Biomechanics of the shoulder and elbow

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Abstract

The shoulder and elbow are complex joints with inherent biomechanical features that allow for a wide range of motion, yet stability at the extremes of movement. The shoulder girdle is composed of three bones and five joints, with multiple muscle attachments. It is predisposed to develop a wide range of pathologies if injury or dysfunction disturbs the biomechanical balance. It is the synergistic effect of static and dynamic stabilizers of the shoulder that work to maintain the congruence of what is inherently an unstable joint. The elbow links the shoulder and the hand, and functions as a fulcrum for the forearm lever. It helps position the hand in space, thus allowing the hand to perform activities of daily living. The elbow must be robust enough to allow it to function as a weight-bearing joint, and therefore complex joint biomechanics are required to maintain its stability and function. Many conditions affect the bony and soft tissue structures of the upper limb. This often results in reduced movement and function, necessitating replacement or restoration of normal anatomy. A comprehensive understanding of shoulder and elbow biomechanics is essential to plan and treat upper limb conditions.

Keywords clinical relevance; kinetics of shoulder and elbow; shoulder and elbow anatomy; static and dynamic stabilizers

The shoulder

The shoulder has the greatest range of movement of any human joint. To enable this there is less constraint than in other joints. This in turn predisposes the shoulder to develop various pathological conditions. Treatment, particularly anatomical reconstruction, and joint replacement, can be technically difficult.

The bony anatomy

The shoulder is composed of three synovial joints (glenohumeral, acromioclavicular and sternoclavicular) and two physiological joints (scapulothoracic and subacromial) (see Figure 1).

The humeral head: the glenohumeral joint is formed by the humeral head and the glenoid. The humeral head is a sphere in 90% of people, with an average radius of curvature in the coronal plane of 24 mm (range 19−28 mm).[2] It is inclined superiorly with respect to the humeral shaft, with a neck-shaft angle of 130−140 degrees, and is retroverted by approximately 30 degrees from the transepicondylar axis of the distal humerus. The head is eccentrically placed on the shaft, approximately 9 mm posterior to the neutral axis.[3] If this version and posterior offset is not recreated during replacement then early failure may result.

The scapula: the scapula is a thin sheet of bone with three borders. The medial border runs parallel to the axial spine, forming an inferior angle with the oblique lateral border at the level of the eighth thoracic vertebra. The oblique superior border runs infero-laterally towards three of the four processes (acromion, coracoid, and articular − glenoid). The fourth process is the spine, which divides the scapula into the supraspinous and infraspinous fossae.

The glenoid is pear shaped, tilted superiorly by approximately 5 degrees from the vertical plane, and retroverted 7 degrees from the plane perpendicular to the scapula plane, which is itself 30−40 degrees anteverted to the coronal plane.[3] The surface area of the glenoid fossa is only a third of that of the humeral head, making joint congruency important. Glenohumeral stability is enhanced by the distribution of cartilage (thicker at the rim) and the presence of the labrum.

The coracoid provides a bony origin for the coracobrachialis, pectoralis minor, and short head of the biceps. It is an important landmark for the deltopectoral approach.

The acromion forms a physiological joint with the head of the humerus of approximately 7−8 mm depth, and has attachments for the acromioclavicular and coracoacromial ligaments, conferring stability.[4]

The clavicle: this acts as a strut, from which the glenohumeral joint is suspended. It antagonizes the action of the pectoralis major and trapezium to prevent medialization of the joint.

The soft tissue anatomy

Muscles: the principal muscles of the shoulder girdle are those of the rotator cuff: the supraspinatus, infraspinatus, subscapularis

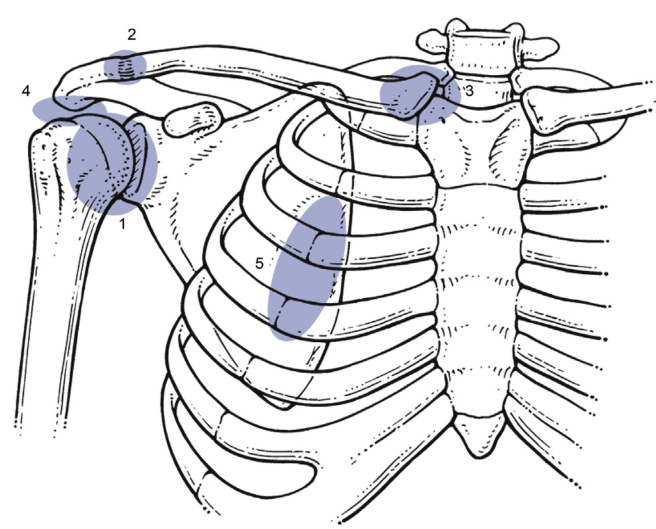

Figure 1 Osseous anatomy of the shoulder girdle: 1. Glenohumeral joint 2. Acromioclavicular joint 3. Sternoclavicular joint 4. Subacromial Joint 5. Scapulothoracic joint. Reproduced from Ombregt 2013,[1] p. e40. With permission from Elsevier.

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and teres minor. Accessory muscles assist them: the deltoid, latissimus dorsi, pectoralis major and minor, and teres major. The levator scapulae, trapezius, and serratus anterior help stabilize the scapula (Figure 2).

Ligaments: the ligaments around the shoulder are both intra- and extracapsular. The intracapsular ligaments are the glenohumeral ligament complex (which comprises the superior, middle and inferior glenohumeral ligaments), and the coracohumeral ligament (which strengthens the superior part of the capsule, blending with the supraspinatus tendon laterally). The extracapsular ligaments are the coracoacromial, and coracoclavicular ligaments (see Figure 3).

Normal joint movement

Movements of the shoulder are complex. They involve muscles of the glenohumeral, scapulothoracic and thoracohumeral groups. The role of each muscle varies with the position of the arm in space.

Glenohumeral joint: during forward elevation, the deltoid and supraspinatus muscles contract to create a vertical shear force. The combined action of the muscles of the rotator cuff oppose this force to hold the humeral head in the joint, and minimize humeral head translation.

The supraspinatus is responsible for the initiation of abduction (normal range 150 degrees), and then the deltoid becomes more active, with similar vectors of each muscle at 90 degrees of abduction. Some external rotation (normal range 90 degrees) is required to achieve full shoulder abduction, and allow the greater tuberosity to clear the acromion. Therefore, patients with an internal rotation (normal range 90 degrees) contracture can only abduct up to 120 degrees. Of the 150 degrees of abduction, 60 degrees is at the scapulothoracic joint. This coordination of scapulothoracic and glenohumeral movement is referred to as scapulohumeral rhythm, and disruption of this due to scapulothoracic dyskinesia, can lead to the development of various pathologies of the shoulder girdle.[5]

The humeral head rolls and translates during shoulder movement, though the degree of translation is limited by scapulothoracic motion.

Scapulothoracic joint: this needs to allow a wide arc of motion but be stable to allow the force vector to be guided through the glenoid fossa. Scapulothoracic dynamics are therefore important to assess in the painful shoulder. Normal scapular rotation has three important functions: Firstly, it allows the length of the deltoid fibres to be preserved throughout the movement arc. Secondly it prevents impingement. Thirdly it enables the glenoid to act as a stable base. These dynamics change throughout the range of glenohumeral movement, with the first 30 degrees of abduction and 60 degrees of forward elevation achieved largely without the need for scapulothoracic motion. Thereafter, scapulothoracic dynamics play an increasingly significant role.[4]

Sternoclavicular joint: the clavicle circumducts around the sternoclavicular joint during shoulder movement. The coracoclavicular and acromioclavicular ligaments stabilize the clavicle at the acromioclavicular joint, preventing scapulothoracic

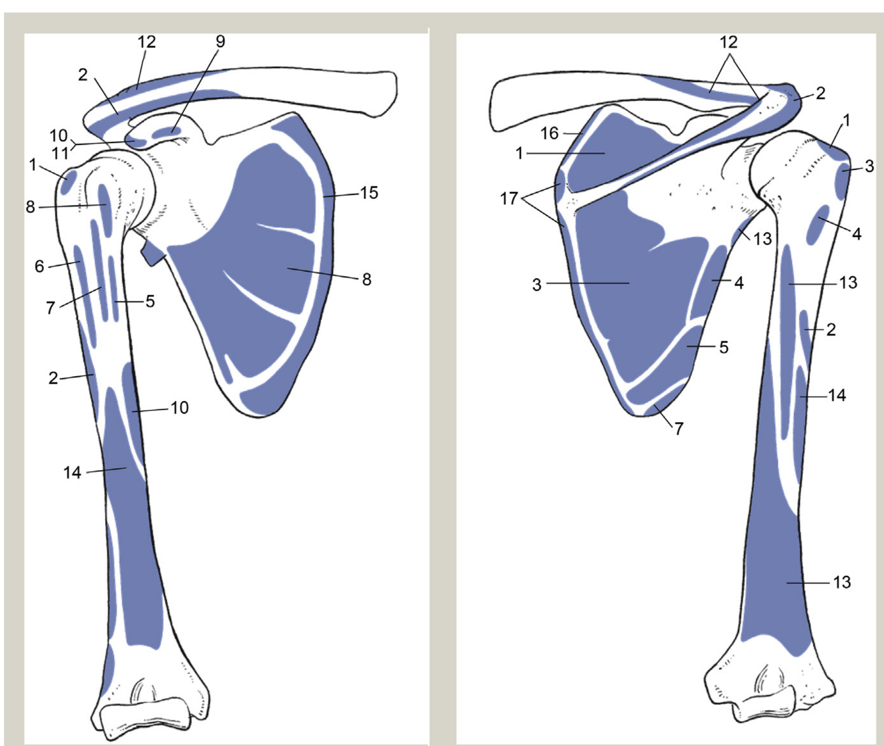

Figure 2 Muscle origins and insertions. 1, supraspinatus; 2, deltoid; 3, infraspinatus; 4, teres minor; 5, teres major; 6, pectoralis major; 7, latissimus dorsi; 8, subscapularis; 9, pectoralis minor; 10, coracobrachialis; 11, short head of biceps; 12, trapezius; 13, triceps brachii; 14, brachialis; 15, serratus anterior; 16, levator scapulae; 17, rhomboid. Reproduced from Ombregt 2013,[1] p. e46. With permission from Elsevier.

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