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The shoulder - anatomical and biomechanics aspects

Umărul - aspecte de anatomie și biomecanică

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Abstract

The shoulder is one of the most complex joints of the human body, representing the pectoral arch. The capacity to perform this complex movement at the shoulder joint still remains a challenge until the present. The objective of this paper is to show a current understanding in the motion and stability of the shoulder joint given the particular anatomy and biomechanical aspects. The presentation of complex biomechanics aspects is important because the upper limb is only connected to the rest of the skeleton through the clavicle bone together with a strong and intricate system of muscles and ligaments that allow this joint its wide array of motion. This review can help us in the future to better approach the treatment of the diverse pathology and to improve rehabilitation techniques.

Keywords: shoulder, biomechanics, motion, stability.

Rezumat

Umărul este cea mai complexă articulație a corpului uman, participând la realizarea centurii scapulare. Performarea complexității mișcărilor la nivelul articulației umărului este în continuare o provocare. Studiul nostru își propune să prezinte aspecte actuale ale realizării mobilității și stabilității umărului, ținând cont de particularitățile anatomice și biomecanice. Prezentarea aspectelor biomecanice complexe este importantă, cu atât mai mult cu cât membrul superior este conectat de scheletul trunchiului doar prin intermediul claviculei ca sistem osos. La aceasta se adaugă un aranjament complex și intricat de ligamente și mușchi, care permite acestei articulații o mobilitate variată. Acest studiu sperăm să ajute în viitor la o mai bună înțelegere realizării mobilității umărului, cu o abordare terapeutică mai bună a patologiei și îmbunătățirea tehnicilor de reabilitare.

Cuvinte cheie: umăr, biomecanică, mișcare, stabilitate.

Introduction

In order to properly understand how all the movements of the shoulder can be achieved and the forces necessary to perform all daily routine, we must first look at biomechanics in normal and pathological situations, which will allow us to get a better insight on how lesions form and to find the best way to repair or prevent them. This will also help us develop more efficient ways for the rehabilitation process so that patients can return to their normal lives in a shorter time period. What makes the shoulder joint special is that load bearing occurs in an opposite manner to the rest of the body, which means that instead of compression being the dominant force, here traction is the main acting force (Lugo et al., 2008).

Anatomy

- *Bones*

The pectoral arch is composed of 2 bones: the clavicle and the scapula.

The *clavicle* is a long bone, shaped like the letter "S", and it connects the manubrium to the acromion. It presents an internal curvature with an anterior convexity and an external curvature with an anterior concavity. This shape offers the collarbone a special resistance, which derives from the purpose of carrying all the weight of the upper limb (Lugo et al., 2008).

The *scapula* is a flat bone, with a triangular shape, and is situated on the posterior external side of the thorax, between the clavicle and the humerus (Braddom et al., 2007), providing large surface areas for muscle insertions. On the posterior side of the scapula, the scapular spine divides its dorsal aspect into two areas (supra and infraspinous) and provides the articular surface for the clavicle at the lateral extremity where it forms a great apophysis called the acromion (Lugo et al., 2008). At the superior internal angle, there is a cavity called the glenoid

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cavity. The neck of the scapula is a narrow portion that connects the glenoid cavity to the body of the scapula, and superior to this formation is the coracoid apophysis providing insertions for muscles and ligaments (Braddom et al., 2007; Renfree et al., 2003).

The *humerus* is a long bone forming the arm skeleton that presents 2 extremities and a shaft. The proximal extremity represents one third of a sphere and is 3-4 mm longer on a vertical axis rather than horizontal. The anatomic neck of the proximal humerus surrounds the articular surface and makes an angle of 130-140 degrees with the shaft (Baciu, 1981). There is also an anteversion of the articular surface, like in the femur, but with an angle between 10-30 degrees (Lugo et al., 2008; Braddom et al., 2007). The great tuberosity is outside the anatomic neck, and represents the insertion point for the rotator cuff (Braddom et al., 2007). The small tuberosity is inside the anatomical neck and provides the insertion for the subscapular muscle (Braddom et al., 2007).

- *Joints*

The shoulder joint actually comprises 5 separate joints that will be looked at separately, but our highest interest concerns the glenohumeral joint.

The sternoclavicular joint is the most proximal of the 5 joints and it represents the only bony bridge that connects the upper limb and the thorax. A small meniscus with a vertical disposition is interposed between the bony surfaces of the proximal clavicle and the sternal angle. The ligaments that ensure the stability of the joint are anterior, posterior, superior and inferior, and are joined by an articular capsule that strengthens them (Braddom et al., 2007). Besides these ligaments, we must focus our attention on the costoclavicular ligament because this is the fixed point of the clavicle and the bone rotates around this point while performing its motions (Renfree et al., 2003).

Distally, the clavicle meets the scapular bone and forms the acromioclavicular joint, which is strengthened by a fibrous capsule and 2 ligaments (superior and inferior) (Renfree et al., 2003).

The scapulothoracic joint is not a “true” joint, but must be treated like one due to its high importance and enters a category that Cloquet termed a syssarcosis (Baciu, 1981).

Our interest is focused on the scapulohumeral joint. The bony components are the distal humeral head and the glenoid surface representing the proximal surface. These joint surfaces are complementary. As such, the humeral head is spherically shaped, while the glenoid surface is almost plane with a glenoid labrum extending to the surface of the proximal component (Lugo et al., 2008). The articular capsule has a hardened superior portion, the coracohumeral ligament, and is strengthened anteriorly by the 3 glenohumeral ligaments.

The fifth joint of the shoulder is the subacromial bursa (Beals et al., 1998), which is also a syssarcosis, like the subscapular joint (Lugo et al., 2008).

- *Muscles*

The shoulder joint allows such a wide array of motions and strength due to its strong muscle groups that act on it in a complex and intricate way. Benninghoff cited 3 muscle arches.

Descending: upper region of trapezius, rhomboid, upper portion of teres major muscles – have the role to oppose gravity and help in climbing.

Horizontal: serratus major, middle part of trapezius, rhomboid and pectoralis major - allow the shoulder to move on a horizontal plane forward, backward and medially and laterally.

Ascending: pectoralis minor, inferior parts of serratus major, trapezius, pectoralis major and the latissimus dorsi – pull the scapula down and act against gravity in hanging position (Baciu, 1981). The action of these muscles consists of fixing and stabilizing the shoulder and also, allowing it a wide degree of freedom; they are aided by the scapulobrachial muscles in doing so. The latter extend from the pectoral arch to the upper limb.

The *deltoid* muscle, given its insertions, can allow the abduction of the upper limb; if all the muscle contracts, the anterior fibers will result in an anterior projection of the arm, while the posterior fibers will antagonize, projecting the arm posteriorly. The fibers in the middle portion of the muscle are abductors by excellence. Also, if both the anterior and posterior fibers contract at the same time, they will antagonize the action of the middle part fibers, thus being adductors. Moreover, they stabilize the abduction motion, giving horizontal freedom and, over 60 degrees of abduction, these fascicles become abductors, helping the middle fibers (Braddom et al., 2007).

The *coracobrachialis* is a muscle that allows the anterior projection of the arm, adduction, and external rotation of the humerus due to its insertions (Braddom et al., 2007).

The *supraspinatus* muscle is mainly an abductor of the humerus and it is thought to initiate this motion (Baciu, 1981), but it was shown that it can perform abduction even without the help of the deltoid (Braddom et al., 2007).

The *infraspinatus* muscle has a role in the external rotation of the humerus (Braddom et al., 2007).

The *teres minor* has a small role in the mobility of the shoulder, but plays a major role in conferring stability to the shoulder, fixing the humeral head in the glenoid cavity, and it is also an adductor (Bechtol et al., 1980).

The *teres major* aids in arm adduction (Bechtol et al., 1980).

The *subscapularis* is the muscle which pulls the scapula towards the humerus while performing the internal rotation of the arm (Bechtol et al., 1980).

All these seven muscles described share a common feature, the triangular shape, with a base facing the clavicle and a tip facing the humerus, thus giving the arm its great range of motion.

The rotator cuff is a tendon blade covering the anterior, superior and posterior side of the shoulder joint capsule. The primary function of the rotator cuff is to keep the head of the humerus depressed and centered into the glenoid fossa, permitting a single center of rotation, while allowing efficient abduction or forward elevation of the arm (Pandey & Willems). This centering in the glenoid by the cuff is achieved by balancing the force couples around the glenohumeral joint. The wide range of motion of the shoulder is allowed by the variety of rotational moments of the cuff muscles. The action of the rotator cuff muscles must be precisely coordinated to obtain the desired movement.

Rotator cuff tendons are subjected to complex tension loads. The rotator cuff provides a stabilizing effect to the shoulder, because of the compression of the humeral head against the glenoid cavity (Lungo et al., 2012). The glenohumeral force couple is a modified force couple because the two forces involved are not opposite to one another. The deltoid produces a superior force, while the subscapularis and infraspinatus/teres minor produce a compressive and inferior force (1). A force couple is a pair of forces that act on an object and cause it to rotate. The *coronal force couple* is a result of the balance of moments created by the deltoid versus inferior rotator cuff, the *transverse force couple* is a balanced moment between the anterior subscapularis and posterior infraspinatus–teres minor muscles (Pandey & Willems). While the current literature suggests improved stability and function after surgical repair of the rotator cuff, higher-quality prospective studies are necessary to make definitive conclusions (Gombera et al., 2014).

Biomechanics

Given the purpose of our paper and the complexity of the shoulder joint, we will emphasize only the biomechanical aspects of the scapulohumeral joint.

The joint in our body with the greatest liberty of motion is the scapulohumeral joint, being the most mobile enarthrosis, which can perform actions in all axes and planes - abduction, adduction, internal and external rotation, ante- and retropulsion and, as a combined effect, circumduction.

Motions

Abduction and adduction: the upper limb weight center during this action is located distally, right over the elbow, and the deltoid muscle balances this resistance while pressing the humeral head in the glenoid cavity (reaching a maximum at 90 degrees of abduction). The amplitude is limited when the great tuberosity is in contact with the upper portion of the labrum and the force the deltoid develops greatly overcomes the weight of the upper limb by over 8 times at 90 degrees abduction (Baciu, 1981). It was believed that the supraspinatus muscle has the role of starting the motion for the first 10 degrees and then the deltoid can take over, but the main role of this muscle is in maintaining the humeral head in a favorable location within the joint surface and, thus, opposing a dislocation neither superior or inferior to the glenoid process. Clinical experience has taught us that patients with tear of the supraspinatus tendon have little to no deficiency concerning the first 10 degrees of abduction (Hansen et al., 2008). Shear stresses that affect the supraspinatus tendon due to narrowing of the coracoacromial arch (extrinsic impingement) have been identified as a plausible cause of rotator cuff injury as they may generate a laminated disrepair of the surfaces of the cuff (Spargoli, 2016). The incidence of rotator cuff tears increases with age, with full-thickness rotator cuff tears present in approximately 25% of individuals in their sixties, and more than 50% of those in their eighties (Edwards et al., 2016). Advances in the understanding of rotator cuff biology and biomechanics as well as improvements in surgical techniques have led to the development of new strategies that may allow a tendon-to-bone interface healing process, rather than the formation of fibrovascular scar tissue (Lorbach et al., 2015). Typically after the deep fibers tear, they retract because they remain under tension, even with the arm at rest. This results in an increased load on the remaining fibers that increases the likelihood of further rupture (Via et al., 2013). Another muscle that has a role in abduction is the long head of the biceps brachialis, but its role is secondary. The normal range of motion is 180 degrees (Renfree et al., 2003). Adduction is opposed to abduction, and the weight of the upper limb plays a major role as an active force, while the abductor muscles control the range of the motion (Braddom et al., 2007). The amplitude of the motion reaches a maximum when the arm reaches the trunk and the agonist muscles go into action only in certain situations (e.g. sport, climbing), which explains why there are so many strong muscle groups involved in this seemingly passive action.

Flexion and extension: the humeral shaft can balance forward and backward around an axis that goes through the center of the glenoid surface and allows an amplitude of 95 degrees anteriorly and 20 degrees posteriorly. These amplitudes can be increased with the aid of the pectoral arch and the spine up to 180 degrees flexion and 35 degrees extension (Baciu, 1981).

Flexion is made possible by the anterior fascicles of the deltoid, pectoralis major and the coracobrachialis, while antagonist motion is performed by the posterior fibers of the deltoid and latissimus dorsi (Braddom et al., 2007).

Internal and external rotation: the muscles involved turn the humeral head within the glenoid cavity and tense the joint capsule in the posterior (internal rotation) and anterior (external rotation) regions (Baciu, 1981).

The maximum amplitude of internal rotation (175 degrees) can only be reached while the patient places his forearm behind his back, which involves some degree of arm retropulsion, and external rotation (80 degrees) can be extended with the participation of the pectoral arch (Hansen et al., 2008). Humeral rotation affects rotator cuff fixation and should be considered in postoperative rehabilitation (Ahmad et al., 2008).

The circumduction motion totals all of the above motions, resulting in a motion around all of the 3 axes, while the humeral head describes a circle, following the contour of the glenoid cavity, whereas the humeral shaft describes a big circle, in an opposite way (the base of the circumduction cone) (Baciu, 1981).

Importantly, the motion of the scapula relative to the thorax can only occur by simultaneous motion at the acromioclavicular and sternoclavicular joints (Teece et al., 2008). This combined motion is what enables the scapula to move across the thorax.

In addition to the coupling of clavicular motion to scapulothoracic motion, during arm elevation in any plane, the scapula relative to the clavicle also moves at the acromioclavicular (AC) joint. These acromioclavicular joint motions may increase or decrease the overall scapulothoracic (SC) joint motion depending on whether they complement or offset the scapulothoracic joint coupled scapular motions. Although somewhat complex to understand, these interrelationships between how SC and AC joints contribute to overall motion of the scapula on the thorax are also important with regard to how they influence muscle function (Ludewig et al., 2011).

Multiple studies describe shoulder motion abnormalities, showing the importance of the scapulothoracic joint in a variety of clinical disorders including impingement, rotator cuff tendinosis, rotator cuff tear, and shoulder instability (Ludewig et al., 2009). Significant abnormal scapular kinematics is seen in multidirectional instability of the shoulder, highlighting the importance of incorporating scapular positioning and stability exercises during rehabilitation (Ogston et al., 2007).

Despite conflicting results, growing evidence suggests that distinct scapular morphologies may accelerate the underlying degenerative process (Moor et al., 2014).

Glenohumeral stability is ensured by static restraints (glenohumeral ligaments, glenoid labrum, articular congruity and version, negative intraarticular pressure) and dynamic restraints (rotator cuff muscles, rotator interval and biceps long head, periscapular muscles) (3). Moreover, joint stability is not helped, but works against gravity, where the weight of the upper limb tries to extract the humeral head from the glenoid cavity, explaining the necessity of an articular capsule reinforced with ligaments in the inferior and superior portions, and strong muscles to press the two components together. The labrum and ligamentous structures are critical for glenohumeral stability because only one fourth of the humeral head is in contact with the glenoid at any point during the range of motion of the shoulder (Campbell et al., 2008). Important in stability is also the vacuum effect, and for this, there are three mechanisms: Intracapsular pressure - this is normally a negative pressure within the shoulder joint. A slightly negative intra-articular pressure existing in a normal shoulder aids in centering the humeral head.

Suction effect and Adhesion cohesion - when two wet surfaces, such as the humeral head and glenoid, come into contact with each other, this creates an adhesion-cohesion bond, which provides stability to the glenohumeral articulation (2). By looking at the whole biomechanics of the pectoral arch, we find that without the intervention of auxiliary components (spine, scapulothoracic gliding space, subacromial bursa, glenoid labrum and the complex distribution of muscle and ligament insertions), the scapulohumeral joint has a rather limited array of motion (4).

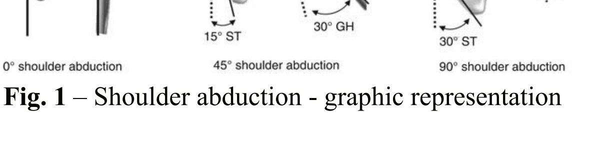

Fig. 1 – Shoulder abduction - graphic representation

However, it should not be forgotten that adjacent structures such as the acromioclavicular joint, blood vessels and nerves, which are generally well displayed, but often neglected in daily practice, should also be evaluated in order to fully exploit the diagnostic possibilities of the method and identify frequent diseases that are easily diagnosed by US (Bianchi & Martinoli, 2007; Yin et al., 2010).

Ultrasound is a new acquisition that gives us benefits, recording the anatomical structure, muscles and tendons. It allows to examine the joint in a dynamic way, while performing all motions, and offers us more biomechanical information (Precerutti et al., 2010). Also, it should not be forgotten that it is a less expensive alternative to MRI in the diagnosis of rotator cuff disorders and not only these (Nazarian, 2008). Musculoskeletal sonography is an important complementary tool to MRI and is essential for clinicians and radiologists who want to provide patients with state-of-the-art musculoskeletal imaging (Nazarian, 2008).

Evidence-based interventions in reviews are specific to musculoskeletal shoulder disorders, and specific intervention recommendations vary depending on the shoulder condition (Marik et al., 2017) and the clinical usefulness of shoulder stability exercises for shoulder pain and joint damage (Choi et al., 2013). Further research is required to measure functional outcomes of combined preparatory interventions and occupation-based interventions.

Conclusions

1. The shoulder biomechanics is a field of future research.

2. The complex ligaments, muscles, bursae and joints interfere through different intricate mechanisms, and although the articular surface is reduced, the area of movement is highly ensured by this interconditionality.

3. There are studies demonstrating that although the supraspinatus muscle plays a role in the second part of the abduction movement after the action of the deltoid muscle, clinical information contradicts this by the fact that damage of the deltoid only allows movement such as in the impingement of the supraspinatus, when abduction cannot be done by the deltoid.

4. Mobility is also ensured by adjacent structures, scapulothoracic gliding planes, bursae, accessory muscles (trapezius, latissimus dorsi), which make the biomechanical mechanism very complex.

5. As a conclusion, it can be said that emphasizing the level of functionality of the 4 other joints than scapulohumeral can improve the range of motion and thus, quality of life.

Conflicts of interest
There are no conflicts of interest.

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