Shoulder Arthroplasty

The Shoulder Club Guide

Gazi Huri
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Editors

INTERNATIONAL SHOULDER CLUB

Springer

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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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Contents

1 Shoulder Anatomy

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.

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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

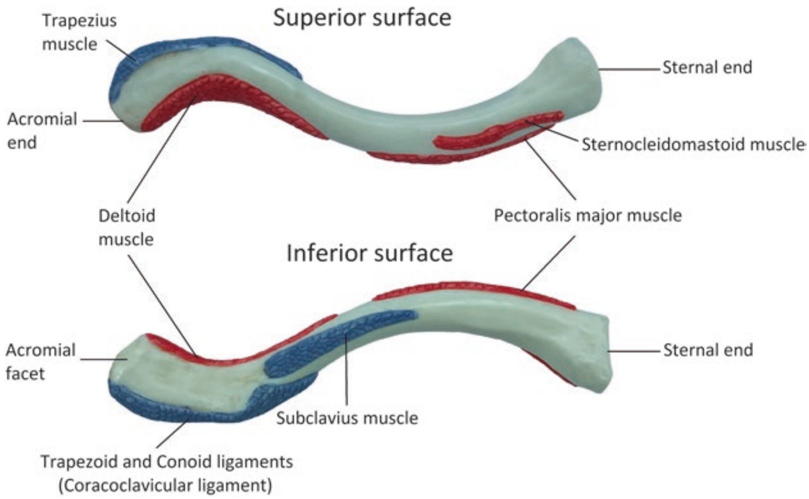

Fig. 1.1 Superior and inferior surfaces of the clavicle. The origins of the muscles are shown with red color, and the insertions of the muscles and the tendons are shown in blue

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

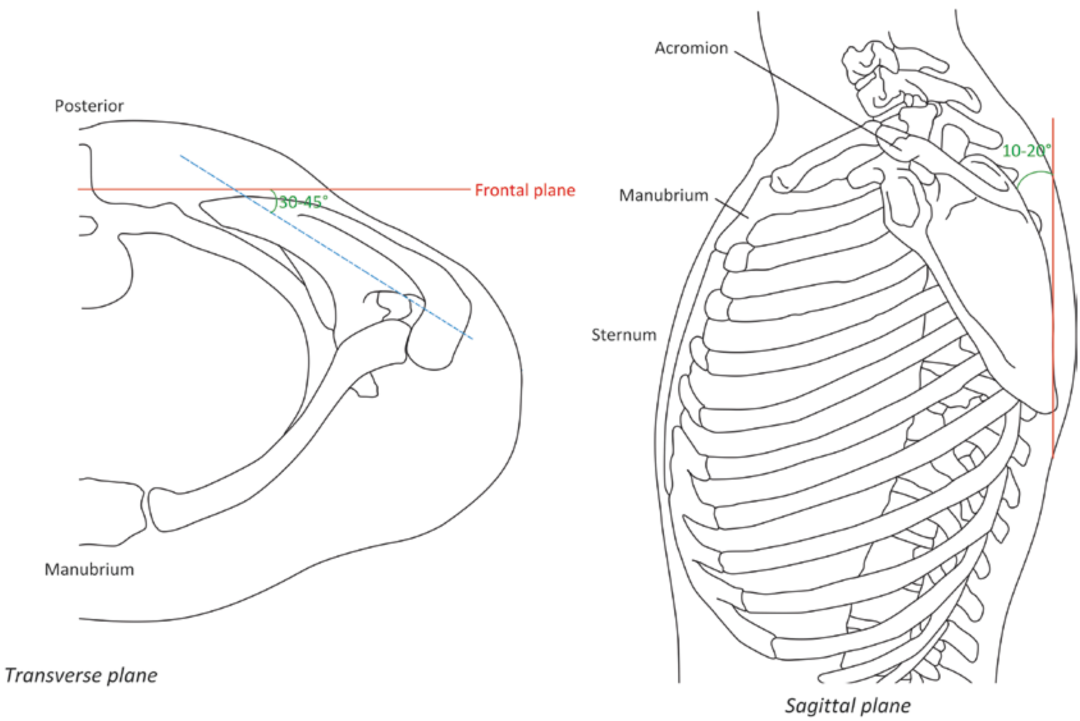

Fig. 1.2 The scapula creates a 30–45° angle with the frontal plane in transverse cross-section and 10–20° angle with the frontal plane in sagittal cross-section

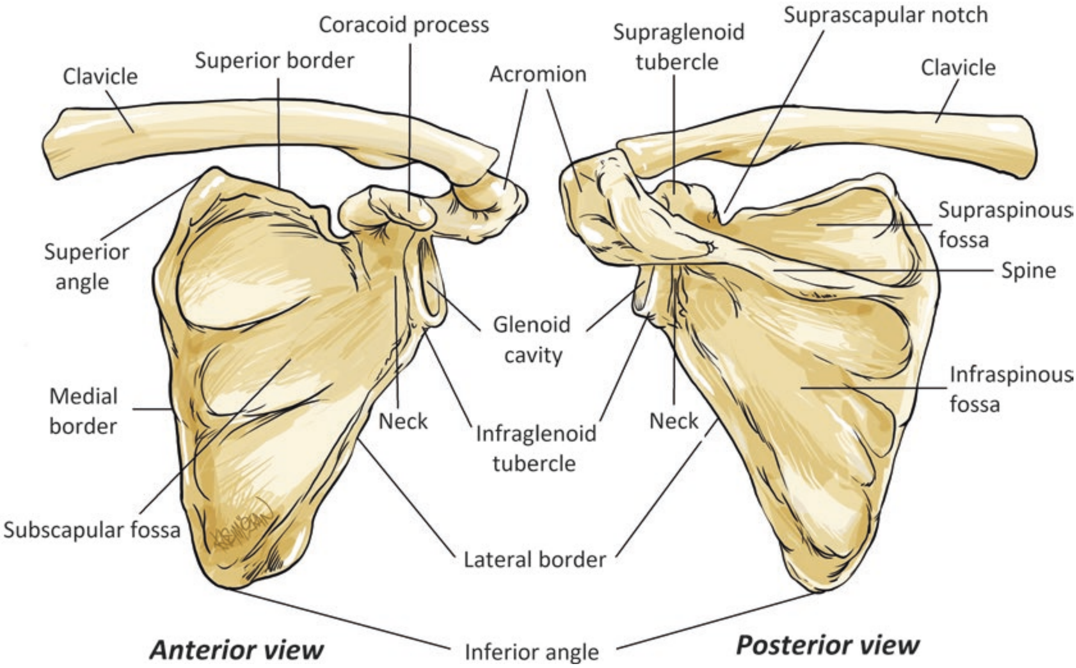

Fig. 1.3 The anterior and posterior views of the scapula

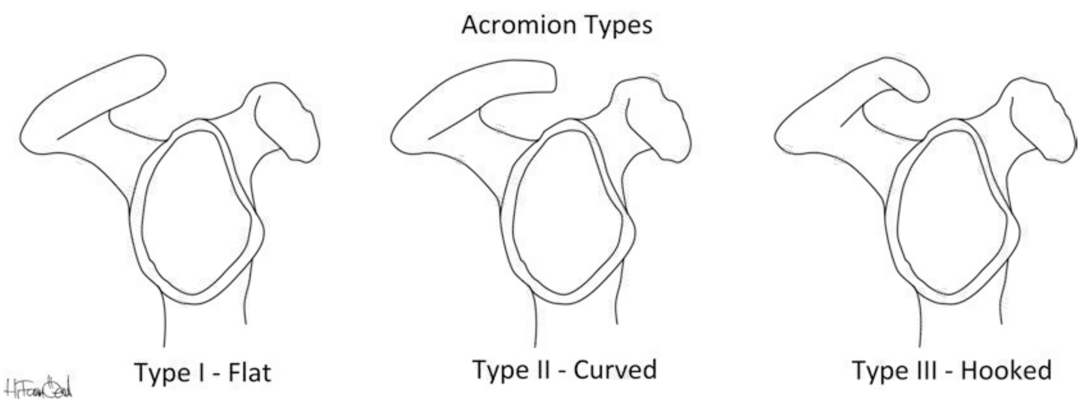

Fig. 1.4 The drawings of the types of acromion (described by Bigliani et al.)

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

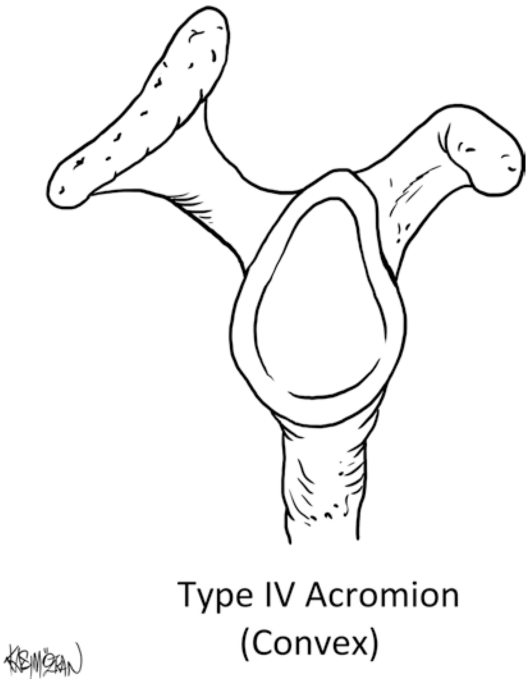

Fig. 1.5 The drawing of the type IV acromion (described by Gagey et al. in 1993)

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

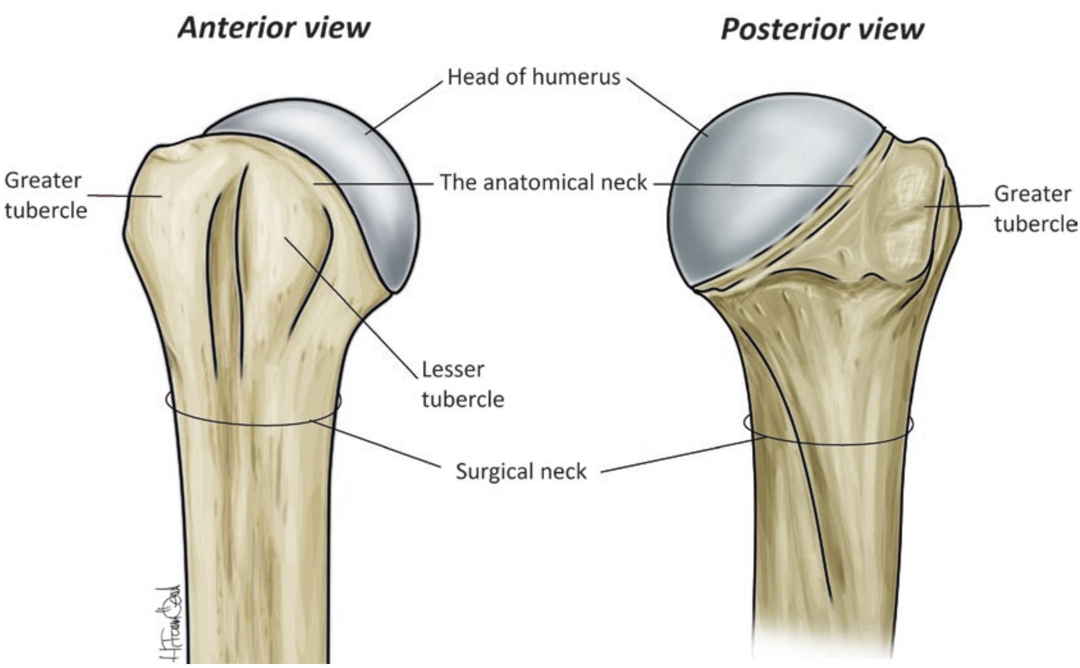

Fig. 1.6 The picture showing the anterior and posterior surfaces of the proximal humerus

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

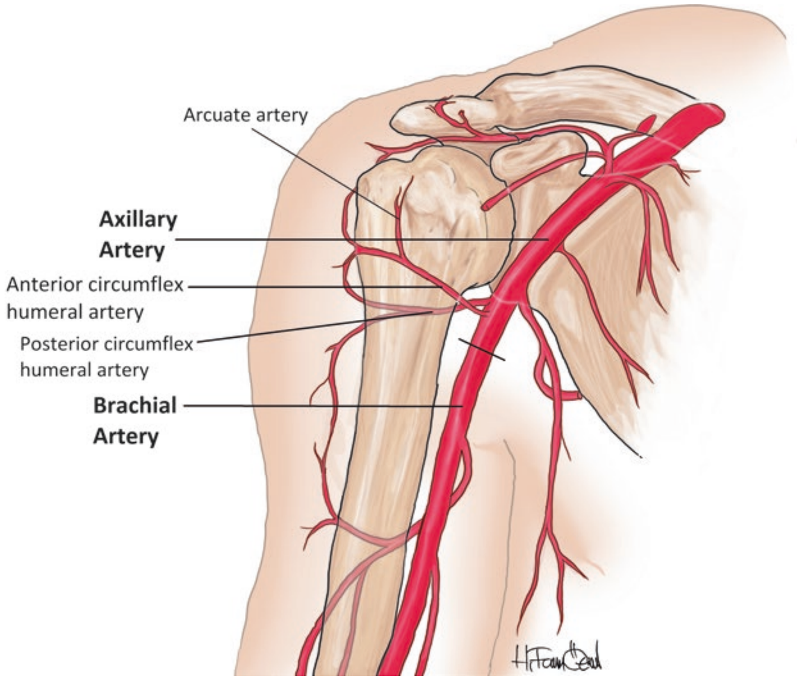

Fig. 1.7 Anterior view of the vessels that supply blood to the proximal humerus

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.

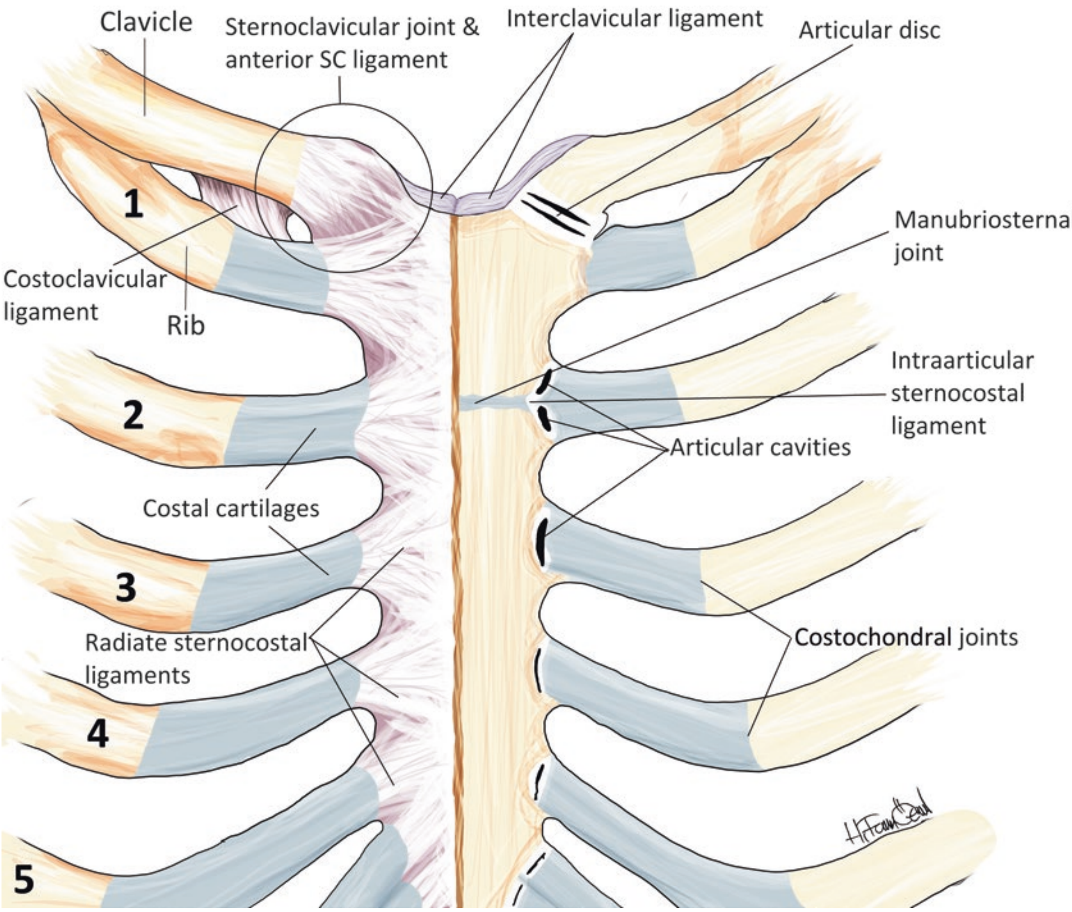

Fig. 1.8 The sternoclavicular joint and associated structures, seen from anterior

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 non-axial 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

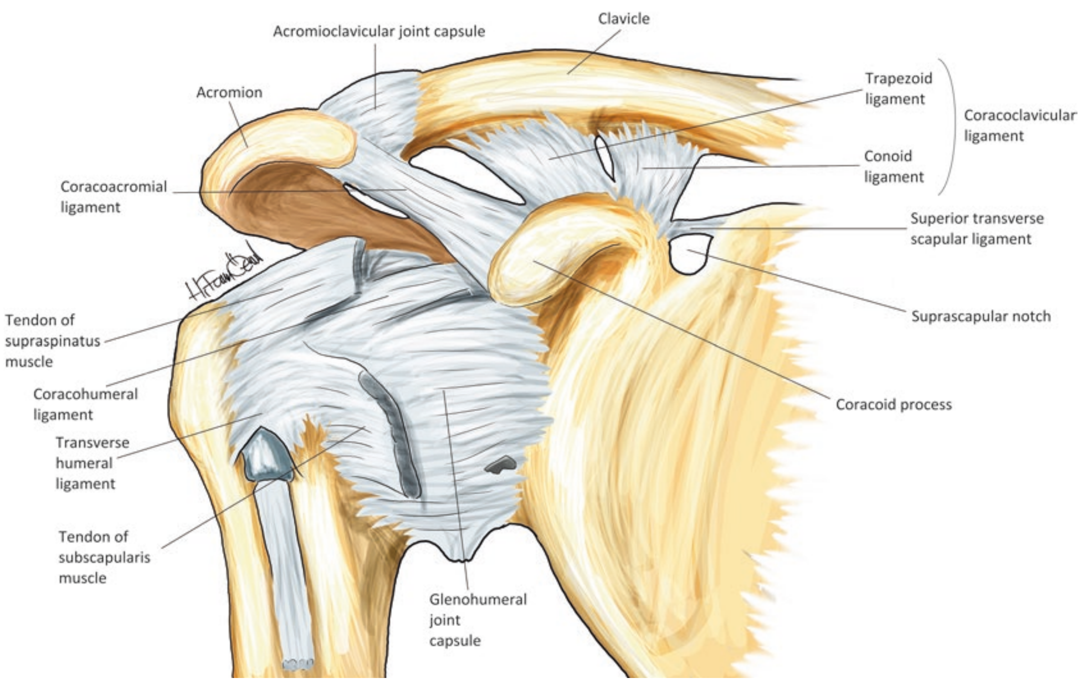

Fig. 1.9 The acromioclavicular joint, the glenohumeral joint, and associated structures seen from anterior

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