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REVIEWS

The importance of the clavicle biomechanics in the shoulder movement

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Abstract

The sternoclavicular joint (SC) provides the attachment belt for the upper limb. It is the only direct joint that attaches the upper limb to the trunk. Practically, the clavicle moves while the sternum remains fixed. The SC joint is an important fulcrum for the movement of the shoulder girdle. The disc and ligaments of the SC joint offer such an effective support that the dislocation of the sternoclavicular joint is rare. The acromioclavicular joint (AC) connects the acromial process of the scapula and the clavicle. The movements of the AC joint are minimal, but crucial for the normal shoulder motion.

In clinical practice, the movement of the clavicle is often neglected. This movement occurs in 3 planes; the integrity of these movement planes is essential in the complex motion of the arm. Any disturbance in the normal movement of the clavicle will automatically limit the range of motion of the arm, especially the abduction.

The researchers consider that, from the practical point of view, the knowledge regarding the biomechanics of the clavicle is critical, since any limitation of the mobility of the shoulder can shroud a pathology that can block the mobility of the clavicle.

Keywords: sternoclavicular joint, acromioclavicular joint, shoulder.

Introduction

The clavicle is a long, paired bone that connects the shoulder girdle to the trunk. The importance of the clavicle is often underestimated when assessing the shoulder.

From an embryological point of view, the clavicle ossifies in membranes and it is the first bone in the skeleton for which ossification begins in the fifth week of pregnancy (Palastanga et al., 2002).

Biomechanics of the clavicle

The sternoclavicular (SC) joint provides an attachment belt for the upper limb. It is the only direct joint through which the upper limb attaches to the trunk. The sternoclavicular joint is a synovial membrane joint that is flat in shape and has a sliding motion in two planes. The movements appear in three planes and accompany the motions of the shoulder girdle. Although these movements are more subtle than those of most joints, they are still important.

Practically, the clavicle moves while the sternum remains fixed.

The SC joint has a synovial membrane, and consequently, it has an articular capsule. It also has three major ligaments and one disc. The articular capsule surrounds the joint and is strengthened by the anterior and posterior sternoclavicular ligaments.

The main function of the articular disc is to cushion, especially by using the forces that appear when an individual falls on the outstretched hand. The disc and ligaments provide such an effective support that the dislocation of the sternoclavicular joint is rare. The fastening of the disc contributes to the possibilities of movement at this level - it has a double fastening, similar to a swing door, and allows movement in both directions. During the lifting and lowering of the shoulder girdle, the movement occurs between the clavicle and the disc. During pre- and post-projection, the movement occurs between the disc and the sternum.

The disc plays an important biomechanical role; according to some MRI imaging studies, the disc is the structure that is most frequently damaged in about 80% of the situations (Benitez et al., 2004). The sternoclavicular

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joint is supported by 3 ligaments: sternoclavicular (anterior and posterior), costoclavicular and interclavicular. The costoclavicular ligament extends from the lower edge of the clavicle to its upper edge and plays a major role in blocking clavicle lifting, but especially in stabilizing the clavicle lifting movement. The interclavicular ligament is located above the handlebar, connecting the superior sternal ends of the clavicles. Its purpose is to limit the lowering of the clavicle. Injuries and pain related to trauma of the anterior, posterior, interclavicular and costoclavicular ligaments were seen in 73%, 39%, 29% and 14% of patients, respectively (Benitez et al., 2004).

The anterior sternoclavicular ligament is the most involved structure during antepulsion and depression movements. During antepulsion, lesions of the posterior sternoclavicular ligament are most frequent during elevation, and the costoclavicular ligament is the most frequently injured ligament. The resistance of the sternoclavicular joint is significantly greater during the antepulsion movement when compared to retropulsion (Negri et al., 2014).

The sternal end of the clavicle and handlebar are incongruous, they are tangent through a small contact surface. The medial upper portion of the clavicle has no contact with the handlebar, but it serves as an attachment site for the sternoclavicular disc and interclavicular ligament. At rest, the sternoclavicular joint has an upper V-shaped opening (Rudzki et al., 2003).

Cadaver studies focusing on sternoclavicular stability have shown that cutting the costoclavicular and interclavicular ligaments had little effect on sternoclavicular joint translation. Cutting the anterior capsule only produced significant increases in anterior translation, but to a lesser degree (25%) than sectioning of the posterior capsule. The conclusion was that the posterior capsule is the most important constraint for posterior and anterior translation of the distal clavicle. The fact that the posterior capsule of the SC joint is stronger than the anterior one also explains the higher frequency of the anterior dislocation (Renfree et al., 2003; Spencer et al., 2002).

Dislocation of the SC joint is rarer, around 1% of all dislocations and about 3% of those affecting the upper limb, well below what appears at the level of the glenohumeral or acromioclavicular joint. It usually occurs in young men after activities with a high-energy mechanism of injury. Most of them, however, are the equivalent of a sprain, and have no long-term functional consequences (Robinson et al., 2008).

Another source of shoulder girdle dysfunction is sternoclavicular instability. Anterior dislocation is often unstable and conservative treatment is recommended if shoulder functionality is maintained. However, surgical intervention is indicated if the pain or disability of the shoulder girdle has an impact on activities of daily living. In case of surgery, the figure-of-eight semitendinosus technique has superior initial biomechanical properties and may produce improved clinical outcomes in SC joint instability (Spencer & Kuhn, 2004; Van Tongel & De Wilde, 2012; Sewell et al., 2013; Thut et al., 2011; Little et al., 2012).

Posterior dislocation is rarer, but with possibly worse consequences due to the anatomical structures that may be damaged. Surgical treatment is often recommended in this case to stabilize the SC joint (Macdonald & Lapointe, 2008; Martetschläger et al., 2014). In surgical stabilization, the figure-of-eight reconstruction using the free tendon graft method is preferred; it has been shown to recreate the native anatomy with the most robust biomechanical profile (Warth et al., 2014a).

The acromioclavicular joint (AC) connects the acromial process of the scapula to the lateral part of the clavicle. It is a flat synovial joint, but it has three planes of motion. The range of motion is minimal, but very important for the normal function of the shoulder. The weaker joint capsule is strengthened by two ligaments, superior and inferior. These ligaments provide support to the joint by maintaining the acromion to the clavicle and thus preventing clavicle dislocation. The coracoclavicular and coracoacromial ligaments are two accessory ligaments of the AC joint. Together, they prevent the scapula from slipping backwards and, individually, each limits the scapula's rotation movements (Lippert, 2006). Cadaver-based studies have shown that sectioning of the AC ligament increased clavicular retraction during sagittal plane elevation and horizontal plane adduction. Sectioning of the trapezoid ligament decreased scapular external rotation during sagittal plane elevation and horizontal plane adduction. Sectioning of the conoid ligament decreased scapular posterior tilting during sagittal plane elevation and horizontal plane adduction. Acromioclavicular and coracoclavicular ligament sectioning also delayed clavicular posterior rotation and increased clavicular upward rotation during coronal plane elevation (Oki et al., 2014).

When elevating and lowering the clavicle, the medial extremity of the clavicle runs and slides on the disc which is relatively fixed. The upper point of the disc serves as a pivot point. When lifting the shoulder, the lateral extremity of the clavicle rotates upward, and when lowering the shoulder the movement is in the opposite direction.

Lifting movements are usually limited to 48 degrees and passive descent to 15 degrees. These movements in daily activities are not usually used to the fullest extent. Biomechanical studies have shown a variation of 15-31 degrees in the SC joint through the rotation of the clavicle during the movements of the arm in the frontal plane (abduction) and less in the sagittal plane (flexion). It was appreciated that the movement of the clavicle is 4 degrees for every 10 degrees of arm lifting, in the movement sector up to 90 degrees. Above this value, the movement of the clavicle appears to be smaller or even negligible. If the clavicle is blocked, the abduction of the arm will not exceed 110 degrees. It has been shown that the rotation movement of the clavicle in the SC joint (approximately 30 degrees) is significantly higher than in the AC joint. This fact has also been demonstrated clinically in different situations: the fixation of the clavicle by the coracoid process with a screw does not significantly limit the abduction of the arm; or, significant ectopic calcifications around the AC joint still allow functional abduction of the arm. On the other hand, ankylosis, trauma, fibrosis of the SC joint cause greater disability in terms of shoulder range of motion (Itoi et al., 2009; Warth et al., 2014b).

Clavicle fractures that strengthen viciously and lead to shortening of the clavicle severely affect the biomechanics of the shoulder girdle. A computational study that simulated a clavicle shortening of 0%, 5%, 10%, 15% and 20% from

its original size demonstrated a decrease in the shoulder elevation movements of the upper extremity muscles during abduction. Internal rotation movements are also decreased with shortening. Flexion movements were affected less through physiologic range of motion. The observed effects are due to a combination of changes in arm movements of the individual muscles, as well as a decrease in the force generating capacity of the muscles. Additionally, shortening of the clavicle increases coronal angulation of the clavicle in the SC joint (Patel et al., 2012).

The movement of the SC joint is reciprocal with the movement of the AC joint for all types of motion, excepting rotation, which of course takes place simultaneously. For example, the lowering of the medial extremity of the clavicle is simultaneous with the elevation of the lateral extremity of the clavicle, and when the lateral clavicle passes to the posterior plane, the medial one passes to the anterior plane (Ludewig et al., 2004).

In the antepulsion/retropulsion of the clavicle, the SC disc and the lower handlebar face of the clavicle serve as a pivot point. In these complex movements of the clavicle, the axis of the movements is not at the level of the SC joint, but rather at the level of the costoclavicular ligament that is located laterally. During antepulsion, the lateral extremity of the clavicle rotates anteriorly, and with retropulsion the rotation is posterior (Fig. 1). It is estimated that antepulsion occurs on an area between 15-20 degrees, and retropulsion between 20-30 degrees. The clavicular rotation along the anterior-posterior axis is the most important movement for the normal functionality of the arm. Particularly, compared to most joints in which rotation can be performed in both directions, the clavicle, from a neutral position, performs only a posterior rotation. Thus, the lower surface is oriented anteriorly. The anterior rotation is basically the return rotation to the neutral position. The posterior rotation is rated up to 50 degrees, and the anterior rotation is rated up to less than 10 degrees. The axis of this movement intersects the SC and AC joint (Ludewig & Borstead, 2005).

Symptomatic individuals consistently demonstrated less sternoclavicular posterior rotation, regardless of the angle, phase, or plane of shoulder motion. Even if the magnitude of these differences is small, from the perspective of functionality it can be important. Symptomatic individuals also demonstrated less scapulothoracic upward rotation at 30° and 60° of humerothoracic elevation during shoulder abduction and scapular plane abduction (Lawrence et al., 2014).

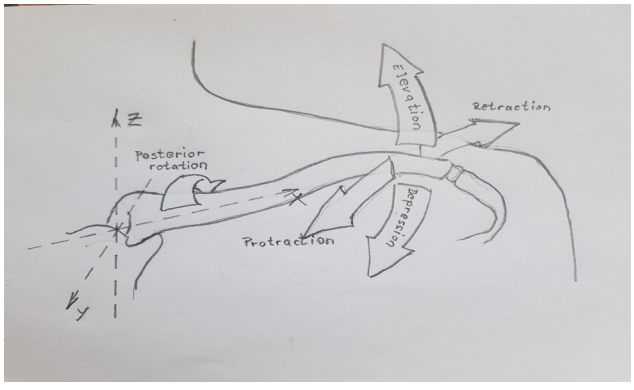

Fig. 1 – Clavicle movement in 3 planes.

Biomechanical studies of the forces in the clavicle during movements have shown that active abduction caused the greatest increase in middle clavicle forces and torque. Abduction resulted in the most significant axial compressive force, while active external rotation caused the greatest tensile force across the intact middle clavicle. This is important not only for the surgical techniques, but also for the rehabilitation protocols that must be considered postoperatively or after a fracture treated conservatively (Iannolo et al., 2010).

Conclusions

From a clinical point of view, it is essential that in any situation in which scapulohumeral redness occurs, the integrity of the clavicle movement should be evaluated. Even if the rotations of the clavicle are difficult to highlight clinically, at this stage a pathology targeting this sterno-claviculo-acromial complex should be excluded. As it has been shown, limiting movement in the SC joint has greater functional consequences than limiting movement in the AC joint.

Conflicts of interest

There were no conflicts of interest during the research period.

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