogging, and golf [18].

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10 Rehabilitation Following Shoulder Arthroplasty

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10.1 Total Shoulder Arthroplasty

10.1.1 Prehabilitation

Often termed "prehabilitation," a couple of sessions followed by a physiotherapist to go over the postoperative rehabilitation program is very helpful to the patient. Emphasis is placed on understanding the goals of therapy and practicing rehab exercises before patients experience postoperative pain and immobilization. Immediate postoperative issues such as dressing, bathing, and activities of daily living are addressed so that the patient feels comfortable with those activities prior to surgery. This is very important especially for elderly patients who live alone and are concerned about restrictions following surgery. We routinely schedule a prehabilitation appointment with a therapist, even when patients are planning to do therapy at home postoperatively.

In total shoulder arthroplasties, postoperative rehabilitation program gives importance to function regaining of an atomic structure repaired with surgery. While previously rehabilitation programs were initiated at later stages in order to preserve surgery and allow for the soft tissue to recover, the recent trend is to begin rehabilitation program at an early stage in a safely manner [1–3].

Postoperative rehabilitation programs reported in the literature generally begin with passive and mild joint movements and progress through active and total joint movement to later on strengthening and endurance trainings. Overall rehabilitation program generally includes three or four phases [1, 3–5], and even though there is no sharp distinction between these phases and although phases differ from each other through the time elapsed following surgery, patient's functional conditions are very important in order to determine transition between phases.

10.1.1.1 Phase 1: Postoperative Early Stage

0–4/6 Weeks After Surgical Intervention

Goals:

- To preserve surgery.
- To allow soft tissue recovery.
- To control edema and inflammation.
- To preserve normal range of joint movement in the surrounding joints.
- To gradually increase passive joint movement of treated shoulder.

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In this phase, passive and then active movements should be started as soon as possible in order to prevent adhesion formation and to stimulate tissue recovery [6], and since new capillaries that are formed as a result of angiogenesis occur at the end of the inflammatory period, a total immobilization is recommended for the first 7–10 days [7]. Shoulder sling should be used for the first 3–4 weeks and should only be taken off during exercises and for personal hygiene. An external rotation higher than 30° with the arm next to the body should not be allowed in order not to expose to loads shoulder anterior capsule and subscapularis muscle. Active shoulder movements should be avoided for the first 4 weeks and active internal rotation should be avoided for the first 6 weeks.

Rehabilitation Program:

- Ice application in order to keep edema, inflammation, and pain under control [8]
- Passive shoulder flexion, abduction, and passive internal rotation exercises
- Active movements of distal joints
- Active assisted wand exercises starting from week 4
- Scapular mobilization
- Isometric shoulder flexion, abduction, and extension exercises starting from week 4
- Scapular retraction exercises in order to obtain scapular stabilization starting from week 4

10.1.1.2 Phase 2: Early Strengthening Period

4/6–8 Weeks after Surgical Intervention

Goals:

– To gain total range of joint motion.
– Transition from passive to active assisted and then to active movement.
– To control pain, edema, and inflammation, when present.
– To correct postural defects.

In this phase, tissues cannot be loaded with abnormal stress even though active movement is started and external rotation is allowed at a slower pace. Shoulder sling should be worn at night even though it can be taken off during the day. Active exercises should be performed without causing exhaustion in shoulder.

Rehabilitation Program:

- Active shoulder exercises should be started toward all directions.
- On patients that cannot perform active exercises, neuromuscular electrical stimulation is recommended.
- Isometric internal rotation exercises can be started.
- Closed kinetic chain exercises can be commenced by conducting load transfer on wall.
- Ice application should be continued especially after rehabilitation sessions.
- Postural exercises can be helpful according to patient's needs.
- Gentle stretches can be started in order to increase range of joint motion excluding external rotation.
- Core stabilization exercises can be started.

10.1.1.3 Phase 3: Intermediate Strengthening Period

8–12 Weeks After Surgical Intervention

Goals:

– Regaining shoulder girdle dynamic stability.
– Regaining neuromuscular control.
– Gradual shoulder girdle strengthening.
– Gradual return to activities of daily living.

In this phase, lifting heavy weights and sudden movements should be avoided. Moreover, excessive stretching of anterior capsule and subscapularis should be avoided.

Rehabilitation Program:

- Joint capsule stretching exercises can be started in order to correct joint biomechanics and, if necessary, to gain total range of joint motion.
- Weight-bearing exercise can be carried out on a Swiss ball.
- Progression through isotonic resistance exercises may be carried out excluding internal rotation.
- By the end of this period, it is possible to progress through internal rotation strengthening exercises.

- Scapular stabilization exercises should be continued.
- Neuromuscular coordination exercises should be continued.
- Core stabilization exercises should be continued.

10.1.1.4 Phase 4: Advanced Strengthening and Home Program Period

From 12 Weeks After Surgical Intervention on

Goals:

- – Gaining of complete upper extremity functionality.
- – Gaining of complete shoulder and scapular control.
- – Gradual return to recreational activities.
- – Gaining maximum external rotation.
- – Gaining normal rotator cuff and shoulder girdle muscle strength.

In this phase, strengthening and endurance exercises should be increased gradually. Sudden movements and activities causing excessive loads on anterior capsule should be avoided.

Rehabilitation Program:

- Capsular stretching exercises can be continued if needed.
- Proprioceptive neuromuscular exercises for shoulder and scapula are continued with progression.
- Rotator cuff strengthening can be commenced at varying degrees of shoulder joint.
- Depending on the condition of the patient, swimming can be commenced gradually at weeks 18–20.

10.1.1.5 Return to Activity

Typically, keyboarding and driving are started at 2 weeks as long as the shoulder is sufficiently comfortable. Gentle water exercises are initiated at 6 weeks. Golf or tennis is started at 3–6 months if the shoulder is comfortable, flexible, and strong. High-impact activities, such as chopping wood, should be precluded for total shoulder arthroplasties.

10.2 Reverse Shoulder Arthroplasty

10.2.1 Prehabilitation

As for total shoulder arthroplasty, a couple of sessions followed by a physiotherapist to go over the postoperative rehabilitation program is very helpful to the patient. Emphasis is placed on understanding the goals of therapy and practicing rehab exercises before patients experience postoperative pain and immobilization. Immediate postoperative issues such as dressing, bathing, and activities of daily living are addressed so that the patient feels comfortable with those activities prior to surgery. This is very true for elderly patients who live alone and are concerned about restrictions following surgery.

In reverse shoulder arthroplasty, rotator cuff muscles function is either at a minimum level or completely lost. In addition, biomechanical characteristics are also different than normal shoulder structure. Because of this, postoperative rehabilitation is different from total shoulder arthroplasty [9].

Functional use of the shoulder following RSA is variable as patients' demands are very different based on age and prior activity levels. Patients in their 90s are often content with the resolution of pain and are pleased being able to complete simple ADLs comfortably. Patients in their 60s and 70s are not content with that level of activity and want to push the limit especially for recreational activities as many are retired and have left the active workforce. Rehabilitation can be anyways planned in four stages.

10.2.1.1 Phase 1: Maximum Protection

From 0 to 6 Weeks After Surgery

Goals:

- – To preserve surgery.
- – To protect joint stability.
- – To ensure gaining passive movement [9].
- – To keep pain, edema, and inflammation under control.

In this phase, patients should be aware about the conditions of the treated shoulder and about rehabilitation timing and objectives. Patients should use a shoulder sling that positions the arm on a scapular plane for 4 weeks on average. The sling can be taken off for personal hygiene and during exercises [10]. In order to prevent dislocation, movements giving load and stress especially to the anterior of the joint such as internal rotation, hyperextension, and hyperabduction should be avoided during this period since they can increase dislocation risk. At early stages, drains can be placed in patients in order to decrease the dislocation risk due to potential hematoma that may occur between acromion and prosthesis. At this stage, it is necessary to maintain pain and edema under control. Active movements of surrounding joints are allowed. During this period, recovery of the soft tissue should be ensured. Considering the soft tissue healing, passive joint exercises can be started on the seventh to the tenth day after surgery in order to prevent an enhancement of the inflammatory process, to stimulate tissue recovery, and to prevent adhesion formation [11, 12]. Active assisted exercises should be started in week 5, depending on patient's conditions in order to ensure deltoid functionality at early stages. Patients with insufficient deltoid function can be treated with neuromuscular electrical stimulation. A range of motion of at least 138° should be targeted by the end of this first phase although studies in the literature report varying data [9, 13].

Rehabilitation Program:

- An absolute immobilization is recommended for the first 10 days in order to allow soft tissue recovery.
- A 15-min ice application is recommended every 2 h.
- In supine position, shoulder flexion and abduction movement in scapular plane should be carried out by a physiotherapist in order to ensure passive range of joint motion.
- Flexion on table and passive abduction exercises on scapular plane are recommended as home program 4 times a day with 10 repeats, between weeks 1 and 4.
- Passive elevation is recommended four times a day with ten repeats on sagittal plane and scapular plane with a Swiss ball as home program from the fourth week on.
- Depending on the condition of the patient, wand exercises can be started with the patient lying on supine position from the fifth week onward.

10.2.1.2 Phase 2: Early Stages Strengthening

From 6 to 12 Weeks After Surgery

Goals:

- Transition to active assisted and active movements from passive movements.
- Joint stability should be improved and strengthening exercises should be started [9].
- Shoulder hyperadduction and internal rotation while shoulder is adducted should be avoided.
- Exercises to achieve joint full range of motion should continue.
- Active assisted rotational movements may be commenced on scapular plane.
- Active assisted shoulder elevation movements should be started and progress should be made toward active movement depending on patient's condition.
- At this stage, isometric exercises can be started and progress should be made in order to move on to isotonic exercises.
- In addition, scapular exercises may be started depending on the tolerance of the patient in order to regain shoulder kinematics.
- In this phase joint is vulnerable to injuries even though active movements can be started. This should be explained to the patient, and the patient should be informed not to carry loads even though using the arm in daily life is permitted. Patients should also avoid sudden movements, crossing the arm against the body and attempting to touch their back.

Rehabilitation Program:

- Ice application and exercises with Swiss ball should be continued.
- Wand exercises in standing position should be started in sagittal and frontal plane.

- Active assistive internal-external rotation exercises on scapular plane should be started and then switched to active rotations.
- Depending on the tolerance of the patient, active arm elevation should be started in sagittal, scapular, and frontal planes.
- In order to increase active range of motion, elevation exercises are done in the form of repetitive contractions throughout the range of motion with the help of a stick.
- Scapular retraction exercises are started with the elbow in flexion with the help of an exercise band.
- Isometric exercises in order to strengthen the deltoid posterior segment should be performed.

10.2.1.3 Phase 3: Mid-Strengthening Period

From 12 Weeks After Surgery to 4 Months

Goals:

– To increase the muscle strength of the extremity.
– To ensure shoulder girdle biomechanics regularity.
– Patient to gain independence in basic daily life activities [9].

When the patient possesses sufficient joint movement and is able to conduct the movement pain-free, and to do mildly resistant exercises, transition to the third phase is possible.

In this phase, progressive strengthening exercises are recommended. However, exercises should be done with lower weights and with multiple repetitive movements. Even though patients gain their independence in daily life to a larger extent, they should still avoid carrying heavy loads and performing sudden and straining movements.

Rehabilitation Program:

- Scapular retraction with resistive band, active arm elevation, and repeated contraction exercises with a stick should continue.
- If the range of joint motion is not on the desired level, Pilates ball exercises should be continued.
- Depending on the condition of the patient, resisted arm elevation exercises are commenced on sagittal, scapular, and frontal plane.
- Active internal rotation of the arm is permitted with the body in sagittal plane, and internal-external rotation exercises can be started on sagittal plane when standing up and in supine position with 90° abduction.

10.2.1.4 Phase 4: Long-Term Home Follow-Up

From 4 Months After Surgery Onwards

When patients gain pain-free range of motion and total independence in daily life activities, they can discharge from physiotherapy and follow a home exercise program.

At this stage, the vital point the patient needs to know is that, although pain is not present and functionality is ensured, the arm that received prosthetics was repaired in a nonanatomical manner and should never be compared with the other healthy arm and that they should take this into account in daily life.

Rehabilitation Program:

- Exercises with weights or Theraband on three planes in order to improve strength and endurance of deltoid muscle should be continued.
- In addition to scapular retraction exercises, push-up exercises on the wall can be done for scapular stabilization.
- Depending on the condition of the patient, internal-external rotation exercises with Theraband can be suggested.

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Indications for Reverse Shoulder Arthroplasty

11

Danny Ryan

11.1 Introduction

Reverse shoulder arthroplasty (RSA) has been used since the early 1970s: in a series of patients between 1973 and 1981, Neer reported that the outcomes of shoulder replacement were poor without a functional rotator cuff [1, 2]. He experimented with three iterations of design, but these attempts were abandoned owing to problems with dislocation and fixation with the scapula [3], preferring to focus on repair of the rotator cuff. Other surgeons continued to experiment with anatomical shoulder arthroplasty with varying degrees of constraint, including the Stanmore and Bickel prostheses. Although results in terms of pain relief and range of movement were reasonable, complication rates remained high, particularly fractures and loosening [4].

Initially, proponents of RSA claimed improved strength and motion without the same risks of dislocation and loosening as the constrained designs, and in the 1970s a number of designs began to emerge, addressing the issues with scapular fixation (e.g., Leeds, Kessel, Liverpool) [4]. In the 1980s, Grammont, returning to Neer's philosophy regarding rotator cuff function, developed the implant that would eventually evolve into the Delta prosthesis in the 1990s and built it around four principles that would move the center of rotation distally and medially to maintain deltoid function [4, 5]:

1. The prosthesis must be inherently stable.
2. The weight-bearing surface must be convex and the supporting surface concave.
3. The center of the sphere must be at or within the glenoid neck.
4. The center of rotation must be medialized and distalized.

In 1993, Grammont reported the success with the Delta shoulder prosthesis, mostly in patients with rotator cuff arthropathy [6], and since then the use of RSA has grown across Europe [7].

11.2 Indications for RSA

11.2.1 Rotator Cuff Arthropathy

Around 2% of people over the age of 80 years suffer from cuff tear arthropathy [8], where glenohumeral arthritis exists in the presence of a massive cuff tear, with the humeral head either remaining concentric (Seebauer 1) or migrating superiorly (Seebauer 2) [7]. Symptomatically, patients may suffer with severe pain, particularly at night, with pseudoparalysis of the arm significantly affecting function. Rotator cuff arthropathy formed the basis for the early studies on RSA, as, prior to this, there were few alternatives

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[9–11]. This remains the primary indication, for which RSA was approved by the FDA in 2004 in the USA, with studies showing excellent clinical outcomes [12–14].

11.2.2 Immunological Arthritis with Rotator Cuff Tears

While good results for pain relief have been reported with anatomical shoulder arthroplasty for inflammatory arthritides, including rheumatoid arthritis (RA), psoriatic arthritis, inflammatory bowel disease-associated arthritis, scleroderma, and ankylosing spondylitis [15], improvements with range of motion and function have been less satisfactory [16–18]. Furthermore, secondary rotator cuff failure, with proximal migration of the humerus and loosening of the glenoid component, remains a risk [19, 20]. Studies exploring the use of RSA in patients with RA, in the presence of a cuff tear, demonstrate good functional and pain outcomes [21, 22]; however, concerns have been raised over the longevity of the glenoid component, given evidence of glenoid radiographic lucencies on follow-up [22, 23]. Ekelund and Nyberg [24] and Guery et al. [25] have refuted this, demonstrating statistically significant improvements in pain and range of movement for patients with RA undergoing RSA, with the latter showing this to be the case regardless of status of the rotator cuff. As with any joint replacement in RA, increased risk of infection should be borne in mind [19, 20].

11.2.3 Acute Proximal Humerus Fractures

RSA also has a potential place in trauma. Patients who suffer fractures of the proximal humerus that are deemed to require hemiarthroplasty carry the risks associated with the poor quality of the rotator cuff and the reliance on adequate healing of the tuberosities in the elderly population [26, 27].

Several studies have described outcomes for patients undergoing RSA for Neer 3- or 4-part fractures or fracture-dislocations of the glenohumeral joint [27–31]. Results for function and pain, as expected for patients undergoing arthroplasty following trauma, were not as good as for those with rotator cuff arthropathy but equivalent to the alternative of hemiarthroplasty, though without the potential complications of nonunion or malunion of the tuberosities, cuff failure, or erosion of the glenoid [32–34]. It has been shown that RSA is not reliant on healing of the tuberosities [35] and recovery can be quicker than treatment with hemiarthroplasty [36].

11.2.4 Complications of Fracture Healing

Following nonoperative management of proximal humerus fractures, pain and stiffness can be common problems, with altered anatomy, wear of the glenoid, and the possibility of cuff failure [37, 38]. Studies investigating the use of RSA for treatment of fracture sequelae have shown improvement in range of motion and pain comparable to outcomes for patients undergoing RSA for rotator cuff arthropathy [37–39].

Malunion of the proximal humerus is not uncommon following fracture. Asymmetry, in addition to fatty atrophy of the rotator cuff [15], does not create a favorable environment for anatomical shoulder replacement, resulting in uneven forces across the glenoid component [40] and failure because of the “rocking horse” mechanism [41]. Poor results have also been associated with greater tuberosity osteotomy, which may be required during surgery [42]. RSA provides a preferably alternative, because, as described above, it does not require anatomical healing of the tuberosities, removing the requirement for an osteotomy [40]. Comparison of anatomical shoulder replacement and RSA for malunited fractures has shown RSA to produce superior postoperative results [43], although results remain inferior to those achieved in patients who have had RSA for cuff arthropathy and complication rates are higher [44].

11.2.5 Shoulder Dysplasias

It is estimated that 3.5% of patients undergoing shoulder arthroplasty had glenoid dysplasia [45]: this can occur as an isolated congenital condition or in association with a variety of other conditions, including epiphyseal dysplasia, muscular dystrophy, post-traumatic injury, post-infection, arthrogryposis, or obstetric trauma [46]. One case report has described the successful application of RSA in a patient with a dysplastic glenoid secondary to Kniest syndrome [15], but these conditions are rare, so evidence for RSA is limited. However, it has been recognized that it is important to distinguish between a type B2 glenoid and the hypoplastic glenoid, as soft tissue can adapt to glenoid morphology to keep the humeral centered, with implications for orientation of implants during surgery [47, 48].

11.2.6 Revision Surgery

Common reasons for revision surgery to the proximal humerus include failed treatment of fractures (as described previously), ongoing pain, and loss of function. Revision with RSA has also been described for infection (either single- or two-stage revision) [49, 50], after cuff failure following an anatomical shoulder replacement or hemiarthroplasty [44, 51] and after baseplate failure with previous RSA involving a large glenosphere [52].

One retrospective study, comparing revisions for all types of failed arthroplasty, showed significantly lower functional scores with RSA than for patients with primary RSA as well as double the complication rate at 1 month [53]. These results should, though, be taken in the context of the alternative to revision with RSA in the situation of a poor rotator cuff being arthrodesis, which has been shown to have poor results [54]. For this reason, it is recommended that arthrodesis remain a salvage option for when revision with RSA is not feasible [54].

11.2.7 Glenohumeral OA with Severe Glenoid Bone Loss

Severe bone loss involving the glenoid can be seen in a number of shoulder conditions, particularly after failed primary shoulder arthroplasty, inflammatory arthropathies, chronic dislocations, and osteoarthritis with posterior instability [55, 56]. Controversies remain regarding the treatment of this bone loss, although bone grafting is recommended for type B2 and C glenoids [57]. In terms of bone loss in the presence of an intact rotator cuff, the principle of management remains removing enough bone to make a flat surface for the glenoid component and using bone graft to fill the defect [15].

RSA has advantages of anatomical implants in this situation, as the use of a glenoid component which utilizes a central screw for purpose (as seen in a number of RSA systems) negates the requirement for bone grafting, although cases of implantation with a hybrid bone graft (cancellous autograft and femoral neck allograft) have been described [58].

Concerns remain over long-term follow-up in these patients, however, as medializing the glenoid to accommodate the bone loss, while more stable with an implant utilizing a central screw, can alter the mechanics of the prosthesis and potentially lead to loosening [15].

11.2.8 Chronic Glenohumeral Dislocation

Chronic dislocations can be associated with a number of complications: rotator cuff tears, bone loss, soft tissue contractures, osteoporosis of the humeral head, and softening of the articular cartilage [59, 60]. Massive rotator cuff tears are often present, with substantial humeral head or glenoid bone loss [15]. Indications for arthroplasty, in terms of chronic dislocations, include humeral head defects of greater than 50% or significant degenerative changes [59, 61]. While treatment with RSA is not common, several studies have demonstrated improvement in pain and range of motion for patients [62–64].

11.3 Contraindications

While indications for RSA exist with differing levels of evidence to support them, contraindications also exist.

11.3.1 Deltoid Function

Deltoid function is necessary for active elevation after RSA, and therefore RSA in the presence of impairment will consistently and predictably result in a poor functional outcome [15, 65, 66]. De Wilde et al. particularly highlighted the anterior and middle heads to be crucial to success of RSA [67]. While case reports exist in which patients have been treated with RSA and augmentation of the deltoid (e.g., via latissimus dorsi transfer [68]), the success of these techniques remain in question.

11.3.2 Active Infection

As with any joint replacement, implantation in the presence of active infection is contraindicated.

11.3.3 Age

While improvement in outcomes for patients, particularly those with rotator cuff arthropathy, can be marked following treatment with RSA, concerns remain over longevity. Guery et al. have demonstrated some decrease in function at a mean follow-up of 8 months and a survivorship of 58% at 10 years [25]. Their recommendation that RSA be restricted to patients over 70 years of age is supported by evidence of long-term failures from other studies [24, 27, 69].

11.3.4 Isolated Supraspinatus Tear

An isolated supraspinatus tear does not, in isolation, produce an unbalanced shoulder. While not an absolute contraindication to RSA, Edwards et al. reported, in over 500 cases with 43 months average follow-up, that patients with glenohumeral arthritis and an isolated supraspinatus tear demonstrated the same functional scores, range of motion, and satisfaction ratings as patients without a rotator cuff tear when treated with anatomical shoulder replacement [48].

11.4 Conclusion

The use and indications of RSA have expanded in recent years. The most predictable outcomes remain for the indication for which it was originally intended: patients suffering with pain and reduced range of motion from rotator cuff arthropathy. However, studies continue to show evidence of success in other areas too, including trauma. Careful consideration should be made when planning RSA, particularly in terms of a patient's age and deltoid function, in order to achieve the best outcomes.

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12 Stemless RTSA

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12.1 Rationale for Stemless Design

The use of reverse total shoulder arthroplasty (RTSA) has been growing rapidly in recent years. The UK National Joint Registry shows that three times as many RTSA were performed in 2015 compared with 2012 [1]. This steep increase has also been mirrored in the USA [2]. In the UK, the number of RTSA performed each year has overtaken the number of anatomic TSA [1]. Indications for RTSA include cuff tear arthropathy, osteoarthritis in the presence of deficient rotator cuff, irreparable rotator cuff tears, proximal humeral fractures or fracture sequelae, inflammatory arthropathy and revision of failed arthroplasty. Good mid-term and long-term results of RTSA have been reported, with significant improvements in outcome scores [1]. However, the complication rates for RTSA have also been high. Reported complication rates in excess of 50% have been published [3, 4]!

Over the last 40 years, implant manufacturers have produced numerous humeral components. It took many years to convince the shoulder world that there is no need for a long stem in shoulder replacement for primary osteoarthritis. Levy and Copeland showed that the results of shoulder resurfacing were at least comparable to those for stemmed prostheses, with a similar length of follow-up and a similar case mix [5, 6]. It was not until the late 1990s to the mid-2000s, following publications of good long-term results for the Copeland shoulder, that a change of perception occurred and long stems were considered obsolete for cases of arthritis. Gradually, the humeral components have evolved with shorter and shorter stems [7]. The most recent generation of stemless or ‘canal sparing’ implants does not have a diaphyseal stem. They rely purely on metaphyseal fixation. Stemless RTSA has the potential to alleviate stem-related complications. Stemless anatomic shoulder arthroplasty has been in use for more than a decade and is becoming increasingly popular amongst surgeons [7]. Review articles have found stemless anatomic implants produce equivalent clinical results and good stability in the short- to medium-term follow-up period [7, 8]. Research demonstrates that primary osteo-integration of stemless implants is almost complete just 3 months after implantation [9]. Reported benefits of stemless design include shorter operative time, less blood loss, bone preservation, ease of revision and the potential to reduce both periprosthetic fractures and stress shielding [7, 8, 10–15].

The most commonly reported complications of RTSA, in order of decreasing frequency, are instability, periprosthetic fracture, infection, component loosening, neural injury, acromial or scapular spine fractures and haematoma [3].

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Authors report that between 10 and 67% of RTSA complications relate to the diaphyseal stem [4, 16–20].

Intraoperative fractures are most common in females [16]. This is particularly concerning because most RTSA are performed for females. The British National Joint Registry shows that 72.5% of RTSA patients are female [1]. The risk of intraoperative fracture is logically higher when using stemmed implants which require preparation and reaming of the humeral shaft, as opposed to the use of a stemless metaphyseal implant which does not require humeral diaphyseal preparation. Choo et al. [21] found that reaming for stemmed arthroplasty weakens the humerus in torsion by as much as 33%. Incidence of intraoperative humeral fracture in RTSA is reported as 2.3% [3]. Such intraoperative fractures are known to result in inferior clinical outcomes [22–26]. Consequently, the potential to reduce the risk of intraoperative fracture by using a stemless implant is particularly attractive.

Postoperative periprosthetic fractures are estimated to affect 1.1% of RTSA patients [3]. The majority of proximal humerus fractures occur in older people as the result of low energy trauma, such as a fall from standing height [27]. The incidence of proximal humerus fractures is rising and women aged over 60, with medical comorbidities, are particularly at risk [28]. Most patients with a RTSA are elderly females, have comorbidities and are at risk of falls. A fall in a patient with a stemmed prosthesis is likely to result in a fracture at the stress riser between the prosthesis and the bone, at the mid-humeral shaft. Periprosthetic fractures around humeral stems fair badly when treated nonoperatively, with high rates of non-union and poor clinical outcomes [23, 25, 29]. Therefore, most of these diaphyseal periprosthetic fractures require revision surgery, which is also associated with inferior clinical outcomes [20, 30]. The use of a stemless metaphyseal implant reduces the risk of mid-shaft diaphyseal periprosthetic fractures. Fractures in stemless cases are more likely to involve the metaphysis, rather than the diaphysis. Interestingly, there is some evidence that metaphyseal fractures may heal better than diaphyseal fractures with nonoperative treatment [18, 31]. This could be because the metaphysis has better vascularity and hence improved potential for healing [11].

Stress shielding, stem loosening and osteolysis are also concerns [3, 32–34]. Bone loss, irrespective of aetiology, reduces reconstructive options, substantially increases risk of intraoperative complications and results in poor clinical outcomes [11, 26, 35–37]. Melis et al. [38] reported radiographic evidence of stress shielding in 5.9% of cemented and 47% of uncemented stemmed implants. They also found partial or complete resorption of the greater tuberosity in 69% of cemented and 100% of uncemented stemmed implants, and resorption of the lesser tuberosity in 45% of cemented and 76% of uncemented stemmed implants. Similarly, Raiss et al. [34] found stress shielding in 63% of uncemented humeral stems. Additionally, Spormann et al. [39] reported full-thickness cortical bone resorption in the proximal posterolateral humerus in 17% of their cases. They identified that larger stem sizes, relative to the diameter of the humerus, increased the risk of bone resorption. Nagels et al. [33] also reported that patients with stress shielding had larger relative humeral stem sizes. Conversely, stemless implants transfer load directly to the metaphysis and can therefore help to avoid the problem of stress shielding.

In recent years there has been an exponential increase in revision surgery for both anatomic TSA and RTSA [1, 40]. At revision surgery the removal of a well-fixed stem can be a technically difficult and lengthy procedure, resulting in further loss of proximal humeral bone [10, 20, 26, 36]. This is proven to correlate with increased surgical complications and worse clinical outcome results [10, 20, 35, 36]. Recently, Holschen et al. [41] reported a series of revision surgeries, comparing the outcomes of patients revised from stemless and stemmed primary implants. They found that patients revised from stemless primaries achieved significantly higher postoperative Constant scores than those revised from stemmed primaries. Mean normalized Constant scores were 82.0 for patients revised from stemless primaries compared with 61.8 for patients revised from stemmed implants. Often, after removal of a stemless implant, the revision can be performed using a standard-length primary stemmed implant [12].

Another potential advantage of stemless implants is the ability to use them in patients with abnormal anatomy. For example, those with a mal-union precluding the placement of a stem may be suitable for stemless implants. Furthermore, patients who already have metalwork from a previous fracture fixation could be more easily treated with stemless implants. Similarly, patients with a long stemmed elbow replacement, and thus insufficient space for a standard humeral stem, could still be treated with a stemless prosthesis.

Moroder et al. [15] reported a trend towards better internal rotation with stemless RTSA implants. They postulate that this may reflect the steeper inclination angle of the humeral component in stemless implants, which they measured as 135°, compared to the fixed 155° angle of a stemmed Grammont-style RTSA. The steeper inclination causes increased lateralization of the humerus which may improve the patient's ability to recruit deltoid fibres to achieve rotation [42]. Similarly, Levy et al. [18], Atoun et al. [31] and Levy et al. [43] also reported improved rotational movements with stemless RTSA prostheses. They attributed these good rotational movements to the design of the polyethylene humeral liners. These liners have a 10° inclination shape, which provides a very low profile medially, thereby reducing impingement between the polyethylene liner and the glenoid neck, thus reducing the risk of scapula notching and also promoting better rotational movements. Furthermore, reduced glenoid impingement could also help to position the most anterior fibres and the most posterior fibres of the deltoid muscle in a more horizontal position, thereby allowing them to be recruited, respectively, as internal and external rotators to improve the patient's rotational range of movement [32].

Whilst the potential advantages of stemless implants are numerous, it is important to appreciate that not all patients are suitable for stemless implants. In acute trauma cases, a stem may be required to bypass the site of the fracture. Similarly, the treatment of non-unions is more suited to stemmed implants. Some surgeons have also raised concerns regarding whether stemless designs can be used in patients with poor bone quality or proximal humeral bone loss. Longer-term follow-up will help to establish an understanding of all the benefits and disadvantages of stemless metaphyseal RTSA.

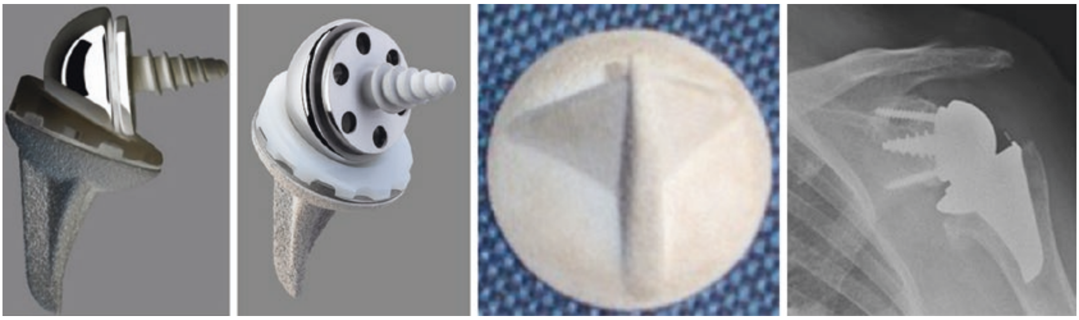
12.2 Types of Stemless RTSA

There are now a number of stemless anatomic prostheses available in the market. Stemless implants have been available since 2004 in Europe and since 2007 in Canada. In the USA, the Simpliciti (Wright Medical, formerly Tornier) arthroplasty was the first stemless implant to be approved by the US Food and Drug Administration (FDA) in March 2015, following promising 2-year follow-up results [44]. However, the FDA has not yet approved any stemless reverse implants.

The first stemless RTSA was the Verso, which was introduced for clinical use in 2005. This was followed, later in the same year, by the TESS reverse shoulder. Outside of the USA, stemless RTSA implants in use are the Verso and TESS since 2005, the Nano since 2012 and the SMR stemless since 2015. Each of these implants is discussed in more detail below.

12.2.1 Verso

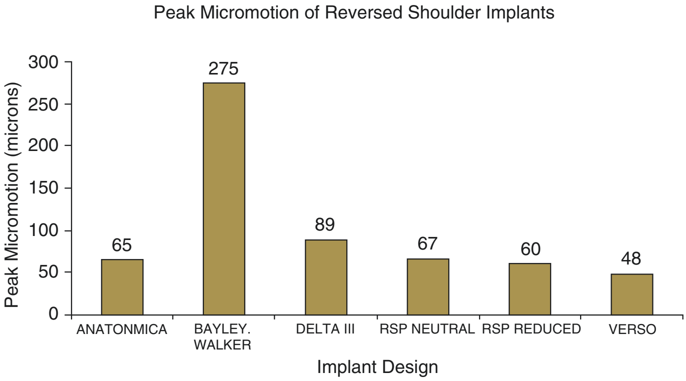
The Verso (Innovative Design Orthopaedics, London, UK; formerly Biomet, Swindon, UK) has been implanted in Europe since 2005.



The Verso stemless or short metaphyseal RTSA (Images provided by Prof. Ofer Levy)

The Verso is designed purely as a RTSA. It is not a platform convertible system and therefore avoids concerns regarding additional modularity and resultant fretting, metallosis and implant breakage [11]. The Verso has a short metaphyseal humeral implant with three thin tapered fins. These are designed for impaction into the humeral metaphysis to provide immediate press-fit fixation. The implant relies on fixation in the metaphyseal cancellous bone, without the need for cortical bone fixation. Consequently, this allows for use of the Verso in the vast majority of patients. Using bone graft impaction, even those with severe osteoporosis or bone cysts can be treated with the Verso. The fins have a titanium porous and hydroxyapatite coating to allow bony ingrowth and improve the biologic fixation of the implant. The glenoid baseplate has a central tapered screw which is also hydroxyapatite-coated titanium. Two anti-rotation screws are used superiorly and inferiorly. The glenoid sphere is fixed to the baseplate with a Morse taper. Polyethylene humeral liners have a 10° inclination shape which provides a very low profile medially, thereby reducing impingement between the polyethylene liner and the glenoid neck and thus reducing the risk of scapula notching and promoting improved rotational movement. The humeral cut is performed at an angle of 155°. The inclined liner results in a final implant angle of 145°. A unique feature of the Verso implant is the ability to 'dial' the humeral liner so that the version and offset of the liner can be changed. This means that the implant can be adapted for each patient, even when the final metal implants have been implanted. For example, if a test of the final prosthesis revealed good internal rotation, but poor external rotation, then the liner can be 'dialled' to achieve more equal rotations.

An independent biomechanical study from Imperial College London compared six different RTSA glenoid components with micromotion set to 50 μm [45]. The six implants were the Verso, the Delta III (DePuy), the Anatomical (Zimmer), the Bayley-Walker (Stanmore), the RSP-reduced (Encore) and the RSP-neutral (Encore). Stability is required to encourage bone ingrowth and long-term survival of the implant. They found that the Verso was the most stable implant. Peak micromotion at the implant-bone interface was lowest for the Verso.



Peak micromotion seen in six different RTSA implants (Reproduced from original article by Hopkins and Hansen [45])

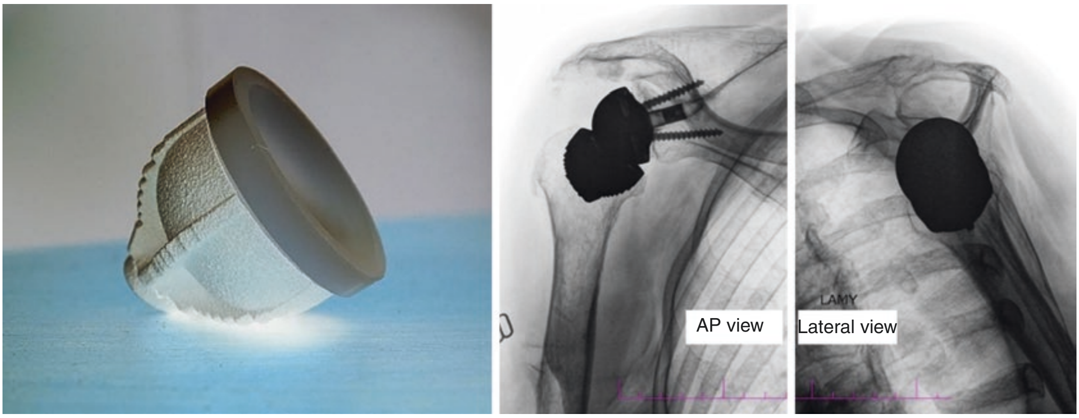
A series of 102 patients treated with the stemless Verso RTSA reported by Levy et al. [18] achieved good outcomes. Indications for surgery included 65 cases of cuff tear arthropathy, 13 cases of rheumatoid arthritis and 12 fracture sequelae. Seventeen cases were revisions. No patients were excluded on grounds of poor bone quality. All patients had a minimum follow-up of 2 years (range 2–7 years). Constant score improved from 14 preoperatively to 59 (age and sex adjusted 86) postoperatively. Mean postoperative movements were 129° of forward flexion, 51° of external rotation and 65° of internal rotation. This unusually good rotation may reflect the ability to 'dial' the liner. At the last follow-up, 96.9% of patients reported either no pain or mild pain. Patient satisfaction (subjective shoulder value) improved from 8, to 85 out of 100. Surgical complications were two cracks of the metaphysis and one crack of the glenoid rim during implantation. All three healed without further treatment, achieving good final Constant scores. Two early postoperative dislocations occurred. One patient dislocated by extending his shoulder and pushing himself out of a chair 1 week after surgery, and one patient had an osteophyte which hinged the liner to dislocate. Both were reoperated and recovered well, achieving good outcomes. There was also one disengagement of the glenoid head from the baseplate which was caused intraoperatively by unnoticed soft tissue interposition between the baseplate and the glenosphere. After removal of the interposed tissue, the patient made a good recovery. Other postoperative complications were two acromial fractures and six late traumatic periprosthetic fractures. The metaphyseal periprosthetic fractures healed well without requiring surgery. One late fracture involving the diaphysis was revised to a stemmed Verso prosthesis. Glenoid notching was present in 21 patients: 18 grade I–II notching and 3 grade III. There were no signs of lucency, subsidence or stress shielding during the 2–7-year follow-up period. The authors concluded that this stemless metaphyseal design provided encouraging short to mid-term results associated with excellent pain relief and function, restoration of movement and high levels of patient satisfaction.

Atoun et al. [31] reported a series of 31 patients treated with the Verso stemless RTSA and followed up for a mean of 36 months (range 24–52 months). Outcome assessments were performed by an independent observer. Constant score improved significantly from 12.7 preoperatively to 56.2 postoperatively (age and sex adjusted 80.2). Similarly, satisfaction improved from 2.4/10 to 8.5/10. Mean postoperative range of movement was 128.5° of forward flexion, 116.5° of abduction, 50.8° of external rotation and 64.6° of internal rotation. Two early dislocations required further surgery, one for reorientation of the liner and one for resection of an inferior osteophyte. There were two cases of grade I–II notching. No loosening, radiographic lucencies or subsidence occurred. Surgical complications were three minor intraoperative cracks which did not require treatment, did not affect the operation and healed without affecting the results. Two cracks occurred in the humeral metaphysis and one in the glenoid. These cracks were considered by the authors to represent part of their learning curve. Five late periprosthetic fractures were sustained after falls. Four of these healed without surgery and resulted in good outcomes. One fracture involving the diaphysis was revised to a stemmed implant. The authors concluded that the clinical and radiographic results of this bone-preserving metaphyseal RTSA implant were encouraging.

Levy et al. [43] also reported a series of 19 patients who received staged bilateral stemless Verso RTSA. Some studies have reported reduced active rotational movement following RTSA [46–48]. Good rotation is essential for activities of daily living (ADL) such as perineal and self-hygiene, eating, drinking and combing hair [49]. This paper aimed to assess whether patients with bilateral stemless RTSA were compromised in ADL, with particular regard to lack of rotation. Mean follow-up was 48 months (range 24–75 months). Constant score improved from 18.7 preoperatively to 65.1 postoperatively. Internal rotation improved from 9° to 81°, and external rotation improved from 20° to 32° with the arm in adduction by the side of the body. Thirty-one shoulders had full external rotation in elevation. Mean postoperative patient-reported ADLEIR (Activities of Daily Living External and Internal Rotations) score was 33 out of 36 points. The authors concluded that bilateral stemless RTSA provided predictably good functional outcomes, including rotations, and that most patients had no postoperative limitation in ADL or leisure activities.

12.2.2 TESS—Total Evolutive Shoulder System (Biomet, Warsaw, IN, USA)

The TESS reverse was introduced in France in 2005. The system has both a stemmed and a stemless metaphyseal fixed humeral implant. The stemless humeral implant is a cup made from cobalt-chrome. The implant has a titanium plasma spray and a hydroxyapatite coating for bone ingrowth. The cup is impacted into the humeral metaphysis and is designed for use with a humeral cut of 150°. There are six anti-rotation wings on the undersurface of the humeral implant. A polyethylene liner clips into the cup and is held in place by a metal ring. The glenoid baseplate is fixed with four screws. The glenosphere is also made of cobalt-chrome and screws onto the glenoid baseplate.



The humeral component of the TESS RTSA and X-rays of the TESS in situ (Reproduced with kind permission of Elsevier)

Tiessier et al. [50] performed 91 TESS stemless RTSA for patients with cuff tear arthropathy or massive cuff tears. All patients had a minimum follow-up of 2 years. Mean follow-up was 41 months (range 24–69 months). Constant score improved from 40 to 68. Mean postoperative forward flexion was 143° and external rotation was 39°. No loosening occurred. However, the authors did not report on the presence or absence of subsidence or lucencies. Nineteen per cent of cases had grade I–II notching. No intraoperative complications occurred. Postoperative complications were one stress fracture of the scapular spine, one fall resulting in a traumatic clavicle fracture and one case of recurrent dislocation requiring revision to a larger polyethylene spacer. Overall, 96% of patients rated their satisfaction as good or excellent. The authors concluded that stemless TESS RTSA is reliable, less invasive than stemmed implants and produces favourable mid-term outcomes with a low rate of complications.

Ballas and Beguin [51] reported 56 patients treated with the TESS RTSA. Most patients had cuff tear arthropathy or massive cuff tears. Mean follow-up was 58 months (range 38–95 months). Constant score improved from 29 to 62, and Oxford Shoulder Score improved from 46 to 17. Range of movement also improved, achieving a mean postoperative forward flexion of 140° and external rotation of 45°. There were no cases of subsidence or implant loosening. One patient had osteolysis of the greater tuberosity. Five patients had stage I notching which appeared at 1 year postoperatively and were non-progressive at the last follow-up. One partial intraoperative crack of the metaphysis occurred but did not require any treatment. Other postoperative complications were one superficial infection, one subscapularis tendon rupture, one stress fracture of the acromion and one haematoma evacuation. Three patients were subsequently revised to a stemmed reverse prosthesis. The authors reported that at revision, the primary stemless implants were easily removable, without damage to the remaining bone stock, and allowed implantation of a stemmed implant in the same orientation as a primary stemmed reverse arthroplasty. They concluded that at almost 5 years of follow-up, stemless RTSA clinical and radiological outcome results were comparable to stemmed implants, whilst avoiding the problems associated with a stem.

Moroder et al. [15] compared 24 patients treated with stemless TESS RTSA with 24 matched patients who received stemmed RTSA with the DELTA XTEND (DePuy Synthes, Warsaw, IN, USA). Patients were matched for age, sex and length of follow-up. All patients had a diagnosis of cuff tear arthropathy. Stemless implants were chosen for patients with an intact cortical ring after osteotomy, no visible cysts at the osteotomy site and when the trabeculae at the osteotomy site were judged to produce sufficient resistance to pressure applied by the surgeon's thumb. After a mean follow-up of 35 months (range 24–75 months), there were no differences in Constant score, pain, satisfaction, strength or range of movement. There was a trend towards better internal rotation in the stemless group. Complications in the stemless group were one traumatic dislocation after a fall downstairs, one acromial fracture which did not require treatment and two cases of grade I notching. In the stemmed group, there were five cases of grade I notching and four cases of grade II notching. This increased notching with the stemmed implant is likely to reflect the shallower inclination angle of the humeral implant in the stemmed group (155° rather than 135° for the stemless TESS). The stemmed group also had two patients requiring postoperative blood transfusion and two postoperative wound haematomas. No transfusions or haematomas occurred in the stemless group. Other stemmed complications were one transient paraesthesia and one case of inlay snapping which was treated with inlay exchange. Surgical time in the stemless group was significantly shorter, at 80.5 min compared to 109.5 min for stemmed implants. No loosening occurred in either group. Two stemless implants had signs of lucency on postoperative X-rays. However, lucencies were more common in the stemmed group, with 29% of stemmed implants affected. All stemmed implant lucencies were in the metaphysis and hence likely to represent stress shielding. The authors concluded that at short- to medium-term follow-up, stemless TESS RTSA implants were not inferior to traditional stemmed implants in patients with good bone quality. Only 18.4% of their patients were deemed to have sufficient bone quality for the TESS stemless RTSA. Consequently, more than 80% of their patients still had to be treated with a stemmed implant.

Von Engelhardt et al. [52] reported a series of 67 TESS RTSA, including 56 stemless implants. Mean follow-up was 17.5 months. Overall, normalized Constant score improved from 11.3 to 78.8. One stemmed patient had loosening of the humeral implant. Conversely, no patients in the stemless group developed loosening. They concluded that stemless implants were able to achieve good clinical outcomes.

Kadum et al. [53] also reported a series of 40 TESS RTSA, including 16 stemless implants. Follow-up ranged from 15 to 66 months. Both stemmed and stemless implants produced improved functional outcomes, improved quality of life and reduced pain. QuickDASH improved from 67 to 29 in stemless cases and from 56 to 35 in stemmed cases. Postoperative forward flexion and abduction were both 110° in the stemless group, compared to 90° in the stemmed group. One stemmed patient developed resorption of the proximal humerus. In contrast, no humeral loosening occurred in the stemless group. However, 2 of the 16 stemless implants were revised within the first postoperative week for corolla displacement. This complication would appear to be implant specific, and it is possible that greater experience and familiarity with the implant might help to avoid this scenario. Overall, the authors concluded that RTSA with a stemless TESS implant is reliable if bone quality is adequate.

12.2.3 Nano

The Nano (Biomet, Warsaw, IN, USA) was launched in Europe in 2012. It is the second generation of stemless implants from Biomet. Its design was based on the TESS stemless prosthesis. The Nano is a stemless convertible platform system which can be used in both anatomic and reverse configurations. The humeral implant is impacted into metaphyseal bone. The Nano has a female Morse taper which locks into the male Morse taper on the head implant. A literature search did not reveal any published case series using the Nano prosthesis. There is a single case report by Giannotti et al. [54] who used the reverse configuration of the Nano to treat a 65-year-old woman with Parkinson's disease and cuff tear arthropathy. At 3 months of follow-up, her X-ray showed a well-positioned prosthesis, and she reported reduced pain. However, in 2014 a safety alert warning was issued by Biomet, reporting that the Nano should not be used in cases of poor bone quality or bone cysts [55].

X-ray of Nano RTSA 3 months postoperatively (Reproduced from the free full text PubMed Central original article by Giannotti et al. [54])

12.2.4 SMR—Shoulder Modular Replacement Stemless Reverse

The SMR stemless (Lima, Udine, Italy) shoulder system was released in 2015. It is a convertible platform system. In reverse configuration the implant consists of a humeral core and a reverse liner. The humeral core is made from trabecular titanium and is designed for impaction, followed by later bone ingrowth. A cobalt-chrome metallic reverse liner is then impacted into the humeral core. This liner articulates with an all-polyethylene glenosphere. All reports in the literature for the SMR system relate to the stemmed version of the implant. No studies were available for the stemless implant in either anatomic or reverse configuration.

12.3 Summary

Promising short to mid-term clinical and radiological results of stemless RTSA have been achieved. However, there are significant design differences between the stemless options and caution needs to be employed as we cannot assume that the results of one implant will be the same as results from a different implant. It is important to continue monitoring the individual implant outcomes, and reporting them in the literature, to build up a robust series of evidence upon which to base future implant choices.

The potential advantages of stemless implants are clear. Stemless RTSA is bone-preserving and is associated with shorter operative time, less blood loss, ease of revision and the potential to reduce stem-related complications such as periprosthetic fractures and stress shielding.

It is important to plan not only for the success of an individual operation but also for the patient's life journey. Stemless RTSA keeps more options available for the future. If the long-term outcomes continue to be favourable, then it is likely that the future of RTSA will be stemless!

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13

Massive, Irreparable Rotator Cuff Tears Treated with an Arthroscopic-Assisted Latissimus Dorsi Tendon Transfer: Indications, Surgical Technique, and Outcomes

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The term irreparable rotator cuff tear (RCT) is commonly and often inaccurately used interchangeably with the term massive RCT. Indeed, not all massive RCTs are irreparable and terminology should be used with care when describing both types of lesion. Massive RCTs are defined as lesions with a diameter of >5 cm [1, 2] or with the involvement of two or more rotator cuff tendons [3, 4]. Different criteria should be used for defining irreparable tears such as tendon retraction, fatty infiltration, and atrophy of the muscle belly [5]. Once a massive and irreparable RCT is identified, it can be further classified as postero-superior if it involves the supraspinatus (SSP), infraspinatus (ISP), and possibly teres minor (TM) or antero-superior if it involves the subscapularis (SSC) and SSP [6, 7].

13.1 Epidemiology

Massive posterosuperior RCTs may account up to approximately 40% of the repaired rotator cuff [8] and irreparable posterosuperior RCTs have been reported as frequent as 7–10% in the general population [9]. Irreparable RCTs can occur in two physiologically distinct patient groups: [1] patients older than 70 years of age (usually females and less active) and [2] patients in the fifth/sixth decade of life (usually men and higher-demand), with a history of previous rotator cuff repair, chronic rotator cuff injury, or with symptoms of pain and disability after an acute event [6].

13.2 Diagnosis

A massive, irreparable RCT can be assessed with the following tests: the SSP is assessed with thumb-down abduction in the scapular plane; the ISP is assessed by measuring external rotation (ER) strength with the arm in adduction; the TM is assessed by evaluating ER strength with the arm in 90° of abduction; and the integrity of the SSC is evaluated using the lift-off and bear-hug tests [7]. Atrophy of the SSP and ISP fossae can denote chronic involvement and a diminished likelihood of repairability. Positive drop arm and ER lag tests are typical findings [10]. Moreover, a massive posterosuperior RCT should be defined reparable or irreparable according to the possibility of reducing the tendon to its footprint after intraoperative mobilization and release [11].

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Imaging plays a pivotal role in the decision-making process. Standard shoulder radiographs (a true anterior-posterior view in ER [Grashey view] [12], an anterior-posterior view in internal rotation, and an axillary view) should always be obtained to determine glenohumeral joint pathology. An important radiographic parameter that may be used to determine whether an RCT is repairable or not is represented by acromiohumeral (AH) distance, with an AH distance of <7 mm (i.e., superior migration of the humeral head) being associated with decreased likelihood of reparability [13]. Moreover, it is important to distinguish between static and dynamic humeral head migration with static migration considered to be a worse prognostic factor than dynamic migration [7]. Diagnostic criteria, usually confirmed by computed tomography (CT) or MRI findings, include stage 3 tendon retraction (according to Patte [14]: stage 1, tear with minimal retraction; stage 2, tear retracted medial to the humeral head footprint but not to the glenoid; stage 3, tear retracted to the level of the glenoid), stage 3 or 4 fatty infiltration (according to Fuchs and Goutallier [15, 16]: stage 0, normal muscle; stage 1, muscle with some fatty streaks; stage 2, fatty infiltration is important, but there is still more muscle than fat; stage 3, as much fat as muscle; stage 4, more fat than muscle), and stage 3 muscle atrophy (according to Thomazeau [17]: stage 1, normal or slight atrophy; stage 2, moderate atrophy; stage 3, severe atrophy).

13.3 Treatment Options

Massive, irreparable RCTs pose a difficult problem for surgeons, especially in young high-demand patients [18]. Massive RCTs may result in pseudoparalysis of the shoulder, with an inability to elevate the arm because of loss of restraint of the humeral head [19]. If left unchecked, the high-riding humeral head and associated abnormal loading of the joint surfaces lead to arthritis of the shoulder joint known as "rotator cuff arthropathy."

When patients fail to respond to nonsurgical measures, surgical treatment should be considered and several techniques have been proposed such as rotator cuff debridement [20–22], biceps tenotomy/tenodesis [23, 24], tuberoplasty [25–27], partial rotator cuff repair [28–31], rotator cuff grafting [32–35], latissimus dorsi tendon transfer (LDTT) [5, 36–46], and reverse total shoulder arthroplasty (RTSA) [47, 48].

Nevertheless, most of these procedures, such as rotator cuff debridement and biceps tenotomy or tenodesis, represent only a symptomatic approach that may be performed in older patients. Tuberoplasty, with or without rotator cuff debridement, and biceps tenotomy are reliable treatments for massive RCTs but are best performed in elderly patients (62, 63, and 69 years, in the available case series) [25–27]. Recontouring of the tuberosities is far from an attempt to restore at least in part the native function of the rotator cuff, as in the case of LDTT. Moreover, few data [25–27] on the results of this procedure for the treatment of irreparable RCTs are available in the current literature (more data are available for the use of this technique to treat fractures or malunions of the greater tuberosity). In addition, evaluating the role of this surgical procedure alone is difficult, because in the published series [25–27], it has been variably associated with other procedures, such as biceps tenotomy or acromioplasty.

Partial rotator cuff repair was originally conceived by Burkhart et al. in 1994 [28] as an open repair of the inferior half of the ISP to create a balanced force couple. In fact, the shoulder has a stable fulcrum of motion when it maintains a balanced force couple (SSC/ISP tendons) in the transverse plane. When this force couple is disrupted by a massive RCT, the shoulder's active motion is impaired. If rotator cuff repair restores the anterior and posterior forces, function will be restored too, even in the presence of a persistent defect in the superior rotator cuff (i.e., SSP tendon) [49]. When there is an irreparable SSP but there is still the possibility to repair the ISP and SSC, the arthroscopic partial cuff repair should be considered as an effective surgical option [31].

During the 1980s, allografts and xenografts using extracellular matrix (ECM) were studied for augmenting the healing of rotator cuff repairs, but their use decreased because of a lack of clinical success [32]. However, several studies have been published in the last decades to demonstrate the biomechanical, histological, and clinical effectiveness of different classes of augmentation devices [32–35]. Currently, the most common method for enhancing the healing of rotator cuff repair biologically is the use natural extracellular matrices (ECMs). Most ECMs are collagen-rich and of small intestine submucosal (SIS), dermal, or pericardial origin [32].

Numerous tendon transfers have been described according the etiology of cuff rupture. Currently, the most commonly used transfers for irreparable RCTs include the LDTT and the pectoralis major (PM) transfer. The goal of tendon transfer is to restore the force couples in the shoulder [7]. With LDTT, the goal is to exert an ER force that allows for a more balanced state in the glenohumeral joint and restore humeral head depression. In effect, it essentially replaces the function of the posterior force couple. The goal of PM transfer is to exert an IR centering force, thereby replacing the function of the SSC. This is intended to function as the anterior force couple.

LDTTs were first described in patients with brachial plexopathies that caused lack of ER. This procedure was originally applied by Gerber et al. [50] to improve shoulder ER in the management of irreparable posterosuperior RCTs with a two-incision open technique. This procedure has been shown to decrease pain, improve outcomes, and increase range of motion in patients with irreparable MRCTs and without glenohumeral osteoarthritis [39]. Accordingly, satisfactory long-term outcomes of this open procedure have been widely reported [51, 52]. With the main advantage of avoiding any major deltoid damage, an arthroscopic-assisted modification of this surgical procedure has been developed [40]. Indeed, it has been clarified that, as injured, the deltoid is unable to regain preexisting strength after an open LDTT.

Currently, RTSA is advocated for patients with [53–55] and without [48, 56] glenohumeral arthritis, with pseudoparalysis of anterior elevation, in the presence of an irreparable posterosuperior RCT. However, there are concerns regarding the longevity of RTSA and limited possibilities for salvage after implant failure. As a result, RTSA is usually not used in young and active patients, and it is usually reserved for patients above 65 years of age.

If arthroscopic partial repair is not possible, our preference for the treatment of younger patients with massive, irreparable RCTs without arthropathy is an arthroscopic-assisted LDTT [37, 38]. The SSC tendon should be intact and functioning, as forward elevation drastically decreases with insufficiency [39, 51, 57]. Additionally, glenohumeral stability increases with an intact SSC in the setting of an LDTT [58]. Supplemental shoulder movement is essential (specifically, passive forward flexion and abduction ≥80°) [59]. A pseudoparalytic shoulder has been demonstrated to correlate with poor outcomes [60]. Axillary nerve lesions and deltoid insufficiencies are contraindications.

Reports of massive posterosuperior rotator cuff repair failures range from 21 to 91% [61–63] and revision failure rates are significantly higher [64]. Recurrent tears typically occur within the first 6 months following primary fixation [65, 66]. Symptoms of retear at 2 years include impaired overhead function, increased pain, limited passive movement, loss of strength, and lower overall satisfaction with shoulder function [64]. Complications also arise when performing revision rotator cuff repairs [67].

The patient cannot have radiographic evidence of glenohumeral arthritis and limited, Hamada stage 1 or 2, rotator cuff arthropathy (according to Hamada [51]: stage 1, AH distance greater than 6 mm; stage 2, AH distance equal or less to 6 mm; stage 3, acetabulization defined as a concave deformity of the acromion under the surface; stage 4, narrowing of the glenohumeral joint; stage 5, humeral head collapse which is characteristic of the cuff tear arthropathy). The irreparable SSP and ISP tendons are typically torn with retraction to the level of the glenoid (Patte stage 3), with fatty infiltration Goutallier stage 3 and/or significant atrophy [14–17, 68]. SSC tears with stage 3 or higher Goutallier atrophy [15, 16] and/or ≥50% tear of the upper border should also be excluded [51]. Atrophy of the

TM assessed preoperatively by MRI was performed by several authors [69–71]. It was concluded that fatty infiltration of Goutallier stage 3 or higher was associated with worse postoperative outcomes and decreased active ER.

13.4 Surgical Anatomy

The latissimus dorsi muscle extends, adducts, and internally rotates the humerus. The main blood supply to the latissimus dorsi muscle is provided by the thoracodorsal artery, and this muscle is innervated by the thoracodorsal nerve (C6, C7), which arises from the posterior cord of the brachial plexus [72]. The latissimus dorsi has a 33.9 cm potential excursion after detachment off its humeral insertion [73]. The LDT always inserts anterior to the teres major insertion, approximately 7 mm lateral [74]. In most cadaver specimens, the LDT overlaps the superior 39% of the teres major tendon [74]. The axillary nerve always lies superior to the LDT. The distance between the axillary nerve and tendon is greatest in ER and shortest in internal rotation [74]. The transferred latissimus dorsi tendon always passes medial to the axillary nerve. The radial nerve is always medial to the coracobrachialis and anterior to the LDT. In one study, the distance between the radial nerve and LDT was greatest in ER and shortest in internal rotation [74].

13.5 Surgical Technique

Patients receive general anesthesia with an interscalene block and are placed in the standard lateral decubitus position with the arm under longitudinal traction for routine arthroscopy (Fig. 13.1). An armrest is used to allow the switch to open surgery, with the shoulder in 90° of abduction to enable internal rotation and facilitate LDT harvesting. The initial diagnostic arthroscopy is performed through standard posterior and lateral portals. After confirming the indication for LDTT (Fig. 13.2), a motorized burr is used to create a bleeding bone bed on the greater tuberosity.

Fig. 13.1 Intraoperative view of the patient in the standard lateral decubitus position with the left arm on the arm rest

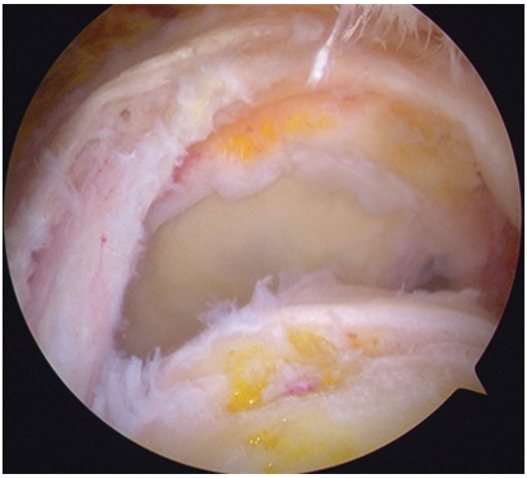

Fig. 13.2 Intra-articular view from the lateral portal shows a massive and irreparable rupture of the posterosuperior rotator cuff

The traction is then removed, and the arm is placed in abduction with the elbow flexed to 90°. A 6-cm to 8-cm curved incision is made in the axilla anterior to the posterior axillary pillar, along the LDT (Fig. 13.3). The LD muscle and its tendinous insertion on the proximal humeral shaft are identified, and with the arm held in internal rotation, the tendon is detached and stitched with

Fig. 13.3 A 6-cm to 8-cm curved incision is made in the axilla anterior to the posterior axillary pillar, along the latissimus dorsi tendon

Fig. 13.4 The tendon is detached and stitched with two nonabsorbable sutures (#2–0)

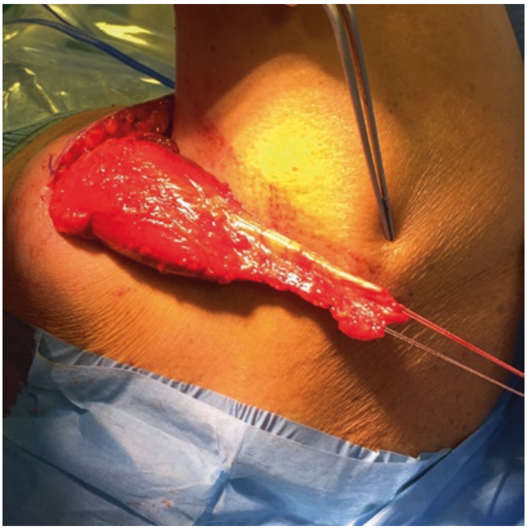

Fig. 13.5 The tendon's final length is evaluated by passing it over the acromion with the arm held in adduction. Forceps pointing to the posterolateral corner of the acromion

2–0 nonabsorbable sutures (Fig. 13.4). The neurovascular bundle (i.e., thoracodorsal nerve, vein, and artery) is identified, and the tendon's final length is evaluated by passing it over the acromion with the arm held in adduction (the tendon should pass at least 2 cm over the posterior border of the acromion) (Fig. 13.5). The teres major muscle is mobilized anteriorly to identify the interval between the deltoid and triceps tendon (Fig. 13.6). At this stage, the arthroscopic procedure is resumed. The arthroscope is introduced into the subacromial space through the lateral portal to identify the axillary nerve and the interval between the deltoid and the residual posterior rotator cuff. A Wissinger rod is inserted through the posterior portal, passed through the deltoid and the teres minor, and up to the space between the deltoid and the previously identified triceps. A Hegar dilator, modified by two holes at the blunt end, is slid over the rod from distal to proximal (Fig. 13.7). The sutures are passed through the dilator, pulling the LDT into the subacromial space. The threads are retrieved from the anterior portal and fixed to the greater tuberosity by two knotless anchors (Fig. 13.8). The first anchor is placed lateral to the articular cartilage and close to the superior border of the SSC. The second anchor is placed more laterally to place the tendon on the bleeding bone. The coverage of the footprint is then checked (Fig. 13.9). A suction drain is used in all cases.

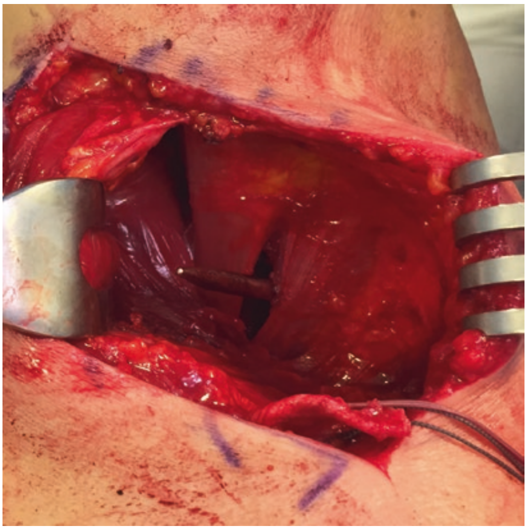

Fig. 13.6 Identification of the interval between the deltoid and triceps tendon

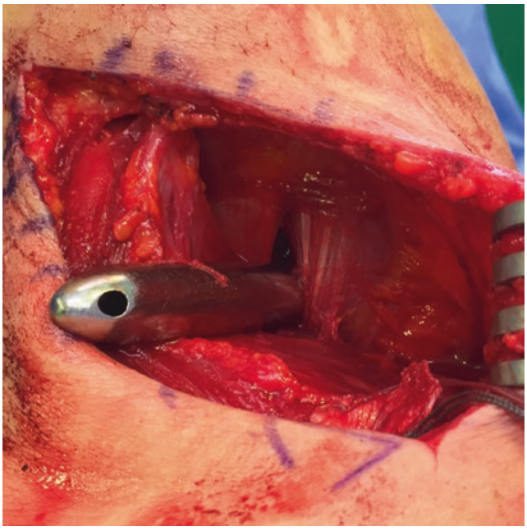

Fig. 13.7 A Hegar dilator, modified by two holes at the blunt end, is slid over the Wissinger rod from distal to proximal

13.6 Postoperative Protocol

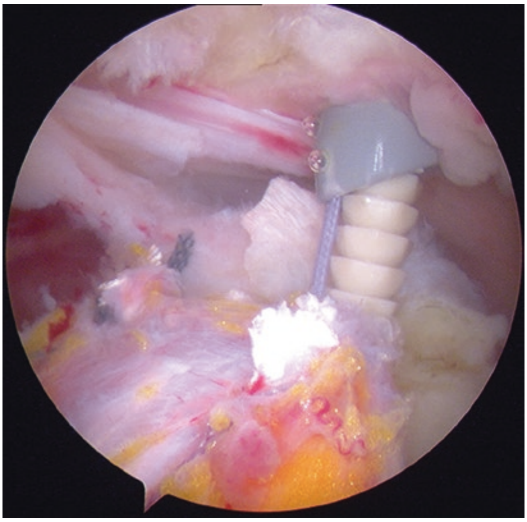

Fig. 13.8 Anchor placement

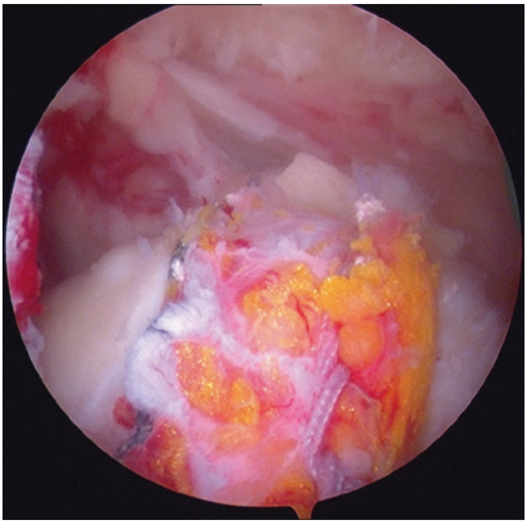

Fig. 13.9 The coverage of the footprint is checked

The arm is placed in a brace positioned in 15° of abduction and ER for 4 weeks. Passive forward flexion is started on the first postoperative day. The brace is discontinued after 4 weeks, and the patients undergo a physiotherapist-assisted rehabilitation program of passive and active mobilization and isometric strengthening exercises. After 8 weeks, isokinetic strengthening exercises are started.

13.7 Results

To the best of our knowledge, there are only five reports published on arthroscopic-assisted LDTT for irreparable RCTs [37, 38, 41, 43, 75]. Castricini et al. [38] reported on 27 patients with a mean age of 60 years (range, 46 to 67 years). The authors showed a significant improvement in the mean Constant and Murley score, pain score, muscle strength in forward elevation, and range of motion in ER ($P < 0.05$) at a mean follow-up of 27 months. The authors used a true anteroposterior radiograph to evaluate the grade of osteoarthritis in the shoulder pre- and postoperatively according to the Samilson and Prieto three-stage classification system [76]. They also assessed the proximal migration of the humeral head on true anteroposterior radiographs in neutral rotation, using a three-stage classification (stage 1, no proximal migration; stage 2, mild proximal migration; stage 3, severe proximal migration). The authors did not report significant osteoarthritis progression and proximal migration of the humeral head after surgery.

Grimberg et al. [41] evaluated the clinical (Constant and Murley score and subjective shoulder value), radiologic (acromiohumeral distance), and MRI (transferred tendon aspect) results of arthroscopic-assisted LDTT performed in 55 patients with a mean age at the time of surgery of 62 years (range, 31 to 75 years). The patients were evaluated at a mean follow-up of 29 months. The authors reported statistically significant improvement in Constant and Murley score, subjective shoulder value, and range of motion ($P < 0.001$) from preoperatively to postoperatively. The authors did not report any statistical difference in acromiohumeral distance and osteoarthritic stage between preoperative and final follow-up. However, four patients had a ruptured LDT on MRI at 1-year follow-up.

Paribelli et al. [75] compared clinical results in two groups of patients with irreparable RCTs treated surgically: one group (20 patients) received an arthroscopic-assisted LDTT and the other (20 patients) an arthroscopic partial rotator cuff repair. The patients were evaluated at a mean follow-up of 2.8 years (1–5, SD 3) using the following tools: University of California Los Angeles (UCLA) shoulder rating scale, range of motion, measurement of the strength, and the rotator cuff quality of life (RC-QOL) questionnaire. The authors reported statistically significant improvement ($P < 0.05$) in UCLA score results, strength, and RC-QOL questionnaire for patients treated with arthroscopic-assisted LDTT compared to patients treated with arthroscopic partial rotator cuff repair, with no differences found between groups for pain relief. One case of LDT rupture was reported (13 months after surgery) and the patient underwent a RTSA surgery.

Castricini et al. [37] evaluated the functional outcomes (Constant and Murley score) and checked for possible outcome predictors of arthroscopic-assisted LDTT in 86 patients (aged 59.8 ± 5.9 years). Of these, 14 patients (16.3%) sustained an irreparable, massive RCT after a failed arthroscopic rotator cuff repair. The patients were evaluated at a mean follow-up of 36.4 ± 9 months. The authors reported statistically significant improvement ($P < 0.001$) in Constant and Murley score at final follow-up. Patients with lower preoperative CMS and a history of failed rotator cuff repair have a greater likelihood of having a lower clinical result. Interestingly, gender and age did not affect the clinical outcomes.

Kanatli et al. [43] clinically (range of motion, UCLA, Constant and Murley score, and visual analog scale pain score) and radiologically (acromiohumeral distance) evaluated a modified technique for arthroscopic-assisted LDTT in 15 patients with irreparable RCTs and pseudoparalysis. The mean patient age was 61.53 ± 6.24 years (range, 52–71 years). The patients were evaluated at a mean follow-up of 26.4 ± 2.58 months (range, 24–31 months). The authors reported statistically significant improvement ($P < 0.001$) in UCLA, Constant and Murley score, visual analog scale pain score, active forward flexion, active abduction, and active ER. The authors reported a statistically significant difference in acromiohumeral distance from preoperatively (3.13 ± 1.40 mm) to postoperatively (5.67 ± 1.67 mm) ($P < 0.001$).

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14 Fundamentals in Shoulder Radiology

Ceylan Colak and Carl S. Winalski

14.1 Introduction

The prevalence of shoulder pain in the general population ranges from 16 to 26% [1, 2]. Shoulder pain has various causes, including rotator cuff disease, adhesive capsulitis or “frozen shoulder,” shoulder instability, calcific tendinosis, and osteoarthritis. Overall, rotator cuff disease is the most common cause of shoulder pain, responsible for approximately 65–70% of shoulder pain cases [3]; the prevalence of this condition increases with increasing patient age [4].

Shoulder pathologies can be treated conservatively or surgically, and imaging often helps to guide treatment planning. Common conservative treatments include physiotherapy, nonsteroidal anti-inflammatory drugs (NSAIDs), and therapeutic intra-articular injections. The most common surgical approaches are arthroscopy and open surgery. Imaging can help direct which approach is best in cases of surgery for cuff repair, labral repair, and shoulder arthroplasty (conventional total, reverse total shoulder, or hemiarthroplasty) [5]. When clinicians are determining the appropriate treatment course, preoperative evaluation with imaging is essential. This article reviews normal shoulder anatomy, shoulder pathologies, and the appearance of these conditions on commonly used imaging modalities.

14.2 Plain Radiography

Plain radiography of the shoulder is commonly performed as an initial imaging examination. This modality is useful for diagnosing fractures and dislocations in patients with acute trauma. For those with chronic or nontraumatic shoulder pain, radiography provides an overall assessment of joint status and some diagnoses including arthritis, degenerative changes, chronic cuff tear, and calcific tendinosis.

The standard radiographic shoulder series includes an anteroposterior (AP) projection (Fig. 14.1) with the arm internally and/or externally rotated and other views added to show the specific structures of the shoulder. The Y view is obtained by turning the patient 60° anteriorly and centering the posteroanterior (PA) X-ray beam on the shoulder. This view is usually ordered when a shoulder dislocation is suspected; the Y view is also helpful in identifying fractures of the scapular blade (Fig. 14.2). The axillary view allows for clear visualization of the relationship between the glenoid and the

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Fig. 14.1 AP view radiograph of a normal shoulder. Humeral head overlaps the lateral aspect of the glenoid. The glenohumeral joint space (arrow) can be estimated by measuring from the medial margin of the humeral head and medial margin of the glenoid (dotted lines)

Fig. 14.2 Y view radiograph of a normal shoulder. Humeral head overlaps the glenoid (Y) which is at the center of the “Y” formed by the junction of the scapular body (SB), spine (SS), and base of the coracoid (C)

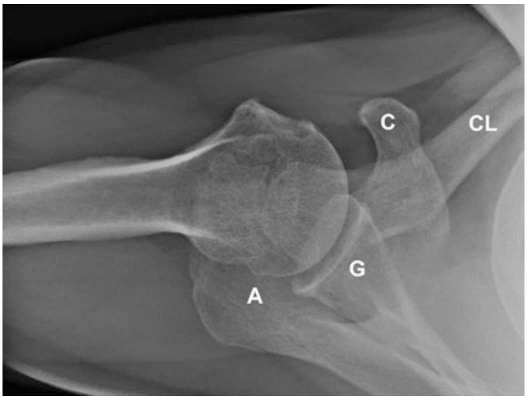

Fig. 14.3 Axillary view radiograph of a normal shoulder. The humeral head is centered on the glenoid (G). The coracoid (C) is anterior. The acromioclavicular joint projects over the humeral head (*A* acromion, *CL* clavicle)

humeral head (Fig. 14.3). This view is acquired with the patient supine, the arm positioned in 90° of abduction, and the X-ray beam centered on the middle of the axilla and angled approximately 30° toward the spine. The Grashey view is obtained by turning the patient 45° posteriorly and using an AP X-ray beam or angling the X-ray beam 45° laterally to the patient. This is a “true” AP view of the glenohumeral joint and is used to show the integrity of the glenohumeral joint without overlapping of the humerus and glenoid (Fig. 14.4). West Point and Velpeau views are variants of the axillary view that are useful in identifying anterior glenoid abnormalities (such as Bankart lesions and posterior dislocations). A West Point view is obtained with the patient prone, the shoulder propped up over the X-ray table, and the arm abducted 90° from the trunk while the hand is pronated; the X-ray beam is angled 25° medially and 25° cephalad. The Velpeau view is commonly used after acute trauma, as it does not require the patient to abduct the arm. The patient sits or stands leaning backward 30° while wearing a sling or Velpeau dressing, and the X-ray beam is directed through the shoulder superoinferiorly. Modified views may need to be obtained when the patient cannot move the arm, particularly in the context of trauma and severe pain.

Fig. 14.4 Grashey radiographic projection is a "true AP" view of the glenohumeral joint obtained with a 35–45° obliquity to show the joint space tangentially. The humeral head should not overlap the glenoid

The medial portion of the humeral head overlaps with the lateral aspect of the glenoid on AP shoulder radiographs, since the glenohumeral joint is anatomically 35–40° oblique to the coronal plane of the patient (Fig. 14.1). In some cases, the humeral head may project slightly lower or slightly higher than the center of the glenoid. Because the humerus is anterior to the glenoid, if the patient is tilted back when the image is taken, the humeral head may appear high relative to the glenoid, whereas if the patient is tilted forward, it may appear slightly low. The distance between the humeral head and acromion should be evaluated. If the humeral head is superiorly subluxed such that the acromiohumeral distance is less than 7 mm, a rotator cuff tear should be suspected. Because the Grashey view is a "true AP" projection of the glenohumeral joint, there should not be any overlap of the humeral head and glenoid on this view. Overlap of these structures on the Grashey view implies subluxation or dislocation of the humeral head. Finally, when reviewing shoulder radiographs, clinicians must also assess the clavicle, scapula, and ribs for fractures and other lesions, as well as the visualized portions of the lungs for any potential pathologies.

Plain radiography is used to diagnose many common shoulder pathologies, including fractures of the humerus, clavicle, and scapula. Proximal humerus fractures are the third most common type of fragility fracture, accounting for nearly 6% of all adult fractures [6, 7]. As the median age of the world's population increases, the incidence of this fracture type has also risen [8]. These fractures and fractures of the mid-humerus present few challenges in radiographic interpretation and thus do not usually require further examinations. These fractures present as a lucency and cortical disruption with variable degrees of angulation, impaction, and displacement on plain radiographs (Fig. 14.5). Determining the degrees of angulation and rotation of the fragments may require full-length images of the humerus that include the shoulder and elbow.

Most clavicular fractures are clinically apparent and occur in the midportion or the distal third of the clavicle. In addition, acromioclavicular (AC) joint separation, which is a common traumatic or sports injury, is easily assessed with radiography. The normal AC joint space usually measures <5 mm, and normal coracoclavicular distance is <11–13 mm. Widening of any of these spaces must be considered as a potential separation. AC joint separation is classified into six subgroups based primarily on the distal clavicular angle and degree of the displacement [9]. Some recommend obtaining additional radiographs while hanging weights from the patient's wrists and comparing these images with images of the unaffected side to detect nondisplaced AC joint injuries.

Fractures of the scapula are relatively rare, although they can occur as the result of a severe, direct blow [10]. Because the scapula is a thin bone, fractures of the body of the scapula may be difficult to appreciate. The Velpeau and West Point variants of the axillary view may be useful for evaluation of the scapular spine and acromion, especially for patients with reverse shoulder arthroplasties who are at risk for fracture (Fig. 14.6). When there is any uncertainly regarding the presence or type of fracture on radiography, a computed tomography (CT) scan may be useful.

Shoulder dislocations are readily diagnosed by radiography. Anterior dislocation of the humeral head accounts for more than 95% of shoulder dislocations. On the AP projection, the displaced humeral head will be inferiorly and

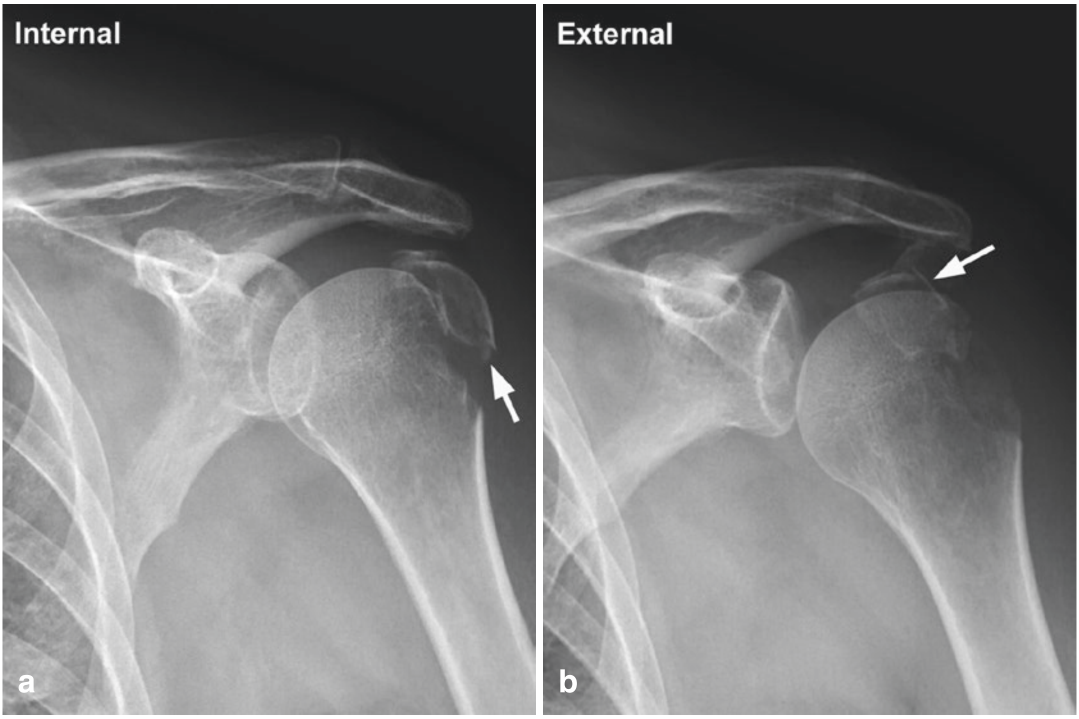

Fig. 14.5 AP radiographs obtained in internal rotation (**a**) and external rotation (**b**) show a displaced fracture of the posterior aspect of the greater tuberosity (arrow)

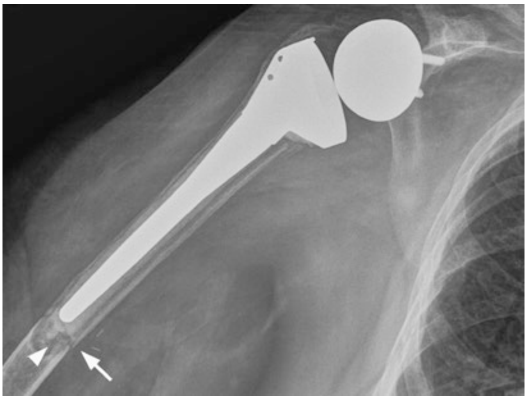

Fig. 14.6 Loosening and periprosthetic fracture following reverse total shoulder arthroplasty. There is lucency around the humeral component with focal osteolysis at the inferior tip (arrowhead). The fracture (arrow) is seen at the tip of the prosthesis

medially displaced, overlapping with the glenoid neck and lying inferior to the coracoid (Fig. 14.7). Impaction of the humeral head on the anterior-inferior edge of the glenoid produces a deformity in the posterolateral portion of the humeral head, the Hill-Sachs deformity, which is best seen on the AP view with the arm internally rotated after reduction of the dislocation. There is often an injury of the anterior inferior glenoid rim, as well; this injury, known as a Bankart lesion, may involve the labrum only or both the labrum and the underlying bone. When there is a bony component, the West Point or axillary view may be diagnostic. When only the soft tissue of the glenoid labrum is involved, magnetic resonance (MR) or CT arthrography will be needed for imaging diagnosis.

Posterior shoulder dislocations are uncommon and more difficult than anterior dislocations to diagnose on a standard AP view of the shoulder. On normal shoulder radiographs using the AP view, there is an overlap of the humeral head and the glenoid with a relatively narrow anterior glenohumeral joint space visible. Radiographs following posterior shoulder dislocation show widening of the glenohumeral joint space; additionally, the humeral head may not appear round because of extreme

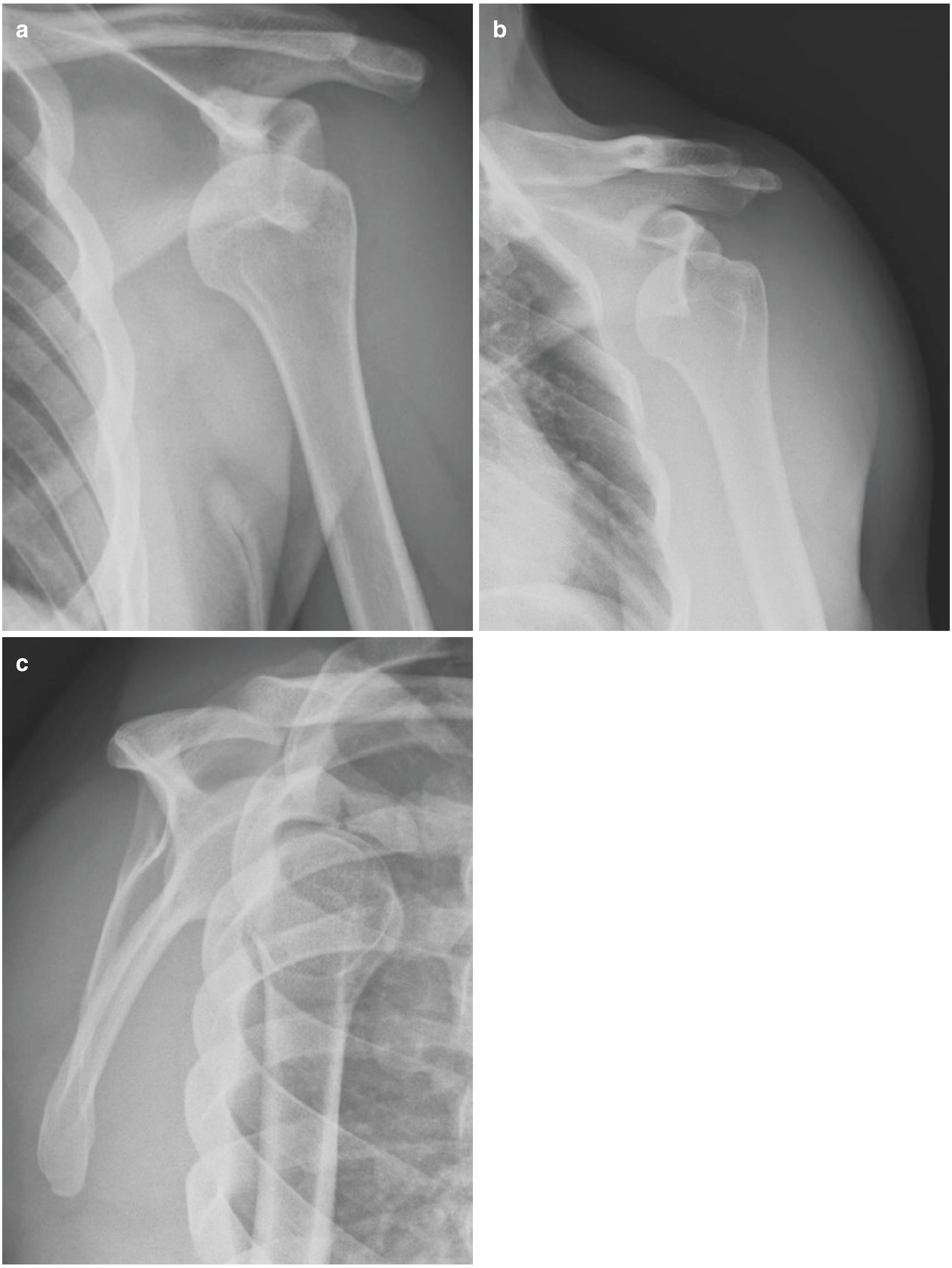

Fig. 14.7 Anterior subcoracoid dislocation. The humeral head overlaps the glenoid on AP (**a**) and Grashey views (**b**). The anterior displacement is well visualized on the Y (**c**) view

internal rotation. On the Grashey view, there will be an abnormal overlap of the humeral head and glenoid. The axillary and Y views will clearly show the posterior dislocation (Fig. 14.8).

Initial evaluation of shoulder arthritis is frequently performed with radiography. Degenerative or post-traumatic osteoarthritis in the shoulder, as with other joints, is frequently associated with osteophyte formation, subarticular sclerosis, subarticular cysts, and joint space narrowing. As the arthritis progresses, there can be loss of the bone stock of the glenoid with alteration of the version of the glenoid face. When planning for shoulder arthroplasty, evaluation of the glenoid version is critical for proper placement of the glenoid component; CT is often performed for this purpose.

Fig. 14.8 Posterior dislocation. Grashey (**a**) and AP internal rotation (**b**) and axillary (**c**) views show the humeral head is reduced, but mildly decentered posteriorly. There is a displaced glenoid fracture fragment (arrowhead) from the posterior articular margin of the glenoid

With septic arthritis of the shoulder, radiographs are typically normal in the early stages, although soft tissue swelling or inferior displacement of the humeral head due to effusion may be seen. With more chronic septic arthritis, radiographs may show decreased bone density, joint space narrowing, and bony destruction. When a septic joint is clinically suspected, joint aspiration should be considered.

Although radiography is not primarily performed for this purpose, radiographic images may be abnormal in the setting of rotator cuff disease. Calcific tendinosis of the rotator cuff (i.e., the deposition of calcific crystals such as hydroxyapatite within an abnormal tendon) can be readily diagnosed on plain radiographs. Typically, this condition presents as amorphous white densities at the greater tuberosity at the insertion of the affected tendon (Fig. 14.9). With large, retracted tears of rotator cuff tendons, the humeral head may migrate superiorly with resultant decentering of the humeral head on the glenoid, thus narrowing the distance between the humeral head and acromion (i.e., the acromiohumeral distance). With time, secondary glenohumeral osteoarthritis, also known as rotator cuff arthropathy, may develop (Fig. 14.10); this condition is suggestive of an irreparable rotator cuff [11].

Bone or soft tissue neoplasms of the shoulder may be initially evaluated or incidentally found on radiography. The proximal humerus is the third most common site for primary bone tumors and soft tissue tumors, with an incidence of approximately 1.8 in 100,000 [12–16]; it is also one of the most common sites of osteosarcoma in children [17]. As with other bone tumor sites, the degree of bone destruction and fracture risk in the shoulder can be estimated with radiographs. However, advanced imaging techniques should be used for further evaluation of potential bone destruction and for identification of soft tissue masses. When an incidental finding of a bone

Fig. 14.9 Calcific tendinosis. Grashey radiograph shows calcifications in the supraspinatus tendon insertion (arrow)

Fig. 14.10 Rotator cuff arthropathy. Grashey radiograph shows superior subluxation of the humeral head with severe narrowing of the subacromial space and remodeling of the inferior acromion indicating a chronic full-thickness rotator cuff tear. Osteophytes and intra-articular bodies indicate concomitant glenohumeral osteoarthritis

lesion (usually an enchondroma) is observed on radiographs, the images should be compared with results from previous imaging studies to determine the biological nature of the abnormality. When a benign lesion is suspected, follow-up radiography is indicated. If an aggressive lesion is suspected on radiographs, MR imaging should be considered.

Although this chapter focuses primarily on preoperative shoulder imaging, there are some important postoperative complications that can be readily evaluated on radiography. Plain radiography is routinely used after shoulder arthroplasty to evaluate implant positioning and baseline appearance for help with future assessment, should symptoms arise. Loosening of an arthroplasty component appears as progressively widening radiolucencies at the bone-implant or cement-bone interface, although plain radiography can sometimes underestimate radiolucent lines [18]. In such cases, CT offers improved sensitivity, especially when metal artifact reduction techniques are implemented. With an infected implant, periosteal reaction may be seen. Scapular notching after reverse total shoulder arthroplasty (i.e., erosion of the scapular neck from impaction of the humeral component) usually occurs within the first few months after surgery. The incidence of scapular notching ranges from 44 to 96% [19, 20], and this condition ranges from grade 1 to 4 in severity (with grade 4 potentially leading to glenosphere loosening) based on radiographic findings. The occurrence of scapular notching may require revision surgery. Therefore, radiographs demonstrating bone loss at the inferior scapular neck should be carefully assessed in patients who have undergone reverse total shoulder arthroplasty (Fig. 14.11). Heterotopic ossification in the triceps origin is common following reverse shoulder arthroplasty (Fig. 14.12). Heterotopic ossification usually does not progress after the initial postoperative period. It usually has no effect on functional movement of the shoulder and usually does not

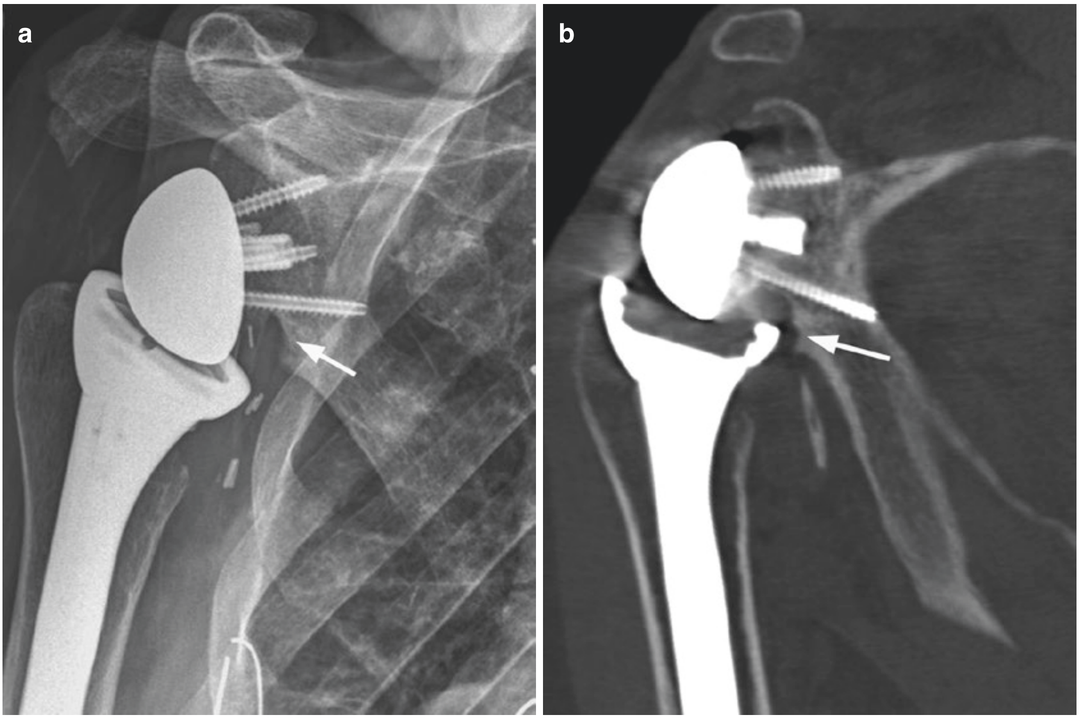

Fig. 14.11 Scapular notching following reverse total shoulder arthroplasty. Grashey radiograph (**a**) shows bone loss (arrow) from the inferior glenoid with exposure of the inferior screw of the glenosphere. The CT (**b**) of the same patient demonstrates the humeral component impacting on the glenoid causing the scapular notching (arrow)

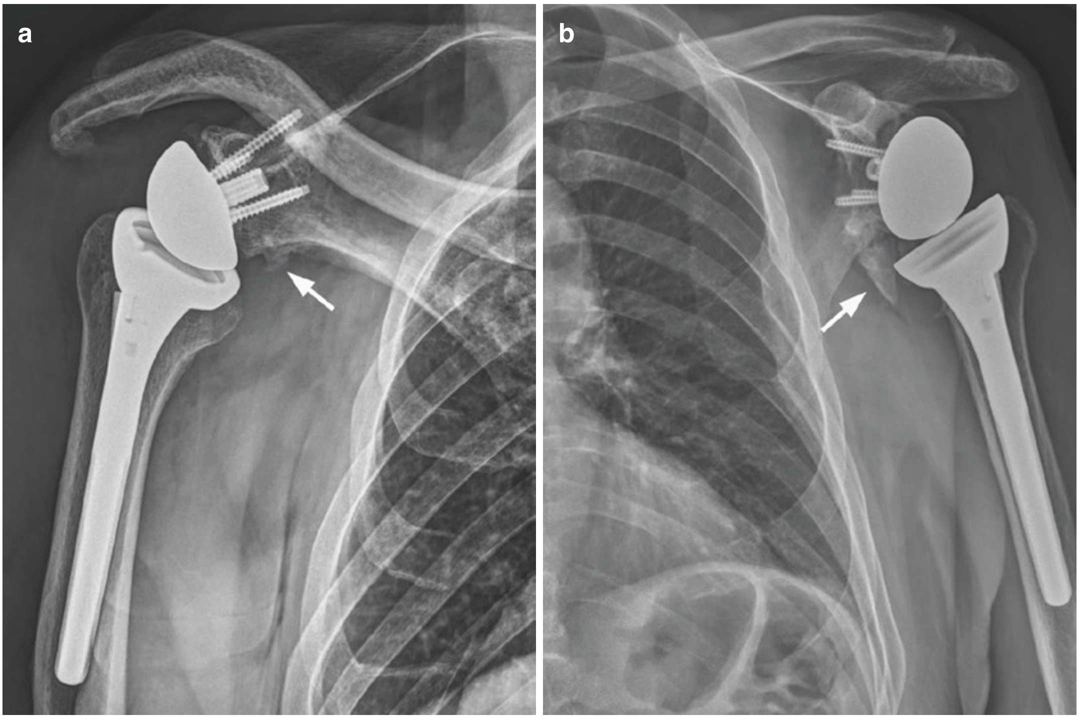

Fig. 14.12 Heterotopic ossifications in (**a**) and (**b**) following reverse total shoulder arthroplasty commonly develop within the triceps extending inferiorly from the scapular neck (arrows). The appearance of heterotopic calcification in (**a**) is differentiated from scapular notching since there is no glenoid bone loss

require treatment. This new bone can mimic scapular notching. However, notching will show loss of glenoid bone, whereas heterotopic ossification is added bone; in addition, notching and heterotopic ossification may coexist [21].

14.3 CT

CT is commonly used in orthopedic imaging to assess cortical bone, trabecular bone, and joint surfaces in patients with fractures, arthritis, shoulder instability, advanced rotator cuff disease, tumors, or infection; however, soft tissue abnormalities are less well visualized by CT than by MR imaging. Because CT is most often obtained with isotropic voxels, 2D multiplanar and 3D reformatted images can be readily created (Fig. 14.13). CT arthrography, which is obtained by injecting iodinated contrast into the shoulder joint before CT imaging is performed, can provide additional information about the articular cartilage, labrum, and rotator cuff. CT

Fig. 14.13 Subcoracoid dislocation. 3D surface rendering reformatted from a CT scan shows the humeral head beneath the coracoid and impacted on the anterior glenoid

arthrography is often used as an alternative for patients who are unable to undergo shoulder MR imaging. CT offers greater spatial resolution than MR imaging, whereas MR imaging offers higher image contrast for soft tissue abnormalities and can demonstrate edema-like signal in the bone marrow [22].

CT can be more effective than radiography in showing the spatial relationship of fracture fragments in complex fractures of the humerus and scapula [23] (Fig. 14.14). Often, radiography is limited in these cases by patient positioning and superimposition of the fracture fragments. Preoperative planning with CT before fracture reduction or in cases of unreducible or recurrent dislocation may be useful. One study of patients with shoulder instability found that preoperative identification and measurement of bony Bankart fragments of the glenoid and Hill-Sachs impaction of the humeral head can be difficult with radiography, leading to challenges in surgical decision-making [24]. Therefore, CT should be considered in the treatment algorithm for accurate quantification of bone loss to prevent a high rate of recurrent shoulder instability. As previously discussed, for patients with severe glenohumeral osteoarthritis, preoperative measurement of the glenoid version with CT is helpful for shoulder arthroplasty planning.

Fig. 14.14 Greater tuberosity fracture. 3D surface rendering reformatted from a CT scan (same patient as Fig. 14.5) demonstrates the displaced fracture (arrow) as well as the cortical defect in the superior lateral aspect of the greater tuberosity (asterisk)

14.4 MR Imaging

Improvements in system hardware and software have led to further reliance on MR imaging for evaluation of the shoulder [25]. This modality provides a thorough overview of both the osseous and soft tissue shoulder structures and has demonstrated a high level of diagnostic accuracy that is improved further with the addition of arthrography [26–28]. Therefore, physicians treating patients with shoulder pathologies must be familiar with shoulder MR imaging.

MR imaging of the shoulder is indicated for the assessment of a wide spectrum of disorders including suspected rotator cuff and biceps tendon tears, intra-articular pathology such as labral tears, articular cartilage defects and underlying bone abnormalities, tumors, and infections. However, the advantages of MR imaging must be weighed against the higher costs and sometimes limited availability of this modality.

14.4.1 Shoulder Anatomy on MR Imaging

The rotator cuff is composed of the tendons of four muscles: the supraspinatus, infraspinatus, subscapularis, and teres minor muscles (Fig. 14.15). The tendons of these muscles attach to the lesser and greater tuberosities of the humerus, with the subscapularis inserting on the lesser tuberosity and the other three tendons inserting on the greater tuberosity [29]. The supraspinatus tendon is best assessed by oblique coronal images that are aligned parallel to the supraspinatus muscle rather than oriented in the true coronal plane. The oblique coronal plane also provides excellent views of the superior and inferior portions of the glenoid labrum as well as the quadrangular and triangular spaces. Oblique

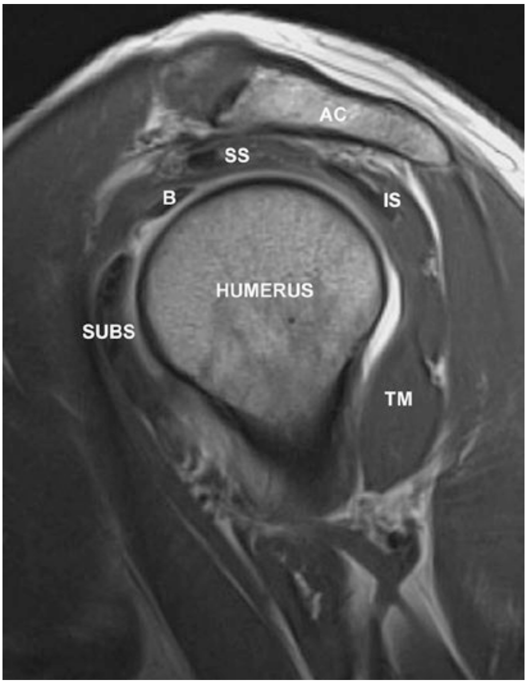

Fig. 14.15 Normal rotator cuff anatomy on a sagittal oblique T1-weighted (T1W) FSE image from an MR arthrogram (*B* biceps, *AC* acromion, *SS* supraspinatus, *SUBS* subscapularis, *IS* infraspinatus, *TM* teres minor)

sagittal images are usually oriented parallel to the glenoid face as seen on axial images and demonstrate the relationship of the rotator cuff tendons with the humeral head (Fig. 14.15). These images provide optimal short-axis views of the rotator cuff tendons and the intra-articular portion of the long head of the biceps tendon. They are particularly helpful for differentiating between nonretracted full-thickness tears and partial-thickness tears and for identifying which tendon(s) is/are involved. These images also help in the evaluation of the glenohumeral ligaments, subacromial-subdeltoid bursa, glenoid labrum, and rotator interval. Axial images are also used to assess the glenohumeral articular cartilage, the anterior and posterior aspects of the labrum, and the subscapularis and biceps tendons.

14.4.2 MR Imaging Protocol

For MR scans, patients are positioned supine with their arm at the side of the body in partial external rotation [25]. A number of different MR imaging protocols have been recommended for evaluation of the shoulder, each of which is effective in showing both normal and pathologic findings. One feature common to these protocols is the acquisition of both fat-suppressed/water-sensitive and non-fat-suppressed fast spin echo (FSE) images. The sequences commonly use echo times (TEs) longer than 35 ms to minimize artifactually bright areas in the tendon from the “magic angle” effect. This magic angle effect occurs when organized collagen fibers, including those in tendons and ligaments, are oriented at 55° to the main magnetic field. T2 relaxation of the tissue is longer, leading to a brighter tendon signal that may mimic tendinosis. Oblique sagittal T1-weighted images are often obtained medial to the spinoglenoid notch to assess fatty infiltration and atrophy of the rotator cuff muscles or to identify edema-like signal that can be seen with muscle denervation resulting from injury or paralabral cysts [29].

Images should be obtained in three planes: oblique coronal, oblique sagittal, and axial. The slice thickness should be less than 5 mm, and a small field of view (FOV) (12–16 cm) is recommended. The glenoid labrum is best seen on high-resolution axial (anterior and posterior labrum) and coronal (superior and inferior labrum) images. Direct MR arthrography (i.e., imaging the joint after intra-articular injection with MR contrast agent) can help to identify articular side partial-thickness cuff tears and can demonstrate nondisplaced labral tears by filling the tears with contrast agent. The advantages of MR arthrography for diagnosing the causes of shoulder instability and SLAP lesions and for the postoperative assessment of labral repairs have been demonstrated previously [30].

14.4.3 MR Imaging of Common Shoulder Pathologies

Early diagnosis of rotator cuff disease is important as untreated disease can result in enlarging tears, increasing pain [31], and irreversible fatty degeneration and atrophy of the cuff muscles [32]. Once these muscle changes occur, the risk

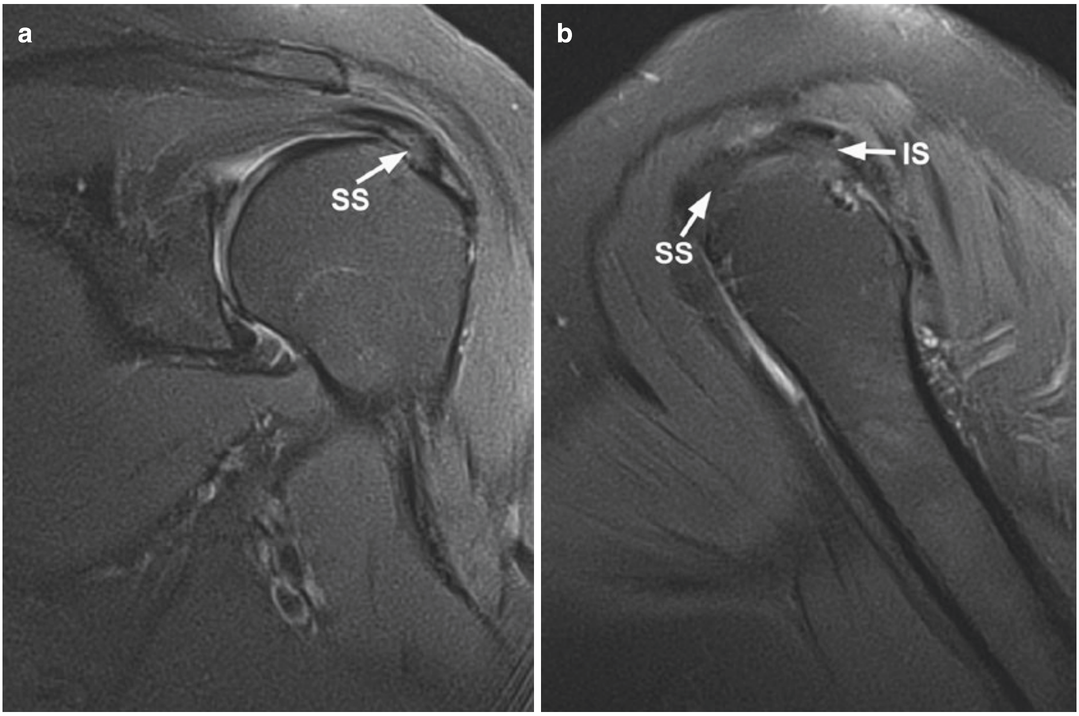

Fig. 14.16 Rotator cuff tendinosis. Coronal (**a**) and sagittal (**b**) oblique T2-weighted (T2W) fast spin echo (FSE) images with fat suppression (fs) show intermediate signal and fusiform swelling in supraspinatus (SS) and infraspinatus (IS) tendon from myxoid degeneration

of a recurrent tear after surgical repair may be as high as 94% [33, 34].

The underlying cause of rotator cuff damage may include shoulder impingement and degenerative arthritis. Patients with uncorrected impingement syndrome may progress along a spectrum from rotator cuff tendinosis to partial-thickness tear to full-thickness tear [34].

MR imaging is effective in assessing rotator cuff pathology, especially full-thickness cuff tears. One study found that with MR imaging, a full-thickness rotator cuff tear could be diagnosed with 92.1% sensitivity and 92.9% specificity; however, MR imaging was less accurate for the diagnosis of a partial-thickness tear with only 63.6% sensitivity (but 91.7% specificity) [35]. On MR images, normal tendons are dark whereas early tendon degeneration (tendinopathy) appears as intermediate signal within the tendon substance accompanied by distortion of the tendon. In the most severe cases, there is fusiform or focal thickening resulting from myxoid degeneration (Fig. 14.16). With more advanced pathology (e.g., partial-thickness tear), the signal becomes brighter on T2-weighted images, and fluidlike signal may be seen across a portion of the tendon. When fluidlike signal traverses the full thickness of the tendon, a full-thickness tear can be diagnosed. In full-thickness tears, retraction of the tendon should be measured, as cases with increasing grades of retraction may require open surgery rather than arthroscopy or may be inoperable (Fig. 14.17).

MR imaging can be very useful in the assessment of patients with shoulder instability. Because only 25–30% of the humeral head contacts the glenoid in the glenohumeral joint, the shoulder has a wide range of motion at the expense of compromised joint stability [36]. The joint is fortified by enlargement of the articular surface by the glenoid labrum and extrinsic components such as the capsule, ligaments, tendons, and muscles. When these components become unbalanced, shoulder instability may occur.

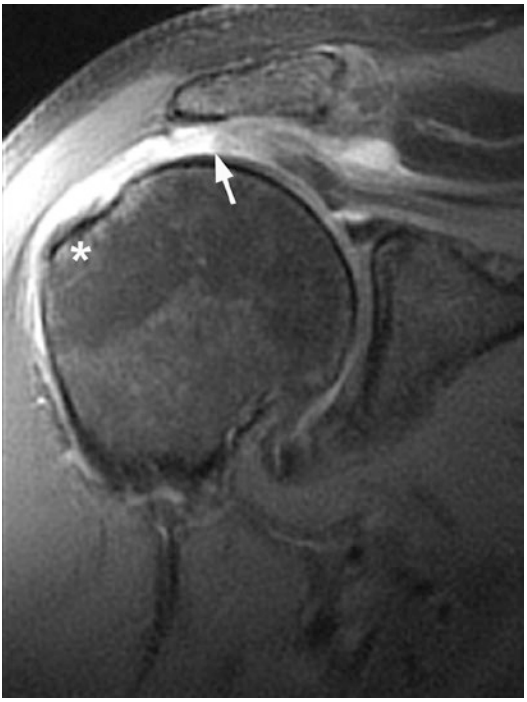

Fig. 14.17 Full-thickness rotator cuff tear. Coronal oblique T2W fs FSE image shows retraction of the torn supraspinatus tendon (arrow) and the empty footplate on the greater tuberosity (asterisk)

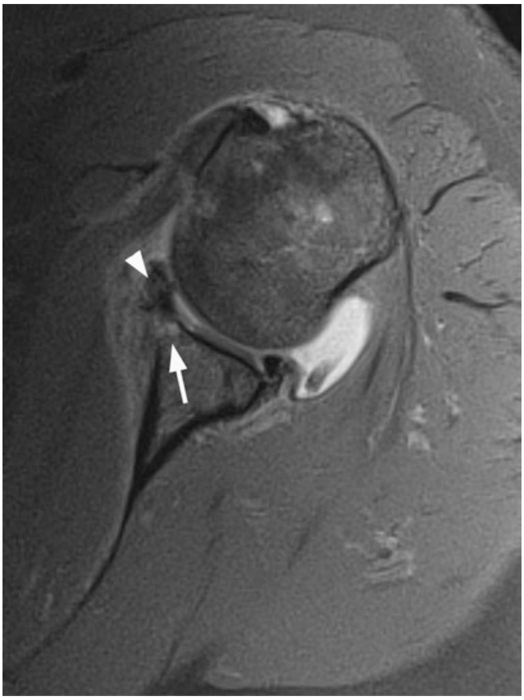

Fig. 14.18 Osseous Bankart lesion. An axial T1W fs FSE image from an MR shoulder arthrogram demonstrates the torn anterior-inferior labrum (arrowhead) and the small glenoid bone defect (arrow) with overlying cartilage damage

Damages to the anterior, inferior, or posterior labrum; the glenoid cartilage; the bony humerus or glenoid; the glenohumeral ligaments; the capsule; the rotator cuff tendons; or the biceps tendons are all potential causes of instability that can be assessed with MR imaging.

Anterior instability is the most common type of shoulder instability. Anterior dislocation usually leads to an injury to the anterior-inferior labrum (i.e., a Bankart lesion) from pulling of the inferior glenohumeral ligament and impaction of the humeral head. Bankart-type injuries may be isolated to the labrum or may include a glenoid bone fragment (i.e., a “bony Bankart”) (Fig. 14.18). On MR images, the lesion appears as a high intensity line on T2- or proton density-weighted images coursing through the base of the normally low signal anterior-inferior labrum or beneath the fragment of a bony Bankart lesion. The anterior labrum may remain in place or may appear displaced, small, or absent. The inferior glenohumeral ligament may also pull from its humeral attachment, resulting in a humeral avulsion of the glenohumeral ligament (HAGL) and producing a characteristic appearance on MR images [37, 38]. This HAGL injury is also associated with a tear of the subscapularis tendon and recurrent anterior instability [39]. HAGL lesions typically result from a first-time dislocation in patients aged more than 35 years [38]. On axial MR images, a HAGL lesion appears as a disruption at the humeral neck attachment producing a “J-shaped” rather than the normal “U-shaped” appearance of the inferior glenohumeral ligament (Fig. 14.19).

Anterior dislocations can also cause bony impaction injuries on the posterior-superior humeral head; this is known as a Hill-Sachs deformity. On MR imaging, this lesion appears as focal flattening or a wedge-shaped defect with or without associated bone marrow edema-like signal (Fig. 14.20). Often these deformities are easiest to see on the superior-most axial slices where the

Fig. 14.19 Humeral avulsion of the inferior glenohumeral ligament (HAGL). A coronal oblique T2W fs FSE image shows fluid between the avulsed ligament (arrow) and the expected attachment site on the proximal humerus

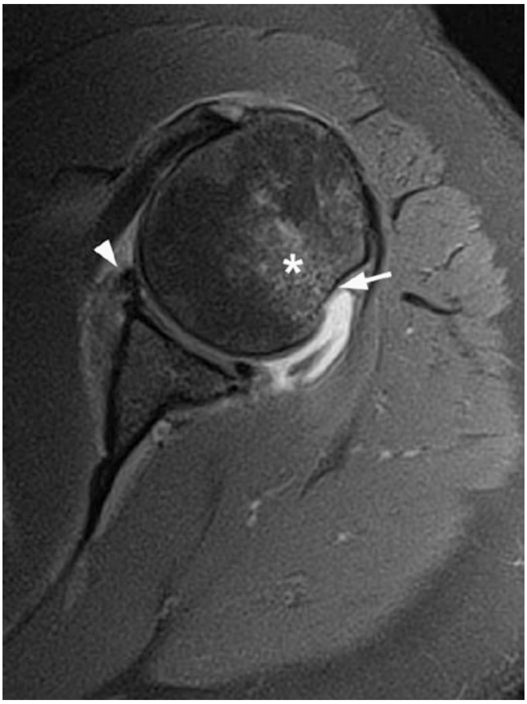

Fig. 14.20 Hill-Sachs lesion following anterior shoulder dislocation. Axial PD fs FSE MR image shows focal impaction of the posterior humeral head (arrow) with underlying edema-like marrow signal (asterisk) from recent contusion and the torn anterior labrum (arrowhead)

humeral head should appear circular. Clinicians should be aware, however, that there is a normal anatomic groove located posterolaterally and caudally on the humeral head; this groove should not be miscategorized as a Hill-Sachs lesion [40].

Posterior labral and capsular tears are less common than anterior tears and are usually seen in association with posterior or multidirectional instability. These tears have signal changes and appearances similar to those of anterior labral tears on MR imaging, but in a posterior location. Posterior dislocation may cause impaction of the anterior humeral head on the posterior glenoid, leading to a “trough sign” or “reverse Hill-Sachs” lesion.

Overhead repetitive motion or acute trauma can cause superior labral lesions, which usually present as nonspecific shoulder pain. Superior labral tears are usually centered at the biceps labral complex extending from anterior to posterior to the biceps anchor (i.e., SLAP lesions). SLAP lesions may extend inferiorly to involve the anterior labrum, posterior labrum, and/or the biceps anchor; they may also involve adjacent capsuloligamentous structures [41]. On arthroscopy, SLAP lesions have a reported prevalence of 3.9–11.8% [42, 43]. On MR imaging/MR arthroscopy, high signal (fluid on T2 or arthrographic contrast on T1) is usually found extending into the superior labrum and tracking into the labral substance and/or the biceps tendon (Fig. 14.21). SLAP tears must be differentiated from the normal variant of a sublabral foramen. Sublabral foramina usually appear smooth, extend medially paralleling the glenoid contour, and do not extend into the posterior-superior labrum. SLAP tears most often have irregular margins, extend laterally within the labrum toward the biceps tendon, and involve the posterior-superior labrum. Differentiating among the various types of SLAP tears with MR imaging may be challenging in some cases.

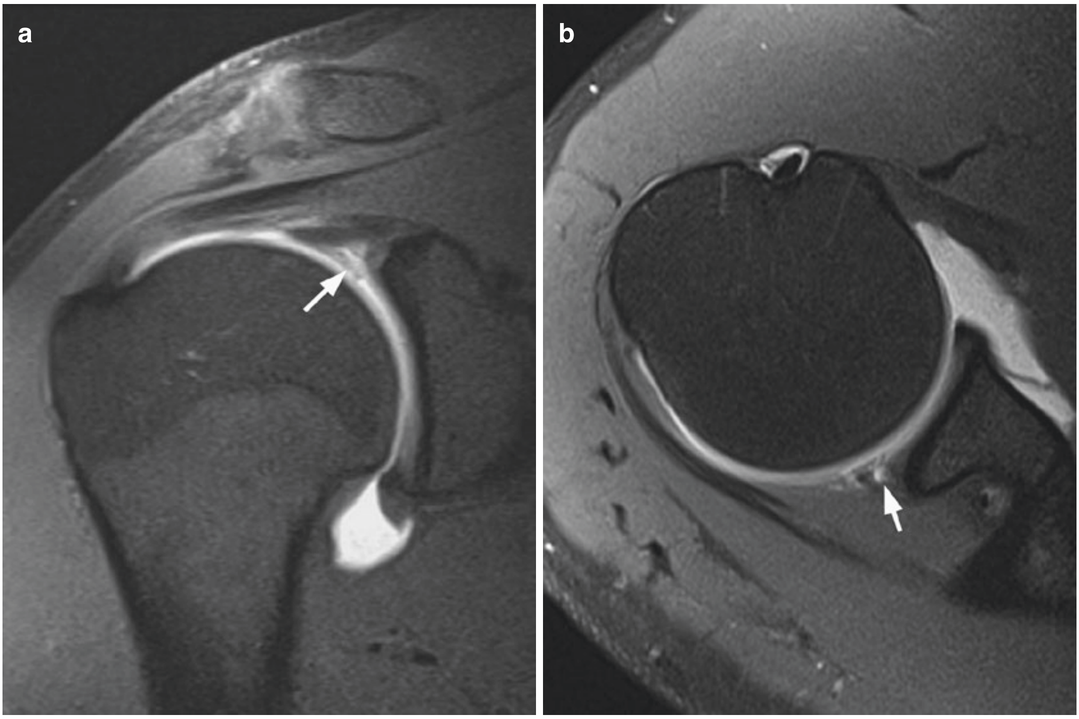

Fig. 14.21 Superior labral tear (SLAP). Coronal (**a**) and axial (**b**) T1W fs FSE images from an MR arthrogram show contrast beneath the labrum at the biceps anchor (**a**) and in the posterior labrum (**b**) (arrows)

Proximal tears of the long head of the biceps tendon, which are more common in patients aged more than 40 years, tend to be proximal to the bicipital groove of the humerus [44]. These tears appear on MR images as absence of the tendon at the biceps anchor since the torn end of the tendon retracts distally. There may be edema surrounding the biceps anchor and a fluid-filled tendon sheath. Because the tendon is "absent," the lesion may be easily overlooked, especially in the setting of massive rotator cuff tears; the intra-articular portion of the biceps tendon must be specifically identified on every shoulder MR image.

MR imaging can be used to assess pathologies of the rotator interval, the space between the supraspinatus and subscapularis tendons through which the long head of the biceps tendon courses. The rotator interval is the site of many biceps tendon lesions, adhesive capsulitis, and anterosuperior internal impingement [45]. Adhesive capsulitis, also known as frozen shoulder, is often idiopathic. Primary myofibroblastic transformation of tissues leads to contracture of the coracohumeral ligament component of the rotator interval [46]. A painful global limitation of both active and passive shoulder motion occurs in these patients [46]. On MR imaging, abnormal thickening and/or edema of rotator interval structures and the inferior glenohumeral ligaments and joint capsule can be seen (Fig. 14.22). Edema-like capsular signal around the glenoid rim may also be apparent on fat-suppressed MR images.

When insufficient information is available from radiographs in cases of complex osteoarthritis or inflammatory arthritis, MR imaging can be useful in demonstrating the changes of early disease, bony involvement, hyperplastic synovium, and treatment response. Rotator cuff tears and effusion-synovitis are also well demonstrated on MR images for these patients.

MR imaging also plays an important role in the diagnosis, characterization, assessment of extent, and treatment planning for bone and soft tissue tumors around the shoulder during preoperative

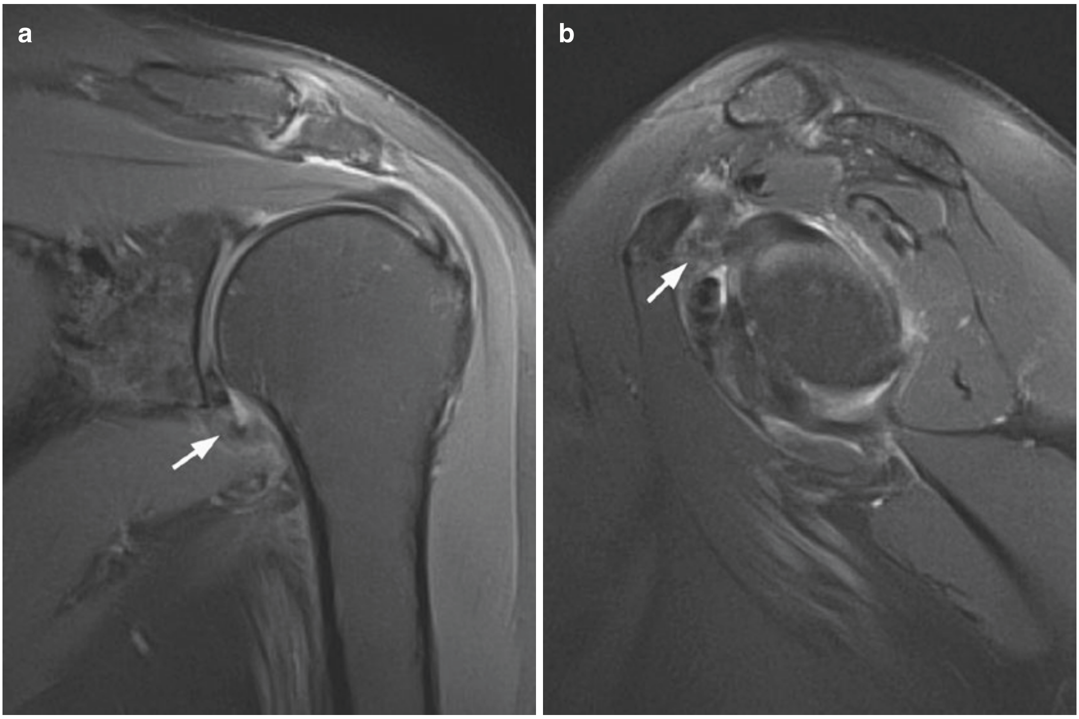

Fig. 14.22 Adhesive capsulitis. A coronal T2-weighted fs FSE image (**a**) with edema in and around the capsule in the axillary recess (arrow, **a**). Sagittal oblique T2-weighted fs FSE image demonstrates edema in the rotator interval (arrow, **b**)

evaluation. These tumors demonstrate wide variations in signal characteristics on MR images.

Finally, MR imaging is useful for evaluating infection of the shoulder, distinguishing between a fluid collection and inflammatory phlegmon, and identifying the occurrence of osteomyelitis via the presence of low subchondral bone marrow signal on non-fat-suppressed T1-weighted images. Following contrast administration, perisynovial edema, inflamed synovium, and soft tissue sinus tracts can be outlined by enhancement on fat-suppressed T1-weighted images.

14.5 Ultrasound

Ultrasound (US) imaging of the shoulder has the advantage of being a less expensive and more rapid and dynamic examination than MR imaging and is therefore commonly used to assess the rotator cuff and biceps for tendinopathy, tenosynovitis, tears, and calcific tendinitis [47]. However, labral tears including SLAP tears are better visualized by MR imaging because the interposed bone obscures portions of these structures on US images. Perhaps most importantly, US is an excellent modality to guide the use of nerve blocks; barbotage treatment of calcific tendinitis; therapeutic injections of the joints, bursae, and ligaments; and other interventions.

Proper performance of US examinations is operator-dependent and requires significant training and experience. The shoulder must be positioned appropriately for the structure or pathology that is to be evaluated. Several patient positions are required for a complete shoulder examination.

14.6 Conclusion

This chapter reviewed the imaging modalities commonly used to assess shoulder pathologies. Radiography, CT, MR, and US imaging are complementary examinations that can provide vital information to clinicians in regard to treatment decisions, preoperative planning, and follow-up, including outcomes assessment and diagnosis of complications. A basic understanding of image interpretation is therefore essential for the optimal treatment of shoulder disorders.

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15

Shoulder Arthroplasty: Pain Management

Filiz Uzumcugil and Fatma Sarıcaoglu

15.1 Introduction

A pain management strategy depending on a single type of analgesic has been proven to be inadequate both because of the inadequate pain control and the side effects of that single type of analgesic depending on its rising dose. This strategy has also been shown to cause inadvertent effects such as nociception-induced central sensitization and secondary hyperalgesia, as well as the functional loss of related joint. The *multimodal approach* mainly depends on the use of additive and synergistic effects of various analgesics of different mechanisms, in order to provide a higher level of pain control with lower doses especially to reduce the side effects [1]. In order to achieve the goal; regional anaesthetic/analgesic techniques, local infiltration and systemic analgesics are employed simultaneously in the perioperative period. This multimodal pain management has also proven beneficial by reducing opioid consumption and shortening the length of hospital stay after shoulder arthroplasty [2, 3].

The pain management strategy should also include *preemptive analgesia* which describes the analgesic medication given before the noxious stimulus begins. This technique aims to prevent hypersensitivity via blocking sensory inputs caused by the inflammatory process. In a study by Kadum et al., the preoperative pain threshold and preoperative pain at rest were found to be significantly associated with functional status of the shoulder after arthroplasty surgery. The findings of this study have shown that the central sensitization which may develop prior to the surgery has a high impact on functional recovery [4]. Hence, the use of preemptive analgesia to prevent central sensitization leading to a high preoperative threshold and low sensitivity to pain may result in low pain scores, thus better functional status after surgery.

The postoperative pain control not only depends on the effective medications and techniques brought into clinical practice during the perioperative period, but also there are some other factors which were suggested to have impact on outcome. Patients' expectations which may vary according to age, demographic characteristics and stage of the functional status of the joint were reported to independently predict outcome [5, 6]. The positive expectations from surgery were shown to be associated with better outcomes [7]. The anxiety and depression which may be interrelated with expectations were also suggested to have impact on outcome. Preoperative acknowledgement about the procedure and the awaiting postoperative period in terms of functional status and pain will decrease the anxiety level before the surgery. The higher pain scores and the worse baseline functional status of the joint enhance the preoperative opioid

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use, which cause a deliberate rise in both the dose and duration of the requirement for opioids in the postoperative period. These factors are all interrelated and may be minimized by employing a multidisciplinary approach by anaesthetist, surgeon, physiotherapist and algologist. Thus, a *multidisciplinary approach* is needed for adequate pain control, as well as a *multimodal approach* for pain management itself.

15.1.1 Regional Anaesthesia

Regional anaesthesia has proven to be beneficial both in the intraoperative and postoperative period. Advancement in regional anaesthesia techniques with the guidance of ultrasound improved the blockade of brachial plexus and identification of its branches. The motor and most of the sensory innervation of the shoulder are supplied by the brachial plexus. *The cephalad cutaneous parts* are innervated by the supraclavicular nerves, which originate from C3 to C4. *The glenohumeral joint, the capsule, subacromial bursa and coracoclavicular ligament and various parts of the skin* are innervated by the suprascapular nerve originating from the superior trunk of brachial plexus (C5, C6). *The cutaneous innervation of the skin covering the deltoid muscle* is innervated by the axillary nerve originating from the posterior cord of the brachial plexus (C5–C6) [1]. These nerves can be blocked by various approaches to brachial plexus.

15.1.1.1 Interscalene Block

Interscalene block is performed to obtain analgesia at the lateral two-thirds of the clavicle, the glenohumeral joint and proximal part of the humerus. The blockade includes the C5 and C6 nerve roots and superior trunk of the brachial plexus *(suprascapular, axillary, musculocutaneous, radial, thoracodorsal, median, anterior interosseous)*, most commonly sparing the ulnar nerve (C8, T1), which limits its effect for distal procedures [1, 8].

The interscalene block which remains the ‘gold standard’ for shoulder surgeries can be performed by using either a single-injection technique or a continuous infusion. The single-injection technique has a limited duration of action, which can be prolonged by using adjuvants in combination with local anaesthetic agents. In a study by Desmet et al., the addition of either intravenous or perineural 10 mg dexamethasone to 0.5% ropivacaine for ISB in patients undergoing arthroscopic shoulder surgery was reported to have similar effect on prolonging the analgesic period [9]. However, in another study by Kawanishi et al., a low dose of dexamethasone (4 mg) either intravenous or perineural as a supplement to ISB with ropivacaine was not found to be similar; perineural low dose was found to be superior in prolonging the analgesic period [10]. In similar studies, buprenorphine was also found to prolong analgesic period when used both systemic and perineural, but perineural was reported to provide longer duration of analgesia [11, 12]. Clonidine is another adjuvant to provide longer analgesic periods; moreover it can be used perineurally in the absence of a local anaesthetic [13, 14]. In a study which used a multimodal perineural analgesia for patients undergoing shoulder arthroplasty, bupivacaine, clonidine, buprenorphine and dexamethasone were combined in a solution. Either 0.375 or 0.2% of ropivacaine combined with the aforementioned three adjuvants was found to provide superior analgesia [15]. In a study by Alemanno et al., tramadol was used as an adjuvant to 0.5% levobupivacaine for single-shot middle interscalene block for patients undergoing arthroscopic rotator cuff repair. This study differs from previous ones due to inclusion of a patient group receiving systemic tramadol. The use of tramadol perineurally as an adjuvant to levobupivacaine was found superior either to placebo plus interscalene block with levobupivacaine or to systemic tramadol plus interscalene block with levobupivacaine in terms of duration of analgesia [16].

On the other hand, continuous infusion is another way to prolong the duration of action. In shoulder arthroplasties, the continuous infusion was reported to decrease the time to discharge, increase the passive range of motion in early period and reduce the opioid requirements [17]. Aside from the advantages of placing continuous indwelling catheters, there are certain factors which may limit its use. The most common failure of a continuous interscalene block (CISB) was reported to be the displacement of the catheter [18]. The catheter may also cause adverse events, especially infection, related to the leakage of solution from insertion site into the operative field in patients undergoing shoulder surgery in sitting position [19]. Aside from catheter-related adverse events, continuous infusion provided by catheter in patients undergoing upper extremity arthroplasty was reported to have higher rate of pulmonary and neurologic barriers to discharge leading to a longer length of hospital stay compared to single-shot injection [20]. The inadvertent effects of continuous brachial plexus block related to these barriers may be overcome by modifying the catheter insertion site. In a study by Auyong et al., interscalene, suprascapular nerve and supraclavicular nerve levels of brachial plexus were compared as different catheter insertion sites. The level of suprascapular nerve which is more distally located along the brachial plexus, sparing the phrenic nerve, resulted in less pulmonary adverse events compared to the continuous block at the interscalene level. A selective suprascapular nerve block catheter may prove to be beneficial in patients with pulmonary comorbidities when compared to CISB [21].

Despite the efforts to overcome adverse events related to ISB, the technique still has some drawbacks due to the inadvertent effects on the nervous system *(central blocks, brachial plexopathy, recurrent laryngeal nerve palsy, Horner syndrome)* and respiratory *(pneumothorax, phrenic nerve palsy)* and cardiovascular complications *(arrhythmias)*. The implementation of ultrasound guidance was reported to reduce the complication rates especially that of Horner syndrome [22]. However, the vital structures such as vertebral and carotid arteries, internal jugular vein, lungs and neuroaxial compartments surrounding the plexus at the interscalene level as well as the close proximity to the phrenic nerve remain to be the major concerns limiting the use of the technique [23].

15.1.1.2 Suprascapular Nerve Block

The shoulder is innervated mainly by suprascapular nerve, which can be blocked in suprascapular fossa by using either an anatomical landmark, nerve stimulator or ultrasound-guided technique in order to provide blockade of the distal branch of C5 and C6 roots [1, 21, 23]. The nerve originates proximally from the superior trunk of the brachial plexus and gives off an articular branch innervating especially the posterior glenohumeral joint capsule and runs with this branch through suprascapular notch beneath the transverse scapular ligament [24]. The primary goal in employing suprascapular nerve block (SSNB) as an alternative to interscalene block is to spare phrenic nerve in order to prevent respiratory complications caused by diaphragmatic paresis. Thus, this block can be preferred in patients who have higher risk of developing morbidity due to respiratory complications [1, 23]. In a case report, the bilateral use of continuous suprascapular nerve block was reported to provide beneficial effects on analgesia for bilateral hemiarthroplasty [25]. The block may also be considered as a rescue technique in case of an unsuccessful interscalene block.

The suprascapular nerve block may require the supplementary blockade of axillary nerve (ANB), which also supplies the sensory innervation of the shoulder to a lesser extent. The suprascapular nerve block without axillary nerve block was reported to reduce morphine consumption, nausea and length of hospital stay after arthroscopic shoulder surgery compared to placebo; however, it was reported to have lower impact on pain control compared to single-injection interscalene block [1, 26]. The suprascapular nerve is the branch of superior trunk and the axillary nerve is the branch of the posterior cord of the brachial plexus; thus the combination of these nerve blocks requires a two-step approach including the suprascapular nerve block at the level of suprascapular notch and axillary nerve block at the quadrangular space [27]. Despite the minority of the contribution, *the lateral pectoral, subscapular and musculacutaneous nerves* also innervate the shoulder and surrounding tissues. Thus, the combination of SSNB and ANB, which spares the blocks of those aforementioned nerves, may provide insufficient analgesia leading to a need for local infiltration analgesia (LIA) in order to provide a complete pain control (*see* Sect. 15.1.2).

The main disadvantage of this block is that it requires the additional axillary nerve block in order to provide a complete analgesia; moreover, it has a limited duration of action with still remaining adverse events such as nerve damage, Horner syndrome and respiratory complications [1].

15.1.1.3 Supraclavicular Nerve Block

The supraclavicular nerve block is achieved at the level of brachial plexus between anterior and middle scalene muscles at the first rib, lateral and posterior to the subclavian artery [1, 28]. At this level the target nerves would be suprascapular (*if the block is too caudal, then the proximally originating suprascapular nerve would not be blocked*), axillary, musculocutaneous, radial, thoracodorsal, median, anterior interosseous and ulnar nerves [28]. The major adverse event associated with this block has been reported to be pneumothorax, which actually limited the use of this block. Because the cupula of the lung is immediately medial to the first rib very close to the plexus, towards which the needle is advanced from the mid-point of clavicle. The risk is higher especially on the right side, because cupula is higher on this side [28]. However, the rate of pneumothorax was reported to be reduced by using the ultrasound guidance during the block [1, 24]. Aside from pneumothorax, which was minimized by the use of ultrasound, there still remain some major complications such as intravascular injection, Horner syndrome, nerve injury and diaphragmatic paresis.

15.1.2 Periarticular Injection

The local anaesthetic injection into the periarticular area and the wound has been suggested to be a complementary technique in multimodal analgesia regimens. The injections into the subacromial or intraarticular space are no longer considered for pain control both due to the insufficient analgesia and the adverse effects such as chondrolysis, although chondrolysis is not much of a concern in arthroplasty surgeries [1]. In a study by Bjornholdt et al., the patients undergoing shoulder replacement under general anesthesia were addressed to compare the effectiveness of local infiltration analgesia (LIA) and continuous interscalene block. Local infiltration analgesia, which included axillary and suprascapular nerve blocks, was provided by using 150 ml 0.2% ropivacaine with epinephrine, whereas the continuous analgesia via catheter was provided by using 0.75% ropivacaine with 7 ml of bolus followed by 5 ml/h infusion for 48 h postoperatively. The continuous infusion of ropivacaine was reported to be superior in terms of opioid consumption and pain scores after shoulder replacement, when compared to local infiltration technique [29]. However, a combination of both techniques was suggested to improve the pain control after shoulder arthroplasty [27]. In a case report by Panchamia et al., the selective blocks of suprascapular and axillary nerves combined with local anaesthetic infiltration of periarticular area and incision were reported to provide sufficient analgesia when supplemented by scheduled multimodal systemic analgesic use after shoulder arthroplasty [27].

Liposomal bupivacaine, which uses a carrier matrix encapsulating and slowly releasing (over 72–96 h) bupivacaine, was reported to have a similar effect on pain management after shoulder arthroplasty with interscalene block by reducing the opioid requirements [30, 31]. The duration of effect of local anaesthetics may be relatively shorter, besides the ideal agent and its volume has not been established clearly yet. Hannah et al. addressed patients undergoing shoulder arthroplasty surgery to compare the effectiveness of local injection of liposomal bupivacaine with preoperative single-injection interscalene block (ISB). The investigators used 30 ml of 5% ropivacaine for ISB before surgery and used *liposomal bupivacaine (266 mg diluted in 40 ml of NS) near the end of* *the procedure infiltrated into the pericapsular area and layers of the wound.* The postoperative pain management was provided by paracetamol and patient-controlled analgesia (PCA) for each and every patient enrolled in the study. The investigators added standard bupivacaine to liposomal bupivacaine injections to provide the pain control in the early postoperative period. Liposomal bupivacaine was found to decrease pain scores at 18–24 h and reduce opioid consumption on the second postoperative day. Local liposomal bupivacaine injection was suggested to provide superior or similar pain control compared to ISB and also proved to be beneficial in shortening the length of hospital stay [30]. In another study by Sabesan et al., the 'gold standard' CISB was compared with a combination of single-injection ISB and periarticular infiltration of liposomal bupivacaine in patients undergoing shoulder arthroplasty [18]. The patients in CISB group received a 20 ml single bolus 0.5% of bupivacaine followed by 0.125% of bupivacaine at a rate of 6 ml/h, whereas the liposomal bupivacaine group received a 20 ml single bolus 0.5% of bupivacaine as the single-injection ISB in combination with intraoperative periarticular infiltration of LB. The standard recommended dose of 266 mg (20 ml) LB was diluted to 80 ml with NS and administered by the recommended moving needle technique. The LB was administered in 48 ml around the bone prior to the implantation of the prosthesis, in 16 ml into the capsule and deep and superficial muscular structures after implantation, followed by the remaining 16 ml into the wound both subcutaneous and into the incision [31–33]. LB administration was performed intraoperatively due to the delay in its efficacy caused by its pharmacokinetic profile. The investigators used a standard postoperative pain management consisted of 20 mg celecoxib and 650 mg acetaminophen, whereas rescue medication was provided by opioids. The patient-reported outcomes measured by Penn Shoulder Score (PSS) and American Shoulder and Elbow Surgeons (ASES) scores were reported to be better in LB group than CISB. Periarticular infiltration of LB in combination with a single-injection ISB was suggested to be a useful pain management technique for patients undergoing shoulder arthroplasty [18].

Yet, it should be kept in mind that the long-acting local anaesthetics have a peak plasma level after 24 h of injection without covering the early postoperative period. Aside from this ineffective period, nausea, vomiting and dizziness with more serious but rare complications such as myocyte toxicity, chondrotoxicity and inflammation may also be encountered with local anaesthetic injections. The efficacy and safety of liposomal bupivacaine and its combinations with adjuvants such as dexamethasone and its use in regional anaesthesia are to remain the main goals for future research.

15.1.3 Oral and Parenteral Medications

Oral and parenteral medications acting systemically are often not preferred as sole analgesic techniques mainly due to their side effect profile. However, the multimodal pain management protocols all include those medications in pre-, intra- and postoperative period. The primary goal in using regional anaesthetic and analgesic techniques is to reduce the consumption of those systemic medications to minimize their side effects. These medications include non-opioids such as acetaminophen, nonsteroid anti-inflammatory drugs (NSAID) and gabapentinoids, which are administered according to a scheduled protocol both prior to surgery and after surgery. In addition, opioids remain in pain management protocols mainly for rescue medications. The studies investigating the patients undergoing shoulder arthroplasty in terms of pain scores and opioid consumption in the postoperative period mostly employed multimodal analgesic techniques. In a study by McLaughlin et al., all patients received ISB with 15–20 ml of 0.5% ropivacaine prior to surgery and enrolled into two groups to receive the standard and multimodal pain management protocols. The standard approach included scheduled acetaminophen and opioid medications, whereas the multimodal approach included preoperative and postoperative scheduled non-opioid medications. All the patients received opioid as rescue medication. The multimodal approach in shoulder arthroplasty was reported to reduce opioid consumption and shorten the length of hospital stay [3]. In a similar study by Auyong et al., brachial plexus block was performed by using 6 ml/h 0.2% ropivacaine for infusion after shoulder arthroplasty [21]. All patients received multimodal analgesic protocol both in the preoperative *(975 mg acetaminophen, 200 mg celecoxib and 600 mg gabapentin)* and postoperative *(650 mg/6 h acetaminophen and 200 mg/12 h celecoxib)* period. Oral oxycodone was administered at a dose according to the severity of pain measured by numeric rating scale (NRS) as the rescue medication [21]. Hence, these systemic medications maintain their role in these pain management protocols as complementary to regional anaesthetic and analgesic techniques.

15.1.4 Cryotherapy

Cryotherapy is another adjuvant method that can be used as complementary to other pain management techniques. The technique alters the inflammatory process in cells leading to a better oxygenation, lower metabolic rate and lower oxygen demand, as well. It decreases the sensitivity leading to higher thresholds and slower synaptic activity. Extended exposures should be avoided [1]. In a systematic review evaluating the effectiveness and safety of cryotherapy in patients undergoing anterior cruciate ligament reconstruction, the cold compression devices were reported to reduce the pain scores for 48 h postoperatively [34]. In a recent systematic review addressing the randomized-controlled trials investigating the effect of pain management techniques in patients undergoing anterior cruciate ligament reconstruction, the cryotherapy was reported to be beneficial [35]. In a very recent study by Boddu et al., the use of cryotherapy was included in a multimodal analgesia regimen for patients undergoing total shoulder arthroplasty. The regimen consisted of a combination including ISB with 0.25% bupivacaine combined with 4 mg dexamethasone, LIA with 20 ml liposomal bupivacaine diluted in 40 ml of NS, scheduled acetaminophen and ketorolac, and immediate cryotherapy was suggested to be considered for selected patients undergoing shoulder arthroplasty [36].

15.2 Conclusion

Pain management strategy for shoulder arthroplasty surgery includes pre-, intra- and postoperative period. Since the main indication for surgery is the pain on the joint, analgesic medications should start in the preoperative period to prevent central sensitization. The analgesia should be maintained by peripheral nerve blocks and local infiltration techniques to cover both the intraoperative and the postoperative period which is important especially for the early rehabilitation in order to facilitate functional recovery of the joint. In the late postoperative period, during which the effect of local anaesthetics and adjuvant agents wares off, oral or parenteral medications should cover the remaining period with pain. The use of such multimodal analgesia helps pain control in the perioperative period and functional recovery after shoulder arthroplasty.

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Shoulder Arthroplasty in the Treatment of Proximal Humeral Fractures

16

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16.1 Intro/Preop Workup

Proximal humeral fractures are the third most common fracture in the elderly population (second to hip fractures and fractures of the distal radius), occurring at a frequency of approximately 105 per 100,000 individuals per year [1, 2]. As the general population ages and predicted life spans increase, the desire for procedures that restore joint function and maintain quality of life will become progressively relevant. Following this trend, it is likely the rate of arthroplasty for treatment of proximal humerus fractures—particularly in the elderly population—will likely rise in the decades to come [2]. For complicated fractures of the proximal humerus, both hemiarthroplasty (HA) and the reverse prosthesis have demonstrated promising short- and long-term results [3–10]. In the elderly population and situations involving complex fractures, each approach has exhibited superior outcomes in comparison to open reduction internal fixation (ORIF) and non-surgical conservative management [11–16]. The reverse prosthesis in particular is selected as a revision procedure for failed HA, ORIF, and non-surgical conservative management [17, 18].

When deciding between the HA and reverse prosthesis for management, it is crucial to weigh the nature of the injury, analyze the advantages and disadvantages of each surgical approach, and understand the patient's perspective before moving forward. Additionally, it is important to convey pertinent information to patients regarding the potential complications of surgical intervention. Various studies have found a correlation between increasing patient age and poor outcomes using prosthetic implants [19–21], and the existence of comorbid conditions has also been linked to a multitude of complications following surgery for the treatment of proximal humeral fracture [22–24]. It is imperative that patients understand the expected recovery process, long-term expectations following surgery, as well as possible future sequelae from intervention [25].

Prior to selecting an appropriate course of treatment for patients, a multitude of factors must be assessed. Calculation of patient age, overall health status, comorbid conditions, current medication regimen, and prior injury must precede any discussion of intervention [26]. After determining the severity of the proximal humeral fracture, and confirming the need for surgical mediation, additional factors—quality of bone stock, rotator cuff integrity, and regional anatomy—must be considered. It is also essential to understand the injury from the patient's perspective. Reflection on desired quality of life and anticipated degree of mobility need to be weighed accordingly in order to minimize potential future morbidity from unnecessary extensive intervention.

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16.2 Selection of Surgical Approach

Both the deltopectoral and the superolateral (deltoid-splitting) approach are appropriate for surgical approach. The advantage of the deltopectoral approach is the ability to extend the incision distally to expose the humeral shaft with relative ease. Surgeons choosing the superolateral approach need to be comfortable with exposing the axillary nerve in order to get distal exposure if needed.

16.3 Initial Approach

The long head of the biceps and the bicipital groove are often a reproducible landmark used during surgery to assist with tuberosity mobilization. The author's preference is to perform a tenodesis or tenotomy of the biceps tendon. The biceps tendon can be followed and released out of the rotator interval. The upper rolled border of the subscapularis can be identified and released medially under the coracoid. This will assist with mobilization of the subscapularis. Once the biceps are adequately mobilized, the specific tuberosity fragments can be identified. A fracture line will occasionally travel through the biceps groove separating the lesser and greater tuberosities. If there is no fracture, the surgeon may choose to osteotomize through the bicipital groove to allow exposure to the joint.

Once the lesser tuberosity and subscapularis are mobilized, a suture can be used at the bone/tendon junction to assist with tagging and traction. Retracting the lesser tuberosity fragment anteriorly and medially can usually expose the fractured articular surface. This can be removed with a clamp. The greater tuberosity can be tagged with one or two sutures to assist with mobilization as well. The cephalad portion of the humeral shaft should be cleaned of callus and the superior insertion of the pectoralis tendon identified.

16.4 Hemiarthroplasty

At this time, if a hemiarthroplasty is planned, the surgeon should inspect the glenoid for any damage or irregularities. If it is determined acceptable to proceed, the next step is to prepare the humerus for stem implantation. There are multiple factors that must be considered when positioning the humeral component including initial tuberosity malposition, tuberosity migration or detachment, as well as prosthetic height and degree of retroversion [19].

The height of the prosthesis is usually the first variable adjusted. There are several landmarks for determining optimal humeral head height intraoperatively. One method involves preoperative planning using a ruler and plain film imaging of both sides. Another method is to look for a fracture key of one of the tuberosity pieces. This will allow the surgeon to estimate the prior position of the anatomic articular surface. Krishnan et al. described restoring the "gothic arch" along the medial edge of the humerus and lateral edge of the scapula. This is analogous to the "Shenton line" of the hip [27]. Another useful intraoperative landmark is identifying the superior edge of the pectoralis major tendon, which is approximately 5.5 cm from the top of the humeral head [28]. The surgeon can also make use of an extramedullary jig [29] or an intramedullary sleeve [30] to assist with positioning of the stem during surgery.

The humeral implant should be adjusted to approximately 20° to 30° of retroversion. Many current implant systems have insertion jigs that allow referencing of the version to the forearm. In addition, the surgeon can verify that the humeral head is pointing directly toward the glenoid fossa with the arm at the side and the arm at 0° of external rotation. Aligning the prosthesis in excessive retroversion risks placing the greater tuberosity in excessive tension with internal rotation of the arm [19]. Conversely, placing a stem with disproportionate anteversion can force tension on the lesser tuberosity and subscapularis during external rotation.

Tuberosity management is usually accomplished with heavy sutures. Prior to final impaction or cementation of the humeral stem, it is useful to place multiple drill holes in the metadiaphyseal bone and place sutures through these holes. These vertical sutures will assist with holding the tuberosities reduced to the shaft of the humerus. The tuberosities themselves are managed with sutures passed through the tendon-bone junction. If there is comminution, it may help to place multiple locking stitches into the tendon [31]. Krishnan et al. recommended using two horizontal and two vertical cerclage sutures to provide stability of the tuberosities [27].

Stem selection is per surgeon preference. There are some lower profile stems which require a graft to achieve appropriate lateralization of the greater tuberosity. Stems with wider proximal bodies can usually restore the appropriate lateral offset without a graft. In addition, having appropriate suture holes in the implant can help with maintaining stability of the tuberosities to allow them to consolidate with the metaphysis of the humerus and to themselves.

Postoperatively a 4- to 6-week period of sling immobilization is generally recommended. Tuberosity stability is evaluated intraoperatively and should be confirmed as adequately stable to allow early passive range of motion. Postoperative x-rays are useful to monitor for any sort of tuberosity migration or resorption. Active range of motion can be started at approximately 6 weeks and strengthening at 12 weeks.

16.5 Reverse Prosthesis

The initial approach to perform a reverse prosthesis is typically similar to hemiarthroplasty. Once the tuberosities are mobilized and the humerus is exposed, the greater tuberosity can be retracted posteriorly behind the glenoid. The lesser tuberosity can be retracted anteriorly by a retractor hooked around the anterior margin of the glenoid. The labrum and soft tissues are released to completely expose the glenoid. Once the glenoid has been identified, it is important to remember the cartilage may need to be removed in these cases. The glenoid base plate is inserted in accordance with the implant manufacturer's technique, aiming for a 10° inferior tilt. The glenosphere can then be placed accordingly.

Much of the humeral preparation is similar to that described above for hemiarthroplasty. Sutures are placed in the metadiaphyseal region for vertical fixation. The implant is placed at approximately 20° of retroversion. The height of the prosthesis can be estimated by the tension on the conjoint tendon and the deltoid. In addition, temporarily reducing the tuberosities can help with judging appropriate height. The surgeon should take care to avoid placing the stem too high, as this may lead to significant overlengthening and a difficult reduction. In contrast, a stem placed too low in the canal can usually be mitigated somewhat by using a thicker polyethylene insert for final reduction.

Prior to insertion of the final stem, it can be useful to place one or multiple sutures around the medial aspect of the prosthesis. Some implants have a hole or smooth area that will not abrade the suture and allow them to slide. This area is often difficult to access once the joint has been reduced. The posterior limbs of these sutures can be passed through the tendon-bone junction of the greater tuberosity. Once the stem is either cemented or impacted into place, the greater tuberosity can be reduced to the appropriate position. The supraspinatus can be resected or recessed to avoid undue rotator cuff tension. The greater tuberosity can be tied down using the sutures around the medial aspect of the stem. Alternately, some reverse implants have holes and fins that can be used to reduce the tuberosity. The lesser tuberosity can be reduced in a similar fashion. The sutures around the medial aspect of the stem can be tied down as a cerclage around both tuberosities and the stem. The vertical sutures can then be used to optimize stability. Once all the sutures have been placed, the tuberosities are tested for stability. This is important to allow for early postoperative range of motion and rehabilitation.

Postoperatively a 4–6 week period of sling immobilization is generally recommended. Tuberosity stability is evaluated intraoperatively and should be felt to be stable enough to allow early passive range of motion. Postoperative x-rays are useful to monitor for any sort of tuberosity migration or resorption. Active range of motion can be started at approximately 6 weeks and strengthening at 12 weeks.

16.6 Results/Outcomes: Hemiarthroplasty (HA)

Internal fixation is often the surgical treatment of choice for displaced fractures in younger patients with intact bone stock and healthy surrounding soft tissue [22]. In the elderly population (>70 years), and situations where fracture location prevents restoration of proper functional anatomy, more invasive surgical intervention is required [32, 33]. For these complex fractures, especially those in which open reduction internal fixation (ORIF) cannot be achieved, primary hemiarthroplasty (HA) can be a stabilizing treatment. Historically, HA was considered the treatment of choice for such complex fractures and is commonly the suggested approach for 3-part fractures, 4-part fractures, complex avulsion fractures, head-splitting fractures, fracture dislocations, and >50% humeral head involvement in impaction fractures [34–36]. The procedure is also often used for fractures with severe displacement and resultant compromised blood supply to the humeral head [37], as well as a salvage for failed ORIF. Moreover, HA is a viable treatment option when ORIF is contraindicated due to risk of malunion, nonunion, implant failure, and osteonecrosis [33, 37].

HA has demonstrated far superior clinical and subjective outcomes for complex fractures compared to ORIF, and nonsurgical conservative management, particularly when humeral head stabilization is not reasonable [5, 10]. A randomized controlled prospective study demonstrated superior outcomes and reported better quality of life following HA as compared to nonoperative treatment in elderly patients with displaced four-part humeral fractures [38]. HA has superior restoration of functional motion compared to internal fixation, albeit with higher reoperation rates [6]. Timing also plays a critical factor in determining treatment, and the decision to perform HA should not be delayed. Early surgical intervention within 2 weeks of the inciting injury is a major factor contributing to positive short- and long-term postoperative functional outcomes [19, 39–42].

Low bone quality frequently present in the elderly population requires cemented stem components, while younger patients may be amenable to non-cemented stems [43]. Modular prosthesis combined with compression osteosynthesis allows for anatomic restoration of tuberosity alignment with the head and shaft, by variable offset of humeral height and retroversion [44, 45]. Natural humeral head retroversion ranges from 19° to 22°, and this should be properly restored when performing HA [46, 47]. In addition to inter-tuberosity fixation, stability of all components is achieved through tuberosity fixation to the selected prosthesis and to the humeral shaft through drill tunnels. Both the deltopectoral approach and the anterolateral deltoid-splitting approach have exhibited comparable success rates [5, 36]

Numerous studies of HA for complex humeral head fracture have demonstrated ideal long-term pain relief from subjectively reported patient data; however, functional outcome and the restoration of full range of motion are not consistent [19, 39]. Various major and minor factors have been shown to influence the outcomes of shoulder HA. It is a technically demanding surgery, and the restoration of natural humeral length, proper anatomic tuberosity reconstruction, as well as ideal retroversion are difficult to achieve [8, 36]. A functioning rotator cuff, avoidance of superior fixation, and anatomically reduced tuberosities are all essential for long-term outcome satisfaction. The most common complications leading to poor long-term outcomes are nonunion and fixation failure, ultimately leading to decreased function [39, 41]. Nonunion of the tuberosity is a relatively rare complication but is often correlated with severe life dissatisfaction and functional results. A retrospective study of 122 consecutive patients with 3- and 4-part fractures demonstrated significantly reduced

($p < 0.001$) Constant scores in patients with tuberosity nonunion ($n = 53$) compared to those with fully healed tuberosities ($n = 61$) at the 3-year follow-up point [48]. The procedure itself has been reported in certain cases to have relatively high failure rates and long-term dissatisfaction. A retrospective review of analyzing over 800 acute fractures treated with HA resulted in an average reported postoperative Constant score of 56.6, as well as poor functional outcomes with an average forward elevation of 105.7 degrees [40]. Similarly, in a retrospective review of 66 patients who underwent HA for proximal humeral fracture, authors noted a 50% incidence of tuberosity malposition and a patient dissatisfaction rate of 42% [19]. In the same study, average final recorded external rotation was 18°, and forward elevation was 101°. Retrospective reviews have confirmed secondary displacement of the greater tuberosity as the key parameter associated with poor clinical outcomes [42, 49, 50]. The maintenance of tuberosity alignment and proper union may also be influenced by humeral head height and version [41, 42] The upper margin insertion site of the pectoralis major tendon is a viable landmark for restoring proper anatomical humeral height and version; 5.6 cm has been recorded as the estimated average when tracing a line between this upper insertion site and the superior point of the humeral head [28]. Greater than 10 mm of humeral head lengthening has been associated with risk of tuberosity detachment due to the extreme tension placed on the supraspinatus [22, 28]. In addition to proper surgical alignment, poor long-term functional and subjectively reported results have been shown to correlate with increasing age and number of comorbidities, especially those related to poor bone stock and degeneration [22, 23].

While some studies have echoed similarities in demonstrating only moderate functional and range of motion improvement, the subjective outcomes reported by patients often exceed these objective shoulder outcomes. In a retrospective multicenter study of 167 shoulders undergoing HA, 79% of patients were asymptomatic or reported only minimal symptoms after the minimum follow-up of 1 year [51]. Of these same patients, only 35% patients were able to abduct past the horizontal plane at the same 1 year follow-up visit (mean abduction of 85–90°). A retrospective review of 82 consecutive patients undergoing HA for severely displaced proximal humeral fracture demonstrated minimal pain in long-term follow-up despite restricted strength and range of motion [24]. Another retrospective review of 71 shoulders at 2 years follow-up reported 93% of patients "pain-free" and satisfied with their results (average ASES 76.6) with average forward flexion of 128, external rotation 43, and internal rotation to L2 [42].

In acute settings HA is preferred over total shoulder arthroplasty (TSA) due to maintenance of normal anatomical landmarks and the avoidance of glenoid-related complications (e.g., component loosening, polyethylene disease). Using HA as the initial surgical management approach also leaves the option of secondary conversion to TSA in the scenario of mechanical failure [52]. Despite reports of functional limitations following HA, certain studies comparing the procedure to reverse total shoulder arthroplasty (RSA) for the treatment of proximal humeral fractures have demonstrated similarities in outcomes. A systematic review comparing the two procedures revealed similarities in subjective outcomes (ASES and Constant score) as well as a 4.0 times greater rate of postoperative complications in RSA in proximal humeral fractures not amenable to surgical fixation [50]. In contrast, while other studies support similarities in early reported outcomes between the two procedures, RSA has demonstrated superior long-term results [53].

16.7 Results/Outcomes: Reverse Prosthesis

Historically, HA was viewed as the gold standard for complex humeral fractures (specifically 3- and 4-part fracture) in the elderly population, and ORIF was seen as the best approach in younger surgical candidates [20, 21]. However, due to the reliance of these procedures—both HA and ORIF—on proper anatomical tuberosity healing, their outcomes have shown to be unpredictable and often result in the need for revision surgery [19, 54]. Reverse shoulder arthroplasty (RSA) has demonstrated long-term stability and patient satisfaction in comparison to HA and has become the surgical treatment of choice for complex humeral fractures, particularly in the elderly population. The RSA prosthetic component provides an advantage over HA by constructing a more balanced anatomical alignment, thereby stabilizing muscular imbalance arising from imperfect glenohumeral orientation. Moreover, the procedure provides the option of grafting bone to fix potential humeral offset [2, 41, 55].

In patients with preexisting shoulder cuff deficiency, clinically significant osteoarthritis, as well as fracture nonunion of the proximal humerus, RSA has exhibited promising short- and long-term results [16, 36, 38, 56]. In comparison to HA, RSA does not rely on proper tuberosity healing, and as such, patients with poor bone quality and osteoporotic degeneration are ideal candidates for the procedure. Additionally, when compared to both conservative management and alternate surgical approaches, RSA has shown superiority in complex 3- and 4-part humeral fractures and with patients suffering pseudoparalysis as a sequela from the injury [2, 7, 57].

While the effectiveness of RSA in comparison to HA has not reached full consensus, the results have nevertheless been promising. In a study comparing functional outcomes of both procedures, 5-year follow-up of patients demonstrated superior Oxford Shoulder Score (OSS) in the RSA group in comparison to HA; 6-month follow-up did not show any significant differences between the two groups [36]. In a network meta-analysis comparing treatment options for 3- and 4-part proximal humeral fracture, *Du* et al. selected Constant score reliability as the primary data point and found RSA to be superior in comparison to HA, ORIF, and conservative management [6]. In addition to patient-reported subjective data, RSA has exhibited superior functional outcomes in certain domains. In a randomized prospective study comparing RSA to HA, elderly patients (>70 years) who underwent RSA for acute proximal humeral fracture had better forward elevation (120.3 vs. 79.8), abduction (112.9 vs. 78.7), better pain scores, as well as lower revision rates at a mean follow-up of 28.5 months [18]. *Cuff* et al. also found superior patient outcomes of RSA in comparison to HA in a prospective randomized trial [58]. At a minimum 2-year follow-up, patients in the RSA group reported higher ASES and SST scores, superior radiographic evidence of healing tuberosities, as well as significant improvement in forward elevation.

RSA for the management of proximal humeral fractures has demonstrated promising results as a primary treatment method and has shown superior outcomes when used as a secondary form of intervention following failure of HA, ORIF, and nonsurgical management.

A key advantage of RSA in comparison to alternative surgical intervention is the significantly lower revision and complication rate. Failure of HA in proximal humeral fracture management is typically due to multiple factors: most commonly rotator cuff tear, general instability, glenoid arthritis, component malpositioning, and infection [23, 41, 42, 59]. Additionally, in contrast to HA and ORIF, the success of RSA is independent of anatomical tuberosity healing and, as such, does not risk the development of tuberosity malunion or nonunion [3, 19, 23]. As such, RSA is frequently selected as revision surgery following failure of primary HA [41, 52]. Holschen et al. followed 35 patients who underwent conversion to RSA following failure of primary HA for proximal humeral fracture [60]. At 61 months follow-up patients reported significant improvements in ASES and Constant scores, as well as increased forward flexion and abduction. Similarly, RSA can be used as a salvage procedure after failed ORIF for proximal humeral fractures [11, 61]. In a prospective study evaluating 53 shoulders with subjectively dissatisfactory outcomes following ORIF, patients who underwent RSA demonstrated a mean relative Constant score improvement of 32% at a minimum 2-year follow-up [11]. In certain situations where tuberosity union cannot be achieved ideally—particularly fractures involving elderly patients—cancellous block autografts have shown positive results as an augmentation to RSA [61].

Although RSA has demonstrated largely positive outcomes following proximal humeral fracture, the procedure itself is associated with certain complications. Scapular notching, glenoid component loosening, and synovitis are all commonly reported complications [62–64] Prosthetic replacement must also be considered in implants set in place for greater than 8–10 years [65, 66] Similar to other surgical procedures, common complications such as infection and severe postoperative pain can occur. Despite the possibility of complications, various studies have demonstrated promising short- and long-term outcomes for RSA, and it is increasingly being selected as the treatment of choice in the management of proximal humeral fracture.

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Operative Technique of Angular Stable Plate Fixation

17

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17.1 Introduction

The shoulder joint has the greatest range of motion because of its complex structure. The shoulder complex is composed of the clavicle, scapula, and humerus and is an intricately designed combination of three joints including the glenohumeral joint, the acromioclavicular joint, and the sternoclavicular joint. This structure connects the upper extremity to the axial skeleton. The subacromial region in which many motions occur and most of joint pathologies develop has recently been considered as the fifth joint [1] (Fig. 17.1).

The prolonged life span leads to proximal humerus fractures as a common clinical condition in general orthopedic practice [2]. Although the different rates have been mentioned in the literature, the commonly accepted view is that it accounts for 4–5% of all fractures [3, 4]. It can be confronted as perfectly recoverable fractures without surgery, as well as complex fractures or fracture-dislocations in which even osteosynthesis is inadequate and which may require arthroplasty [5]. The fact that specialists interested in this subject have wide knowledge on the anatomical structure of the region and the type of the fracture as well as on the surgical approach are useful for achieving the best outcome in treatment.

Although proximal humerus fractures are seen at all ages, they frequently appear at older ages. In a 5-year prospective study involving 1027 patients, Court-Brown et al. [6] found that the mean age was 66 years and that the incidence of proximal humerus fractures was 3 times higher in women than that in men. In another study involving 586 patients, it was shown that the incidence of proximal humerus fractures was 4 times higher in women than that in men [7].

When risk factors for proximal humerus fractures are investigated, low bone mineral density and increased risk of falls can primarily be counted. In the elderly, proximal humerus fractures often occur due to low-energy traumas in the home. When the reasons of proximal humerus fractures are examined, low-energy falls constitute a large part (87%). Direct traumas such as falls from height (4%), traffic accidents (4%), sports injuries (4%), and assaults (1%) can cause proximal humerus fractures [6].

Although many direct or indirect factors may cause proximal humerus fractures, the trauma energy, biomechanics of injury, and anatomical features and vascularity of the humerus affect fracture type, classification, and treatment. The treatment to be administered to the patient should maximize the functional expectation of the patient and reduce the pain to the lowest level.

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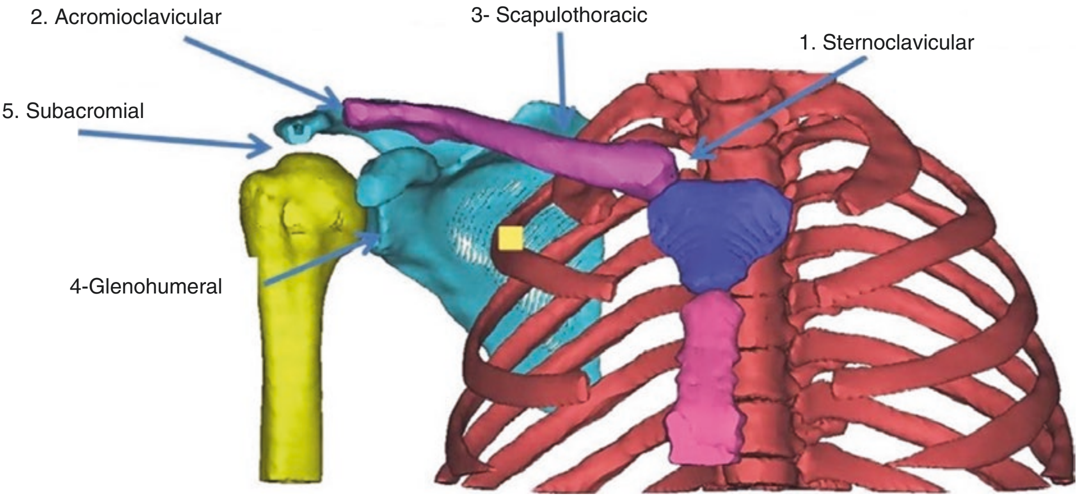

Fig. 17.1 Five joints around the shoulder (Kanatlı U)

17.2 Pathoanatomy

The glenohumeral joint is the most mobile joint in the human body due to the excellent fit between bones, muscles, and soft tissues. It is mainly located between the humerus, scapula, and clavicle and connects the upper extremity to the axial skeleton. This provides the range of motion with four joints. The subacromial region in which many motions occur and most of joint pathologies develop has recently been considered as the fifth joint. The anatomy of the shoulder girdle can be examined as three parts as bones, muscles, and soft tissues (joints and ligaments). Bone structure is comprised of the proximal humerus, scapula, and clavicle.

The clavicle is one of the main bones of the glenohumeral joint and is anchored to the axial skeleton by a single, highly mobile joint. It plays a role in transmitting compression forces from the upper limb to the axial skeleton. The scapula is a large, triangular flat bone that is parallel to upper posterior thorax and extends from second to seventh ribs. The scapula lies approximately 30° forward of the coronal plane. The acromion and clavicle form the acromioclavicular joint. The subacromial space is between the acromion and the head of the humerus where subacromial impingement might be seen. The supraspinatus tendon exits through the joint from a space as a normally 9–10 mm in the coronal plane. The lateral corner of the scapula makes the main shoulder joint with the humeral head through the pear-shaped glenoid cavity. It has a retroversion angle of about 2–7°. The glenoid has also a superior inclination of 0–5°. The coracoid process extends forward and outward on the glenoid cavity.

The proximal humerus which articulates with the scapula at the glenohumeral joint consists of the head, neck, and greater and lesser tubercles. The supraspinatus, infraspinatus and teres minor muscles attach to the greater tubercle. On the front side, the subscapularis muscle attaches to the lesser tubercle. The bicipital groove between these two tubercles passes over the long head of the biceps muscle and attaches to the glenoid fossa [8, 9]. The angle between the humeral head and the humeral shaft is approximately 130–150°. The angle between the humeral body and the anatomical head of the humerus is approximately 45°. The humeral head is retroverted approximately 30° (0–50°) with respect to the epicondylar axis. The glenoid joint surface is much smaller than the humerus. Therefore, when the arm is lifted upward, the glenoid slides lateral and forward to hold the humeral head in the glenoid socket, and the scapula rotates forward and upward [10].

The shoulder joint, which has the greatest range of motion in the human body, performs its ability with three diarthrodial joints: the glenohumeral joint, the acromioclavicular joint, and the sternoclavicular joint. Because the scapula can move on the chest wall, the scapulothoracic joint, which is considered to be a functional joint, can be included in them.

All four rotator cuff muscles extend from the scapula to the proximal humerus. The biceps tendon and glenohumeral ligament are the most important components of shoulder stability together. They provide this stability with creating concavity compression by contracting together in the coronal and transverse planes (dynamic stability). The deltoid and supraspinatus muscles contract in the coronal plane during abduction and provide both motion and dynamic stability by compressing the humeral head to the glenoid. The teres major and minor muscles originate at the lateral part of the scapula. The teres minor muscle attaches to the greater tubercle of the humerus and performs an external rotation of the humerus. The teres major muscle attaches to the lesser tubercle of the humerus and performs extension and adduction of the humerus. While the supraspinatus muscle is innervated by the suprascapular nerve, the axillary nerve innervates the teres minor muscle and the subscapular nerve innervates the teres major muscle [9] (Fig. 17.2a, b).

Six arteries have been found to regularly contribute to the arterial supply of the rotator cuff tendons: suprascapular, anterior circumflex humeral, posterior circumflex humeral, thoracoacromial, suprahumeral, and subscapular. While all blood vessels of the supraspinatus tendon are filled with blood during shoulder abduction, the last 1 cm segment (critical zone) of tendon insertion site is filled with blood during shoulder adduction. The vascular supply of the proximal humerus is derived from the axillary artery, the anterior humeral circumflex artery (AHCA), the ascending branch of the anterior humeral circumflex artery, the arcuate artery, the posterior humeral circumflex artery (PHCA), the ascending branch of the posterior humeral circumflex artery, and the branches of the thoracoacromial artery and the suprascapular artery supplying the rotator cuff muscles. The fracture line passing through the humeral neck affects blood flow to the humeral head. In short fractures with medial calcar, all vascular structures that make anastomosis to the arcuate artery supplying the humeral head are injured. In fractures with a medial calcar greater than 8 mm in length, the head is supplied by preserving the ascending branch of the posterior humeral circumflex artery [9, 11, 12]. Although the AHCA is classically considered the most important structure that supplies the proximal humerus, recent studies have emphasized that the PHCA is at least as important as the AHCA. According to this study, since 64% of the head is supplied by the PHCA, it is emphasized that the risk of avascular necrosis is low in well-treated fractures in which bone integrity is preserved [13] (Fig. 17.3a–c).

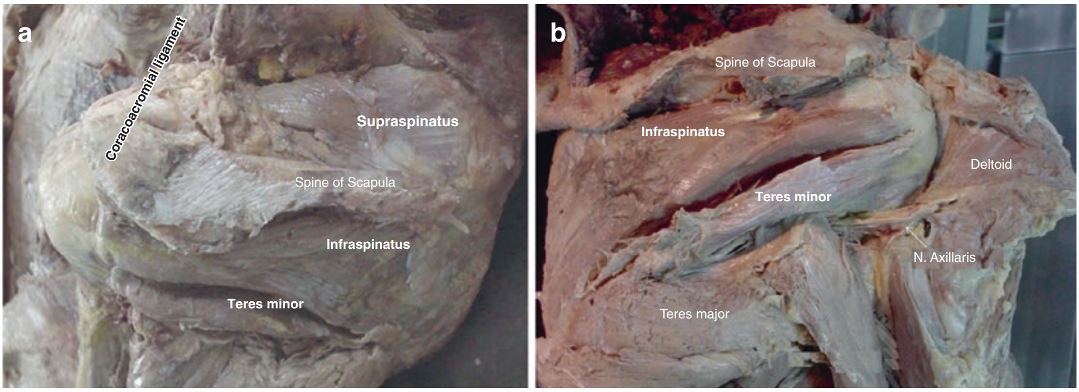

Fig. 17.2 (**a**) The superior view of rotator cuff. (**b**) The posterior view of rotator cuff (Kanatlı U)

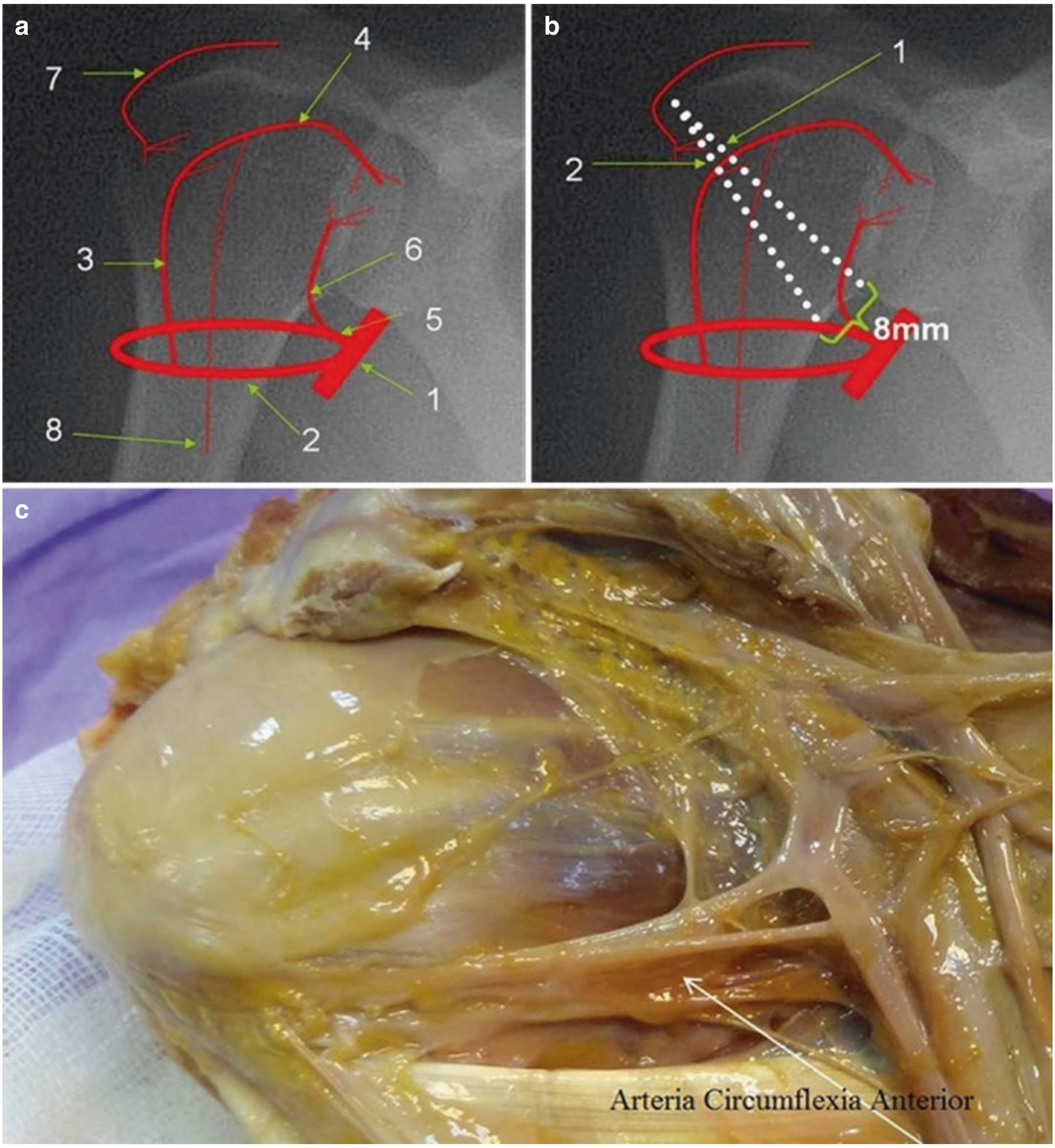

Fig. 17.3 (**a**) The vessels of proximal humerus. (1) Arteria axillaris, (2) AHCA, (3) the ascending branch of AHCA, (4) arcuate artery, (5) PHCA, (6) the ascending branch of PHCA, (7) toracoacromial and suprascapular branches, (8) intraosseous metaphyseal branch. (**b**) Short medial calcar fractures affect AHCA and long medial calcar fractures, that is, longer than 8 mm affect PHCA. (**c**) AHCA

In studies of avascular necrosis conducted according to the four-part Neer classification system [14], it has been emphasized that the fracture needs soft tissue support, and it has been reported that there is a difference in the rate of avascular necrosis according to different fracture types.

17.3 Clinical Evaluation

As in all types of fractures, the complete history and physical examination are also important in proximal humerus fractures. While it is focused on the shoulder region, injuries that may accompany the shoulder girdle, cervical region, and upper extremity should not be neglected.

True AP, lateral, or scapular Y views and axillary views are helpful for evaluation following physical examination. Computed tomography is the most appropriate evaluation method to determine the type of fracture and to plan treatment. Magnetic resonance imaging can be used if malignancies or rotator cuff injuries are suspected.

The AO classification (which divides proximal humerus fractures described in the previous sections into the classic 27 subgroups) or Kocher, Codman, Jacob, and Ganz systems can be used in the classification of fractures. The Neer classification is the most commonly used scheme for proximal humeral fractures. It separates fractures into fragments according to 1 cm of displacement or 45° of angulation and divides the proximal humerus into four conceptual and functional "parts" [14, 15].

Many humerus fractures can be treated with nonsurgical methods due to the low incidence of displacement. Besides shoulder sling, shoulder exercises are recommended as early as possible.

The basic functional status of the patient before fracture, dominant hand, and adaptation to rehabilitation program affect the treatment method to be chosen. In proximal humerus fractures, clinical conditions having an absolute requirement for surgery include open fractures and progressive neurovascular deficits. In addition, surgery should be considered urgently for fracture-dislocations that cannot be reduced. Other clinical conditions that require surgery include fractures being severely displaced or unstable after closed reduction, three- to four-part fractures, and greater tuberosity fractures greater than 5 mm preventing rotator cuff function [4, 5, 16].

17.4 Aproaches to the Shoulder Joint

17.4.1 Deltopectoral Approach

The anterior approach to the shoulder joint is the most commonly used surgical approach. Many regions of the joint are easily accessible.

The patient is placed in the supine position on the operating table. The operative extremity is approached to the edge of the operating table so that it can move freely. By placing an elevation between the scapula and the spine, the operative extremity is raised forward of the body. The venous pressure is reduced with the head of the table elevated to 30–45°, thus helping bleeding control. The patient's head is slightly turned to the nonoperative extremity and is then fixed (Fig. 17.4).

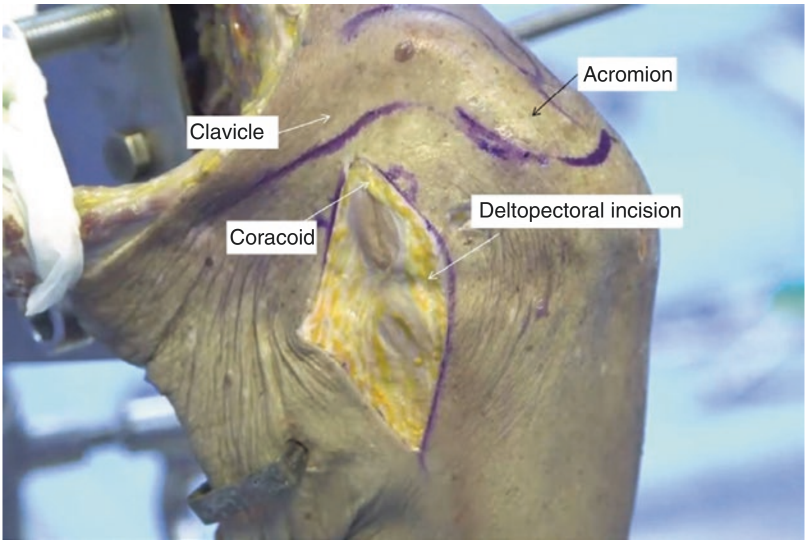

Fig. 17.4 The view of deltopectoral approach (Kanatlı U)

The skin incision starts from underneath the clavicle and the lateral border of the coracoid process and is obliquely advanced about 10–12 cm distally throughout the deltopectoral interval. After it is passed through the subcutaneous tissue, it is advanced from the medial border of the coracoid process toward the deltoid insertion. The cephalic vein is identified and released. It is preferably taken to the lateral or medial side. Since the cephalic vein runs in the deltopectoral groove, it helps us find the deltopectoral space. After the deltoid and pectoralis major muscles are removed, the deep fascia confronts us when the deep dissection is performed. When the deep fascia that is very thin is opened, the coracoid process and conjoint tendon confront us. When the conjoint tendon is dislocated medially with a blunt retractor, the minor tubercle and subscapularis muscle are reached. In addition, the cephalic vein runs through the intervenous plane (between the deltoid muscle innervated by the axillary nerve and the pectoralis major muscle innervated by the lateral-medial pectoral nerves). While the proximal humerus is reached under the capsule, the neck and distal part can be reached with the help of a blunt retractor [17].

17.4.2 Lateral (Deltoid Split) Approach

It is an approach that can be used to reach the head and neck of the humerus. However, caution should be taken because of the course of the axillary nerve in the deltoid muscle in the distal part. It is used mostly in large tubercle fractures, in surgeries associated with the subacromial bursa, and in rotator cuff repair [18].

As in the deltopectoral approach, the patient is placed in the supine position on the operating table, and the head of the table is elevated to 30–45°. An approximately 5 cm skin incision is made distally to the lateral border of the acromion. The incision should not be extended since it runs between the axillary nerve and deltoid fibers in the distal part. After the deltoid fibers are separated by the raphe connecting the anterior and lateral fibers by a blunt retractor, the subacromial bursa can be reached underneath the acromion. The bursa can be opened with a longitudinal incision to reach the lateral part of the humeral head and the rotator cuff muscles attached to the greater tubercle under the deltoid muscle (Fig. 17.5).

The axillary nerve that runs transversely 5–7 cm distal to the edge of the acromion is the

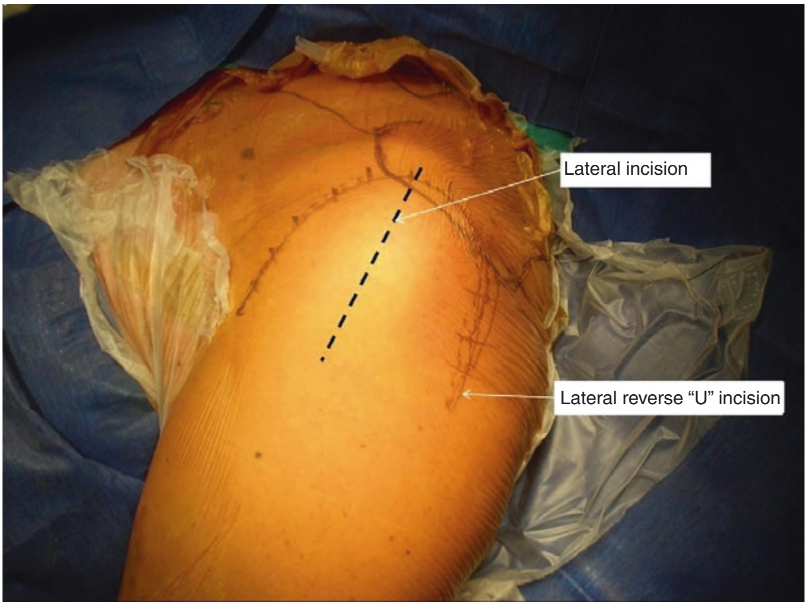

Fig. 17.5 The view of lateral approach (Kanatlı U)

most important structure to be protected. If the nerve is cut, there is denervation in the anterior deltoid fibers and is sensory loss in the skin overlying the lateral side of the deltoid muscle.

17.5 Surgical Technique

In patients in whom we consider plate and screw fixation, our preference is the deltopectoral approach in the beach chair position. After the approach is applied as mentioned above, in order to primarily provide the proper angle of view and to fully understand the anatomy of fracture, sufficient amount of soft tissue dissection is performed with an elevator or a finger so that the soft tissue support of fracture parts is not impaired. Then, the position, size, and bone quality of fracture fragments as well as the tendons of rotator cuff muscles and the long head of the biceps tendon are evaluated before reduction. After the anatomy of fracture is fully understood, No. 5 nonabsorbable sutures are placed into the rotator cuff tendons in such a way as to include the bone close to the bone-tendon junction as possible as by considering the fracture fragments (in order to help reduction if there is a displaced tuberosity fragment). Because these sutures are used for the manipulation and reduction of fracture fragments and are fixed to the plate after plate placement, they create resistance to the deforming forces of the rotator cuff vector [19].

It is tried to be reduced by the help of an elevator or a finger. In order for the vector of the pectoralis major muscle to not prevent the reduction, the pulling force can be reduced by moving the arm in adduction and flexion [20]. K-wires are used to provide temporary stabilization of particularly proximal parts before plate placement. The medial head-neck junction of the humerus should not be separated as much as possible, and the anterior circumflex humeral artery, which is important for the blood supply of the humeral head, should be preserved. The most important point to keep in mind for maintenance of stabilization in the reduction is to maintain medial continuity. Then, the length of the plate is adjusted according to the extension of the fracture to the humerus shaft. If the fracture configuration is appropriate, compression is first applied by pulling the humerus shaft toward the lateral side with non-locking cortical screws through the oval hole of the plate corresponding to the humerus shaft. The proximal parts are reduced by the manipulation of sutures during compression. When compression is completed, the greater tuberosity appears to be compressed in the proximal part of plate. The anterior-posterior, lateral, and oblique views are taken with the help of C-arm fluoroscopy, and the reduction and plate position are assessed. It should be kept in mind that one of the most important points in maintenance of reduction is to provide medial support. The ideal placement of locking plate used for the proximal humerus is the lateral side of the proximal humerus so that the anterior edge of the plate is as close as possible to the posterolateral aspect of the biceps tendon. It is very important that the proximal of the plate is completely inserted into the tuberosities so that it does not extend to the superior. Superior placement results in subacromial impingement. Therefore, when the first screw is placed through the oval hole of the plate corresponding to the humerus shaft, the plate may be displaced proximally and distally. If reduction and plate position are appropriate, unicortical locking screws are inserted into the humeral head (at least five or six divergent screws). While the proximal locking screws are inserted and the first cortex is passed by the drill, it is advanced until the subchondral area by depth gauge and K-wires. It should not be forgotten that at least two screws placed along the calcar are important in terms of maintaining stability. Then, the screw holes at the distal part are filled with locking or cortical screws, taking into account bone quality. The anterior-posterior, lateral, and oblique views are taken with the help of C-arm fluoroscopy, and reduction and screw length are checked. Before the procedure is terminated, proximal sutures are fixed to the plate to reinforce stability. If there is a tear in the rotator cuff, it should be repaired. The hemovac drain is placed, and the skin and subcutaneous tissues are closed (Fig. 17.6a–d).

17.5.1 Two-Part Surgical Neck Fractures

Surgical treatment is planned for especially patients with an angle >45°, although they are mostly fractures followed by closed reduction. No. 5 nonabsorbable sutures that are inserted into the rotator cuff tendons during reduction in such a way as to include the bone close to the bone-tendon junction are used to control the proximal part. Anatomical reduction can be achieved by inferior traction of sutures in the reduction of the humeral head in the varus position. Then, the plate is placed on the anterolateral surface of the humerus to adjust the plate position on the greater tuberosity. The plate is fixed onto the humerus shaft with the help of a bone clamp. While reduction is maintained, K-wires are inserted through the K-wire holes in the proximal plate. Fracture reduction and plate position are evaluated by C-arm fluoroscopy. The screws are inserted as described above.

17.5.2 Three-Part Proximal Humeral Fractures

Three-part proximal fractures of the humerus are tuberculum majus fracture in addition to surgical

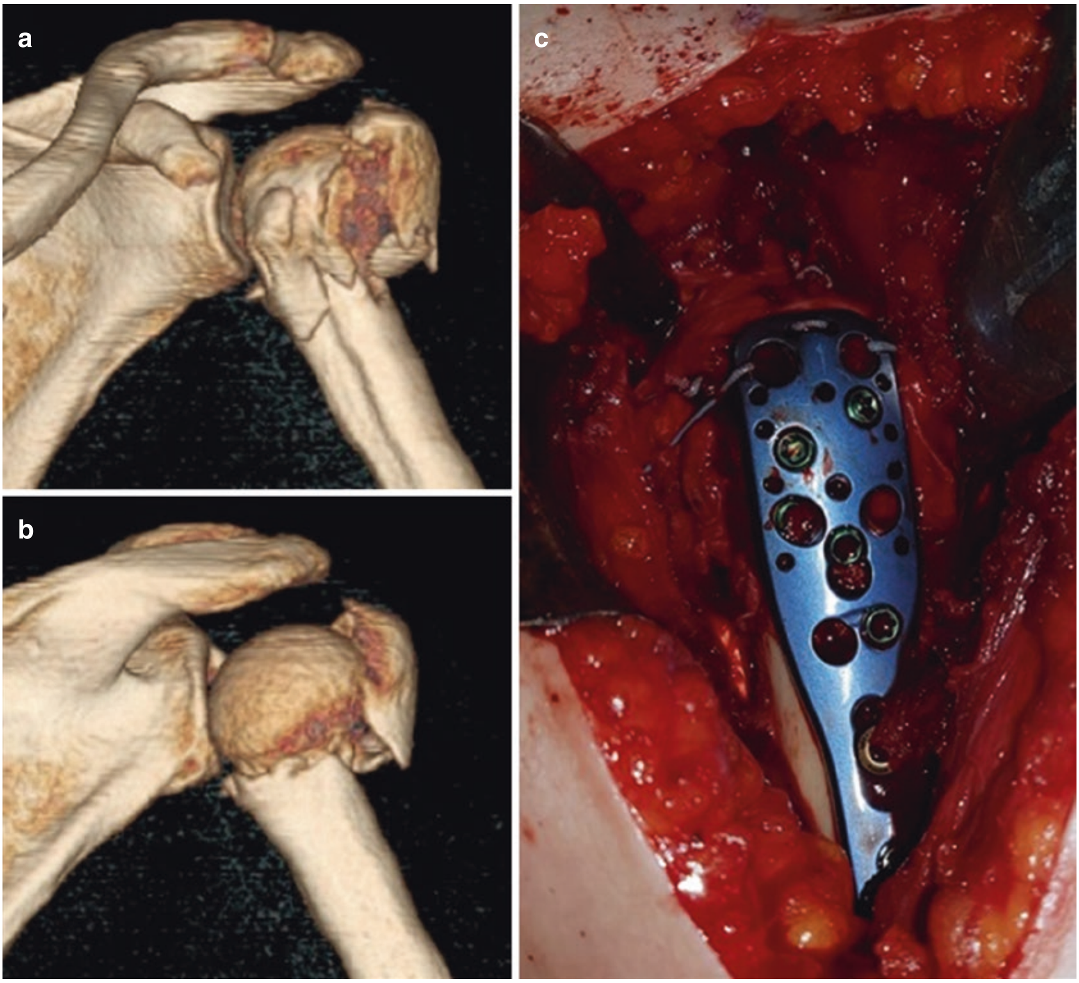

Fig. 17.6 A 67-year-old women four-part proximal humerus fracture. Preoperative, anterior (**a**) and posterior view (**b**) of the fracture site. 3D CT scan (**c**). Anterior radiogram after plate fixation (**d**). Lateral radiogram after plate fixation (**e**)

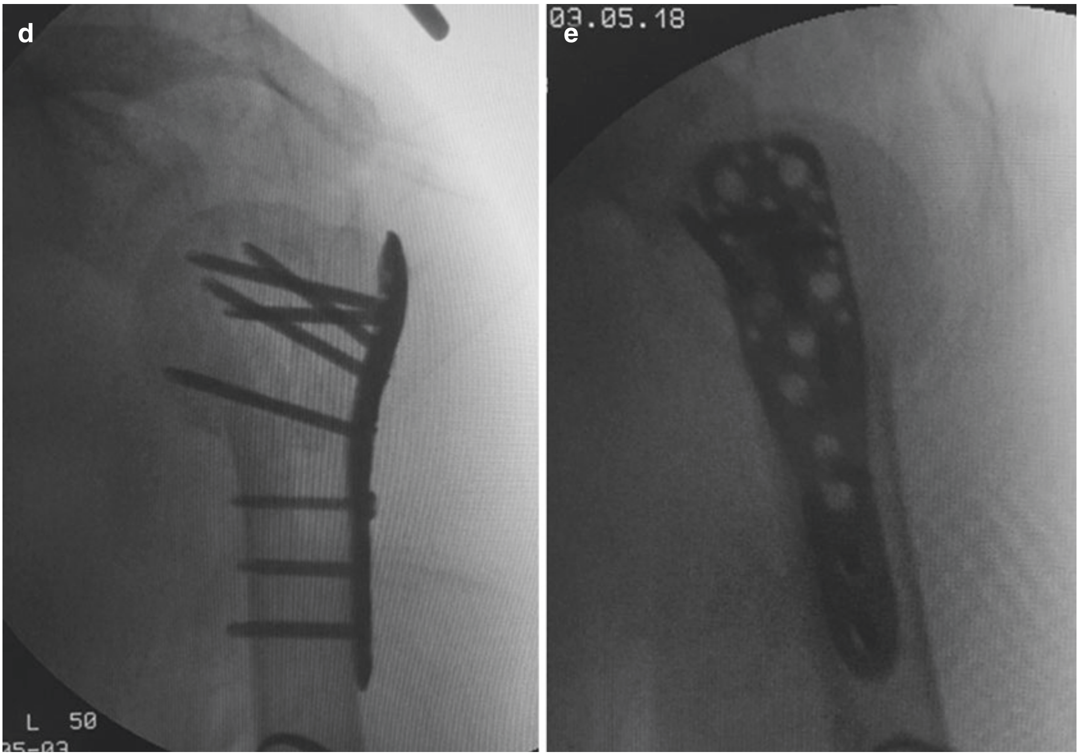

Fig. 17.6 (continued)

neck fracture [21]. Fracture fragments are displaced according to the vector direction of the muscles they attach to. The tuberculum majus moves into the superior and external rotation, the humeral head moves into the internal rotation, and the humeral shaft moves into the medial. The humeral head may be in the varus or valgus position. If the humeral head is in the valgus position, clinicians should be very careful for traction and manipulation of sutures during reduction, and the stable medial periosteal cortical hinge of the head should be preserved. If the humeral head is in the varus position, it attempts to raise the humeral head from the inferior part with an elevator or a finger to bring the humeral head to its anatomical position. As mentioned above, fracture reduction should be completed, and plate should be placed. In multipart fractures, biceps tenodesis may be useful for postoperative pain control and early motion tolerability.

17.5.3 Four-Part Proximal Humeral Fractures

Four-part proximal fractures of the humerus are composed of humeral head, tuberculum majus, tuberculum minus, and humeral shaft fractures. If at least 8 mm of space is preserved on the medial aspect of the humeral head, or if there is medial separation less than 2 mm, it can be said that blood flow to the humeral head is not deteriorated in general [22, 23]. Open reduction and locking plate osteosynthesis should be preferred in these patients. It is reported that blood supply can be achieved after anatomical reduction and stable fixation provide medial continuity in patients with radiologically impaired blood flow [24]. For this reason, the first choice in young patients should be anatomical reduction and locking plate osteosynthesis, regardless of the type and configuration of the fracture.

If especially osteoporotic patients and patients with poor medial continuity have doubts about maintenance of fracture reduction, the fibular allograft is placed into the humeral head and shaft in selected patients to support maintenance of the normal anatomical position [25].

The humeral head should be anatomically reduced for successful results. We never want that the humeral head is in the varus position. The varus position is directly related to major complications such as avascular necrosis and screw cutout [26]. In particular, attention should be paid that the suture which is passed through the anterior aspect of the subscapularis tendon is not passed through the rotator interval due to the possible limitation of joint movement.

17.5.4 Impacted Valgus Fractures

It can be defined as that metaphyseal bone impaction results from the humeral head hitting the glenoid due to compressive loading during arm abduction mostly in osteoporotic patients. In particular, patients with preserved posteromedial periosteum (the posterior humeral circumflex artery) have a lower risk of avascular necrosis [27]. In general, the prognosis is much better than four-part proximal humeral fractures [28]. During reduction, impacted humeral head is raised indirectly through the tubercles. After the appropriate height is reached, the reduction of the tubercles is performed with sutures passing through the tubercles. Cancellous bone defects due to impaction in the humeral head should be supported by the graft if they negatively affect the stability of reduction. Locking plate fixation should also be preferred for this type of fracture.

17.6 Postoperative Rehabilitation

After surgery, the arm is placed in a sling or an immobilizer (4–6 weeks). The elbow, wrist, and hand movements are actively started on the first day after surgery. Considering the fracture type, fixation stability, and bone quality, shoulder movements except for pendulum exercises are not allowed for 2–4 weeks. Passive movements are started after 2–4 weeks, active movements and stretching exercises are started after 6–8 weeks, and strengthening exercises are started after 10–12 weeks. It is important to observe adequate fracture healing on the radiograph during muscle-strengthening activities.

The early initiation of shoulder movements is of course very important for rapid functional recovery. However, early movement increases the risk of reduction loss, screw pullout, and screw penetration. For this reason, it is important to plan the time to start shoulder movements considering all the parameters.

17.7 Outcomes

Since conventional plates (T-buttress, small fragment cloverleaf, one-third tubular, distal tibial) previously used in proximal humerus fractures are non-locking plates, nonunions and malunions related to implant failure have been frequently observed especially in patients with poor bone quality [29–31]. It has been reported that there is an avascular necrosis rate of up to 35% and an implant failure rate of up to 25% in conventional plates [30, 32, 33]. Locking plates we use today provide better screw fixation quality and angular stability especially in osteoporotic bone, which are the most important advantages [34, 35]. Since they provide more stable reduction and fixation, another advantage is that they allow for early movement.

Gaheer and Hawkins [36] reported that 90% of 56 patients with displaced three- and four-part fractures of the proximal humerus who were operated with locking plates returned to the preinjury level and that only four patients had complications (infection, screw penetration, persistent stiffness, and mechanical failure) [36]. Many studies have shown high fusion rates and good functional results with locking plates [37–41]. In a prospective study evaluating functional outcomes of 64 patients undergoing locking plate fixation due to a proximal humerus fracture, the overall complication rate of 35.9% (including the screw penetration rate of 7.6%) was reported

[42]. In this study, it was found that complications were significantly higher in patients with four-part fractures and without medial continuity. Solberg et al. have reported that important markers for functional outcomes after application of the locking plate in elderly patients with three- or four-part proximal humerus fractures are the amount of angulation at the humeral head due to trauma and the amount of the metaphyseal segment remaining intact in the articular fragment [43]. They reported that patients with impacted valgus fractures with a metaphyseal segment length >2 mm had a better functional outcome [43]. In a prospective multicenter observational study of Sudkamp et al. evaluating 187 patients undergoing locking plate fixation due to a proximal humerus fracture, they found that the functions of the operative shoulder reached normal level at 1-year follow-up after surgery in 85% of patients [41]. They reported that 34% of patients had complications and that 40% of the complications occurred due to incorrect surgical techniques. Locking plate applications with good functional outcomes reduce complications when they are performed carefully with appropriate surgical techniques [44]. In the study of Ricchetti et al. evaluating 52 patients undergoing locking plate fixation due to a proximal humerus fracture, they reported good functional outcomes, a major complication rate of 15% (nounion, varus malunion, avascular necrosis), and a minor complication rate of 6% (impingement, hematoma) [45]. They attributed the absence of intra-articular screw penetration in any patient to the fact that the screw length was adjusted as 5–10 mm shorter than the subchondral bone of the humeral head.

17.8 Complications

Possible complications after locking plate applications in proximal humerus fractures include technical errors, poor bone quality, lack of anatomical reduction (especially lack of medial cortical continuity), and early aggressive rehabilitation.

Malunion related to the humeral head is generally well tolerated [46]. However, impingement and limitation of movement may occur due to malunion related to the tuberosity [47]. Arthroscopic tuberoplasty can be performed to prevent impingement and increase the range of motion if the deformity in the tuberosity is small enough to require osteotomy and fixation. Although proximal humerus fractures do not usually have a fusion problem, nonunion may be seen in surgical neck fractures especially in osteoporotic patients.

Screw penetration that is the cause of limitation of joint movement and pain can be seen with an incidence rate of 16% [48]. Patients with screw penetration were reported to be older and more osteoporotic and to have no medial continuity. Since abrasion and degeneration on the articulating surfaces of the glenohumeral joint over time with movement are the most important problems, the surgery should be planned as soon as if such a situation is detected. Providing anatomical reduction and medial continuity also reduces the risk of varus collapse and screw cutout [49, 50].

The avascular necrosis of the humeral head is associated with fracture type and fixation stability. The risk of avascular necrosis is increased in patients with three- or four-part proximal humerus fractures with a medial metaphyseal segment <2 mm [51]. In addition, careless and excessive soft tissue dissection may cause iatrogenic avascular necrosis. Avascular necrosis can develop 15–20% after three-part fractures and 50–75% after four-part fractures [11]. Avascular necrosis is a complication that is directly related to pain and functional poor outcomes. Surgery should not be considered as possible as in patients without pain and limitation of movement but with radiologically positive avascular necrosis.

The risk of stiffness in patients undergoing the locking plate is related to the amount of the dissected soft tissues and the duration of immobilization. The risk of possible extraarticular soft tissue adhesions is reduced with early rehabilitation after stable fixation.

After the application of locking plate in proximal humerus fractures, excellent soft tissue coverage and good vascular supply of the region reduce the risk of infection. Clinical trials have reported that the incidence of infection after locking plate is 1–9% [38, 41, 48, 52].

Other possible complications include neurovascular injuries due to direct or indirect injury, heterotopic ossification, hemarthrosis, and instability due to deltoid/rotator cuff dysfunction.

17.9 Conclusion

Even if the locking plate gives very good results in proximal humerus fractures related to the most mobile joint in the human body, it should be kept in mind that 80% of these fractures can heal without problems with conservative follow-up. The most important criterion for success in patients undergoing surgery is stable anatomical fracture reduction that can provide medial support in particular. Locking plates are necessary for osteosynthesis in patients with unstable osteoporotic multipart fractures. Proper rehabilitation is essential for success as it is in other treatment modalities.

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18

Complications of ORIF in Proximal Humeral Fractures

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18.1 Introduction

The incidence of proximal humeral fractures (PHFs) has increased considerably during recent decades [1]. After distal forearm and hip fractures, PHFs represent the third most common fracture type [2, 3]. More than 70% of patients with these fractures are older than 60 years of age, and they are almost two to three times more common in women than in men [4]. In the elderly population, most of these fractures are related to osteoporosis [5]. Non-displaced fractures and fractures with minimal displacement and adequate stability usually are successfully treated non-operatively [6].

In contrast, the treatment of displaced and unstable fractures remains controversial. The optimal management and expected outcomes of displaced PHFs vary on the basis of the characteristics of the fracture and the patient, including but not limited to the number of parts of the fracture, predicted viability of the head fragment and bone quality of the patient. A variety of surgical options have been proposed, including open reduction and internal fixation (ORIF) with proximal humeral plates, hemiarthroplasty, and percutaneous or minimally invasive techniques such as pinning, screw osteosynthesis and intramedullary nails [7–14].

ORIF for PHFs (involving humeral head, neck and proximal shaft) represents a good option in selected patients, with encouraging clinical and functional outcomes reported in the literature. Several complications related to ORIF of the proximal humerus have been described over the years. The aim of this chapter is to present an overview of the complications affecting ORIF in proximal humeral osteosynthesis, with some tips and tricks to avoid them.

18.2 Complications of ORIF for PHFs

Although significant advances have been made in the operative management of PHFs, complications still occur not infrequently. Many complications, both local and systemic, are reported after surgery for PHFs [15]. Complication rates after ORIF have been reported to be high despite technologic improvements such as locked plating [16, 17]. Fracture reduction and anatomic healing become more difficult with a higher number of fracture fragments, with greater displacement

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and comminution of the fragments. Thus, 3-and 4-part fractures, especially in elderly patients with osteopenia, are particularly challenging [18]. Angular stable implants with rigid fixation of the head and shaft screws have been introduced to specifically address comminuted fractures and improve fixation in osteopenic bones. Today, these implants are increasingly used and widely accepted, but a notable number of complications, with rates of up to 36%, are also reported with a rate of revision surgery of up to 25% [19–22]. Complication rate has also been correlated to surgeon's experience. Patients who underwent ORIF at low-volume hospitals had a 90-day readmission rate of 16% compared with medium-volume (15%) and high-volume (14%) hospitals ($p = 0.002$) [15]. Postoperative management can also influence the 90-day readmission rate. Patients who were discharged home with home health services had a 19% greater risk of readmission than patients who were discharged home without ancillary support, whereas patients who were transferred to a rehabilitation or nursing facility had nearly a twofold greater risk of readmission [15]. Complications after ORIF of the proximal humerus can be broadly categorized in three subgroups: (1) alterations of the healing process (malunions, non-unions, avascular necrosis of the humeral head and heterotopic ossifications), (2) hardware failure (screw loosening and pull-out, implant failure, malpositioning and articular perforation) and (3) others (surgical infections, neurovascular lesions, etc.).

18.3 Complications Related to Alterations of the Healing Process

There are various predisposing factors for the onset of complications related to the healing process after ORIF, including general factors and fracture-site-specific factors [21]. The general risk factors for the onset of complications during healing include old age (particularly in females because of hormonal imbalances after menopause); uncontrolled diabetes; neurovascular problems (some of these have been observed to decrease the formation of collagen and cells involved in formation and maturation of bone callus); osteoporosis; muscle atrophy; living habits (diet, smoking, alcohol); and drugs, such as non-steroidal anti-inflammatory drugs (NSAIDs) taken for pain control after surgery. Local risk factors are related to the trauma. High-energy traumas are associated with more comminution and dislocation of the bone fragments and significant soft tissue and vascular system involvement, which impacts greatly on blood support at the fracture site [23].

18.3.1 Malunions

Malunion may result from a superiorly displaced or externally rotated greater tuberosity, medialization of the lesser tuberosity, varus or valgus neck-shaft angle or a combination of these factors. The described mechanisms and applied loads can result in bone, joint or combined bone and joint malunion, and they can consequently alter the articular function.

The misalignment and/or remodelling of the humeral head results in joint incongruity, which does not provide optimal mechanical conditions; this can lead to stiffness due to the retraction of the capsule and ligaments or impingement of the surrounding structures during shoulder motion and may alter rotator cuff tension. Three situations may be at the origin of the malunion after ORIF as described by Duparc et al. [24]: (1) problems with the initial reduction, (2) problems with the fixation leading to secondary displacement (3) and problems with the protection/stability leading to secondary displacement.

The main symptoms of malunion are pain and limited joint range of motion. The pain must be characterized as precisely as possible. Any isolated signs of subacromial impingement or long head of biceps involvement can direct the therapeutic decision. Examiner should take in mind that malunion at different sites can lead to different pathological scenarios. A patient with malunion of the greater tuberosity may exhibit perceived weakness caused by a shortened functional offset of the posterosuperior rotator cuff.

Anterior instability could be also referred by a patient presenting with greater tuberosity malunion because of the posterior abutment. Malunion of the lesser tuberosity may result in weakness in internal rotation. Alterations in the intertubercular groove, involving both tuberosities, are often associated with exceptionally painful, chronic biceps tendinopathies. Electromyographic studies should be performed if a nerve dysfunction is suspected. Radiographic evaluation includes three views of the shoulder: a true AP view in the scapular plane, an axillary view and a scapular lateral view. Most malunions will be detectable in these images. Although displacement of the articular surface or tuberosity is evident on plain radiography, the relationship between the fragments may not be completely well delineated. Compared with plain radiography, CT scan provides more details: bony malunion, articular incongruity and the degree of tuberosity displacement are more clearly visualized [25]. MRI is recommended for detecting osteonecrosis and evaluating soft tissue structures, including the rotator cuff, long head of the biceps tendon and labrum. Proximal humeral malunions have been traditionally classified according to Beredjiklian [26]. This classification evaluates radiographical aspects, focusing on different anatomical sites disruption. Type I malunion includes misalignment of the greater or lesser tuberosity greater than 1 cm from the anatomic position. Type II is distinguished by articular surface incongruity, and type III involves articular surface malalignment with malunion of the tuberosities (>1 cm) and humeral head relative to the shaft.

Boileau et al. [27] proposed another classification system that included the sequelae of displaced PHFs and the implications for surgical management with reverse shoulder arthroplasty (RSA), dividing them in two categories. Category 1 refers to intracapsular injuries and the sequelae of impacted fractures. This category comprises type I, characterized by humeral head necrosis or impaction, and type II with chronic dislocations or fracture-dislocations. In this category, implantation of RSA for the treatment of malunion will not require greater tuberosity osteotomy and provide good and predictable results. Category 2 comprehends the sequelae of extracapsular fractures, dividing them in malunion of the surgical neck (type III) and in severe malunion of the tuberosity (type IV). In this category, tuberosity osteotomy during RSA implantation will be mandatory; however in types III and IV, surgical procedure is characterized by poor and unpredictable results.

Based on these classification systems, the various cases of malunion can be grouped in the following manner: (1) bone malunion (tuberosity, inter-tuberosity, subtuberosity), (2) joint malunion (with or without associated humeral head osteonecrosis) and (3) combined bone and joint malunion (with or without associated humeral head osteonecrosis). Orthopaedic surgeons should accurately evaluate all the features of the patient affected by proximal humeral malunion after ORIF to adequately manage this complication. Not only the fracture characteristics but also the patient’s general condition, functional request and postsurgical compliance should be evaluated. In patients with low activity levels, tolerable pain, significant comorbidities that preclude surgical intervention and in those who are unable to comply with rehabilitation and/or who are willing to accept some loss of shoulder function, nonsurgical management of proximal humerus malunion has been found to provide acceptable results [28–30]. Physical therapy (with NSAIDs and occasional cortisone intra-articular injections) may be useful in low demanding patients to progressively strengthen shoulder musculature and maximize ROM. For patients with persistent dysfunction or pain secondary to malunion after ORIF, surgical intervention may improve quality of life. Patients should be accurately informed that improved function rather than restoration of function is the goal of the surgical treatment. The technique used to address malunion is guided by the existing deformity. Surgical options are broadly divided into two categories: humeral head-preserving or humeral head-sacrificing techniques [26]. In the setting of a preserved articular surface and intact blood supply to the humeral head, the use of a head-preserving technique is indicated. Arthroscopic soft tissue releases and rotator cuff retensioning for tuberosity malunion [31–33], open osteotomies and removal of bony protuberances [34, 35] are the main head-preserving procedures. Head-sacrificing techniques are applied in the setting of glenohumeral joint incongruity or degeneration and the development of osteonecrosis. These techniques include hemiarthroplasty, anatomical reduction and RSA [36–39]. Adequate treatment of soft tissue dysfunction should be mandatory in all the aforementioned techniques, to appropriately address specific post-traumatic articular restrictions. Soft tissue management may include release of the subdeltoid and subacromial spaces, rotator interval and subscapularis.

18.3.2 Non-unions

The prevalence of non-union in proximal humeral fractures after ORIF is 1.7%, although it increases to 8% in those cases with metaphyseal comminution and to 10–13% if more than one-third of the surgical neck is involved [22, 40, 41]. Several factors such as soft tissue interposition, severe displacement, poor anatomical reduction and early mobilization have been reported to promote non-union. Non-union in patients who received ORIF after proximal humeral fractures represents a mechanical problem related to internal fixation, with a strong influence of biological factors and comorbidities. This complication, therefore, should be considered as a multifactorial problem [42, 43]. Mechanical outcomes of internal fixation for proximal humeral fractures are influenced by soft tissue interposition, extensive comminution, hanging arm casts, poor surgical technique or any combination thereof. Recognized predisposing biological factors, contributing to non-union development, include personal pre-existing pathological conditions and living habits. Pre-existing personal pathological conditions promoting non-union include advanced age, female sex, osteoporosis, diabetes mellitus and neurovascular dysfunctions [42, 44]. Age over 60 must be considered at high risk of non-union, particularly in females because of hormonal imbalances after menopause [23]. Uncontrolled diabetes and vascular and neurotrophic problems have been reported to influence the non-union development decreasing the formation of collagen and cells involved in formation and maturation of bone callus. Persons who smoke are at 5.5 times higher risk than non-smokers for developing non-union [29]. Living habits as diet, smoking, alcoholism, as well as drugs taken for pain control after surgery, usually non-steroidal anti-inflammatory drugs (NSAIDs), or non-adherence of the patient in postoperative management (such as temporary bracing in selected cases) can predispose the complication onset. The time to surgery has been demonstrated to not influence the risk for non-union, independent of fracture type [45]. Although not all patients with humeral non-unions are clinically symptomatic, those presenting with symptoms are typically severely disabled by pain and loss of motion.

18.3.3 Avascular Necrosis of the Humeral Head

One of the main complications after ORIF in proximal humeral fractures (PHFs) is avascular necrosis (AVN) of the humeral head. It represents a devastating event with serious sequelae. The incidence of AVN varies from 3 to 90% [46, 47] throughout the literature. Traditionally this complication has been related with displacement and the number of parts created by the fracture lines (as described by Neer). The humeral head articular surface is characterized by a tenuous blood supply [46, 48, 49]. The arcuate branch of the anterior humeral circumflex artery provides a significant proportion of the flow to the humeral head articular surface in a retrograde fashion. Recent studies have attempted to use deltoid-splitting or minimally invasive approaches with the belief that less soft tissue disruption in proximity to the humeral head would preserve its blood supply. Surgical approach has been demonstrated affecting the AVN incidence in patients affected by proximal humeral fractures. Comparing the minimally invasive approach to the deltopectoral approach, Liu et al. [50]

reported lower rate of AVN in the latter group. The authors believed that the minimally invasive approach decreased soft tissue stripping and preserved the blood supply around the proximal humerus. Hertel presented a useful classification to predict development of humeral head ischaemia according to fracture pattern. Good predictors were the short metaphyseal head fragment extension (<8 mm), the integrity of the medial hinge and the basic fracture pattern [51]. Following first observation, the same author few years later described that initial ischaemia after intracapsular fracture of the humeral head did not necessarily lead to the development of avascular necrosis [52]. On the other side, avascular necrosis may occur unexpectedly in initially perfused heads as a long-term complication. Patients who develop this complication can face significant long-term disability and few reliable surgical options for treatment. Burrus reported that TSA in patients with humeral head AVN is associated with significantly increased rates of numerous postoperative complications compared to patients without a diagnosis of AVN, including infection, dislocation, revision arthroplasty, stiffness, periprosthetic fracture and medical complications [53]. Archer et al. [54] recently investigated the relationship between the timing of PHF fixation and rates of AVN. A temporal relationship between time to ORIF of displaced femoral neck fractures and development of AVN has been established. It follows that the same could be true for the proximal humerus, and therefore a shorter time to ORIF may correlate with a smaller incidence of AVN in these fractures. No correlation between time to surgery, either early (less than 72 h) or late (greater than 72 h), and incidence of AVN was identified in the population studied. Xia et al. [55] evaluated the effectiveness of virtual planning for ORIF of proximal humeral fractures. Computerized preoperative planning facilitated ORIF and showed good results for patients with complex proximal humeral fracture, representing a favourable option with reported lower rate of AVN. Hardware selection can also affect the AVN incidence. CFR-PEEK plates proved as reliable as metallic plates in the treatment of proximal humeral fractures. The advantages of these new devices include a better visualization of fracture reduction during intraoperative fluoroscopic assessment and easy hardware removal due to the absence of screw-plate cold fusion [56]. Schliemann et al. [57] reported a lower incidence of AVN in patients treated with their CFR-PEEK implant compared to conventional locking plate, with a minimum follow-up of 2 years.

18.3.4 Heterotopic Ossifications

Heterotopic ossification (HO) in the shoulder represents a rare consequence after ORIF of the proximal humeral fractures, with a reported incidence ranging from 0 to 10% [58]. It consists in formation of lamellar bone in non-osseous tissues such as muscles, nerves and connective tissue. Despite periarticular ossification after shoulder surgery has been reported since the nineteenth century, the underlying pathogenetic processes are not yet fully understood. HO formation is presumed to result from inappropriate differentiation of pluripotent mesenchymal cells into osteoblasts; however the definitive pathophysiologic causal factors remain uncertain [59]. Bone morphogenic protein (BMP2) has been shown to promote this differentiation interacting with the Wnt/b-catenin in osteoblasts [60]. Differentiation usually occurs 16 hours after surgery and peaks at around 32 h postoperatively. Heterotopic ossification is typically asymptomatic and detected only as an incidental finding on radiograms, usually 4–6 weeks after surgery. When symptomatic, it most commonly causes decreased range of motion at the affected joint, and in most severe cases complete bony ankylosis may occur. HO has been reported to be related with symptoms as local tenderness and pain, and if located superficially, there may be symptoms as localized warmth, mild oedema and erythema [61]. Recognized risk factors for developing HO include male gender, osteoarthritis, duration and complexity of the surgery and previous personal history of HO at a particular anatomical site [62]. The decision to provide prophylactic treatment must balance a patient's risk of heterotopic bone formation against the potential risks of preventive treatment. The two primary prophylactic modalities are radiation therapy (RT) and non-steroidal anti-inflammatory drugs (NSAIDs). However, both treatment options have disadvantages. For NSAIDs therapy, prolonged bleeding time, gastrointestinal side effects and an increase in non-union of associated fractures have been observed. A well-known risk of NSAID-related therapy is related to patient compliance: up to 37% of the patients that used NSAIDs to prevent HO had to cease these medications because of serious side effects [63–65]. When using radiation therapy, the potential risk of cancer and infertility should be considered in addition to higher costs, including transportation of patients to the radiation department [66, 67]. NSAIDs administration and subsequent prostaglandin inhibition effect (in particular prostaglandin-E2) have been shown to significantly reduce the incidence of HO, specifically indomethacin [68, 69]. Indomethacin is commonly used for prophylaxis, given its ease of administration and low cost. It is typically given over a period of 5–6 weeks at 25 mg three times per day. Other NSAIDs like ibuprofen, tenoxicam, naproxen, flurbiprofen, ketorolac and diclofenac are proven to be effective [70, 71]. COX-2 blockers have been proposed as a reasonable alternative to NSAIDs prophylaxis to prevent HO. Seven-day treatment with etoricoxib 90 mg once daily represents a promising treatment option, associated with fewer gastrointestinal side effects than non-selective NSAIDs [72]. A further advantage of COX-2 inhibitors compared with non-selective NSAIDs is that COX-2, which do not interfere with platelet function, can reduce perioperative blood loss [73, 74]. In the past, diphosphonates were also used for prophylaxis. These agents were largely abandoned after they were found to only prevent mineralization of the ectopic bone matrix [75]. The appearance of periarticular ossifications of the shoulder after surgery seems to be related to a minor clinical impact, rarely painful and with little influence in joint function [76]. Severe cases with major functional deficits should and can be prevented by a fast and atraumatic operation technique [77]. It's difficult to accurately delineate the real amount of HO in shoulder function impairment, due to its usual association with other complications. Malunion or non-union of the humeral head after ORIF is frequently associated with HO, being reasonably more influent to determine articular dysfunction.

18.4 Complications Related to Hardware Failure

Surgical solutions for proximal humerus fractures treatment have been rapidly evolved in last decades. Development of the locking screw technology represented a milestone in the management of proximal humerus fractures. Locking screws have threaded heads that lock into the plate's screw holes to create an angular stable fixation. While the conventional non-locking screws rely on the bone-plate interface for stability, locking screws are reliant on the bone-screw interface instead, resulting in theoretically lower friction [78]. The failure mode of locking plates also differs from that of conventional non-locking ones. Non-locking plates typically fail in series due to the toggling, loosening or the pulling out of the screws, whereas the failure of locking plates demands simultaneous pull-out or failing of all screws [79]. As a result, locking plates exhibit superior pull-out strength and stiffness as these properties are related to the construct in entirety and not to individual screws [80].

18.4.1 Screw Loosening and Pull-Out

Introduction of locking plates for proximal humeral fractures has significantly reduced problems related to epiphyseal screws mobilization. Screw loosening has led in the past to multiple anatomopathological scenarios, ranging from absence of any symptoms to very severe consequences as lesions to adjacent structures such as lungs and vessels. Tingart [81] investigated the three-dimensional trabecular bone mineral density (BMD) in the humeral head and determined the effects of trabecular BMD on the pull-out strength of cancellous screws. Five regions of interest (ROI) were defined in the humeral head (superior-anterior, superior-posterior, central, inferior-anterior, and inferior-posterior). The trabecular BMD of each region was determined by use of peripheral quantitative computed tomography. Cancellous screws were inserted in each ROI and cyclically loaded. The superior-anterior ROI had a lower trabecular BMD than all other ROIs ($P < 0.001$). The central ROI had a higher trabecular BMD than the inferior-anterior ROI ($P < 0.01$), whereas no differences were found between the inferior-posterior, superior-posterior and central ROIs. Pull-out strength was lower in the superior-anterior ROI compared with all other ROIs ($P < 0.01$). The trabecular BMD and pull-out strength were significantly correlated ($P < 0.01$). The author concludes that placement of screws in regions with a higher trabecular BMD may help to prevent implant loosening and may also improve patient outcome. Proximal humerus fracture fixation can be problematic because of osteoporosis making it difficult to achieve stable implant anchorage in poor bone stock even when using locking plates. This may cause implant failure requiring revision surgery. Krappinger et al. [42] pointed out the relevance of preoperative assessment of local bone mineral density. Local bone mineral density, restoration of the medial column, non-anatomic reduction, and age were significant predictors of fixation failure ($p < 0.01$). Osteosynthesis of osteoporotic fractures with non-reconstructable comminution of the medial column is prone to failure. Several strategies have been proposed to improve stability in proximal humeral fractures treated with ORIF. In patients with impaired bone mineral density, cement augmentation either directly to the head prior to screw insertion or via cannulated and perforated screws has been demonstrated to be a valid option to decrease the risk of varus impaction [82]. Cement augmentation of particular screws of a locking plate in the regions of low bone quality has been demonstrated to be effective in improving stability in a proximal humerus fracture model [83]. Locked plating of proximal humeral fractures with trauma cement augmentation of humeral head screws showed similar clinical outcomes but reduced the rate of early implant-related complications compared to locked plating without additional cement augmentation [84].

18.4.2 Implant Failure

Failure rate should be influenced by the different locking plate design including overall profile, manufacturing, material and screw configurations. Although these variations are small, they are likely to have some impact upon fixation failure. Specifically, implant stiffness has a direct effect upon the bone-implant interface [85]. Under cyclic loading, rigid implants lead to early loosening and failure of the bone-implant interface presumably due to the mechanical mismatch of the bone and the implant [86]. Less rigid and smaller-dimensioned implants, although potentially ‘poorer’ in terms of the early stability that they offer, exhibit lower peak stresses at the bone-implant interface compared with more rigid and oversized osteosynthetic devices and may be better suited to the treatment of osteoporotic fractures where screw cut-out is a significant problem. There is ongoing work to produce proximal humeral locking plates that have an elastic modulus that is more similar to that of human bone while still maintaining implant strength. Lab-based research investigating carbon fibre-reinforced polyetheretherketone (PEEK) is extremely promising [57], and interesting results from high-quality multicentric clinical studies have been recently published on this topic [56, 57]. Where medial column stability is suboptimal, fracture stability can be improved using a medial supporting screw(s) that is inserted into the inferior most portion of the humeral head, by using an endosteal implant, through impaction of the shaft into the humeral head fragment to restore load transfer through the ‘new’ calcar or by inserting an intramedullary fibular strut graft. The literature demonstrates that a medial support screw(s) enhances the primary stability of locking plate fixation in the majority of fixations and therefore should be used in all cases where technically feasible to support the medial column. The accurate placement of the calcar screws within the bottom 25% of the humeral head has also been shown to decrease the risk of fixation failure [87]. A minimum of five screws should be inserted into the humeral head aiming if possible for the central, inferior-posterior and superior-posterior regions [85]. Anatomical reduction is the aim, but achieving inherent bone to bone mechanical stability is questionably more important especially if an anatomically acceptable and inherently stable fracture configuration can be obtained. Varus mal-reduction and lack of medial column support are high predictors of failure and should be avoided at all cost. Finally, in addition to obtaining optimal fracture reduction and/or fracture stability, there is good evidence that a medial column support screw should be used routinely.

18.4.3 Malpositioning

Adequate intraoperative plate positioning frequently represents a challenge for the surgeon, in particular in 3- and 4-part fractures. Subacromial primary impingement can be the result of poor intraoperative plate positioning, while secondary has been related to sequelae of humeral head collapse. Impingement rate after ORIF ranges from 4.8% [88] to 18.5% [89] in literature. ORIF represent a good surgical option for severely displaced proximal humerus fractures, but functional impairment related to the hardware malpositioning can persist. Acklin et al. [90] analysed the functional outcome after locking plate removal in proximal humerus fractures, showing statistically significant improvement of the Constant score after implant removal. Major concerns against hardware removals are very high complication rates of 20–47% [91]. Particularly in locked compression plates, the most frequently observed complications were jammed screws (11% risk) and damaged recess in which the screwdriver turned freely [92]. A longer time in situ contributed to the complication rate. A proper surgical technique is mandatory for avoiding this specific complication: increased attention to plate placement and preventing varus collapse are the methods surgeons are using to decrease this complication [93].

18.4.4 Articular Perforation

In a systematic review of the literature in 2011, Sproul et al. [88] looked at 12 studies with a total of 514 patients and found that screw perforation occurred in 8% of patients and was the most common cause for re-operation. More recently in 2013, in a cohort of 121 patients, Jost et al. [18] found secondary screw cut-out in 57% of patients.

Screw penetration can be primary, due to the screws being placed too close to the articular surface or indeed perforating the articular surface intraoperatively, leading to patient morbidity from screw impingement upon the glenoid, chondrolysis and the need for further surgery especially if the prominent screws involve the major articular component of the humeral head.

Standard intraoperative images may miss nearly half of screw penetrations, and it is recommended that a combination of four projections (axial view with 30 degrees abduction and anterior-posterior views in internal rotation, neutral and external rotation) have 100% sensitivity for identifying screw perforation [94]. Secondary penetration occurs due to loss of fracture reduction and head fragment subsidence. Brunner et al. reported 35 screw penetrations (22 primary and 13 secondary) in a cohort of 158 patients [95]. In both types of penetration, surgical technique is invariably the main culprit. With proximal humerus locking plates, the locking of the threaded screw heads within the plate provides increased axial and angular stability. However, if there is head collapse post fixation, the screws are unable to back out, and therefore the screws penetrate through the head. Clinical studies for locking plates report a significant number of complications due to the perforation of screws through the humeral head. One potential solution is to use polyaxial screws in them. This has been named the second-generation locking technology as it allows the screw direction to be adjusted before locking, as opposed to the conventional locking systems where screw angles are predefined and therefore monoaxial. Egol et al. [96] performed a retrospective study on patients with acute traumatic fracture of the proximal humerus with metaphyseal defect treated with open reduction-internal fixation with a locked plate. Metaphyseal defects were treated with 1 of 3 strategies: no augmentation, augmentation with cancellous chips or augmentation with calcium phosphate cement. Findings of joint penetration were significant among patients treated with plates and screws alone versus those augmented with calcium phosphate ($P = 0.02$) and for those augmented with cancellous chips versus those augmented with calcium phosphate ($P = 0.009$). Augmentation with calcium phosphate cement in the treatment of proximal humeral fractures with locked plates decreased fracture settling and significantly decreased intra-articular screw penetration.

18.5 Miscellaneous

18.5.1 Neurovascular Injuries

Surgical management of proximal humeral fractures is graved by a recognized risk for axillary nerve injury [97]. Neurologic lesions during ORIF for proximal humeral fractures are often related to surgical approach. The deltoid-splitting approach is characterized by a higher risk of axillary nerve lesion during preparation, because the anterior branch of the axillary nerve perpendicularly crosses the incision. Wu et al. [98] compared electrophysiological results between two groups operated using deltopectoral approach or deltoid-splitting approach at 3 months of follow-up. They found that 12.5% in the deltopectoral group and 25% in the deltoid-splitting group showed signs of reinnervation or denervation of the deltoid muscle. Another cohort study by Gavaskar et al. [99] prospectively analysed 50 patients with proximal humeral fractures who underwent open reduction and internal plate fixation using the extended deltoid-splitting approach. Electrophysiological findings showed three temporary and one permanent axillary nerve lesion. The permanent lesion did not correlate with clinical findings because the patient did not show any sensory or motor deficiencies. Some authors proposed intraoperative trick to reduce nervous lesions: they indicated the nerve with the index finger in the subdeltoid bursa, and its course was marked on the skin. Additionally, they used a five-hole plate that was inserted with its tip contacting the bone, and screws were fixed in the three distal holes, far away from the axillary nerve [100–102]. Vascular sequelae can also affect outcomes after ORIF in proximal humeral fractures. The anterolateral acromial approach, which uses the anterior deltoid raphe and axillary nerve protection, has recently been advocated as a minimally invasive technique. Splitting the anterior deltoid raphe from the acromion distally allowed direct access to the lateral plating zone of the proximal humerus. The bare spot in this region may be a safe area for plate application. These findings may be of particular importance if the vascular supply to the humeral head has already been partially compromised by preceding trauma. This direct approach to the lateral bare spot on the proximal humerus may minimize iatrogenic vascular injury when treating these fractures [103]. The reported incidence of venous thromboembolism (VTE) after ORIF for proximal humeral fracture was 0.82% [104]. Diabetes mellitus, rheumatoid arthritis and previous ischaemic heart disease were identified as major risk factors for VTE in patients [105, 106].

18.5.2 Infections

The reported rate of infections after ORIF for proximal humerus fractures ranges from 0 to 8% [107]. Recently published studies, comparing the intramedullary nailing for PHF with ORIF, reported a higher rate of infections after the second technique [108]. Common causative organisms are coagulase negative *Staphylococcus* species and *P. acnes*. *P. acnes* has been implicated as a common cause of deep shoulder infections [109]. The length of surgery also increased the risk of infection (OR, 1.009; P ¼ 0.05). Blonna et al. [110] highlighted that preoperative skin preparation with chlorhexidine gluconate, length of surgery and type of prophylactic antibiotic play an important role in the rate of acute deep infections after surgical treatment for proximal humeral fractures. They recommend, if not contraindicated for referred patient's conditions, preparing the shoulder with chlorhexidine gluconate and avoiding the use of first-generation cephalosporin in favour of a more effective prophylactic therapy such as third-generation cephalosporin or vancomycin to reduce the postoperative infection rate. Preoperative axillary hair removal is a common preoperative standard care, considered as a method for infection prevention. Marecek et al. [111] clipped one randomly selected axilla in 85 healthy male volunteers with commercially available surgical clippers. Aerobic and anaerobic culture specimens were taken from the clipped and unclipped axillae. Each shoulder was then prepared with 2% chlorhexidine gluconate and 70% isopropyl alcohol. Repeated culture specimens were then taken from both axillae. There was no difference in the burden of *P. acnes* between the clipped and unclipped axillae before or after surgical preparation ($P = 0.109$, $P = 0.344$, respectively). There was a significantly greater bacterial burden in the clipped shoulder compared with the unclipped shoulder before preparation ($P < 0.001$) but not after preparation ($P = 0.285$). There was a significant reduction in total bacterial load and *P. acnes* load for both axillae after surgical preparation ($P < 0.001$ for all). Removal of axillary hair showed no effect on the burden of *P. acnes* in the axilla. Clipped axillae had a higher total bacterial burden. A 2% chlorhexidine gluconate surgical preparation was proved to be effective at removal of all bacteria and specifically *P. acnes* from the axilla. The diagnosis of acute deep infection after the surgical fixation of proximal humeral fractures represents a challenge, and the diagnosis can be easily missed or delayed. Incisional erythema and drainage are findings common to all patients, and constitutional symptoms are rarely present. Laboratory data, such as leukocyte count, erythrocyte sedimentation rate and C-reactive protein, can assist orthopaedic surgeon with the diagnosis; however, they are by no means definitive [109]. The presence of a deep infection after ORIF can negatively affect the fracture healing process, determining septic non-unions. In this unlucky event, surgical management is mandatory for most patients, requiring combined surgical and medical procedures for tissue debridement and infection eradication. The standard treatment of acute deep infection includes serial surgical debridements and intravenous organism-specific antibiotics. Surgical debridement should be complete, removing all necrotic, non-viable and fibrinous debris. Fixation hardware should remain in situ to stabilize the fracture until healing occurs. Grossly loose hardware with a poorly stabilized fracture should be removed and revised. Patients should be informed that the results of treatment of acute deep infection after surgical fixation of proximal humeral fractures are beset with high complication rates, poor functional outcome and a notably high non-union rate [109].

18.6 Conclusions

Open reduction and internal fixation for proximal humerus fracture represent a good option in selected patients, with encouraging clinical and functional outcomes reported in literature. Several complications related to ORIF have been described with subsequent surgery failure. Complications are related not only to the fracture pattern but also to the patient's personal comorbidities. Surgeons should carefully select patients for this treatment to minimize the risk of postoperative failure.

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Acromioclavicular Joint Injuries

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19.1 Introduction

Acromioclavicular (AC) joint injuries are relatively frequent, as approximately 10% of all shoulder injuries, especially in males participating in contact sports, such as rugby, wrestling, hockey, and football [1, 2]. The mechanism of injury can be either indirect trauma or more frequently direct trauma to the superolateral border of the shoulder. Detailed clinical evaluation is necessary in order not to miss these injuries in clinics and to manage them properly. In this chapter, anatomy and biomechanics of the AC joint, clinical evaluation, classification, and management of AC joint injuries will be summarized with a timeline perspective under the light of current studies in the relevant literature.

19.2 Anatomy and Biomechanics

AC joint is a synovial joint with a joint capsule and intra-articular fibrocartilage disc as meniscus homologue, which connects the acromion to the lateral end of the clavicle. Morphologically, the duplication of the acromioclavicular joint may also be seen in clinics very rarely [3]. Its main blood supply is from suprascapular and thoracoacromial arteries. The innervation of the joint is mainly supplied by suprascapular and lateral pectoral nerves. On one hand, as it connects the upper extremity to the trunk, AC joint has an important functional role in the transmission of the load [4]. On the other hand, it is an important component of the superior shoulder suspensory complex, described by Goss [5].

Biomechanically, the AC joint is a highly dynamic joint together with sternoclavicular joint. All movements of the scapula along the contours of the ribcage in three planes are possible as scapular protraction/retraction, elevation/depression, and upward/downward rotation.

Regarding the stability, the AC ligaments (superior, inferior, posterior, anterior), coracoclavicular (CC) ligaments (trapezoid and conoid), coracoacromial (CA) ligaments, and joint capsule play important roles as static restrainers

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under physiological loading of the AC joint. Dynamic stabilizers are trapezius muscle and anterior fibers of the deltoid muscle. The main restraint to anterior and superior translations is conoid ligament, to posterior translation and distraction is AC ligament, and to compression is trapezoid ligament [6]. In a recent biomechanical study, it was demonstrated that injury to the deltopectoral fascia resulted in a quantitatively small but significant increase in anterior rotation and a tendency in lateral translation of the clavicle in relation to the acromion (7). But the contribution of deltopectoral fascia to the joint stability warrants to be investigated in terms of clinical relevance.

Our attitude on the management of the AC joint injuries has been changed greatly from previous focus on solely vertical displacement of the lateral end of the clavicle. Moreover, a recent cadaveric study demonstrated that borders of the acromion and clavicle were not perfectly aligned, and the most reliable landmarks were their articular facets [8]. Especially in cases of high-energy injuries of the AC joint, the capsuloligamentous balance is lost due to multidirectional dislocating forces [4]. Nearly three decades ago, the emphasis on the importance of the ligamentous structures on stability has been the basis for most current surgical methods, which aim the restoration of the native anatomy during the biological healing process of soft tissues [9]. In this context, the understanding of the structural and functional evaluation of this joint is of utmost importance in terms of a proper clinical approach and management of the AC joint injuries.

19.3 Clinical Evaluation and Classification

Patients usually admit to the clinics with the complaints of acute or chronic posttraumatic pain, deformity, or as missed diagnosis or as treatment failure. In order not to miss these injuries in clinics, history taking, careful physical examination, and necessary radiological imaging methods of the joint are necessary [10]. Especially for associated intra-articular lesions, magnetic resonance imaging is required. Typical injury pattern is a direct trauma to the acromion, when the shoulder is in adduction. The terminology regarding the chronicity of the orthopedic injuries is usually not precise and changes depending on the site of the lesion. Acute and chronic AC joint injuries are usually defined as <3 weeks and >6 weeks post injury [11].

The older classification by Tossy et al. [12] and Allman[13] was further developed by Rockwood et al. [14]. Currently, the Rockwood classification has been the most frequently used system, mainly according to the degree and direction of displacement of the distal clavicle [14]. Although this classification system was found to be highly reliable [15], a recent study demonstrated that the Rockwood classification does not correlate with clinical symptoms and that its reliability is unclear [16].

Recently, Ibrahim et al. found that the accurate classification of AC joint injuries requires the use of bilateral weighted comparative radiographs as first-line investigation, to unmask a grade V injury [17]. But the cost effectivity of this additional view is questionable. Moreover, to improve the evaluation and management of the controversial types II, III, and V, the subsequent novel quantitative radiological parameters in a single Alexander view for vertical and horizontal instabilities were recently introduced with excellent reliability and validity: acromial center line to dorsal clavicle (AC-DC) and glenoid center line to posterior clavicle (GC-PC), respectively [18].

Recently, ISAKOS Upper Extremity Committee has provided a more specific classification of the AC joint injuries in order to enhance the knowledge on and the clinical approach to these injuries [19]. In this classification, grade IIIA and grade IIIB injuries were added to the modified Rockwood classification. On one hand, grade IIIA is defined by a stable AC joint without overriding of the clavicle on the cross-body adduction view and without significant scapular dysfunction. On the other hand, the unstable grade IIIB is defined by an overriding clavicle on the cross-body adduction view and therapy-resistant scapular dysfunction.

19.4 Management

Considering the current evidence, low-grade (Rockwood grade I and II) and high-grade (Rockwood grade IV, V, and VI) dislocations are managed conservatively and surgically, respectively. Type III AC dislocations can be managed nonoperatively or operatively, depending on the expectations, functional status of the patients, and implant availability.

Nonoperative management includes immobilization with a sling and analgesics. The immobilization period should be as short as possible. In this respect, range of motion exercises should begin within the first week. Progressively, strengthening of the rotator cuff and periscapular muscles and scapular stabilization exercises should be performed without allowing return to sports and lifting heavy objects, in this period. Currently, nonoperative management is successful in patients with type I and II and selected type III AC dislocations [20, 21]. If long-term problems, such as instability and osteoarthritis, are observed with symptoms interfering daily activities, symptomatic treatment, injections, and Mumford procedure of distal clavicular resection are available treatment choices, depending on the chronicity of the lesion and patient-related factors [22–24].

Since the first surgical fixation of the AC joint in 1861, over 100 procedures were described [25]. The description of each technique in detail is out of scope of this chapter. The main aims of surgical management of AC joint dislocations should be the restoration of the native anatomy, biomechanics of the joint, and the optimal function of the patient, by allowing biological healing of the surrounding ligaments. For the reconstruction of the AC joint, there are various previously described techniques, which can be classified into four main categories: anatomical reduction, CC ligament reconstruction, anatomical reconstruction, and salvage procedures.

Anatomical reduction of the AC joint by closed or open approaches can be preserved with internal fixation. The devices for the fixation include K-wire, tension band, screw, plate and screws, loops, and biological or synthetic methods. Among these, K-wires, tension band, and screw-only (Bosworth) fixation are nearly abandoned currently, due to poor clinical and functional results and severe complications, specific to each technique: Steinmann pin migration, recurrence of the dislocation, neurovascular injury, soft tissue injury due to large exposures, insufficient horizontal plane stability, development of AC joint osteoarthritis, screw breakage, requirement of secondary procedures, etc. [26–32]. Currently, more frequently used reduction and fixation alternative technique is performed by hook plates. It can be used alone, together with CC ligament reconstruction techniques, or in revision cases (Fig. 19.1). Although successful results were reported, the surgical technique should be strictly followed [28, 33–38]. As variable clinical outcomes are present in the literature, the surgeons should also be aware of possible complications of the hook plates: positional

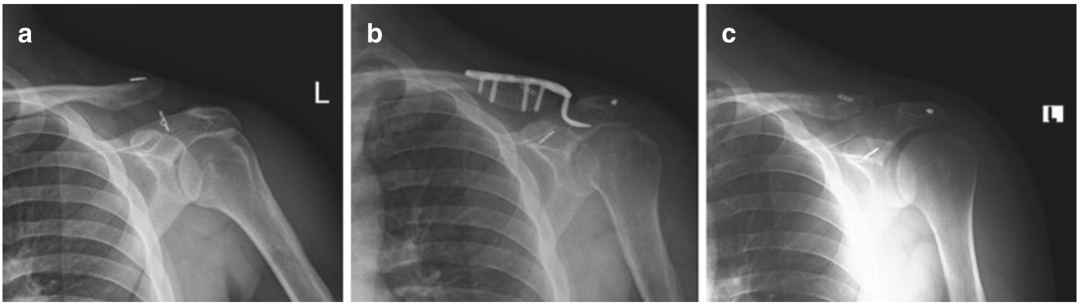

Fig. 19.1 (**a**) 45 years old, male patient who was referred to our clinics with failed distal clavicular resection and suspensory loop fixation. (**b**) Anatomic reconstruction of CC and AC joints with TightRope, temporary hook plate, and allograft with anchor fixation. (**c**) Anatomic reduction of the AC joint after removal of hook plate at postoperative sixth month

change of the implant, loss of reduction, redislocation, high infection rates, osteolysis, penetration, and fracture of the acromion [35–40].

Regarding CC ligament-only reconstruction, the procedure is performed nonanatomically or anatomically. Nonanatomic reconstruction is not currently used alone. Instead it is used especially in chronic AC joint pathologies, as an additional procedure. In the literature, the reconstruction procedures such as Weaver-Dunn procedure, its modification, and other surgical method variants yielded controversial results in previous studies ([20, 41–50]).

In the recent study of [53], it was stressed out that the cadaveric studies are very limited, and none of these studies assess the stability in all three planes of motion and are limited by older CC reconstruction techniques (North et al. 2018, [51–54]). A recent meta-analysis demonstrated that loop suspensory fixation in acute unstable AC joint dislocation had higher Constant-Murley scores, lower postoperative pain, but higher complication rates when compared with hook plating [55]. In the study of North et al., advantages and disadvantages of CC ligament reconstructions were summarized as follows: vertical stability equivalent to native AC joint complex, single procedure, better clinical outcomes with double TightRope technique, and significantly less horizontal stability and lack of higher evidence comparative studies, subsequently (North et al. 2018, [30, 51–54, 56]). Currently, higher level of evidence and comparative studies are necessary to put forward more concrete conclusions.

Currently, the anatomical AC and CC joint reconstruction has been increasingly and more frequently performed [57, 58]. For the anatomical reconstruction, tendon grafts (autografts, allografts), synthetic materials, and loop suspensory fixation repair have been used [38, 44, 56, 59–61]. The advantages of anatomical reconstruction are summarized as the best biomechanical results comparable to the native joint, restoration of both vertical and horizontal stability of the joint, and successful clinical results at early and mid-term (North et al. 2018, [62–65]). On the other hand, technical difficulties, lack of long-term results, and lack of determination of the best method among various techniques are the main drawbacks of the anatomical reconstruction, for now.

There is a broad spectrum of protocols for the rehabilitation after AC joint injuries. In general, following anatomic reconstruction, postoperative rehabilitation may be as follows: simple sling for 2 weeks, pendulum exercises at 2 weeks, active range of motion exercises at 6–8 weeks, and resistive exercises at 12 weeks [21]. The return to play for professional athletes is usually at fourth and sixth month in cases of acute and chronic injuries, respectively [66, 67].

Special emphasis should be given for the “gray zone” type III injuries. In all meta-analyses about the comparative analysis of surgical versus conservative management of type III acromioclavicular dislocations, it was stressed out that there has been still insufficient evidence to establish the effects of surgical versus conservative treatment on functional outcome of patients with type III AC joint dislocations and that higher level of evidence studies are required to establish whether there is a significant difference in functional outcome between surgical and nonsurgical methods [34, 68, 69]. In a recent systematic review by Longo et al. [68], it is emphasized that there is growing evidence demonstrating that persistent pain was less frequently observed in patients with type III AC joint dislocation, who were treated by surgery, comparatively. In another recent meta-analysis by Longo et al., although nonoperative treatment of Rockwood type III AC dislocations resulted in a lower incidence of ossification of coracoclavicular ligament and osteolysis of the lateral clavicle compared with operative treatment, no statistical difference was found between operative and nonoperative treatments in terms of clinical outcomes [70].

Regarding timing of the surgical treatment, early surgery yielded more satisfied reduction with better functional outcomes and lower complications rates, when compared with delayed procedure, in a systematic review [71]. In the same study, it is emphasized that higher level of evidence studies are warranted to provide stronger support for this finding.

Arthroscopy-assisted techniques have been increasingly used by the time. Although they are soft tissue friendly and minimally invasive methods with lower infection rates, surgical morbidity, learning curve, and experience of the surgeon are the main limiting factors. In the meta-analysis by Helfen et al., it was shown that currently there was insufficient evidence demonstrating significant superiority of arthroscopic/minimally invasive and open procedures to another, in terms of functional outcomes and complications rates [72].

In chronic, symptomatic cases, resistant to conservative management, and AC joint degeneration, open or arthroscopic distal clavicular resection is applicable as a salvage procedure and offers similar clinical results at long term [73, 74].

19.5 Conclusion

The AC joint dislocations are frequently encountered and can be easily missed if not evaluated properly and sufficiently in clinics. Currently, nonoperative treatment is used for low-grade (type I and II) injuries, whereas surgery is used for high grade (types IV, V, and VI) and for selected patients with type III injuries. Although there are many described old and novel techniques for the surgical management, and the best surgical method has not been defined yet, the techniques that provide the anatomic reconstruction of the CC ligaments—by the restoration of the anatomy, biomechanics, vertical and horizontal stability, function, and biological healing of the AC joint, CC joint, surrounding ligaments, and deltotrapezial fascia—are currently preferred and recommended. As a future prospect, higher level of evidence and comparative biomechanical and clinical studies are needed to clarify the uncertainty of choosing the best method of surgical treatment.

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20

Complications of Reverse Total Shoulder Arthroplasty

Alexander Bitzer, Ronak Kotian, Jorge Rojas, and Edward G. McFarland

20.1 Introduction

Reverse total shoulder arthroplasty (RTSA) has proven to be a valuable solution for not only cuff tear arthropathy but a variety of other shoulder conditions [1–3]. For most conditions, RTSA provides excellent pain relief and variable degrees of improved motion. However, like any evolving technology, there are a variety of complications that are unique to this prosthesis and may affect the final clinical results and what to expect from this procedure by the patient and provider alike. Some of these complications are not seen with anatomic total shoulder arthroplasty (TSA) and are unique to RTSA because of their design. Other complications are possibly due to the increased use of RTSA for conditions not easily treated with standard TSA. RTSA's broadened indications, options in modularity, improved product development, and increased surgeon experience have propelled the RTSA implant towards preeminence in the world of shoulder surgery. Nevertheless, no implant is perfect, and the ability of RTSA to solve complex reconstructive problems comes at a cost of increased complications compared to its anatomic counterpart [4].

20.2 Complications and Rates

With the introduction of any new technology, there is going to be a learning curve in its application and in the appreciation of all of the things that can go wrong. Previous studies reported complication rates for RTSA ranging from 0 to 68% [5, 6]. However, a recent systematic review reported an overall complication rate of 13.6% after primary RTSA with varying incidences depending upon the primary indication for RTSA. The highest complication rates after primary RTSA were seen when performed for rheumatoid arthritis, followed by fracture sequelae and cuff tear arthropathy (CTA) (Table 20.1). When combining both primary and revision cases, the most frequent complication was instability at 4.7%, followed by deep prosthetic shoulder infection at 3.8%, and then aseptic glenoid baseplate loosening (AGBL) at 2.5% and 5.8% depending on medialized versus lateralized prostheses, respectively. The complication rate for revision RTSA compared to primary RTSA was more than double at 33.3% versus 13.4%, respectively. Another systematic review showed that the complication rates for RTSA are 19.4%

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Table 20.1 Rates of problems, complications, revisions, and reoperations relative to primary indication for RTSA

				Reinterventions ($n = 105$)	
Etiology	No.	Problems ($n = 70$)	Complications ($n = 188$)	Reoperations ($n = 260$	Revisions ($n = 79$)
Total	782	44%	24%	3.3%	10.1%
PAG	566	6.0%	13.4%	3.0%	6.3%
CTA	318	6.9%	19.5%	11.9%	–
Frx Seq	41	N/S	5%	4.9%	–
RA	23	21.7%	45%	26.1%	–
Acute Frx	18	11.1%	36%	6.3%	12.5%
Tumor	6	N/S	N/S	N/S	–
N/S	160	N/S	N/S	N/S	–
Revision	216	12.5%	33.3%	4.2%	15.7%

PAG primary arthroplasty group, *CTA* cuff tear arthropathy, *Frx Seq* fracture sequelae, *RA* rheumatoid arthritis, *Acute Frx* acute fracture, *N/S* no clear etiology reported. Table from Zumstein et al. JSES 2011 [34]

and 14.3% when performed for failed TSA or RTSA, respectively [5].

As RTSA has become a more common operation, the training of surgeons who perform this surgery has been evaluated by several studies. One study found that the complication rate decreases after ten cases [8]. Other studies have suggested that the learning curve may even extend beyond 100 cases [9]. A study of surgeons in the United States who were submitting cases for their board certification found that the complication rate was similar between those who were fellowship trained and those who were not [10]. This may be explained by the complexity of the cases of the fellowship trained group, but it may also indicate that the complications may be inherent to the use of RTSA. There is little doubt that the variety of complications and the number of complications of RTSA make it a challenging operation.

20.3 Deep Prosthetic Shoulder Infection

Deep prosthetic shoulder infection is one of the most frustrating complications for patients and surgeons alike. The need for multiple surgical procedures, intravenous antibiotics, and decreased functionality after several operations can be time-consuming and painful for patients. Reconstruction of both the humerus and glenoid sides can be challenging due to the bone and soft tissue loss, which occurs as a result of infected shoulder arthroplasty. Deep prosthetic shoulder infection after RTSA occurs roughly 2–3% of the time in primary cases and between 5 and 6% in revision cases [11]. This rate is higher compared to the infection rate of anatomic total shoulder arthroplasty which is roughly 1–2% and closer to the incidence of deep infection in knee or hip replacements [12, 13]. The increased incidence of deep prosthetic shoulder infection compared to anatomic shoulder replacements is thought to be secondary to prosthesis design, as with RTSA there are larger areas of dead space and there is more implant mass available for the formation of bacterial biofilm [2]. Additionally, the rotator cuff is typically absent in RTSA surgeries resulting in less viable tissue to protect the implant against bacterial colonization [14]. The most common microorganisms in deep prosthetic infections of RTSA are *Staphylococcus aureus, coagulase-negative staphylococci,* and *Cutibacterium acnes* [15]. *C. acnes* is of particular interest as it rarely presents in hip or knee replacement infections, and its slow growth rate explains the sometimes late presentation after RTSA. Risk factors associated with deep prosthetic shoulder infections after RTSA include diabetes, chronic steroid therapy, systemic lupus erythematosus, rheumatoid arthritis, previous surgical procedures, and remote sources of infection [16].

The diagnosis of deep prosthetic shoulder infection can be somewhat challenging especially in the setting of *C. acnes* as it is a low-grade infection and clinical symptoms are usually subtle. Swelling of the shoulder is rare, and limitations of range of motion can be masked by compensatory motion in the scapula-thoracic joint. Obviously the most diagnostic symptom is drainage from either the surgical wound or from a distant site, such as the anterior and posterior shoulder, biceps in the mid-arm, and the axilla. Pain after surgery, especially with a known history of a previous wound complication, is one of the most common symptoms of deep prosthetic shoulder infection [17]. Surgeons should ask when the pain began and if there was ever a period of pain relief after surgery. White cell count can be normal in deep prosthetic shoulder infection; however the erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) are typically elevated [18]. It is important to keep in mind that uncomplicated RTSA surgery itself will elevate ESR and CRP levels; however these should fall within normal limits at about 3 weeks after surgery [19]. Inflammatory markers in *C. acnes* infections however can be negative given its ability to produce only a low-grade inflammatory state [19].

Imaging can aid in the diagnosis of deep prosthetic shoulder infection when radiolucent lines are present or are increasing over time around the glenoid or humeral prosthesis [15] (Fig. 20.1). While baseplate loosening can be due to aseptic causes, loosening of the humeral component should be suspected of infection until proven otherwise. Aspiration of the shoulder joint using fluoroscopy can be helpful in making the diagnosis of deep prosthetic shoulder infection, but unfortunately a dry tap occurs in 20% of cases and false negatives occur 53% of the time [20]. When obtainable, aspirates with a white blood cell count beyond 3000 cells/mm^3 with more than 80% of cells present being polymorphonuclear cells are suspicious for infection [11]. Lastly, intraoperative cultures can be helpful in diagnosing deep prosthetic shoulder infection when three or more cultures are positive for the same organism [21]. Importantly, cultures must be followed for an extended culture time of 14 days to confirm a negative culture for slow-growing organisms like *C. acnes* [19].

Management of deep prosthetic shoulder infection primarily depends upon the time of presentation after the surgical procedure. Infections can be divided into acute infections (1–3 months), subacute infections (4–12 months), and chronic infections (>1 year). Superficial acute infections can be treated with local wound care and IV antibiotics, while deeper acute infections should be treated with irrigation and debridement, polyethylene inlay exchange, and antibiotics. Unfortunately irrigation and debridement with

Fig. 20.1 Radiographic evidence of infection in RTSA can include radiolucent lines along the humeral and glenoid components along with signs of loosening. This radiograph shows radiolucent lines between the cement mantle and the bone extending throughout the entire humeral prosthesis. The glenoid prosthesis has radiolucent lines along the undersurface of the baseplate as well as around all of the screws indicating likely infection with possible loosening

polyethylene exchange only successfully eradicates the infection in roughly 50% of acute infections and rarely works for subacute or longer infections [22]. One study by Zavala et al. emphasized the importance of recognizing deep prosthetic shoulder infections as early as possible [23]. In infections diagnosed in less than 2 weeks after surgery, irrigation and debridement, component retention, and 6 weeks of intravenous antibiotics cleared the infection in all cases.

Chronic infections are more difficult to treat and require more invasive techniques. Chronic infections typically require either a one- or two-stage procedure with direct prosthesis exchange in one-stage and prosthesis explant with placement of an antibiotic spacer followed by prosthesis reimplantation in two-stage revisions. A systematic review comparing these two treatment options suggested one-stage revisions might have a slight advantage over two-stage revisions [24]. Jacquot et al. had 100% healing with one-stage revision compared to 64% in two-stage revision although this difference was not significant [25]. Beekman also found that one-stage revisions for infected RTSA provided a 90% healing rate [26]. One-stage revisions reduce costs and duration of treatment with good functional outcomes.

Revision of infected arthroplasties can be fraught with many challenges. The first is to eradicate the infection. Recurrence of infection after revision for infected shoulder arthroplasty has been reported to be as high as 14.3% compared to an infection rate of less than 2% in primary RTSA [24]. Also the incidence of aseptic baseplate loosening after revision of RTSA is around 4%, whereas the incidence is around 1% for primary RTSA [27]. Other options for infected RTSA include removal of the components and implantation of an antibiotic spacer alone. While not a common treatment, some patients tolerate the spacer long term despite the limitations of pain and loss of motion with the device. Resection arthroplasty is another option for treatment of an infected RTSA; however the outcomes are typically poor [23]. As a result, this option should be reserved for patients with recurrent and incurable infections, multiple medical comorbidities, or inability to successfully carry out revision reconstructive procedures [23].

20.4 Instability

The prevention and management of instability after RTSA has been addressed in previous chapters, but briefly, prosthetic instability after RTSA has proven to be a nagging complication due to the challenges of successful treatment. Early studies on the incidence of RTSA instability reported rates of 2.4–31% [28], while a recent systematic review reported the incidence of dislocation to be 4.7% [7]. Most dislocations of RTSA occur within the early postoperative period (<3 months), and most are anterior or lateral [29] (Fig. 20.2).

There are multiple factors that can contribute to instability after RTSA. The two major factors are the type of prosthetic design and the use of RTSA for revision of a previous shoulder arthroplasty. The Grammont prosthesis with a medial center of rotation and a more horizontal head-neck angle (viz., 155°) has been shown to have a higher dislocation rate than prosthesis with a more vertical head-neck angle (viz., 135°) [30]. Revision procedures have been found to have a higher instability rate regardless of the type of RTSA prosthesis system utilized [31].

Other variables, which may contribute to instability of RTSA, include the indications for surgery, technical aspects during surgery with implant-soft tissue tensioning, high patient BMI, male gender, and glenoid failure [31]. Additionally, like many of the complications after RTSA, infection may lead to instability by destruction of the soft tissues, bony erosion, and loosening of the components such that the prosthesis becomes unstable.

There are several nonoperative and operative options to address instability after RTSA. We recommend closed treatment for the first or second dislocations after RTSA. Once reduced under fluoroscopy, a thorough range of motion examination should be performed in order to determine what arm positions are associated with instability. Once the stable position of the RTSA is established, bracing or immobilization to avoid that position can be successful. Teusink et al. found that the treatment of early dislocations (defined as <90 days from the index surgery) with closed reduction and brace immobilization is a viable

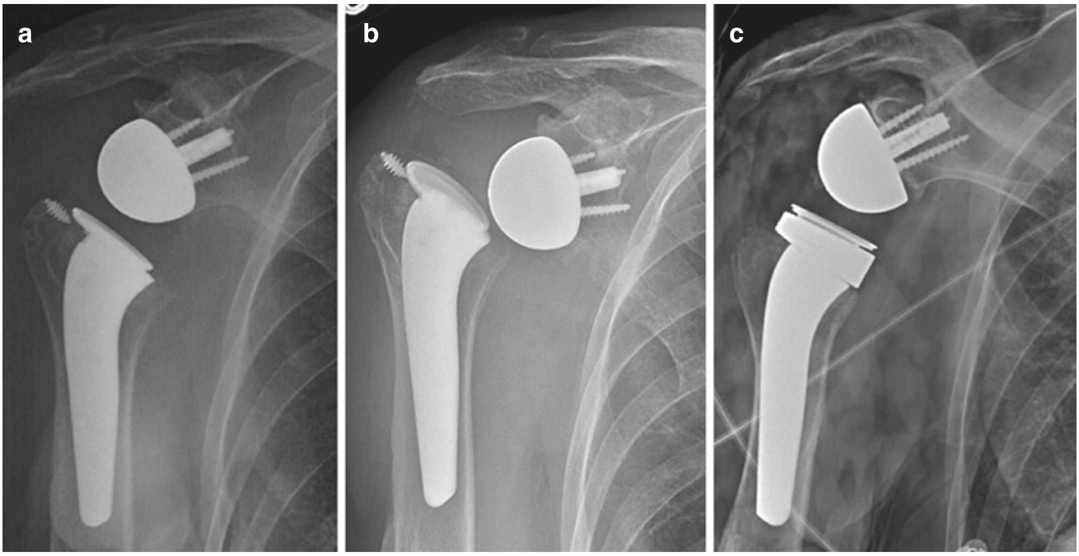

Fig. 20.2 Radiographic evaluation and management of RTSA instability. (**a**) Immediate postoperative Grashey view of RTSA without evidence of instability. (**b**) 9 weeks post op Grashey view shows dislocated RTSA prosthesis. (**c**) Postoperative Grashey view after revision of humeral component including metal insert buildup and increase in polyethylene thickness. Intraoperative tensioning improved after humeral components revised. Modification to glenoid component was unnecessary

treatment option [32]. They found that closed reduction followed by 6 weeks of immobilization in a 30° external rotation brace resulted in 62% of shoulders stable at 28-month follow-up, while 29% continued to be unstable and required surgery. Another study by Chalmers et al. also reported around a 60% successful rate when treating instability with closed reduction and brace immobilization [33].

If closed reduction is unsuccessful and instability recurs after a previously successful closed reduction event, surgical intervention is often indicated. Operative strategies when revising a RTSA for instability include increasing the size of the polyethylene liner, increasing the height of the metal metaphyseal humeral component, and using retentive liners. Increasing the polyethylene liner thickness is a simple and often successful way to improve soft tissue tensioning via increasing offset, decreasing the socket-glenoid sphere space, and lengthening the deltoid lever arm (Fig. 20.2). Chalmers et al. were able to achieve stability in unstable primary RTSA only by increasing the polyethylene thickness in 80% of cases of instability [33].

Another strategy for surgically treating RTSA instability is to increase the size of the glenosphere. Retentive polyethylene cups may be beneficial, but they increase the rigidity of the construct, which increases concerns for implant loosening. Operative management should include a thorough evaluation of bony and soft tissue malpositioning that could cause impingement with subsequent levering of the prosthesis. If impingement is suspected, soft tissue debridement and resection of heterotopic ossification and previous bony spurs may be necessary. Unfortunately, in cases where bony and soft tissue resection is not enough to restore stability, extensive revision of the baseplate and humeral polyethylene components may be needed [34].

20.5 Scapular Notching

A complication unique to RTSA is notching of the scapula, which has been reported in up to 96% in some case series [2]. The phenomenon of scapular notching occurs via mechanical impingement when the humeral polyethylene component abuts the inferior glenoid scapular neck during adduction [35]. This mechanism is reproducible in biomechanical studies but clinically has been challenging to translate into practical solutions. A study by Kolmodin et al. applied kinematic simulation CT to demonstrate that areas of impingement during clinical range of motion matched notching sites on patient imaging studies [36]. After several cycles of impingement, the inferior aspect of the glenoid and scapular neck begins to erode which can be seen radiographically. The progression of this notching and its classification has been described by Sirveaux and is graded from 1 to 4 [3] (Fig. 20.3). Notching is graded based on the amount of lucency ranging from involvement of just the scapular neck (Grade 1), up to the inferior screw (Grade 2), to the central screw (Grade 3), and underneath the entire baseplate (Grade 4). Notching has been found to be more frequent and to a greater degree in Grammont style prostheses compared to RTSAs with more lateral centers of rotation [37].

The exact clinical significance of scapular notching is not known, but the concern is that it is a harbinger of baseplate loosening. Several studies show no significant decrease in functional outcomes or increase in implant failure rates despite the presence of notching on radiographs [38, 39]. The majority of notching seems to occur in the first 2 years after the index surgery, and studies suggest that progression after 2 years is minimal [40, 41]. Simovitch reported a 44% notching rate when using a Grammont-type prosthesis at an average of 4.5-month follow-up [40].

Nevertheless, there are documented cases of notch progression leading to implant failure as well as increased radiolucency around both humeral and glenoid implants after notching occurs [42]. One study by Levigne found that there was a higher incidence of radiolucent lines around the glenoid baseplate postoperatively when scapular notching was present [43]. Clinically however, there was no correlation between these radiolucent lines and baseplate failures. Several studies report that regardless of whether notching is present postoperatively, function and pain scores were equivalent for all groups [39, 44]. Other studies contradict these findings and show inferior clinical results when notching is present [3, 40, 45]. Mollon et al. found that patients with notching when compared to patients without notching had decreased range of motion, strength, inferior ASES, SST constant, and UCLA scores [46].

Despite the continued unclear role of scapular notching in RTSA, many strategies, including surgical technique and prosthesis design, have been developed to decrease its incidence. Nyffeler et al. performed a cadaveric biomechanical study to determine the optimal baseplate placement to avoid notching and found that inferiorly placed glenospheres develop less notching than those placed superiorly [47]. Another study confirmed these biomechanical findings by showing that optimal glenosphere positioning leads to decreased notching in a clinical setting [48]. Another technical strategy that is used to prevent notching includes placing the baseplate and glenosphere with 10–15° of inferior tilt. The belief is that increasing the prosthesis-scapular neck angle (PSNA) increases the available arc of motion before the humeral component impinges on the scapula. Gutierrez et al. showed using a

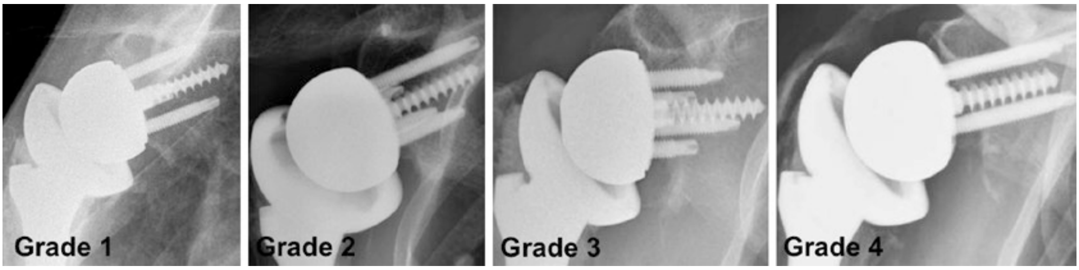

Fig. 20.3 Scapular notching classification. Grade 1: notching below the level of the inferior screw. Grade 2: notching at the level of the inferior screw. Grade 3: notching above the level of the inferior screw. Grade 4: notching above the level of the inferior screw and involving the undersurface of the baseplate

computerized model that inferior tilt of the glenosphere improves impingement-free range of motion, which in theory would result in decreased scapular notching [35]. Despite these findings, clinical evidence is still lacking on whether inferior tilt prevents notching. Kempton et al. did not find any clinical benefit when comparing a neutrally versus inferiorly tilted glenospheres [49].

Prosthesis design can also affect the amount of notching. Prostheses with a lateralized central of rotation have been shown to have a decreased incidence of notching when compared to traditional Grammont-type implants with a more medial center of rotation [37, 50]. RTSA with a 145° humeral neck angle also shows decreased rates of scapular notching. The use of a larger glenosphere allows a larger surface of curvature around which the humerus polyethylene can rotate before it comes in contact with the scapular neck and is thought to prevent notching as well [51].

20.6 Glenoid Baseplate Loosening

Baseplate loosening can be either septic or aseptic, but regardless of the cause, the result can be catastrophic due to pain and wear of the glenoid bone by the loose components. The first goal when a patient has baseplate loosening is to determine which of these two processes is causing the loosening. Baseplate loosening should be presumed to be due to septic causes until proven otherwise. Consequently, blood studies (viz., erythrocyte sedimentation rate and CRP), aspiration, and, when available, metal reduction MRI should be performed.

Aseptic glenoid baseplate loosening/failure (AGBL) is a multifactorial process and can present unique challenges to the surgeon treating patients with RTSA. Baseplate loosening is best demonstrated with plain radiography by comparing serial radiographs. The most common AGBL findings on radiographs include lucencies around the screws, fracture of the screws, or a shift in position of the baseplate compared to previous films (Fig. 20.4). Systematic reviews of complications after RTSA have reported baseplate loosening and failure rates ranging from 1.8 to 8.8%. It is important to note that many of the studies included did not distinguish primary from revision cases [7, 52, 53].

The incidence of baseplate loosening has been reported to be higher in prosthetic systems with lateralized baseplates compared to traditional more medial center of rotation Grammont-type baseplates. The reason for this has been the concern that there are increased shear forces across the bone-metal interface of baseplates in RTSAs

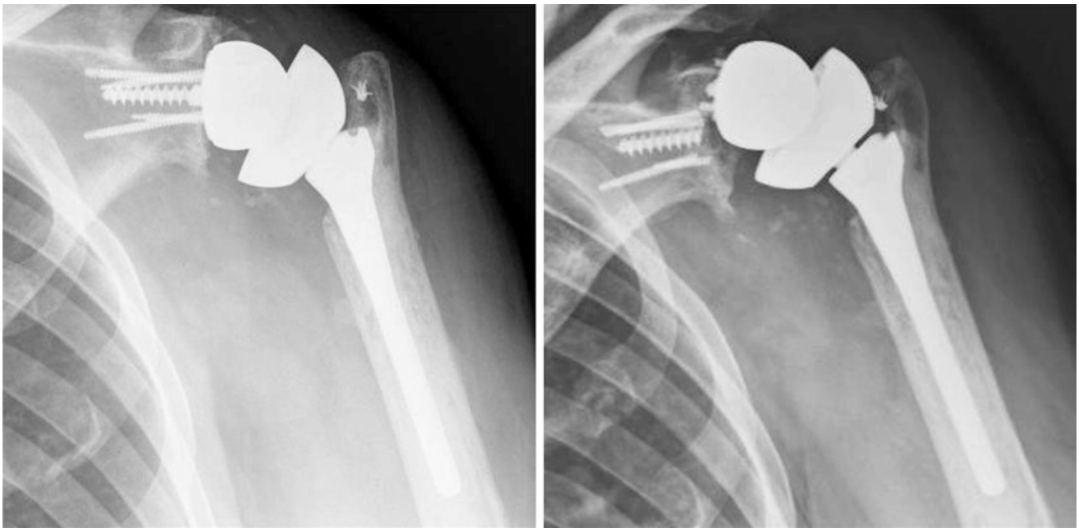

Fig. 20.4 Pre- and post-failure radiographs taken at different time intervals reveal a gross difference in baseplate positioning with associated hardware failure indicating AGBL

with a lateralized center of rotation compared to a more medial center of rotation type of implant. Frankle et al. reported an initial AGBL rate of 11% using a lateralized component, but subsequent design changes lead to an AGBL rate of 2.5% [54, 55]. A study by Bitzer et al. found that primary RTSA with a more lateral center of rotation prosthesis had an AGBL of 1.2% [56]. A systematic review by Zumstein et al. noted a statistically significant difference in AGBL when comparing medialized versus lateralized RTSA [7].

One major cause of AGBL after RTSA is the lack of bone ingrowth into the baseplate after implantation. Lack of bony ingrowth into the glenoid baseplate is believed to be due to increased levels of micromotion at the prosthesis-bone interface. Formaini found that micromotion increases significantly once baseplate coverage by the glenoid is less than 50% of the baseplate surface [57]. Micromotion less than 150 microns is required for bony ingrowth. Excessive micromotion results in a fibrous ingrowth, which is less secure than bone ingrowth. Lack of bony ingrowth on the undersurface of the baseplate is a consistent intraoperative finding that has been reported in retrievals from revision surgery performed for AGBL [58].

Several risk factors for AGBL have been reported in the literature [52, 59–61] including the use of non-locking screws, revision surgery, rheumatoid arthritis, surgeon technical error, notching of the inferior glenoid, and prosthesis design. Revision surgery and rheumatoid arthritis are risk factors for AGBL as both conditions are associated with decreased glenoid bone stock and/or quality, thus decreasing the strength of baseplate fixation [40, 62]. One study in RA patients found the incidence of AGBL to be 29% using the Delta III RTSA medialized center of rotation prosthesis [59]. The use of non-locking screws is a risk factor for AGBL as glenoid bone is largely cancellous, and locking screws improve rigidity of the system and presumably decrease micromotion. Additionally, locking constructs do better in osteopenic bone which is a common finding in RTSA candidates. Walker and Frankle found that the rate of baseplate failures decreased significantly after the introduction of locking screws for baseplate fixation when using the same implant [63]. Finally, the need for bone grafting also appears to be a risk factor for AGBL as studies show an increased incidence of AGBL when bone grafting is performed versus when it is not in both primary and revision settings [56, 62, 64].

The treatment options for baseplate failure depend upon many factors, including patient demographics, the patient's health, the degree of symptoms, and the amount of bone left after removal of the loose components. Some patients refuse further surgery as the baseplate and glenosphere become fixed in a position of superior tilt and may not be painful. Another option is conversion to a hemiarthroplasty with or without bone grafting of the glenoid defects. This typically will not restore function and may also continue to be painful. One- or two-stage revision depends entirely upon the amount of glenoid bone available. Resection arthroplasty or fusion may be an option after baseplate failure when revision RTSA is not possible, but functional outcomes are poor [65].

20.7 Humeral Implant Loosening

Humeral implant loosening is an uncommon complication of RTSA, and like in anatomical TSA, a loose humeral implant should be considered to be due to infection until proven otherwise. The evaluation for a possibly infected RTSA humeral component is the same as for an infected anatomical TSA. Besides infection, other causes of humeral component loosening are uncommon for RTSA. These other possible causes of humeral loosening include inadequate bone stock from the disease process for which the RTSA was performed (e.g., juvenile rheumatoid arthritis, deformity after proximal humerus fracture, severe proximal humerus bone loss) and osteolysis from particle disease. .

Cuff et al. performed a biomechanical study using humeral components from several different RTSA systems and found an increased humeral loosening rate in bone loss cadaver models with deficient metaphyseal bone stock versus cadaver models with an intact metaphysis [66]. They also found that modular humeral components were at higher risk of loosening compared to monobloc implants. Other risk factors for humeral component loosening include severe osteoporosis or also very young patients who are extremely active (e.g., playing tennis or chopping wood). Osteolysis due to polyethylene and metal wear can also contribute, but the incidence does not appear to be high in RTSA compared to lower extremity implants. However, osteolysis from polyethylene debris created in the notching process might be a contributor to humeral component loosening [67].

Allograft augmentation has been suggested to help with proximal humeral bone loss during RTSA implantation. Traditionally, allograft has been used during oncological procedures where large resections are not uncommon and large bony defects are created. Allograft augmentation is thought to enhance prosthesis static stability via increased bone bulk and dynamic stability by facilitating repair of the subscapularis tendon [68]. Downsides to allograft include infection, resorption, nonunion, and increased operative time and cost. Budge et al. reported no episodes of humeral loosening despite not using any bone graft for revision RTSA cases with large proximal humeral bone loss [69].

The treatment of humeral component loosening after infection is with either one-stage or two-stage revision. Meta-analysis of these two approaches seems to suggest that one does not produce exceptional results over the other [70]. In cases of aseptic loosening, the simplest way to revise a loose humeral stem with mild to moderate bone loss is with cement augmentation. If bone loss is moderate to severe, a structural allograft can be utilized as a composite with a long-stem humeral component. Proximally augmented humeral component typically used for tumor cases is also an option, but there are few studies upon the long-term success of these implants. Revision humeral stems can be press fit or cemented depending on what is needed intraoperatively to achieve the best bony fixation with overall glenohumeral stability.

20.8 Stress Fractures

A complication that is unique to RTSA is the development of stress fractures of the scapula, the acromion, coracoid, or scapular neck [71–74]. Of these, stress fractures of the acromion and scapular spine are the most common with an incidence of 3.1–10% [75]. These fractures typically begin insidiously with just pain. However, patients usually report a sudden and acute increase in pain when the fracture completes. Careful examination of the patient with palpation of the bony prominences is critical when making the diagnosis. Plain radiographs can confirm the diagnosis, but in some instances, CT scanning may be necessary to define the fracture. Otto et al. were able to diagnose only 32% of displaced scapular fractures on initial imaging after RTSA using conventional radiographs with axillary view being the most helpful for assessment [76].

There are several factors which contribute to the generation of these fractures. The first is the altered biomechanics of the shoulder girdle after RTSA where stress is increased by the screws and the implants to the scapular structures. Kennon et al. recommend that the superior screw in the baseplates be omitted from the baseplate as it can increase stresses across scapular spine leading to fracture [77]. Inferior positioning of the baseplate on the glenoid increases deltoid tensioning, and more stress is placed on the acromion. A previous os acromiale is also a risk factor for acromial fracture and for displacement of the acromial fragment.

Fractures of the scapular spine can cause significant pain and loss of function, and making the diagnosis can also be challenging due to the fact that they are uncommon. Levy and colleagues proposed a classification scheme based on the origin of the deltoid muscle from the acromion [78](Fig. 20.5). Type I involved portions of the anterior and middle deltoid origin. Type II is the middle deltoid origin with some, but not all, of the posterior deltoid origin. Type III is the entire middle and posterior deltoid origin. Importantly, this study highlighted the inaccuracy and poor interobserver reliability of diagnosing acromion fractures with standard radiographs and emphasized the need for computed tomography imaging. Crosby et al. proposed another classification system based upon where the scapular fracture is located relative to the acromioclavicular joint [79] (Fig. 20.6). Type I fractures are located in the anterior acromion, type II involve the acro-

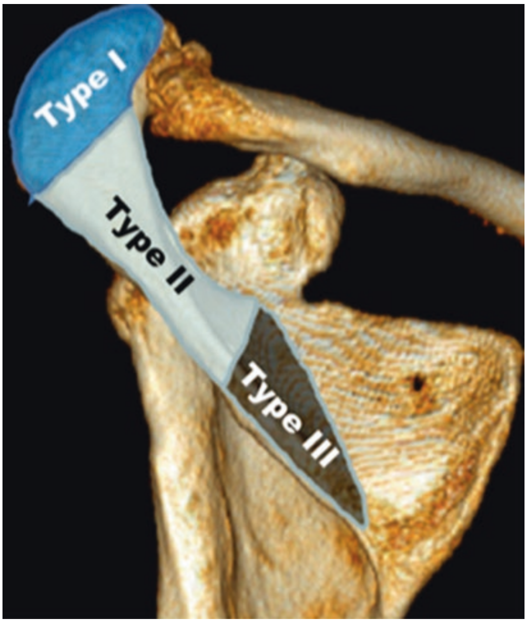

Fig. 20.5 Classification scheme of acromion and scapular spine fractures by Levy and colleagues. Levy JBJS 2013 [56]

mial body posterior to the acromioclavicular joint, and type III fractures include the scapular spine. Scapular spine fractures tend to be easier to identify since they are further from the prosthesis and thus are less often obscured by humeral or glenoid implants (Fig. 20.7). Ultimately, although the point of reference varies, they similarly classify scapular fractures beginning at the anterior aspect of the acromion and ending along the posterior scapular spine.

Treatment of scapular fractures varies depending on patients' symptoms, the amount of pain, and the location of the fracture. Treating these fractures can be difficult given their location, high rates of malunion and nonunion, and variable results with surgical treatment. Hattrup reported a case series of nine scapular fractures treated with sling immobilization with only one union and eight nonunions with moderate to poor functional outcomes [80]. Hamid et al. reported eight scapular fractures also treated with immobilization with slightly improved functional scores compared to Hattrup, but again six fractures resulted in nonunions and two in malunions [81].

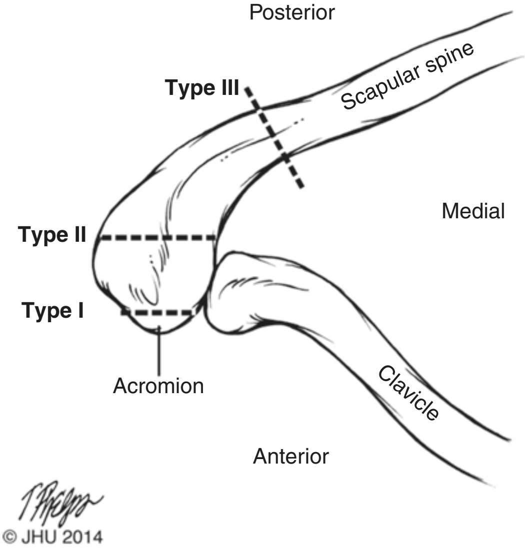

Fig. 20.6 Classification scheme of acromion and scapular spine fractures by Crosby et al. Clinical Orthopedics & Related Research 2011 [57]

Given that nonoperative measures result in frequent nonunions and malunions, operative interventions have been attempted to improve functional outcomes and healing rates. At this time, there is limited data with only small case series regarding operative management of scapular fractures after RTSA. One technique is fixation via tension band wiring which shows similar healing and function compared to nonoperative management. Another technique is rigid plate fixation, which has shown some success, but the data is limited to only a few very small case series. Crosby and colleagues recommend observation of type I fractures, acromioclavicular resection with open reduction internal fixation for type II fractures, and open reduction internal fixation for unstable type III fractures [79].

20.9 Dissociation of Components

Another set of complications unique to RTSA includes dissociation of the components on either the humeral side or glenoid side. Some of these issues were related to device design, and others were related to suboptimal implan-

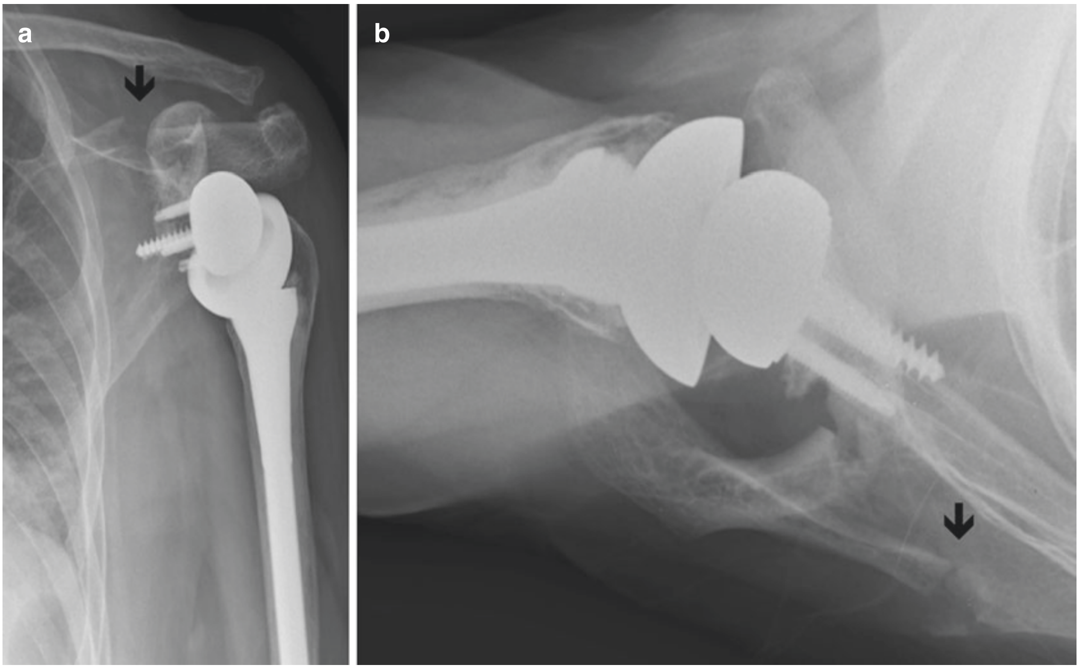

Fig. 20.7 (**a**) Grashey view of RTSA with associated scapular spine fracture seen along the superior border of the scapula. (**b**) Axillary view of RTSA with associated scapular spine fracture. Black arrows pointing to fracture site

tation of the components. On the humeral side, early Grammont-type prosthetic humeral stems consisted of two parts, and in a few cases the upper portion would unscrew from the distal portion of the stem [82] (Fig. 20.8) Also, there have been cases of the metal insert, which holds the polyethylene liner, becoming detached where the Morse tapers of the metallic shell and humeral stem meet [83]. Dissociation of the polyethylene liner from the metal insert has also been described and can result in pain and instability of the prosthesis [84]. On the glenoid side, the common design feature is a baseplate onto which a glenosphere is secured via a Morse taper feature. There have been cases of the glenosphere becoming either partially or fully detached from the baseplate resulting in varying degrees of pain and requiring revision surgery [85]. Cusick et al. found significantly higher rates of glenosphere dissociation with the use of larger glenosphere sizes and that the primary etiology related to the failure was fretting wear at the glenosphere-baseplate interface [86].

20.10 Nerve Injury

Nerve injury is a serious but uncommon complication after RTSA. The incidence of neural impairment after RTSA has been reported to be around 2%, although the vast majority of these are neuropraxias and resolve by themselves over time [87]. The brachial plexus is of primary concern during exposure and prosthesis implantation due to its proximity to the glenoid. McFarland et al. performed a cadaveric study and showed that the brachial plexus can be as close to the anterior glenoid rim as 5 mm in some cases [88]. The axillary nerve is also at risk and is of particular concern as it is in close proximity to the inferior glenoid rim. As a result, it is not surprising that it is the most common isolated nerve injury after RTSA [87, 89]. Many surgeons focus on the proximity of the axillary nerve to the inferior glenoid rim, but it is also very close to the humeral component. Ladermann performed an anatomic study on cadavers after RTSA and found that the main anterior branch of the axillary nerve is on average 5.2 mm away from the humeral prosthetic

Fig. 20.8 Grashey view of RTSA with demonstrating dissociation of the distal humeral stem from the proximal metaphyseal modular component. Black arrow points to gapping between metaphyseal modular component and humeral stem, which should not be present

implant [90]. Because of this, it is important to be careful with retractor placement as damage can occur via direct compression. Also, release of the capsule around the inferior glenoid with electrocautery may damage the axillary nerve.

Despite their close anatomic relationship, direct iatrogenic injury to nerve structures during RTSA is uncommon, and the majority of cases are neuropraxias due to increased traction during the operative case. RTSA is at a higher risk of producing nerve injury compared to anatomic TSA given the increased glenoid exposure required during the surgery and the resulting arm lengthening after surgery. Parisien and colleagues showed a higher incidence of nerve "events" when using intraoperative neuromonitoring with RTSA compared to TSA [91]. The arm is lengthened typically in RTSA on average 2.5 cm in order to increase the deltoid lever arm which may result in a neuropraxia secondary to nerve tensioning. Van Hoof et al. demonstrated that nerve damage is related to strain which is important since nerve lengthening of up to 19% lengthening occurs after RTSA [92]. Nerve stretch also occurs as a result of intraoperative arm manipulation required to perform RTSA. Thus, it is important to note that when the arm is externally rotated and adducted during the glenoid or humeral preparation stages of RTSA, increased tension and strain are placed on the brachial plexus. Placing the arm in a neutral position as often as possible during surgery can prevent excessive strain and tension on the neurovascular structures of the shoulder girdle.

20.11 Vascular Complications

Vascular complications include arterial injuries and deep venous thrombosis. The incidence of arterial injury after RTSA is low, and the majority of documented cases involve intraoperative injury to the axillary artery. These injuries can be due to direct laceration by a knife or retractor, or they can be avulsion injuries due to excess tension on the vessels. Arterial injuries after RTSA are fortunately rare, but if they are encountered intraoperatively, the best course of action is to have the vessel repaired by a surgeon familiar with vessel repair. If that is not possible, then arrangement for immediate transfer to a facility where those resources are available is recommended. There are several reported cases of arterial injury related to RTSA, which provide some insight into these uncommon injuries. Wingert described pulsatile bleeding while repairing the subscapularis tendon during the closure of a RTSA [93]. Upon exploration, an avulsion-type injury in the third zone of the axillary artery was encountered and repaired with a synthetic arterial bypass graft. During exploration, the axillary artery was found to run within the plexus just 1 cm medial to the glenosphere. The estimated limb lengthening in this patient was 2.2 cm, which is within what has been reported after routine RTSA. Ghanem et al. described a case of a patient with extremity shoulder stiffness and pain 1 month after RTSA [94]. The initial evaluation was consistent with a transient neuropraxia. Over time, the patient's extremity began to feel cool along with increasing of tingling and numbness. The diagnosis of thrombotic axillary artery occlusion was made via angiography, and the patient recovered well after treatment with angioplasty. A careful neurological and vascular evaluation after RTSA is recommended after surgery especially when there are complaints of paresthesias in the extremity.

Deep venous thrombosis after RTSA has not received attention in the literature, but it is presumed to be similar to that of anatomical TSA. One systematic review found an incidence of 0.52% after analyzing 42, 261 shoulder arthroplasties although they did not differentiate between RTSA and anatomic TSA [95]. Tashjian et al. evaluated the incidence of VTE after various arthroplasties and found no difference in rates between primary RTSA, primary anatomic TSA, and primary hemiarthroplasty [96]. However they did recognize revision shoulder arthroplasty as an independent risk factor for VTE after shoulder surgery.

Hematomas and phlebitis can occur after RTSA. Both complications are usually mild and transient [97]. The incidence of hematoma ranges from 1 to 20% and, although common, does not appear to affect the overall outcomes of RTSA. The relatively high incidence of postoperative hematoma after RTSA is due to implant design and the increased amount of dead space relative to other implants [98]. Both hematoma and phlebitis can be thought of as nonspecific complications.

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