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Scapulohumeral RYTHM: Anatomical Highlights and Clinical Implications

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ABSTRACT:- Musculoskeletal disorders including shoulder complain and low back pain has become widely prevalent in India. Approximately 50% of patients, including young adults visit general practitioner with a new episode of persistent shoulder complain. Numerous medical research publications have repeatedly pointed towards the correlations between scapular position with impingement symptoms, rotator cuff dysfunction, scapular dyskinesis and instability. When analyzing research surveys it becomes clear that there is a need for guidance in the rehabilitation management of shoulder patients, but probably the best scapular rotation exercise programme has not yet been established. Our article has put forward a sincere attempt to add ourselves to the review of literature by compiling retrospective information which may answer the following questions: (1) What is the correct position of the scapula at rest and how the probable scapular movement looks like?, (2) In which way can the muscular imbalance Glenohumeral rhythm compensated?, and (3) How does the optimal rehabilitation approach looks like?

Key words: Shoulder, Scapula, Glenohumeral rhythm, scapular rotation, scapular dyskinesis.

I. INTRODUCTION

Anatomical function of the shoulder is relevant on the coordinated movement of the humerus and the scapula. [(1)] Modifications in scapular position and scapular stabilizing muscles have been documented to dis-balance Anatomical stability and biomechanical function of the gleno-humeral joint, resulting in shoulder pathologies including impingement, musculotendinous cuff or rotator cuff complains and shoulder instability.[(2,3)] Thus the correlative functions of the scapula in shoulder function or the coordinated motion of the scapula and humerus otherwise known as scapulohumeral rhythm,[(4,5)] significantly have wide spread clinical implications not only in routine Anatomy but especially for athletes and patients with gleno humeral pathologies.[(6)]

In sports such as baseball, golf, and tennis, the shoulder remains the focal point for repetitive overuse injuries in sports as baseball, golf, and tennis.[(7,8)] The athletic shoulders usually have been diagnosed with rotator cuff strain, impingement, glenoidal labral tears, and instability.[(9)] In Indian sub continent, shoulder pain is the third most common musculoskeletal condition.[(10)] The published annual incidence of shoulder pain in primary care hospital is about 14.7 per 1000 patients, with a lifetime prevalence of approximately 70%. 20% of the adult populations in our country have complained of shoulder dysfunction symptoms. Most common causes of shoulder pain in primary care are reported to be acromioclavicular joint and or gleno-humeral joint disorders.[(11)] The prevalence of shoulder pain in India has been reported to be 2% (urban) and 7.4% (rural) population.[(12)] Eighteen studies on prevalence for different age groups figured out 6.9 to 26% for point prevalence, 18.6-31%, for 1-month prevalence, 4.7-46.7% for 1-year prevalence and 6.7-66.7% for lifetime prevalence on shoulder pathologies. [(13)]

Analysis of these surveys have brightly reflected that the need of the hour is to understand the scapulohumeral and gleno-humeral anatomy including correlative function and rehabilitation with clear guide lines on exercise protocols to maintain the force, stability, neuromuscular coordination and physiological balance. This is so because scapular muscle training is an essential component of shoulder rehabilitation.

II. DEFINITION

Scapulohumeral Rhythm or glenohumeral rhythm is defined as the movement relationship or kinematic interaction between the humerus and the scapula in terms of both static and dynamic pattern differences during shoulder movements resulting in interplay of four articulations – sternoclavicular, acromioclavicular, scapulothoracic and glenohumeral joints of the shoulder complex for optimum function of the shoulder.[14,15] The involved movements at each joint are continuous, although occurring at various rates and at different phases of movement of the shoulder. Scapulohumeral rhythm is a multiple kinematic couple where scapular contribution to shoulder elevation is changeable depending upon the type of arm movement. [16] Putting in simple language, it is a pattern of muscle contraction and motion that occurs between scapula and humerus. [17]

III. HISTORY AND BACKGROUND INCLUDING REVIEW OF LITERATURE

The term scapulohumeral rhythm was first coined and published by Codman in 1930. [5] Inman, Saunders and Abbott [3, 17, 18] were the first to measure scapulohumeral rhythm using radiography and suggested what became the widely accepted 2:1 ratio between glenohumeral elevation and scapulothoracic upward rotation. Since then imaging modalities [3] (X-ray and magnetic resonance imaging), cinematography, goniometry, and more recently 3-dimensional tracking systems have been used to gain a better appreciation of shoulder kinematics. This evolution in kinematic assessment has resulted in new understandings of scapulohumeral rhythm in both healthy and injured populations. Some of the literature suggests the 2:1 ratio is not consistent across an entire arc of shoulder elevation[18,19] and that variability in this ratio may increase when considering the scapulohumeral rhythm exhibited by shoulder injured subjects.[3,20,21]

The scapulohumeral rhythm has been the focus of several investigations. Despite the three dimensional dynamic nature of the scapulohumeral rhythm, most of these studies has primarily used static plane film X-rays or goniometry during varying positions of arm elevation to describe the scapulohumeral rhythm. There have been some attempts at three dimensional analyses as well. Taken collectively, reported ratios of humeral elevation to scapular upward rotation have ranged from 1.35: l to 7:1, often departing from the classic 2.0: l ratio first described by Inman et al. [15] The phase-wise scapulohumeral rhythm ranged from 7.9: l to 2.9:l for unloaded elevation, 3.1:l to 4.3:l for the light load elevation, and 1.9:l to 4.5:l for the heavy load elevation [15]. The wide range of reported ratios appears to be due to differences in measurement techniques, points in the range of motion where data are collected, and the methodologies for describing and defining scapulohumeral rhythm. Inter subject variation may also affect comparisons across different studies.[22] In addition, since with arm elevation the scapula can rotate about three independent axes, accurate measurement of scapulohumeral rhythm requires the ability to discern these rotations independently. This is problematic because it is difficult to place multiple markers on the surface of the scapula, which are frequently required for three- dimensional motion measurements. [15, 23]

The study from Ludewig et al [24] states that the scapula demonstrates a pattern of progressive upward rotation, decreased internal rotation, and movement from an anteriorly to posteriorly tipped position as humeral elevation angle increases. Ekstrom et al discovered that the scapula usually finds a position of stability within the first 30-60° of glenohumeral elevation or abduction where negligible upward rotation occurs. A different view described by Voight et al [25] states that the scapula already rotates upwards in the space of 30-50° of humeral abduction. The findings of Voight et al militate in favor of the scapulohumeral rhythm which was defined as 2:1 by authors such as Cools, Inman, Mottram Voight etc.. Despite this, Mottram supports in her study the opinion of Ekstrom that the scapula does not move remarkable in the first 60° of flexion and 30° of abduction. [26] Whether we consider exposure to electromagnetic radiation associated with radiography or the expense and time intensive nature of electromagnetic tracking systems, there are some limitations associated with quantifying the relative contributions of the glenohumeral and scapulothoracic joints to shoulder elevation in clinical settings. To enhance accessibility, Johnson et al [27, 28] validated use of a digital inclinometer to quantify scapulohumeral rhythm.

Several methods for the evaluation of scapular dyskinesis have been reported in the literature. First, two studies concluded that the observation of tilting and winging during movement is a clinically applicable tool for assessing patterns of scapular motion.[29, 30] Second suggest not to rate the scapula with a selected deviation (winging and tilting), but instead to classify scapular positioning as normal, subtle dyskinesis or obvious dyskinesis. The study described subtle dyskinesis as a mild or questionable evidence of abnormality which was not consistently present. In addition, obvious dyskinesis was defined as striking, clearly apparent abnormality, evident on at least 3/5 trials (dysrhythmias or winging of one in (2.54 cm) or greater displacement of scapula on thorax). This rating system of McClure et al achieves satisfactory reliability for clinical use. In addition, shoulders visually judged as having dyskinesis showed distinct alterations in three-dimensional motion, which supports the validity of this observation system. Third[30, 31] concluded that a yes/no rating system provided a reliable evaluation system, which achieved high sensitivity (76%) and high predictive value (74%). They compared this rating system to Kiblers four-type rating system, which required a single-forced choice among

four categories, including three subtypes of dyskinesis: types I (inferior angle prominence), II (medial border prominence), III (excessive superior border elevation) and IV (symmetric and normal scapular motion). A shoulder was scored yes when one or more of the first three types of Kiblers [(30)] rating system were observed. The clinician scored no is type IV was seen.

Shoulder disorders and pain commonly affect athletes who predominantly use their upper extremity in the sport. During throwing efforts the shoulder complex is exposed to a large range of motion, being extremely dependent on the combined movements among the sternoclavicular, acromioclavicular, scapulothoracic and glenohumeral joints. [(28)] The glenohumeral joint shape and scapular mobility in relation to the thorax are mainly responsible for the great mobility found in this complex. The three-dimensional pattern of integrated movement between glenohumeral and scapulothoracic joints is known as the scapulohumeral rhythm. Such integration allows the scapula to provide a stable base for glenohumeral movements and to be mobile to position the arm throughout its range of motion [(29)]. If the scapular position is altered this normal pattern of integrated movement is expected to be affected. For this reason, the scapulohumeral rhythm is assumed as a movement quality index of the shoulder complex in clinical practice. Altered scapular kinematics and associated shoulder dysfunction have clearly been demonstrated by some researchers. They have shown an association between abnormal scapular movement and shoulder pathologies such as impingement syndrome and glenohumeral instability, among others. Based on such evidence, rehabilitation programmes and protocols were developed focusing and emphasizing on appropriate scapular motion and stability retraining. [(28, 29, 30)]

In the past years the stake of the scapula and scapular muscles in shoulder disorders has become articulate.[(32, 33, 34, 35, 36)] Correlations between abnormalities in scapular position and motion with impingement symptoms, rotator cuff dysfunction, and instability have been identified in numerous studies. Authors like Cools, Kibler, Ludewig, Mottram, or Ekstrom are concerned with this topic. In the last eight years they have published around eleven studies dealing with the context of the scapula and scapular muscle activity in conjunction with shoulder dysfunction. Even the abundance of recently published studies on this subject reflects the therapeutic relevance.

IV. FUNCTIONS OF SCAPULA IN SCAPULOHUMERAL RHYTHM

The shoulder girdle or pectoral girdle is the set of bones in the appendicular skeleton which connects to the arm on each side. In humans it consists of the clavicle and scapula.[(32, 33)] It allows all movements of the arm and shoulder. The shoulder consists of 5 muscles namely, Trapezius, Levator Scapulae, Rhomboids (Major and Minor), Serratus Anterior and Pectoralis (major and minor) which attach between clavicle, scapula, sternum and ribs for the coordinated movement between the 5 joints namely (a) Sternoclavicular (b) Acromioclavicular (c) Glenohumeral (d) Scapulothoracic and (e) Scapulocostal. The bones namely Clavicle, Scapula, sternum and ribs, the muscle connecting them, Trapezius, Levator Scapulae, Rhomboids (Major and Minor), Serratus Anterior and Pectoralis (major and minor) and the articulations formed Sternoclavicular, Acromioclavicular, Glenohumeral, Scapulothoracic and Scapulocostal are together referred shoulder girdle complex. Among the joints named some are True joints or Anatomical joints (Sternoclavicular, Acromioclavicular, and Glenohumeral) formed by bones and the others, Scapulothoracic and Scapulocostal, are false or Physiological joints where only muscles bring about the attachment between the concerned bones.[(37, 38, 39, 40)] Any perturbation in the described Anatomy have shown fool proof disastrous biomechanical consequences leading to functional compromise and eventual pain of the said articulations.[(41,35)]

The functions of Scapula in maintaining the integrity and coordination of the Scapulohumeral rhythm include: [(32, 33, 34, 35, 42)]

(a) Maintaing the functional balance or stability of the shoulder girdle complex.
(b) Scapula increases the glenohumeral joint congruency by providing the proximal part of glenoidal cavity.
(c) Provides attachment to Glenoidal labrum for optimum contact with humeral head.
(d) Acts as a pivotal mediator angle for movements in shoulder joint which coordinates stability and movement by transmitting high forces and energy to the arm facilitating movement.
(e) Gives the muscle a stable base for attachment which stabilizes length – tension relationship of the muscle for acting as prime and or accessory mover. This base completes the kinetic chain of scapula – clavicle – sternum – vertebral column. Hence the muscles dynamically stand the scapula at angle of 30 degrees anteriorly rotated to the frontal plane which compresses humeral head into glenoid fossa. The muscles also maintain the optimum position of scapula at rest which is light anterior tilt, internal rotation and upward rotation so that the inferior angle comes to lay a little posterior and the glenoid cavity becomes cranial and anteriorly oriented.

(f) The muscles of the scapula are either glenohumeral movers or scapula rotators. They constantly change the axis of rotation and lines of action and maintains length tension activation pattern. The muscles raise the acromion preventing impingement syndrome.
(g) Retraction and protraction to facilitate cocking, throwing and serving motions.
Alterations in the given biomechanical functions results in scapular dyskinesis which gives way to increase in glenohumeral angulations and tension of the glenohumeral ligaments and rotator cuff injury.

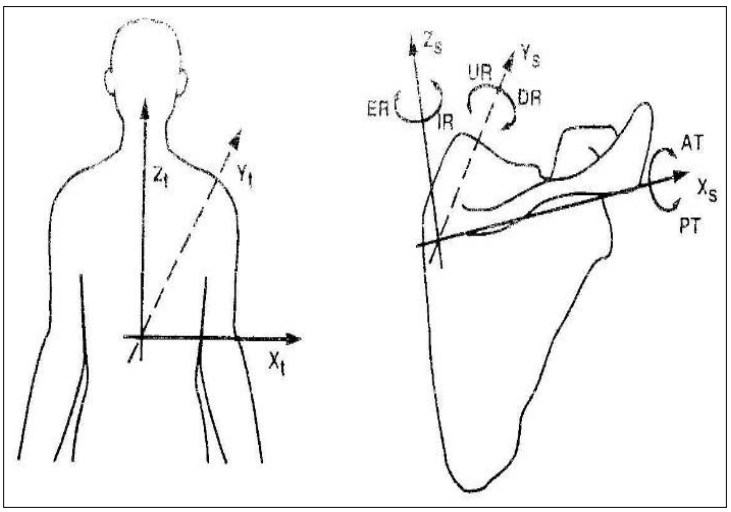
Muscles groups of the Scapula

The muscles of the Scapula can be grouped according to their attachment and functional component [(43)].

a. Axio-scapular muscles (Attaching the scapula to the trunk): Trapezius, Rhomboids, Serratus Anterior and Levator Scapulae. These muscles must move the scapula correctly in order for the humerus to move correctly on the glenoid cavity.
b. Scapulo- humeral muscles (Attaching scapula to the humerus, also called as intrinsic muscles): Deltoid, Teres Major, and the four rotator cuff muscles (Supraspinatus, Infraspinatus, Subscapularis and teres minor). These muscles control the glenohumeral joint.
c. Axio-humeral muscles (Attaching trunk to humerus by bypassing the scapula): Pectoralis Major, Pectoralis Minor and Latissimus Dorsi. They are sometimes called as hamstrings of upper extremity.

Movement possibilities of scapula

The scapula moves the shoulder girdle complex around three different axes [(42)]. (Figure 1)



(Figure 1: Axis orientation of Scapula. X_S=horizontal axis, Y = sagittal axis, Z= longitudinal axis AT= anterior tilt, PT= posterior tilt, UR= upward rotation, DR= downward rotation. ER= external rotation, IR= internal rotation) [(42)]

a. In the frontal plane (Around a sagittal axis) - an upward or downward rotation. During an upward rotation (or lateral rotation), the inferior angle (Angulus inferior) of Scapula moves laterally and slightly cranial over the thorax. Downward rotation (or medial rotation) occurs is the opposite direction wherein the inferior angle swings medially. In our script we decided to use the term upward and downward rotation.
b. In the sagittal plane (around a horizontal axis) – Scapula moves in a posterior and anterior direction over the thorax. The Angulus inferior becomes better defined during anterior tilt as compared to posterior tilt.
c. Finally, in the transversal plane, Scapular external and scapular internal rotation (around the longitudinal axis) in the transversal plane is a definite possible movement. The Glenoidal cavity (Cavitas Glenoidalis) aligns posteriorly either during external rotation or anteriorly during internal rotation.

The study from Ludewig et al [(4, 25)] states that the scapular movement demonstrates

I. Progressive upward rotation,
II. Decreased internal rotation and
III. Movement from an anteriorly to posteriorly tipped position as humeral elevation angle increases.

Thus the big 3 of Scapulothoracic Motion include (a) Upward rotation (b) Posterior tilt and (c) External rotation [4, 25]. Scapula (1) upwardly rotates and posteriorly tilts during arm elevation and (2) externally rotates during elevation especially as the end ranges [4]. Scapulothoracic dysfunction, impingement syndromes and rotator cuff dysfunction or instability should be evaluated with movements of both sides of the shoulder distinguish between

normal and abnormal movement. "Scapular dyskinesis (alterations in scapular position and motion in arm activity) leads to traumatic and micro-traumatic glenohumeral instability.

Decreased upward rotation is the most common dysfunction with Scapulo humeral rhythm seen on subjects. These results in painful consequences –

a. Decreased elevation of the Acromion
b. Shoulder shrug movement and
c. Pain in the shoulder.

During arm elevation the Acromion has to elevate. Otherwise, the humerus will impinge against it causing pain which further limits elevation movement. Impingement of Humerus irritates the tendinous structures of the rotator cuff leading to the painful disorder - impingement syndrome.

The shoulder shrug phenomenon occurs with the activity of the upper fibres of Trapezius muscle. In shrugging, the scapula is unable to neatly rotate upwards. The fibres of Trapezius give a helping hand to Scapula for ensuring a pure cranial movement.

Ekstrom et al [36, 42] documented a negligible upward rotation of the scapula during the first 30-60° of glenohumeral elevation or abduction which is also a position of optimum stability. Substantial amount of rotation takes place during the mid range (80-140°) of the elevation. Towards the end of the entire movement, rotation decreases. But Voight et al [27] researched an altogether different view. They said that scapula rotates upwards in the range of 30-50° of humeral abduction. The scapula rotates another 65° during full elevation level. The findings of Voight et al [27] was defined as 2:1 in favor of the scapulohumeral rhythm by authors such as Cools Inman, Mottram et al [26, 42], etc. Thus the crux of the discussion is that the scapula moves from its resting position 60° upward during the full range of elevation. This clarifies the scapulohumeral rhythm, because during 180° elevation proceeds 120° only in the glenohumeral joint and 60° rotates the scapula upwards. However, the challenge is to keep the scapula relatively stable while it has to rotate upwards to allow a full range of elevation and abduction.

Jason Brumitt et al [7] are of the view that, for an athlete to achieve full shoulder elevation, scapulohumeral rhythm plays a pivotal role. For every 2° of elevation contributed by the glenohumeral joint, 1° of motion must occur from the scapulothoracic articulation. The scapular muscles facilitate the upper-extremity movement via the scapular movement of protraction, retraction, upward (lateral) rotation, and downward (medial) rotation. The main muscles providing scapular stabilization are the rhomboids, Trapezius, and Serratus anterior. Weakness of these muscles causes scapulohumeral rhythm destabilization leading to shoulder injury. According to Cools et al [25], among the muscles acting on Scapula, two primary muscles namely Trapezius and Serratus Anterior are together called as muscles producing force couple as per biomechanical concept. (Figure 2)

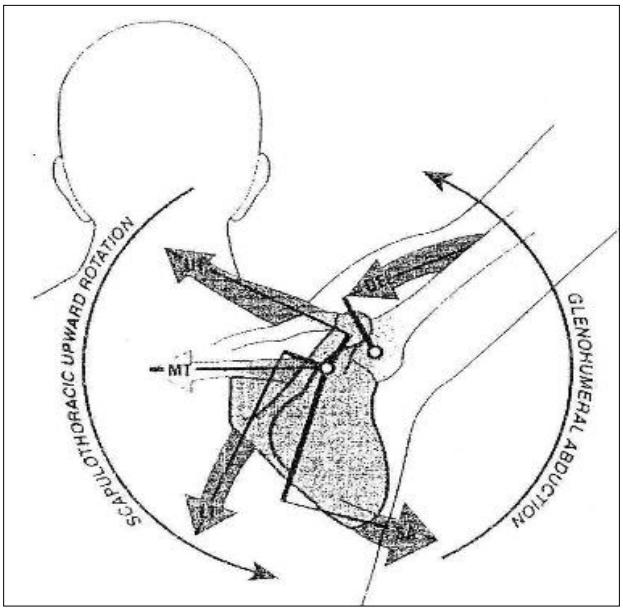


Figure 2: Force couple of Serratus Anterior (SA), upper Trapezius (UT), middle Trapezius (MT), and lower Trapezius (LT) during upward rotation. [42]

A force couple is comprised of two or more muscles which give a pseudo view of having an opposing function on the moving scapula. On the contrary, if these muscles work together a fluid rotation movement will occur. This means Serratus anterior and Trapezius muscle produce a fluid upward rotation of the scapula as a simultaneous force couple [1, 26]. The variation in force couple produced by these muscles is one of the primary causes of early stages of shoulder disorders or Scapular dyskinesis. The muscles of force couple stabilize the Scapula during movement of up to 180º. The muscles together suppress the strong downward rotational force of Deltoid producing a steady upward rotation which prevents impingement syndrome [1, 26]. The Serratus anterior muscle is in charge to prevent winging of Scapula and produces an upward rotation and posterior tilt movement [30, 42]. Multiple manuscripts [4, 26, 27, 28, 42] characterize Serratus anterior as the prime mover of the scapula. The upper Trapezius elevates the scapula mostly during the first 60° of abduction. But the lower fibres of Trapezius bundle has a tonic function in decelerating the excessive elevation produced by the upper fibres of Trapezius, or the excessive protraction by the Serratus anterior. The middle part of the Trapezius plays a minor role in coordination of the force couple [42]. At 90° of abduction all muscle parts of the Trapezius work together to antagonize a too huge pull of the Serratus Anterior [4, 25]. If the force couple works correctly the scapulohumeral rhythm accounts 2:1, as already described [4, 32]. But literature review have strongly pointed that the Scapulohumeral rhythm changes as the load over the raising arm changes where during passive range of motion, the scapulohumeral rhythm decreased from 7.9:1 to 2.1: 1 as the arm was elevated. Light shoulder loads caused an increase of the scapulohumeral rhythm from 3.1:1 to 4.3:1 as the arm was elevated. Heavy shoulder loading resulted in an increasing scapulohumeral rhythm from 1.9:1 to 4.51 as the arm was elevated[15].

Imbalance of force couple cause abnormal kinematics as in Impingement Syndrome where, reduced upward rotation of the scapula during the 31-60° phase of elevation is a decreased Serratus Anterior activity, which is compensated by increasing activity of upper and lower fibres of Trapezius. The shoulder-shrug phenomenon is a further abnormality of scapula kinematics. It occurs by the time the upper Trapezius is more powerful than the rest of the force couple. Hence documentary evidence has been obtained that excess activation of the upper Trapezius, combined with decreased control of the lower Trapezius and Serratus Anterior, contributes to abnormal scapular motion [4, 25,32,33,44].

Thus appropriate training of force couple is essential to maintain inter muscular and intra muscular balance for optimum functions of Scapula. Specific rehabilitation exercises must be developed with low upper Trapezius ratios and high lower and middle Trapezius and Serratus Anterior ratios to compensate the imbalance because it is harder for the Trapezius to compensate a weak Serratus Anterior muscle activity during flexion than in abduction [4, 25, 44].

Clinical assessment: Criteria for normal Scapular motion[4, 43]

1. Scapula should elevate but only slightly (6 to 10 degrees)
2. Vertebral border of scapula should remain in contact with Thorax.
3. Normal Gleno-humeral: Scapulothoracic rhythm is 2.1:1 for abduction, 2.4:1 for flexion, and 2.2:1 for Scapular plane abduction.
4. By the end range of arm elevation:

a. Acromion should be aligned with C6-C7.
b. The vertebral border of Scapula should reach 55 degrees to 60 degrees (±5º).
c. Normal Scapular abduction is 3º from vertebral spine to the root of the spine of the scapula.
d. Scapula should posteriorly tilt 10º.
e. Scapula should externally rotate so it is 10º - 20º anterior to the frontal plane.

5. The normal resting standing alignment of Scapula include:

a. 19 º sternoclavicular joint Clavicular retraction.
b. 6 º Sternoclavicular Clavicular elevation.
c. 41 º Scapular internal rotation.
d. 5 º Scapular upward rotation.
e. 13.5 º Scapular anterior tilt.

Corrective therapeutic exercises for stabilizing normal scapulohumeral rhythm (Top exercises for scapular stabilization) [2, 4, 36]

Muscles	Moseley (1992)	Ekstrom (2003)
Upper Trapezius	Rowing	Unilateral shoulder shrug
Middle Trapezius	Horizontal abduction	Shoulder horizontal extension with external rotation and overhead arm raise in line with lower Trapezius (prone position)
Lower Trapezius	Abduction or rowing	Overhead arm raise in line with lower Trapezius (prone position)
Rhomboids	Horizontal abduction	Not tested
Serratus Anterior	Push up with a plus	Shoulder abduction of scapula above 120 degrees

IV. CONCLUSION

The shoulder complex made up of several joints is a part of a larger kinetic chain. As discussed, the glenohumeral joint and scapula functioning independently results in dysfunction at either joint. A functional scapula with surrounding musculature is vital for a normal anatomy of glenohumeral joint. With ever increasing knowledge regarding the role of the scapula, improved treatment approaches for dyskinesis continue to emerge. While musculotendinous cuff strengthening has been treatment of choice for various pathologies, effective rehabilitation exercise program improving the strength and function of the muscles that control the position of the scapula is of immense clinical need especially for the overhead athlete or swimmer. Weakness of these anchoring muscles causes biomechanical dysfunction of the glenohumeral joint. Rehabilitation programs of the shoulder complex must include Scapular strengthening exercises. . Effective advancement in the knowledge of shoulder complex biomechanics with Electromyography (EMG) patterns along with simultaneous interaction between the scapula and glenohumeral joint needs to be further clarified and investigated.

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