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Scapular Positioning in Athlete's Shoulder

Particularities, Clinical Measurements and Implications

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Abstract

Despite the essential role played by the scapula in shoulder function, current concepts in shoulder training and treatment regularly neglect its contribution. The 'scapular dyskinesis' is an alteration of the normal scapular kinematics as part of scapulohumeral rhythm, which has been shown to be a nonspecific response to a host of proximal and distal shoulder injuries. The dyskinesis can react in many ways with shoulder motion and function to increase the dysfunction. Thoracic kyphosis, acromio-clavicular joint disorders, subacromial or internal impingement, instability or labral pathology can alter scapular kinematics. Indeed, alteration of scapular stabilizing muscle activation, inflexibility of the muscles and capsule-ligamentous complex around the shoulder may affect the resting position and motion of the scapula. Given the interest in the scapular positioning and patterns of motion, this article aims to give a detailed overview of the literature focusing on the role of the scapula within the shoulder complex through the sports context. Such an examination of the role of the scapula requires the description of the normal pattern of scapula motion during shoulder movement; this also implies the study of possible scapular adaptations with sports practice and scapular dyskinesis concomitant to fatigue, impingement and instability. Different methods of scapular positioning evaluation are gathered from the literature in order to offer to the therapist the possibility of detecting scapular asymmetries through clinical examinations. Furthermore, current concepts of rehabilitation dealing with relieving symptoms associated with inflexibility, weakness or activation imbalance of the muscles are described. Repeating clinical assessments throughout the rehabilitation process highlights improvements and allows the therapist to actualize rationally his or her intervention. The return to the field must be accompanied by a transitory phase, which is conducive to integrating new instructions during sports gestures. On the basis of the possible scapular disturbance entailed in sports practice, a preventive approach that could be incorporated into training management is encouraged.

The shoulder complex is involved in a great many sports and athletic activities requiring specific gestures.[1-7] Shoulder function represents a focus of interest both for many sports medicine specialists and for trainers. An understanding of shoulder biomechanics is of premium importance, even more so since athletes who participate in repeated overhead activities appear to be most specifically at risk of developing shoulder pain.[2]

The scapula plays an important role in normal shoulder function.[8-12] In sports in which demands placed on the shoulder are extremely high, the quality of movements depends on the interaction between scapular and glenohumeral kinematics. Abnormal scapular kinematics and associated muscle dysfunction are assumed to contribute to shoulder pain pathology.[5,6,13]

However, up until recently, the role of the scapula in sports gesture, as well as in the clinical evaluation or treatment of shoulder disorders has received little attention from researchers and clinicians.[5]

With the aim of describing more precisely the motion capacity of the shoulder, the kinematic interaction between the scapula and the humerus was introduced by Codman[14] and termed 'scapulohumeral rhythm'.[14,15]

Kibler et al.[8-10] have summarized several roles for the scapula function into the shoulder complex (figure 1). The 'primary' role indicates that the scapula moves in coordination with the moving humerus, so that the instant centre of rotation is constrained within a physiological pattern throughout the full range of the shoulder motion.[6,10,11] The proper alignment of the glenoid allows optimum function of both the bony constraints and the muscles of the rotator cuff. The intrinsic muscles of the rotator cuff provide dynamic stabilization of the shoulder by improving the concavity-compression effect.[1,6,11]

The 'second' role of the scapula is to provide adapted motion along the thoracic wall because the patterns of scapular motion are related to the type of task being performed. For example, for the shoulder involved in physical work, scapular retraction creates a stable base for tasks that require reaching, pushing or pulling.[3,4,10,11,16]

The 'third' role of the scapula in shoulder function is the elevation of the acromion to clear the acromion from the moving rotator cuff, so as to decrease impingement and coraco-acromial arch compression.[6,8,10,13]

The 'fourth' role of the scapula in shoulder function is that of being a link in the proximal to distal sequencing of velocity, energy and forces.[6,8,16] The largest proportion of kinetic energy and force in the 'kinetic chain' is derived from the larger proximal body segments (the legs, back and trunk).[8] The scapula, providing a stable and controlled platform regulating the forces, is pivotal and transfers the strong forces and high energy to the distal body segments: the arm and the hand.[6,8,12,16]

The intricate role of the scapula into the shoulder movements oblige the therapists to consider the pattern of motion and position of the scapula in the frame of shoulder dysfunction. Set apart from the scapula's normal status, 'scapular dyskinesis' is defined as an observable alteration in the position of the scapula and the patterns of scapular motion in relation to the thoracic cage.[10,17] Several factors might create these abnormal patterns and this alteration in position: a resting posture of excessive thoracic kyphosis associated with an increased cervical lordosis, fractures of the clavicle and acromio-clavicular joint injuries or athrosis can alter scapular kinematics.[10] Likewise, subacromial impinge-

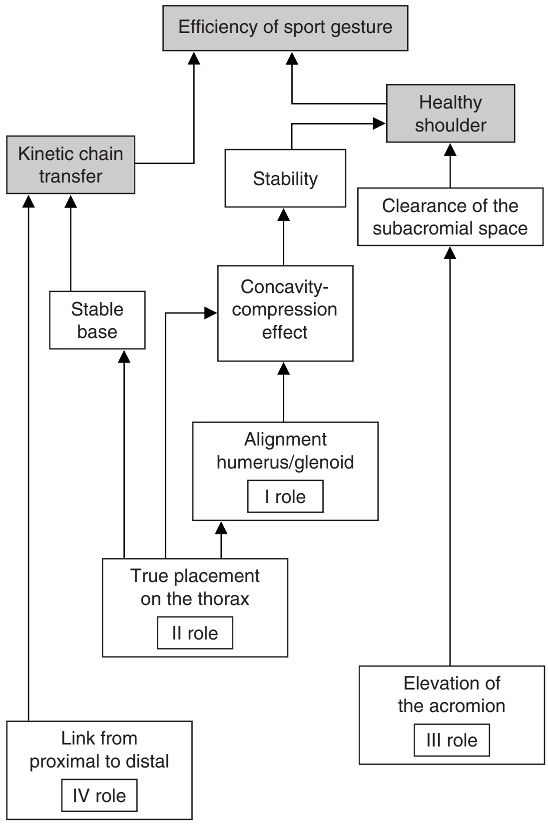


Fig. 1. Four roles of the scapula inspired from Kibler.[8]

ment,[13,18-20] instability,[12,17,21,22] SLAP (Superior Labrum, Anterior to Posterior) lesion[23] and internal impingement[24] are shown to be associated with scapular dyskinesia. Alteration of scapular stabilizing muscle activation or coordination most frequently entails scapular dyskinesis.[13,25] Similarly, inflexibility or contracture of the muscles and ligaments or capsule around the shoulder can affect the resting position and motion of the scapula.[10,26,27] The muscle inhibition leading to pain and scapular instability appears to be a nonspecific secondary response to certain glenohumeral and scapulothoracic causes.[12] Moreover, to date, no reproducible association has been shown between specific shoulder pathological diagnoses and specific dyskinesis patterns.[5] Dyskinesis exists in symptomatic patients, in that it alters scapulohumeral rhythm and efficient joint mechanics; consequently it creates dysfunction. It therefore represents part of the overall treatment of the shoulder dysfunction with which the patient presents.

1. Laboratory Measurement of Scapular Kinematics

Laboratory measurements of scapular displacements are typically capable of quantifying the scapular kinematics 3-dimensionally (3-D).[28,29] Parameters such as the type of instrumentation (electromagnetic tracking device,[4,28,29] magnetic resonance-based techniques,[21] Moiré topography,[17] reconstruction from radiographic assessment,[30,31] fresh frozen cadaver shoulder experimentation[1,32]), rotation matrix used, anatomical body landmarks, local reference system orientation, specific task requirements and planes of arm elevation (cardinal vs scapular) have differed widely across studies according to the goal pursued.[10,15,29,31-35] Recently, with the aim to facilitate and encourage communication among researchers or clinicians, the International Society of Biomechanics is recommending use of the standardized description of scapular motion, anatomical landmarks, local coordinate axes and Euler angle sequences for angle calculation.[34,36]

The scapula moves simultaneously around the following three axes of motion (figure 2):[28,29,37,38]

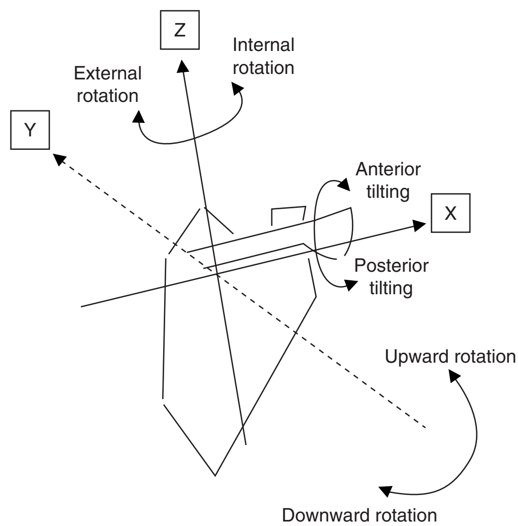


Fig. 2. Scapula axes (X, Y, Z) and 3-dimensional rotations. Upward and downward rotations occur around Y, internal and external rotations occur around Z and anterior-posterior tilting occurs around X.

- scapular anterior/posterior tipping (or tilting) in the sagittal plane (thanks to a transversal axis);
- upward/downward rotation in the frontal plane (corresponding to an antero-posterior axis);
- internal/external rotation in the transverse plane (thanks to a vertical axis).

Elevation and depression of the scapula corresponds to a translatory motion of the scapula on the thoracic wall.

Comparing data on the pattern of scapula motion across studies is difficult because of several important methodological differences.[35] Based on the various studies, the humeral elevation was combined with a general pattern of scapular external rotation (or retraction), upward (or lateral) rotation and posterior tilting (or backward) along with clavicular elevation and retraction.[34,35,39,40] For example, Ludewig et al.[40] measured, in a 3-D analysis, a mean scapular motion of 13° of external rotation, 34° of upward rotation and 15° of posterior tilt from 0° to 140° of humeral elevation in the scapular plane.

McClure et al.[35] observed, in a 3-D analysis that compared the humeral elevation through the scapular and sagittal planes, that the scapular upward rotation amounted to 50°, on average, in the scapular plane and 46° in the sagittal plane through the humeral motion. Meskers et al.[41] found an increased scapular upward rotation during the humeral elevation in the sagittal plane in comparison with the frontal plane. According to those different studies,[35,41] the scapular plane allows the highest upward rotation during humeral elevation.

In the study by Borstad and Ludewig,[38] an electromagnetic tracking device described 3-D scapular kinematics during humeral elevation and lowering in the scapular plane. Small, but statistically significant, differences in internal rotation and scapular tipping during the eccentric phase (lowering) of arm elevation have been identified at higher humeral angles, while no significant difference for scapular upward rotation has been found.[38] Internal rotation was significantly increased in the eccentric phase at 100° and scapular anterior tipping was significantly decreased during the eccentric phase at 80° and 120° angles.[38]

McClure et al.[35] found that upward rotation of the scapular and clavicular rotation occurred approximately linearly throughout humeral elevation, especially beyond 50° of elevation. Posterior tilting and external rotation motions were non-linear, with the majority of these motions occurring after 90° of arm elevation.[35] In the study by McQuade and Smidt,[15] the scapulohumeral rhythm (describing the change in humeral elevation proportional to the change in scapular upward rotation) ratio decreased from 7.9 **:** 1 to 2.1 **:** 1 as the arm was elevated, due to a non-linear scapular upward rotation with humeral elevation.

McQuade and Smidt[15] studied the effect of external load on the scapular kinematics; they observed that the unloaded (passive) arm scapulohumeral rhythm was higher than the light load (active elevation against the weight of the limb) or heavy loaded (against maximal resistance) arm, but there was no statistically significant difference between the light and heavy resistance loads.[15] During repeated measurements of scapulohumeral alignment in a population of healthy volunteers, Price et al.[42] found no significant difference in scapula motion during passive and active humeral elevation in the coronal plane, between 10° and 50° of abduction. They concluded that passive manipulation treatment may have an effect through replication of the scapulohumeral alignment, which is adopted during active exercise.[42] Ebaugh et al.[43] highlighted the same findings as Price et al.[42] from the early phase of arm motion (in the scapular plane). Nevertheless, the scapular upward rotation increased under the condition of active arm elevation through the mid-range (90–120°) of arm elevation due to the activity of the upper, lower trapezius and serratus anterior muscles.[43] For the unloaded (passive) condition, the study by McQuade and Smidt[15] reported less upward rotation already during the first phases of the motion. These discrepancies could be attributable to different methods of passively elevating the arm resulting in a different amount of muscle activity.[43]

2. Clinical Measurement of Scapular Kinematics

Nevertheless, those laboratory studies used equipment or data collection that were not available to the clinical setting.[9,44,45] Conversely, clinical measures (inclinometer, tape measure) are only capable of measuring scapular kinematics 2-dimensionally (2-D), but can easily be used by the clinician.

The inclinometer is capable of measuring angles (in degrees) from a horizontal reference[45] to assess static positions of scapular upward rotation. Different authors have demonstrated that these clinical assessments give valid and accurate information regarding scapular kinematics.[10,45] Johnson et al.[45] compared 2-D measurements using an inclinometer and obtained 3-D measurements using a magnetic tracking device both with the arm fixed and during arm movement (0°, 60°, 90° and 120° of humeral elevation in the scapular plane). The digital inclinometer showed good to excellent intrarater reliability and good to excellent validity when measuring scapular upward rotation during a static position or humeral elevation in the scapular plane.[45] Watson et al.[46] established very good intrarater reliability with a plurimeter gravity inclinometer. They found scapular upward rotation ranged between 2.8 ± 6.1° at rest and 39.1 ± 8.4° at 120° of humeral elevation.[46] Borsa et al.[44] confirmed the highest upward rotation in the scapular plane in comparison with the sagittal plane using an inclinometer measurement. Despite the fact that inclinometer measurements concern only the upward rotation, it can easily be used by clinicians when evaluating the scapular motion.

Linear assessment using tape measures aims to evidence the possible scapular asymmetries between the pathological and healthy sides of a patient.[8,9,47-50] Kibler and McMullen[10] described patterns of abnormal motion in scapular dyskinesis based on simple bilateral visual observation of scapular position with the patient's arms at rest at the side and during elevation and lowering in the scapula plane. Even if such an approach remains subjective, Kibler et al.[51] showed that, with refinement, clinical observation is a qualitative method that allows clinicians to categorize dynamic scapular dysfunctional patterns.

Quantitative measurement of scapular positioning, as proposed by Kibler et al.[8,9] can be achieved with the lateral test (LSST – lateral scapular side test), by evaluating scapular symmetry as varying loads are placed on the supporting musculature.[8,9,47,49,50] Three positions of the upper extremities are proposed:

- position 1, the subject's arm is relaxed at the side (0° of humeral elevation);
- position 2, the subject places his or her hand on the lateral iliac crest;
- position 3 corresponds to an internally rotated and abducted arm to 90°.

Two measurements are performed using a tape in each position (between the inferior angle of the scapula and the closest spinous process) in order to allow calculation of an average value.[8,9,47,49,50]

In one group of injured patients, Kibler et al.[8-10] observed that the degree of asymmetry actually increased when moving from the first to the third position; therefore, a 1.5-cm asymmetry in any of the positions has been established as a threshold for the identification of an abnormal pattern.

Kibler et al.[9] studied the reliability and validity of this measurement concept. Studies on the accuracy of marking this infero-medial border of the scapula in comparison with radiographic evaluation have shown a correlation of 0.91 with the different positions.[8] Test-retest and intertest reliability indicated that the test-retest (intratester) relationship was between 0.84 and 0.88 and that the intertester reliability was between 0.77 and 0.85, depending on the position.[8]

Based on personal findings, Gibson et al.[50] reckoned that intratester reliability of the Kibler LSST method ranged from good to high, although the intertester reliability was poor. In a 71-subject study, Koslow et al.[52] observed that 52 of the overall sample displayed a difference of at least 1.5 cm in one or more of the three positions. They concluded that the specificity of the LSST test was of 26.8%.[52] Odom et al.,[49] comparing a heterogeneous sample of control subjects and patients with multiple types of shoulder injury, found that the sensitivity and specificity of the LSST measurements were poor. In their opinion, the LSST should not be used to identify people with shoulder dysfunction. Nijs et al.[47] observed coefficients of >0.70 (interobserver reliability in intraclass correlation coefficients), but they found no association between the outcome of the tests and the self-reported pain severity or disability.

Based on our clinical experience, we believe that the LSST method contributes towards assessing scapular asymmetry and to quantifying possible improvement through the rehabilitation process. Despite an apparent lack of specificity regarding the nature of the pathology, the scapular dyskinesis concept is regularly integrated into the rehabilitation process.[53]

Muscular force production and muscular balance have been postulated to be major factors in the postural alignment of a healthy population.[48] Kendall et al.[54] have proposed that muscle weakness would affect postural alignment and that an imbalance in muscle strength could lead to postural deviations. For example, tightness in the pectoralis minor or in the short head of the biceps, both of which are attached to the coracoid process, would create an anterior tilt and forward pull on the scapula. Kendall et al.[54] used a supine measurement of the pectoralis minor muscle. This method quantifies the distance between the treatment table and the posterior border of the acromion. Borstad,[37] in a comparison of several postural measurements, questioned the validity of measurements for determining pectoralis minor muscle resting taken with the individual positioned supine. For the pectoralis minor muscle measurement, the author used a validated method: different digitizing landmarks represented the origin and insertion of the muscle, the electromagnetic motion capture system determines the vector distance between the landmarks and consequently, the pectoralis minor muscle length.[37] In that study, the distance from the sternal notch to the coracoid process showed the highest correlation with pectoralis minor muscle length.[37] Borstad[37] gave evidence that internal rotation of the scapula at rest was correlated with pectoralis minor muscle length: an increased scapular internal rotation in a relaxed standing position corresponded to a shortened pectoralis minor muscle.

Diveta et al.[48] investigated the relationship between the position of the scapula and the force production of the middle trapezius and pectoralis minor muscles. In that study, the scapular abduction was assessed by dividing the total scapular distance from the third thoracic vertebrae to the postero-inferior angle of the acromion by the length of the scapula (determined by placing the tape from the postero-inferior angle of acromion across the spine at the medial border of the scapula); a lowered ratio signalled an abducted scapula.[48] The isometric force was assessed using a hand-held dynamometer through specific muscle testing.[48] Diveta et al.[48] found no relationship between isometric muscle performance of either the middle trapezius or the pectoralis minor muscles and scapular abduction positioning.

3. The Scapula in Sports Activity

3.1 Adaptive Patterns

Downar et al.[55,56] demonstrated, using a digital inclinometer, that professional baseball players exhibited a higher degree of total scapular rotation in the throwing shoulder. This shift towards upward rotation may be a functional adaptation to ensure maintenance of the subacromial space during overhead throwing.[55,56] Myers et al.[4] studied the scapular position and orientation during scapular plane humeral elevation assessed with electromagnetic tracking in a group of 21 throwing athletes and 21 control subjects. They showed that, in comparison with non-throwing athletes, healthy throwing athletes exhibited significantly increased upward rotation, combined with a retraction of the scapula during humeral elevation. Neither differences in anterior/posterior tipping nor in elevation/depression were observed.[4] For these authors, the presence of sufficient upward rotation during throwing is vital to injury-free performance by clearing the acromion from the underlying subacromial structures, thus preventing subacromial impingement.[4]

3.2 Scapulothoracic Muscle Fatigue

McQuade et al.[57] imposed, in healthy subjects, a fatigue-inducing exercise with a pulley mechanism attached to a Cybex II® **1** isokinetic dynamometer, the subjects were instructed to elevate the arm with maximal effort as many times possible. They observed a decrease in scapulohumeral rhythm (increased upward rotation in proportion to glenohumeral motion) with fatigue.[57] This was a primary result of increased mobility of the scapula in the midrange of arm elevation accompanied by the lower and upper trapezius, serratus anterior and

1 The use of trade names is for product identification purposes only and does not imply endorsement.

middle deltoid showing myoelectrical signs of fatigue. McQuade et al.[57] suggested that, if excess motion of the scapula occurs, this might place increased stress on the glenohumeral capsular structures and lead to increased glenohumeral instability, as currently shown by Weiser et al.[1] with an increased tensile load on the inferior glenohumeral ligament created by excessive protraction of the scapula.

Through two fatigue protocols, Ebaugh et al.[58] found a particularly important increase in upward rotation and external rotation of the scapula, mainly during a low-load, high-repetition protocol (the high-load, low-repetition protocol entailed similar, but lower changes), accompanied by a decrease in the level of activity across scapular muscles.

Tsai et al.[59] induced muscle fatigue during an exercise in a glenohumeral external rotation with a rubber band (until the subject could no longer perform the task). They found that this entailed a significant fatigue effect for all scapular rotations in the early to middle phases of humeral elevation, the biggest mean difference concerning the decrease in posterior tilting. Additionally, they found fair to good correlations (r = 0.39–0.60) between the changes in scapular posterior tilting and the amount of external rotator muscle fatigue; a disruption in the balance between internal and external rotation torques would result in scapulothoracic motion modifications.[59] Ebaugh et al.[60] found, with a similar external rotation fatigue protocol, less posterior tilt of the scapula in the beginning phase of arm elevation, accompanied by more scapular upward rotation and clavicular retraction in the mid ranges of elevation. Changes observed in scapular kinematics may affect the amount of area in the subacromial space and may facilitate impingement.[59] To date, it remains unknown whether the observed changes in scapular orientation are a primary result of direct face alterations of the infraspinatus and teres minor muscles or something secondary to compensatory changes in the activity of the scapulothoracic muscles, which help maintain scapular stability.[59]

According to these different studies, fatigue tends to result in changed motion of the scapula, which alters the scapulohumeral rhythm.[57-60] Generally, the modification in scapula mobility accompanied by scapulothoracic muscle fatigue corresponds to an increased upward rotation during humeral elevation.[57,58,60]

3.3 Pathological Patterns

Cumulative stresses may place excessive stress on the shoulder complex, the throwing gesture representing a relevant example. Burkhart et al.[2] defined the acronym 'SICK' (Scapular malposition, Inferior medial border prominence, Coracoid pain and malposition, and Dyskinesis of scapular movement) as a recognized overuse muscular fatigue syndrome, which could entail shoulder pain in the throwing athlete.[2,3] The hallmark feature of this syndrome consists of asymmetric malpositioning of the scapula in the dominant throwing shoulder. This statically observable position is suggestive of underlying muscle activation alteration, which could produce altered kinematics of the scapula upon dynamic use.[1-3,9,12] A thrower with this syndrome presents an apparent 'dropped' scapula in his dominant symptomatic shoulder in comparison with the scapular position of the contralateral shoulder: viewed from behind, the inferior medial scapular border appears very prominent, with the superior medial border and acromion being less prominent.[2] For Burkhart et al.,[2] this forward tilting and protraction of the scapula is a consequence of tightness of the pectoralis minor as the coracoid tilts inferiorly and shifts laterally away from the midline. The limitation of this theory is that it is based on observation and they do not actually have scapular kinematics measurements.

Alterations of scapular position at rest or through motion are commonly associated with injuries that create clinical dysfunction of the shoulder.[8-10] According to Kibler et al.,[8-10] these alterations, called 'scapular dyskinesis', do not suggest aetiology or define patterns that correlate with specific shoulder injuries. However, classification of scapular dyskinesis patterns and positions can be of help in designing a treatment plan.[10] Kibler et al.[9,10] described four categories of dyskinetic patterns based on patient observation and which correspond to the three planes of motion on the ellipsoid thorax.

- Type I is characterized, at rest, by prominence of the inferior medial scapular border due to a rotation around the transverse axis through the sagittal plane.[9,10] During arm motion, the inferior angle tilts dorsally and the acromion tilts ventrally over the top of the thorax.

- Type II corresponds, at rest, to the prominence (winging) of the entire medial scapular border and represents abnormal rotation around a vertical axis (through the horizontal plane).[9,10] During arm motion, the medial scapular border tilts dorsally at the thorax.
- Type III represents a superior translation of the entire scapula and prominence of the superior medial scapular border due to a rotation around the antero-posterior axis through the frontal plane.[9,10] During arm motion, a shoulder shrink initiates movement without the occurrence of significant winging of the scapular.
- Type IV corresponds to the symmetrical scapular position, taking into account that the dominant arm may be slightly lower.[9,10]

With respect to types I and II, Burkhart et al.[3] observed an abnormal position with excessive scapular protraction at rest and a decreased retraction during cocking and early acceleration. In throwing athletes, the alteration in stabilizer muscle function may change the relationship between the glenoid and humerus as the arm moves through the throwing phases, causing abnormalities in force generation.[12] Indeed, for most shoulder activities, the scapula plays the link in the proximal-to-distal sequencing of velocity, energy and forces; this sequencing starts at the ground and the individual body segments, or links, are coordinated in their movement by muscle activity and body positions to generate, summate and transfer force through these segments to the terminal link; this sequencing is usually termed the 'kinetic chain'.[6,8,61] In the case of 'scapular dyskinesis', the kinetic chain is then interrupted as the unstable scapula aberrantly transmits the large forces generated from the ground through the lower extremities and torso to the shoulder and arm.[4,8,16]

3.3.1 Impingement Syndrome

In comparison with non-impaired subjects (34.6 ± 9.7°), Lukasiewicz et al.[39] found that the shoulder with subacromial impingement syndrome demonstrated a significantly lower posterior tilting of the scapula in the sagittal plane (25.1 ± 9.1°). Subjects with impingement also demonstrated a higher superior scapular position with arm elevation (5.2 ± 1.6 cm below the first thoracic vertebrae) in comparison with non-impaired subjects (7.5 ± 1.5 cm). Endo et al.[30] observed, in shoulder subacromial impingement syndrome evaluated on digital images at 0°, 45° and 90° of abduction, that both upward and external rotations of the scapula were impaired at the painful arc angle of abduction. This tended to be more apparent for the external rotation of the scapula than for the upward rotation, reducing available clearance for the rotator cuff and greater humeral tuberosity as the shoulder was abducted.[30]

In a study by Hebert et al.,[62] 3-D scapular attitudes in symptomatic and asymptomatic shoulders of subjects with unilateral subacromial impingement were found to be similar, and both the shoulders of subjects with impingement differed from the shoulders of healthy subjects, mainly through a scapular asymmetry in anterior tilting. The authors speculated that inappropriate neuromuscular strategies affecting both shoulders might have been used.[62] There is evidence that unilateral attitudes increase the tension level of shoulder and neck muscles on the other side of the body[63] and controlateral coactivation has been shown during maximal activity in shoulder and neck muscles.[64] One way to confirm this assumption would have been to record, during unilateral shoulder elevation, 3-D scapular attitudes of the controlateral scapula and bilateral activation during electromyography.[62]

After a swimming session, Su et al.[18] observed no significant differences in scapular kinematics (assessed with an inclinometer with the arm at rest, and at 45°, 90° and 135° of humeral elevation) for healthy swimmers, despite muscle fatigue indicated by a significant reduction in force generation (measured with a hand-held dynamometer). However, the shoulder with subacromial impingement was significant, accompanied by decreases in scapular upward rotation concomitantly with a decrease in force developing in subjects after swimming.

Likewise, Ludewig and Cook[13] found a decreased scapular upward rotation, increased anterior tipping and increased scapular internal rotation under load conditions in a group with subacromial impingement relative to a group without impingement. At the same time, upper and lower trapezius muscle electromyographic activity increased in the group with impingement and the serratus anterior muscle demonstrated decreased activity across load and unload phases.[13]

In a case report of a tennis player with right shoulder pain for 2 months, with a shoulder diagnosis of stage II anterior shoulder impingement, Host[65] observed the patient's posture while he was standing. He presented bilateral forward shoulders, with the right shoulder more forward than the left ('forward' was defined as the shoulder appearing anterior from the coronal plane) from a lateral view.[65] From a posterior view, the right scapula appeared to be more abducted from the vertebral spinal processes than the left scapula. In addition to these resting scapular position asymmetries, faulty scapulohumeral rhythm was thought to occur when the patient flexed and abducted his right humerus: the observed abnormality corresponded to an immediate and excessive scapular abduction and elevation and appeared to be mainly excessive (>60°) at the end range (180°) of abduction and flexion.[65] The low level of evidence of this case report is the limitation of this article.

Schmitt and Snyder-Mackler[19] also described the secondary subacromial impingement syndrome of an overhead athlete resulting from scapulo-thoracic muscle weakness (serratus anterior, middle and lower trapezius) and resultant scapular instability. The specific targeting of treatment to strengthen the weak muscles resulted in a rapid return of function.[19] Besides, Cools et al.[25] showed, in overhead athletes with subacromial symptoms, a decrease in force in the serratus anterior muscle (isokinetic evaluation) and an imbalance in the lower trapezius muscle.

Karduna et al.[66] showed an original approach in their study of eight glenohumeral fresh frozen humeral cadavers. Contrary to other studies about scapular kinematic and impingement syndrome, they showed that subacromial clearance decreased with an increase in upward rotation. Results demonstrated no significant effect of posterior tilting and external rotation. Karduna et al.[66] suggested that changes in upward rotation observed in patients with impingement syndrome may serve to open the subacromial space. Major limitations in this study resulted from the lack of contact location measurement and the fact that the effects of combination patterns may have been missed in these cadaveric studies.[66] Moreover, they only considered a single humeral orientation: 90° of elevation in the scapula plane, with maximal internal rotation.[66] In a recent study, McClure et al.[20] observed slightly greater scapular upward rotation and clavicular elevation during flexion and slightly greater scapular posterior tilt and clavicular retraction during scapular plane elevation in an impingement group compared with a control group; this could be interpreted as favourable compensatory responses to increase subacromial space. There were no differences in resting posture between the groups.[20]

The results of Warner et al.,[17] employing the static Moiré evaluation (where the subject holds both arms forward and flexed at 90° for 5 seconds with 4–5 kg weights in each hand) demonstrated a scapulothoracic asymmetry in 57% of an impingement group versus only 14% among asymptomatic subjects. Furthermore, their application of the dynamic Moiré test (where the subject lifts 4–5 kg weights simultaneously in both hands from 0° to 120° in the forward plane) demonstrated an abnormal pattern in 100% of subacromial impingement subjects as against 18% in the normal group.[17]

Laudner et al.[24] assessed 11 throwing athletes diagnosed with pathological internal impingement of the supra-spinatus and infra-spinatus between the greater tuberosity with the posterior-superior glenoid labrum. They observed a statistically significant increased sternoclavicular elevation and an increased posterior scapular tilt position in the humeral elevation from 30° to 120°, compared with the control group.[24] This increase scapular elevation may be an adaptation by the internal impingement group to avoid a position of contact between the humeral head and the posterior-superior position of the glenoid.

3.3.2 Unstable Shoulder

Investigating five fresh frozen cadaver shoulders, Weiser et al.[1] observed that, for anteriorly directed loads, there was increased *in situ* strain on the anterior band of the inferior glenohumeral ligament with increased simulated scapular protraction. These findings suggest that repetitive or chronic protraction of the scapula may imply excessive strain and, ultimately, insufficiency in the anterior band of the inferior glenohumeral ligament.[1]

Eleven fresh frozen cadaver shoulders were studied by Itoi et al.[32] in order to examine the influence of scapular inclination on inferior instability of the glenohumeral joint. In the sulcus test, all of the shoulders dislocated when the scapula was downwardly inclined at 15°. However, when the scapula was upwardly inclined at 30°, none of the shoulders dislocated either in the sulcus test or with an application of a 1.5-kg load.[32] Itoi et al.[32] concluded that scapular inclination contributes significantly to inferior stability of the glenohumeral joint. They also concluded that increased scapular upward inclination prevents inferior displacement of the humeral head, probably because of a 'bony cam effect'. An increase in the scapular inclination tightened the superior capsule and the increase in the slope of the glenoid fossa acting as a bony cam further tightened the superior capsule-ligamentous structures, thus stabilizing the humeral head in the glenoid fossa.[32] The limitation of the cadaver study is that the dynamic stabilizers are taken out of the picture, and therefore applicability to the moving shoulder needs to be interpreted with caution.

Von Eisenhart-Rothe et al.[22] hypothesized that changes in humeral head position correlate with alterations in scapular positioning. Using open magnetic resonance imaging, they examined, in various arm positions, the shoulders of 28 healthy volunteers and 14 patients with atraumatic instability.[22] They found that the glenohumeral to scapulothoracic ratio in the scapular plane increased in 9 of 14 atraumatic shoulders (corresponding to a decreased upward rotation) and that the ratio decreased in three patients.[22] At the same time, the internal scapular rotation in the transverse plane was increased in all unstable shoulders. The unstable shoulders also presented malcentring of the humeral head in the direction of instability during various arm positions.[58] In healthy and atraumatic unstable shoulders, the correlation between scapular position and glenohumeral positioning was high during passive elevation ($r = 0.60–0.87$), especially at 30° and 90° of abduction, suggesting that scapula positioning is relevant for humeral head decentring.[22] Interestingly, in cases where altered scapular positioning and humeral centring were most prominent on the affected side, the authors also reported alterations on the asymptomatic side.[22]

In a second study, the following was observed by Von Eisenhart-Rothe et al.[21] during muscular relaxation at 90° of abduction and external rotation: an increased glenohumeral translation (anterior–inferior) in traumatic unstable shoulders in comparison with their respective contralateral side (3.6 ± 1.5 vs 0.7 ± 1.6 mm), and the same in both atraumatic unstable shoulders through a non-uniform direction (4.7 ± 2 mm). During isometric muscle activity in the same position (90° of abduction with external rotation), the humeral head became significantly more centred ($p < 0.05$) in comparison with its position during muscular relaxation, but only in shoulders with traumatic instability and not in those with atraumatic instability. This observation suggested, in atraumatic instability, an alteration of the active stabilizers, and emphasized the paramount importance of the rehabilitation process.[21]

Glousman's[67] evaluation of skilled athletes with an isolated diagnosis of anterior glenohumeral instability revealed electromyographic differences from athletes having normal shoulders. In these athletes with instability, Glousman[67] recorded a marked decrease in activity levels on the pectoralis major, subscapularis and latissimus dorsi (in fact, these muscles contract eccentrically to protect the anterior part of the shoulder joint) and he also observed decreased activity of the serratus anterior throughout the pitch. Such serratus anterior activity reduction diminishes scapular rotation during the late cocking motion, giving a possible decrease in the subacromial space.[67]

3.4 Summary

The healthy throwing athlete's shoulder exhibits a significantly increased upward rotation combined with a retraction of the scapula during humeral elevation in comparison with non-throwing athletes. This might represent an adaptive pattern warranting vital to injury-free performance by clearing the acromion for the underlying subacromial structures.

The shoulder muscle fatigue induces a modification of scapula motion during humeral elevation (mainly an increased scapular upward rotation), which alters the scapulohumeral rhythm. Alterations of scapular position at rest or through motion ('scapular dyskinesis') are commonly associated with injuries that create clinical dysfunction of the athletic shoulder. Classification of scapular dyskinesis patterns and positions can be of help in designing a treatment plan.

Classically, subacromial impingement syndrome results in decreased upward rotation, increased anterior tipping and increased scapular internal rotation during humeral elevation. Likewise, periscapular muscles have altered muscle activation patterns in impingement patients. Abnormal scapulohumeral rhythm during humeral elevation have been linked to imbalances in force production of the scapulothoracic muscles. The internal impingement syndrome is accompanied by a significant increased scapular elevation, which could be a position compensation of the pathology.

The unstable shoulder presents malcentring of the humeral head into the glenoid fossa. Some correlations between scapular position and glenohumeral positioning during passive elevation suggest that scapula positioning is relevant for humeral head decentring. In atraumatic instability, an alteration of the active stabilizers emphasizes the paramount importance of improving the scapular muscle function through the rehabilitation process.

4. Conservative Management of Scapular Malposition – Rehabilitation

Undoubtedly, classification of scapular dyskinesis patterns and positions may help to optimize treatment of shoulder disorders; we recommend that scapular evaluation includes both static and dynamic testing of motion.[10] Inflexibility of the muscles and ligaments around the shoulder can affect the position and motion of the scapula;[3,26,27,37] likewise, weakness or alteration of muscle activation could also give rise to scapular dyskinesis.[3,13,25,67] This implies that most of the abnormalities in scapular motion or position would have to be treated by physical therapy in order to relieve symptoms associated with inflexibility and to normalize muscle strength and activation patterns (figure 3).[10]

Muscle inhibition or imbalance frequently finds its roots in glenohumeral internal disturbance, such as instability, labral tears, rotator cuff injury or tendonitis.[10] When structural problems, as well as the internal disturbance have been corrected, scapular muscle rehabilitation may be initiated, focusing on some specific factors.

4.1 Flexibility

The pectoralis minor, the sole anterior scapulothoracic muscle, is passively lengthened during the active scapular upward rotation, external rotation and posterior tipping that accompany arm elevation in healthy individuals.[27] A non-adaptively shortened muscle would potentially limit these normal scapulothoracic motions, reduce the size of the subacromial space, and then create an environment leading to pathology.[27] The pectoralis minor has also been identified as a muscle requiring stretching in individuals with forward shoulder posture.[27] For Burkhart et al.,[2] the anterior tightness may be treated by placing a rolled towel between the shoulder blades of the supine patient and steadily pushing posteriorly on the shoulders to stretch the pectoralis minor.

Another issue with inflexibility is the lack of full internal rotation of the glenohumeral joint caused by capsular or muscular posterior cuff tightness.[3,26,68-71] Borich et al.[26] demonstrated a significant relationship between glenohumeral internal rotation deficit (measured with subject in supine position, shoulder 90° abducted in the frontal plane) and

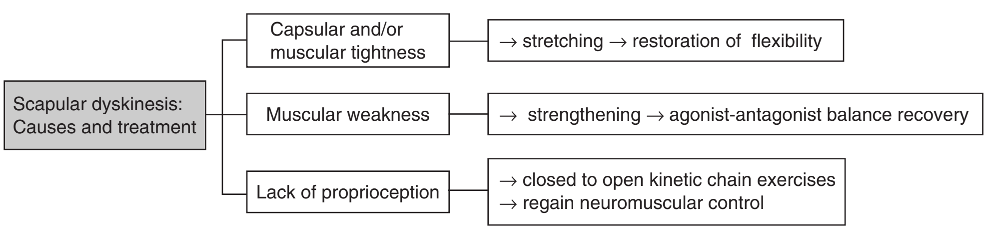


Fig. 3. Scapular dyskinesis: causes and treatment.

abnormal scapular positioning, particularly increased anterior tilt. The glenohumeral translation resulting when the capsule is asymmetrically tight was measured in the study by Harryman et al.,[68] and also in current researches.[69-71] Huffman et al.[70] found that posterior capsular tightness alters the humeral head position most profoundly during the deceleration and follow-through phases of throwing. Myers et al.[69] observed that tightening of the posterior elements of the shoulder may contribute to internal impingement in throwing athletes. A tight posterior inferior capsule could also produce a SLAP lesion by pushing superiorly the humeral head towards the posterosuperior biceps labral attachment.[3,71]

On the basis of the clinical observation, one of the stretching techniques for the posterior capsular tightness is the 'sleeper stretches',[2] in which the athlete lies on his or her side with the shoulder in 90° flexion and the elbow in 90° flexion. The shoulder is internally rotated passively by pushing the forearm toward the table around a fixed elbow, which acts as a pivot point (figure 4). The roll-over sleeper stretch is the same as the sleeper stretch except that the shoulder is only flexed 50–60° and the patients rolls forward 30–40° from vertical side lying.[23] The cross-arm stretch has the patient standing with the shoulder flexed 90° and passive adduction applied by the non-dominant arm to the dominant elbow.[23,72] Seemingly, this posterior stretch primarily stretches the posterior musculature to a greater degree than the posterior inferior capsule.[72]

Fig. 4. 'Sleeper stretch' devoted to the capsular and muscular posterior cuff stretching.

4.2 Strengthening

The scapula acts as a base of support and an anchor to which 17 different muscles firmly attach, thereby justifying the view that scapulothoracic motion is controlled by several force couples.[73]

Classical exercise techniques to strengthen the scapular muscles may enhance dynamic stability during arm motion, while specific exercise drills enhance the dynamic control of the scapulothoracic musculature.[72-74] These drills are designed to challenge maximally the scapular force couples, which rest on:

- the upper trapezius counterbalanced by the lower fibres of the serratus anterior;
- the middle trapezius/rhomboids opposed by the serratus anterior;
- the lower trapezius and upper serratus anterior fibres.[73,74]

Rehabilitation of patients with scapular dyskinesis should include the kinetic chain concept based on a proximal to distal control sequence.[2,10,74] This emphasizes the achievement of full and appropriate scapular motion and the integration of that point into a subsequent, more global, approach including trunk and hip movements (scapular retraction is facilitated by trunk and hip extension).[10]

Once scapular motion is normalized, this movement pattern serves as the framework for strengthening exercises targeting the scapular muscles.[10] The early stages of strength rehabilitation include exercises in the closed kinetic chain and coordinated activation of all components in force couples, rather than isolated activation of individual muscles.[2,10,73,74] For example, a very safe exercise to be proposed in the early phase consists of the 'low, middle or high row': it involves trunk extension, scapular retraction and arm extension as the patient pushes against resistance in a posterior direction.[2] More advanced closed-chain exercises include the 'scapular clock' (figure 5), in which the hand is placed on the wall, eliminating the weight of the arm and moving the scapula in elevation and depression (the 12 and 6 o'clock positions), as well as retraction and protraction (the 9 and 3 o'clock positions).[2,74] Thereafter, closed-chain exercises will include humeral head depressions and rotations on a ball, 'wall

Fig. 5. 'Scapular clock' (closed kinetic chain at: (**a**) 12 o'clock; (**b**) 9 o'clock; and (**c**) 3 o'clock positions).

washes' (starting position in retraction of the scapula, extension of the arm to protraction of the scapula, flexion of the arm) [figure 6] and 'punches' (figure 7) [punch out may be varied: diagonal, upward or downward], which combine closed-chain shoulder activation with open-chain arm motion. Hintermeister et al.[75] studied the muscle activity (measured by electromyography) and applied load during shoulder rehabilitation exercises done with an elastic resistance device such as seated rowing exercises, shoulder shrug or forward punch exercises. These open-chain exercises target the rotator cuff and require a stable scapular base, since all the rotator cuff muscles have their origin on the scapula. Indeed, closed-chain exercises require less rotator cuff muscle activation than open-chain exercises.[76] Likewise, vertical patterns, with the arm closer to the body, creating a shorter lever arm, requires less activation than diagonal patterns, with a long lever arm.[76]

Many other strengthening exercises are reported in the literature; they allow a regaining of control over scapular protraction, retraction, depression, elevation and rotation (figure 8 and figure 9). For example, the patient lies on his or her side on the uninvolved arm, and the affected arm is abducted to 90° and internally rotated (figure 9), or the patient's hand is placed on the table to fixate the distal segment, and the scapula is slowly elevated, depressed and protracted.[2] Ellen et al.[12] proposed scapulothoracic stabilizer exercises using a light hand weight: the patient lies on their back with arms up straight above their chest, and gently pushes their arm higher (scapular protraction using serratus anterior) or the patient lies on their stomach with their arm hanging down comfortably, and lifts their arm up slowly until it is just below parallel to floor (horizontal abduction), soliciting the rhomboids or the middle trapezius muscles (regarding the position of the thumb-down or up). Blackburn's retraction exercises are used to strengthen the scapular retractors and posterior rotator cuff.[2] Seated push-up exercise stimulates, in particular, the scapular depressor or retractors, the triceps, the latissimus dorsi and the teres major.[2]

On the basis of electromyographic analysis, Ekstrom et al.[77] and Ludewig et al.[78] observed that the standard push-up plus demonstrated the highest electromyographic activation of the serratus anterior. Moseley et al.[79] and Decker et al.[80] also analysed scapular muscle activity during selected rehabilitation exercises: the exercises that maintained and upwardly rotated scapula while accentuating scapular protraction elicited the greatest electromyographic activity from the serratus anterior muscle.[80] The serratus anterior is also activated maximally with exercises requiring a great amount of upward rotation of the scapula: as shoulder abduction in the plane of scapula above 120° and a diagonal exercise with a combination of shoulder flexion horizontal abduction and external rotation.[77]

Plyometric exercises (dynamic stretch-shortening), such as the medicine ball toss and catch, or tubing plyometrics, will be initiated when scapular control and motion throughout the range of shoulder elevation are recovered.[10] Cordasco et al.[81] observed a high level of activity of the upper trapezius during the acceleration phase during a two-handed medicine ball throw. Their findings support the use of medicine ball training as a bridge between static resistive training and dynamic throwing in the rehabilitation of the overhead athlete.[81] Neuromuscular and proprioceptive exercises represent the transition between the reinforcement and the use of the shoul-

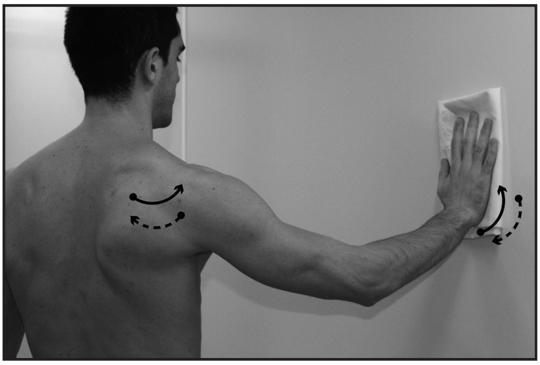


Fig. 6. 'Wall washes' (closed kinetic chain).

der through some specific functions and before the return to the field by the athlete.[5,74] The goals of awareness of proprioception are to re-establish afferent pathways from the mechanoreceptors at the injured joint to the CNS and to facilitate supplementary efferent pathways as a compensatory mechanism.[82] Humeral head and scapular stabilization on unstable surface,[83] dynamic stabilization[82] or functional rehabilitation that mimics athletic function are called 'proprioceptive neuromuscular facilitation exercises'.[82]

Before the return to the field, a transitory phase, which is conducive to integrating new instructions during the throwing gesture, is of paramount importance.[2,3,8,72] The leg and trunk are essential to provide a stable base for arm motion, and a rotational momentum for force generation; for example, these segments generate half of the total force and kinetic energy in the tennis serve.[2] Inflexibility of the non-dominant hip and trunk, as well as weakness of hip abductors or trunk flexors, break the kinetic chain.[2,6,83] This breakage increases lumbar lordosis in acceleration, which places the arm behind the body.[2,6,83] Likewise, a hypersagittalization of the scapula creates a hyperabduction/external rotation position of the throwing shoulder.[72] During the late cocking phase of the overhead throw, because the thrower's humerus excessively abducts horizontally and hyperangulates posterior to the plane of the scapula with a 'dropped elbow', posterior compression loads on the structures, including the labrum, may occur.[2,72] One key point to avoiding these compensations is that the abducted arm must stay in the plane of the scapula through use of the scapular stabilizers with the elbow high enough to keep the upper arm at or above the horizontal plane.[2,72]

On the basis of the underlying biomechanical concepts, the context of a 'preventive approach' must be encouraged: strengthening of the scapular muscles, stretching of the posterior rotator cuff and pectoralis minor muscle and retraction of the scapula during the throwing gesture.

4.3 Scapular Taping

Scapular taping might be helpful to decrease excessive abduction and winging and also to promote upward rotation. Host[65] proposes that a first strip would be applied, pulling proximally from the upper trapezius muscle belly region distally to approximately 5–8 cm below the inferior angle of the scapula. Another strip would then be applied from the posterior lateral carcomion diagonally across the back and ending just lateral to the thoracic spinous process, in order to pull the scapula back into adduction and slightly upward.[63]

Likewise, Schmitt and Snyder-Mackler[19] introduced taping in a patient with an impingement syndrome in order to improve scapular position during elevation, and to assist in the function of the scapula stabilizers. The taping was used to prevent stretching of the serratus anterior and middle and lower trapezius by decreasing the winging scapula. Such an adaptation decreases the demand placed on these muscles as well as on the glenohumeral musculature during daily activities.[19]

Lewis et al.[84] showed a statistically significant difference in scapular position with the taping among subjects with subacromial impingement syndrome. Changing posture was associated with a

Fig. 7. 'Punches' (open kinetic chain).

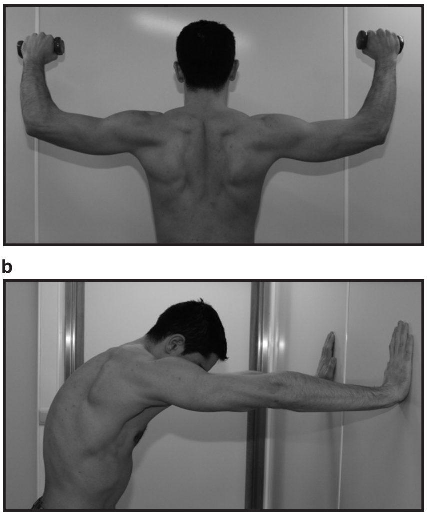
a b


Fig. 8. Scapular strengthening exercises including (**a**) retraction and (**b**) protraction.

significant increase in the range of motion in shoulder flexion and abduction in the plane of the scapula, thereby the point in the range of shoulder movement at which the subjects experienced their pain was significantly higher ($p < 0.01$).

Ackermann et al.[85] evaluated the effects of taping the scapula of violinists into a position that could prevent excessive elevation and protraction while playing. During violin playing of varied musical excerpts, scapula taping was associated with increased electromyographic activity levels in the upper trapezius muscle, thus scapula taping may have acted to restrict forward and upward movement of the shoulder, thereby increasing the amount of isometric tension generated in the upper trapezius.[85] Ackermann et al.[85] observed that taping had significant negative effects on the subject's reports of concentration and comfort; this was associated with a reduction in musical performance quality.

5. Conclusion

The scapula plays an important role in shoulder function. In sports in which demands placed on the shoulder are extremely high, the quality of movements depends on the interaction between scapular and glenohumeral kinematics. Set apart from the scapula's normal status, 'scapular dyskinesis' is defined as an observable alteration in the position of the scapula and the patterns of scapular motion in relation to the thoracic cage.

Laboratory measurements of scapular displacements are typically capable of quantifying the scapular kinematics in 3-D, but are not available to the clinical setting. Clinical measures (inclinometer, tape measure) are only capable of measuring scapular kinematics in 2-D, but can easily be used by the clinician. Inclinometer assessment gives valid and accurate information regarding static positions of scapular upward rotation. A bilateral tape measurement between the inferior angle of scapula and spinous process, in three positions of the upper extremities (Lateral Scapular Side Test), provides a quantitative measurement of possible scapular asymmetry. The distance from the sternal notch to the coracoid process at rest gives a quantitative measure of scapula internal rotation, which is correlated with pectoralis minor muscle tightness.

Different patterns of abnormal motion in scapular dyskinesis are also described, based on simple bilateral visual observation of scapular position with the patient's arms at rest at the side and during elevation and lowering in the scapula plane. Classification of scapular dyskinesis patterns and position may be of help in designing a treatment plan.

Healthy athletes shoulders show adaptive patterns, particularly in the shape of significantly increased upward rotation combined with retraction of the scapula. Fatigue, impingement (subacromial or internal) context, labral pathology or unstable shoul-

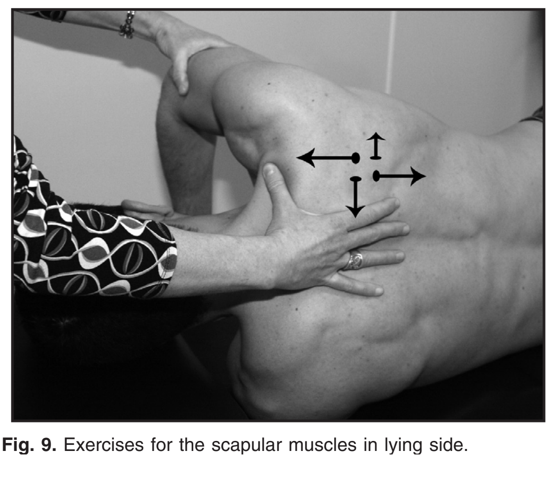


Fig. 9. Exercises for the scapular muscles in lying side.

der results in alterations of scapular position at rest. Abnormal scapulohumeral rhythm during humeral elevation is also described. Even if scapular dyskinesis represents a nonspecific response to shoulder pathology, it is linked to weakness or alteration of scapular muscle activation and inflexibility of the muscles (pectoralis minor, posterior rotator cuff) and ligaments around the shoulder. This implies that most of the abnormalities in scapular motion or position must be taken into account through the rehabilitation process.

The pectoralis minor and the muscular posterior cuff tightness are classically treated with specific stretching techniques. Exercises to strengthen the scapular muscles enhance dynamic stability during motion, while specific exercise drills are designed to challenge maximally the scapular force couples. Rehabilitation of patients with scapular dyskinesis should include the kinetic chain concept based on a proximal to distal control sequence. Before the return to the field by the athlete, neuromuscular and proprioceptive exercises represent a transition between the muscle reinforcement and the use of the shoulder through specific functions. We recommend the regular use of assessments throughout a treatment programme of scapular disorders in order to establish improvements and to individually bring up to date the rehabilitation techniques.

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