

Biomechanics of the Shoulder

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Abstract

The shoulder is a complex of 5 joints and disturbances at any of these joints are likely to interfere with the smooth rhythm observed in movements of this complex. The overall ratio of scapulothoracic to glenohumeral movement of 1:2 is made possible by a clockwork mechanism that involves movements at these 2 articulations with axial rotation of the clavicle that connects the shoulder girdle to the torso. Stability of the scapulothoracic, glenohumeral joints and acromio clavicular joints rely not only on the intrinsic capsular ligaments, bony architecture and musculature, but also on extrinsic ligaments that need to be addressed in management of instability at these joints. Of the soft tissues, premature degeneration and tears of the rotator cuff tendons pose special clinical problems by disturbance of the delicate balance between the cuff and the deltoid muscle.

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Introduction

The shoulder is a complex of 5 articulating surfaces that together form the shoulder girdle. The glenohumeral joint together with the scapulothoracic articulation form the main components of the girdle. The acromioclavicular joint with the sternoclavicular joint form an important link between the former two and the torso via the clavicle. A less well-recognised component is the articulation between the acromion and the coracoacromial ligament and the humeral head. The subacromial bursa and its extensions form the lining between the humeral head and the others. These 5 articulating surfaces move with clockwork precision to provide the global mobility of the entire upper limb based on the shoulder girdle.

Besides the sternoclavicular and acromioclavicular joints and their strong ligaments, suspension of the shoulder girdle and the entire upper limb is provided by the trapezius, levator scapula, rhomboids and the serratus anterior passing from the torso to the girdle. Passive tension exerted by these muscles is sufficient to suspend the arm. Little or no electrical activity is detected in these muscles when the upper limb is freely suspended.¹ The movement at the scapulothoracic articulation is also provided by these muscles.

The glenohumeral joint is held together by the rotator cuff muscles—subscapularis, supraspinatus and infra-

spinatus—and teres minor, as well as the deltoid. Movements occur when these muscles act in conjunction with the pectoralis major, teres major and latissimus dorsi muscles.

Movements

The clockwork mechanism in the movements of the shoulder girdle involves a “setting phase” when the scapula is stabilised on the thoracic cage, followed by movements at the glenohumeral in combination with that at the scapulothoracic articulation. In abduction, the ratio of scapulothoracic to glenohumeral movements varies from 1:1.43 in the initial 45° to 1:2.73 in the last 45°² with a 1:2 ratio overall.³ To enable abduction beyond 90°, the scapula rotates away from the clavicle and this requires axial rotation of the clavicle at the acromioclavicular and sternoclavicular joints. This is made possible by the S-shape of the clavicle which enables it to work like a crank shaft being rotated by the pull of the coracoclavicular ligaments (conoid and trapezoid) between the clavicle and the coracoid process. Disruption or disease at any one of the joints or the clavicle will therefore interfere with the smooth rhythm of shoulder girdle movement.

Stability of the Scapulothoracic Joint

The stability of the shoulder girdle is provided by the acromioclavicular and sternoclavicular articulations, the

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bony link provided by the clavicle, the important ligamentous support provided by the capsular ligaments of the 2 joints as well as that provided by the coracoacromial and coracoclavicular ligaments. The musculature provides passive stability but become deforming forces together with gravitational forces when the skeletal or joint integrity is compromised. The “floating shoulder” illustrates this concept clearly. Fractures of the shaft of the clavicle and the surgical neck of the scapula alone will not produce this entity. Neat experimental studies have shown that a rupture of the acromioclavicular and also the coracoacromial ligaments must also occur for the integrity of the shoulder girdle to be disrupted.⁴ Muscular action together with gravity then become deforming forces. The same is observed in “scapulothoracic dissociations” except that in the latter soft tissue disruption is predominant.

Stability of the Glenohumeral Joint

Enough has been covered in the literature on the subject.^{5,6} All that needs highlighting is that the glenohumeral joint is basically unstable. The surface area of the humeral head is 3 times that of the glenoid.⁷ This provides for the global mobility at the glenohumeral joint not seen in any other. The surface area of the glenoid is increased by the fibrocartilaginous labrum that makes it more a bowl than a plate. Disruption of the labrum (Bankart’s lesion) will therefore lead to instability. The humeral head spins on the spot on the glenoid behaving like a typical ball and socket. Dislocation implies sliding of the humeral head off the glenoid surface. The humeral head is held firmly against the glenoid surface by the rotator cuff muscles. This provides a firm fulcrum on which the deltoid is able to act to provide flexion, abduction or extension.

Tears of the rotator cuff allow the humeral head to slip off the glenoid superiorly by the action of the deltoid. This disturbs the length tension relationship of the latter leading to a weak abduction and disturbance of the normal rhythm. The rotator cuff is, therefore, important in keeping the humeral head down maintaining the length tension relationship of the deltoid optimal. As abduction proceeds, rotation of the scapula must also occur so that the acromion keeps moving away from the humeral head, thereby maintaining the deltoid at optimal length of all times. Abduction also increases the moment-arm of the deltoid, as the humerus abducts in relation to the scapula and, thereby, facilitates maintenance of adequate deltoid tension while its length may be shortened slightly by the abduction.⁸

Besides the rotator cuff, stability of the humeral head also relies on an intact long head of the biceps tendon that keeps the humeral head from superior migration and also plays a major role in controlling anterior humeral head translation.^{9,10} The capsule of the glenohumeral joint is not

a tight structure unlike that of the hip or elbow joint. Mere puncture of the capsule with a hollow needle allowing entry of air and elimination of the vacuum within the joint results in immediate subluxation (though not dislocation) of the humeral head.¹¹ The capsule is also relatively lax to allow the great mobility observed in the glenohumeral joint. The integrity of the skeletal components also plays a role in the stability of this joint. In a traumatic dislocation, failure occurs in the capsule and subscapularis tendon (in anterior dislocation) as well as in the bone of the humeral head (Hill-Sach’s lesion). The Bankart lesion results in the loss of the dish effect of the glenoid allowing the humeral head to slide off the socket. Surgical reconstruction should therefore restore the delicate balance and restore the normal relationship between the volume of the skeleton and volume of the capsule. Standard, open stabilising procedures allow one to address the labral pathology as well as the capsular and subscapularis tendon pathology. Slight overtightening of the capsule will indirectly address the decrease in volume of the bony skeleton that results from a Hill Sach’s lesion as this pathology is usually not routinely addressed.

Stability of the Acromioclavicular Joint

The integrity of this joint relies on an intact and strong capsular ligament, the coracoclavicular ligaments and the aponeurosis of the deltoid and trapezius muscles. In complete grade III and worse dislocations, all these supporting structures are disrupted. The ability of the clavicle to keep the scapula and the humerus “out there” is compromised, allowing medial translation of the glenohumeral joint. The result is a disturbance of the length tension relationship of the thoraco-scapular muscles (trapezius, levator scapula, rhomboids, pectoralis minor and serratus anterior) as well as the thoraco-humeral muscles (latissimus dorsi and pectoralis major). This manifests clinically as weakness in the shoulder girdle. Surgical procedures, however, address only the superior displacement of the clavicle by reconstructions, using various static and dynamic techniques, neglecting the stability provided by the strong capsule of the acromioclavicular joint.¹² Hence, to date, no significant difference is demonstrable clinically between the outcomes of surgical and conservative treatment of dislocations of this joint. The ideal reconstruction is yet to be found, and in the meantime, acromioclavicular dislocations may be managed conservatively.

Rotator Cuff

The rotator cuff applies a compressive force on the humeral head keeping it against the glenoid. This enhances joint stability. Dysfunction of the cuff either by inflammation, tear or paralysis of the corresponding muscles leads to loss of this compressive force enabling superior

subluxation of the humeral head by the action of the deltoid, resulting in repeated trauma to the subacromial bursa. This results in shoulder pain from bursal inflammation. A local steroid infiltration is effective in relieving symptoms in this situation.

Tears of the rotator cuff frequently affect the supraspinatus and then the other components. Considerable debate prevails on the underlying cause or causes for the early degeneration and tear of the rotator cuff. External abrasion from an abnormally beaked anterior lip of the acromion has been blamed.¹³ Intrinsic vascular insufficiency from a “wringing” out of the blood supply in the critical zone of the supraspinatus by the humeral head in the dependent position of the limb thereby resulting in premature ischaemic damage and degeneration of the tendon is the second aetiology.¹⁴ However, it is likely that both factors are important and contributory.

Tears of the rotator cuff present initially as weakness and inability to abduct the arm from mechanisms described earlier. However, with a course of intensive physiotherapy abduction to a full range ultimately results, the exception being massive tears. Healing of the tear is unlikely to occur as forces are centrifugal and are only likely to enlarge the tear with time. The only explanation is compensation by the remaining cuff muscles that take over the head depressor function thereby keeping the head against the glenoid and allowing the deltoid to work efficiently. Full abduction returns, and even pain from subacromial bursitis resolves; but weakness remains.

Surgical procedures that fail to repair a massive cuff tear do, however, relieve symptoms of pain by providing a subacromial decompression. An important structure that prevents continuous proximal migration of the humeral head antero-superiorly above the acromion by action of the deltoid in massive cuff tears is the coracoacromial ligament which must be preserved or reconstituted at all cost after acromioplasty. The wide attachment of the coracoacromial ligament on the under surface of the acromion allows it to be elevated before acromioplasty and then reconstituted with sutures back to the remnant acromial process at the end of the surgery.

Total shoulder arthroplasty also poses a major problem in patients with cuff tear arthropathy. Superior migration of the humeral component creates a “rocking-horse” effect on the glenoid component resulting in early loosening of the latter.¹⁵ One solution may be perhaps to utilise the coracoacromial arch and a glenoid component implanted in a superiorly tilted position as one large glenoid and to

“overstuff” the subacromial space with a larger than normal humeral component. The deltoid and the remaining cuff muscles then provide a satisfactory range of movements.

The biomechanics of the shoulder is complicated, as it is not one joint but a complex of several articulations. Understanding of the biomechanics enables a better appreciation of the common clinical problems posed by this joint and, even more importantly, facilitates a rational approach to their management.

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