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MASTERCLASS

Kinesiologic considerations for targeting activation of scapulothoracic muscles - part 1: serratus anterior

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Abstract
Background: The serratus anterior (SA) is capable of a wide range of actions across the scapulothoracic joint. Furthermore, the lack of control, strength, or activation of this important muscle is believed to be associated with several painful conditions involving the shoulder complex. Studies and clinical intuition have therefore identified several exercises that selectively target the activation of the SA.
Methods: This paper reviews the anatomy, innervation, testing, and complex actions of the SA. In addition, this paper describes the classic signs and symptoms of weakness or reduced activation of the SA. Several exercises are described and illustrated that purportedly target the activation of the SA, with the intention of optimizing muscular control and encouraging pain free shoulder motion.
Conclusions: This review provides the theoretical background and literature-based evidence that can help explain the SA's complex pathokinesiology, as well as guide the clinician to further develop exercises that likely challenge the muscle. This paper is written along with a companion paper entitled: Kinesiologic considerations for targeting activation of scapulothoracic muscles: part 2: trapezius. Both papers prepare the reader to expand their pallet of exercises that target and challenge these two dominant muscles, with a goal of improving function of the shoulder for several painful conditions caused by their reduced or altered activation pattern.

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Introduction

The serratus anterior (SA) is one of the most important and clinically relevant muscles of the shoulder complex. This review paper will first describe the muscle's anatomy and role in normal shoulder kinesiology. This will be followed by a discussion of how a weakened or otherwise inhibited SA muscle negatively affects the natural fluidity and ease of movement and the posture across the shoulder complex. A firm understanding of this muscle's anatomy, kinesiology, and pathokinesiology provides insight into the development of creative exercises that can specifically target this muscle for strengthening and improved control and function. This paper is part 1 of a two-part companion paper. Part 2 describes the kinesiologic considerations for targeting the different parts of the trapezius muscle.[1]

Anatomic considerations

The SA arises from the lateral aspects of the first nine ribs (Fig. 1).[2] These attachments appear ''serrated,'' hence explaining the origin of the muscle's name. From the ribs, the expansive muscle flows posteriorly, in front of the scapula, ultimately attaching to the anterior surface of the entire medial border of the scapula. These attachments are close to and often interconnect with some medial attachments of the subscapularis. Furthermore, the costal attachments of the SA partially interconnect with the costal attachments of the external oblique abdominis.

The SA is innervated by the long thoracic nerve. This nerve arises from the C5 through C7 nerve roots of the brachial plexus.[2,3] The nerve roots coalesce to a single nerve which descends the upper-most costal fibers of the SA. The nerve travels in a thin fibrous sheath that adheres to the external surface of the SA, innervating muscle fibers as it descends. The relatively long and exposed path of the nerve renders it relatively vulnerable to mechanical-based neuropathy due to trauma or excessive stretch associated with upper limb movement.[4] In addition, neuropathy may be associated with neuritis or from unknown causes.[5,6] The SA may also be weakened or paralyzed from pathology or insult to the cervical nerve roots or the spinal cord.

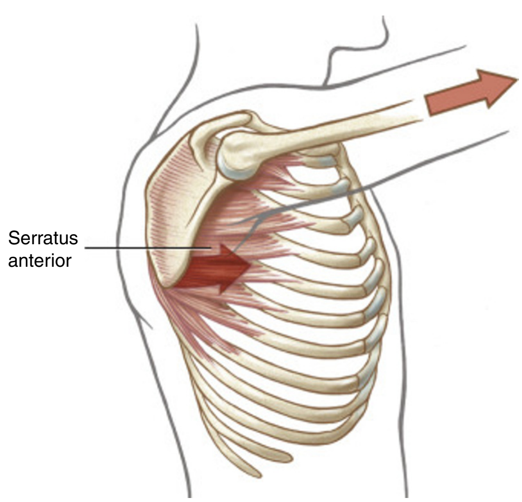

Figure 1 The serratus anterior, showing muscle attachments and overall line of force.

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Functional considerations

The primary actions of the SA are protraction and upward rotation of the scapulothoracic joint. Both actions are essential to optimal movement of the shoulder complex. The strong protraction function is based on the muscle's overall near horizontal line of force (Fig. 1), coupled with its long moment arm (leverage) relative to the sternoclavicular joint.[1] Scapular protraction occurs naturally when increasing the functional forward length of the upper limb, such as when reaching forward or pushing objects away from the body. When combined with activation of the lower trapezius, the SA may be used to extend the functional length of the upper limb in oblique inferior-anterior directions. These actions provide an important force to help transfer one's body to and from a wheelchair or bed surface, or other similar functional activities. Subsequently, the SA and lower trapezius are both important muscles to target when working with persons with mid-level cervical spinal cord injury.

The protraction function of the SA is essential to performing a full prone ''push-up''. While the triceps and pectoralis major are essential for extending the elbow and horizontally adducting the shoulder during the early and middle phases of the maneuver, the late phase is dominated by protraction-forces produced by the SA. Only with strong contraction of this muscle can the chest (and trunk) be lifted maximally from the supporting surface. Such an action becomes clear by mentally rotating the body (Fig. 1) 90° in the clockwise direction, then reversing the direction of the arrow depicting the force direction of the SA. This bilateral ''reverse action'' of the SA at the scapulothoracic joints *lifts the ribs-and-trunk* up to the fixed scapula. This action requires that the scapula is well stabilized by other muscles such as the trapezius, rhomboids, levator scapula, and pectoralis minor. Understanding this ''reverse action'' of the SA is critical to significantly challenging this muscle through targeted exercise.

The SA provides a foundation for active shoulder abduction and flexion. These movements are essential for maximizing the functional potential, reach, and grasp of the upper limb.[7,8] The SA and the trapezius interact as the primary force-couple which *upwardly rotate* the scapula during shoulder abduction and flexion. This force-couple is shown in conjunction with the active middle deltoid during shoulder abduction in Fig. 2. Although the supraspinatus is also a primary abductor of the glenohumeral joint,[9] it was omitted from Fig. 2 for purposes of clarity. The dominant role of the SA in this force-couple is due to the muscle's favorable moment arm (leverage) for upward rotation, combined with the convergence of multiple fibers which attach to the inferior angle of the scapula.[1] Because the SA is a primary muscle for *both* protraction and upward rotation of the scapula, paralysis, weakness, or fatigue of this muscle can dramatically alter the over kinesiology of the shoulder complex.[4] Even though the middle trapezius may have

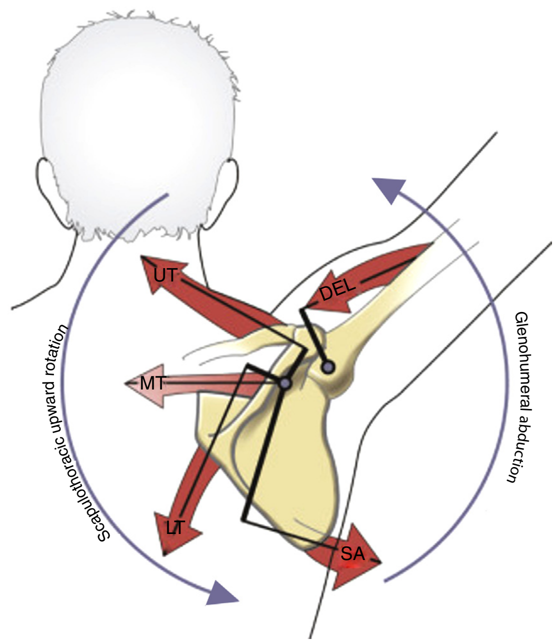

Figure 2 Posterior view of a healthy shoulder during shoulder abduction. The model shows the primary muscle interaction between the scapulothoracic upward rotators and the glenohumeral abductor muscles. The primary force-couple is between the serratus anterior and trapezius. Note two axes of rotation: the scapular axis, located near the acromion, and the glenohumeral joint axis, located at the humeral head. Internal moment arms for all muscles are shown as dark thicker lines. *DEL*, middle deltoid; *LT*, lower trapezius; *MT*, middle trapezius; *SA*, serratus anterior; *UT*, upper trapezius.
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limited leverage relative to the scapula's axis of rotation for upward rotation, the muscle's force is essential to offset the strong protraction force of the SA. Without adequate force from the middle trapezius, active shoulder flexion or abduction in the scapular plane may still be possible; although, due to the unopposed pull of the SA, the upwardly rotating scapula typically drifts far out into protraction.[1,10]

Focused research has attempted to understand the overall muscle and joint interactions at the shoulder associated with activation of the SA.[8,11–14] Much of the impetus behind this research is to better understand the muscle-driven kinematics of the scapula, and specifically how these scapular kinematics influence mechanical stress placed across the glenohumeral joint. In addition to the primary functions of upward rotation and protraction of the scapula, the literature also suggests that the SA also directs the movements of *posterior tilt and external rotation* of the upwardly rotating scapula during elevation of the arm.[7,8,11] Fig. 3 offers a biomechanical model that provides theoretical evidence that the SA and parts of the trapezius are involved in still another force-couple that can control these subtler scapular kinematics to varying degrees, at least relative to the acromioclavicular joint.[1] Clinical interest has been raised on this topic because in vivo data suggest that upward rotation combined with posterior tilt and, to a lesser extent, external rotation of the scapula, may increase or least maintain the volume of the subacromial space.[15–17] Several research or review papers have stressed the importance of strengthening or increasing the control over SA and middle and lower trapezius to reduce the likelihood of a shoulder impingement or other stress and pain related pathology of the glenohumeral joint.[1,17–20] Although much has been learned in the last decade, more research is required to fully understand the muscular control and complex kinematics across the entire shoulder complex.

Classic manual muscle tests for the strength of the serratus anterior

Clinicians frequently find it useful to manually test the strength of the SA. Two general approaches are used for this assessment, based largely upon the work of Florence Kendall with patients with poliomyelitis.[21] In the *shoulder abduction* test, the examiner applies simultaneous resistance against scapular plane abduction of the shoulder at about 120–130° and against upward rotation of the scapula (Fig. 4). A weakened SA typically results in the shoulder prematurely ''breaking'' into adduction, as the scapula fails to produce a significant upward rotation force against the examiner's hand.

A second method of testing the strength of the SA applies manual resistance against *protraction* of the scapula and entire upper extremity (Fig. 5). This test can be performed with patient supine or sitting, with the shoulder flexed to about 90–100° with elbow held in full extension. In cases of a weakened SA, the scapula is unnaturally ''pushed'' (by the examiner) into a position of *retraction and internal rotation*, causing the medial border of the scapula to flare away from the rig cage. The resulting distorted position of the scapula is often referred to generically as scapular ''winging.'' Winging is a form of scapular ''dyskinesis'' which may also include varying amounts of downward rotation and excessive anterior tilt. The severity of the ''winging'' tends to be proportional to the degree of SA weakness. This abnormal winging posture is described and illustrated more in the next two sections.

Pathomechanics of a ''winging'' scapula

During abduction or flexion of the shoulder, the SA must provide a large upward rotation torque to the scapula. Although this torque occurs across both sternoclavicular and acromioclavicular joints, it may be visualized as occurring about a near anterior-posterior instantaneous axis of rotation through the scapula itself (Fig. 2). This torque, generated by the force-couple formed by the SA and upper and lower trapezius must *exceed* the downward rotation torque produced by the contracting middle deltoid and supraspinatus.[22] With SA weakness, the unopposed strong pull of the glenohumeral abductors can cause the scapular to paradoxically *downwardly* rotate during active attempts at shoulder abduction (Fig. 6). In addition to the obvious downwardly rotated position, the scapula is also slightly *anteriorly tilted* and *internally rotated* (evident by the ''flaring'' of the scapula's inferior angle and medial border,

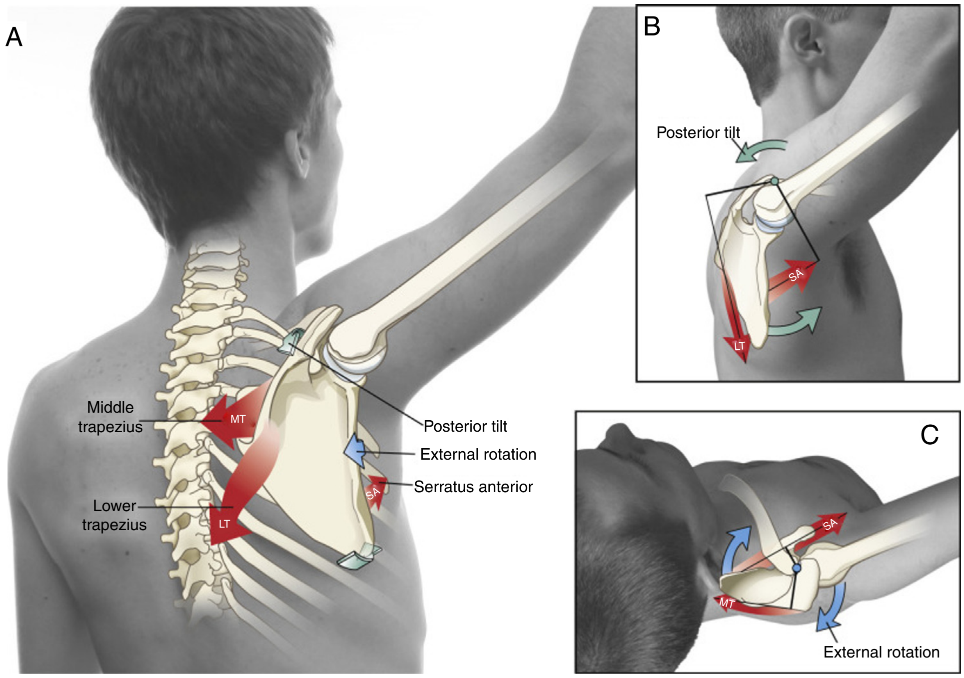

Figure 3 (A) Theoretical mechanism of how the serratus anterior (SA) and middle trapezius (MT) and lower trapezius (LT) muscles can control the posterior tilt and external rotation of the upwardly rotating scapula during scapular plane abduction. (B) The SA and LT act in a force-couple to *posteriorly tilt* the scapula relative to the axis of rotation at the acromioclavicular joint (indicated by the green circle). (C) The SA and MT act in a force-couple to *externally rotate* the scapula relative to the axis of rotation at the acromioclavicular joint (indicated by the blue circle). Each muscle's moment arm is indicated as a dark black line, originating at the axis of rotation of the acromioclavicular joint.
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Figure 4 Muscle test for the serratus anterior (shoulder abduction test). The examiner simultaneously resists maximal-effort scapular plane abduction and upward rotation of the scapula.

Figure 5 Muscle test for the serratus anterior (scapular protraction test). The examiner resists maximal-effort protraction of the scapula and the entire upper extremity.

respectively). Such a distorted ''winging'' posture shows *all* the actions that a fully functioning SA naturally limits.

A position of winging, if maintained, would likely cause adaptive shortening of the pectoralis minor muscle. This muscle would further promote an anteriorly tilted and internally rotated position of the scapula.[23] In addition to a combined tight pectoralis minor and weakened SA, the abnormal posture or kinematics of the scapulothoracic joint may be associated with altered alignment of the cervical and thoracic spine; slumped sitting posture; perpetuation of neck pain, or increased activation of the upper trapezius muscle.[17,24] An abnormal position of the scapula can alter the natural line of pull of the rotator cuff muscles, potentially limiting their ability to control the arthrokinematics and dynamic stability normally associated with GH joint abduction.[1] Furthermore, and as stated, abnormal scapular

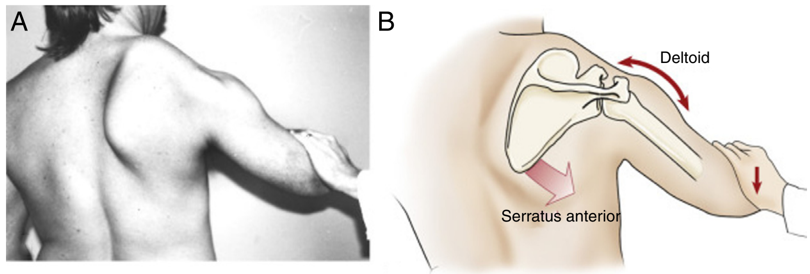

Figure 6 The pathomechanics of the winging right scapula after paralysis of the right serratus anterior caused by an injury of the long thoracic nerve. (A) The scapula is its downwardly rotated position, anteriorly tilted, and internally rotated. (B) Kinesiologic analysis of the extreme downward rotated position. Without an adequate upward rotation force from the serratus anterior *(fading arrow)*, the scapula is not properly stabilized and cannot resist the pull of the deltoid. Subsequently the force of the deltoid *(bidirectional arrow)* causes the combined actions of downward rotation of the scapula and partial elevation (abduction) of the humerus.
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kinematics can, in some persons, potentially cause compression or shearing of the supraspinatus or other tissues in the subacromial space.[11,17] Although the diagnosis label of subacromial impingement is often used clinically, it is likely this pathology is multifactorial and not the only source of the patients perceived pain.[18] Nevertheless, it is a generally accepted premise that being able to optimally control the position and kinematics of the scapula during shoulder abduction is an important step to reduce potential stress at the glenohumeral joint.

Clinical measurement of scapular dyskinesis

Scapular dyskinesis may be defined as an abnormal position or movement of the scapula, without regard to the factors that cause the abnormality. Depending on severity, scapular dyskinesis can reduce the ease and efficiency of shoulder movement, and may contribute to shoulder impingement, generalized anterior shoulder pain, or rotator cuff pathology.[17] The manner to which scapular dyskinesis affects shoulder kinematics can be hard to visualize and is typically studied using sophisticated equipment.[25] The following section however shows a relatively simple method of measuring a main component of the abnormal kinematics of scapular dyskinesis with the aid of a standard goniometer.[1] Consider an analysis of *normal* scapulohumeral rhythm as a healthy, pain-free male actively performs scapular plane abduction (Fig. 7A). The picture shows the subject holding a position of 70° of shoulder abduction, measured by a goniometer between a vertical reference line and the shaft of the humerus. The position depicted in Fig. 7A represents only one of 17 static measurements made of *shoulder abduction*, between 10° and 170° (see column of table and horizontal axis in the graph). At each 10-degree increment of shoulder abduction, the *scapulothoracic position* of upward rotation was determined as the angle made between a vertical reference line and the medial border of the scapula (see column of data and associated green data points in graph). These relatively simple measurements allow the clinician to visualize the amount of glenohumeral joint abduction as the *difference between the position of shoulder abduction and the scapulothoracic rotation* (see blue data points in graph). Because the scapula is upwardly rotated 20° at 70° of shoulder abduction, the assumed angle of glenohumeral joint abduction is about 50°. Note that at 170° of shoulder abduction, the scapula is upwardly rotated 54° and the glenohumeral joint is assumed to be in 116° of abduction: a kinematic pattern generally expected based on a normal scapulohumeral rhythm.

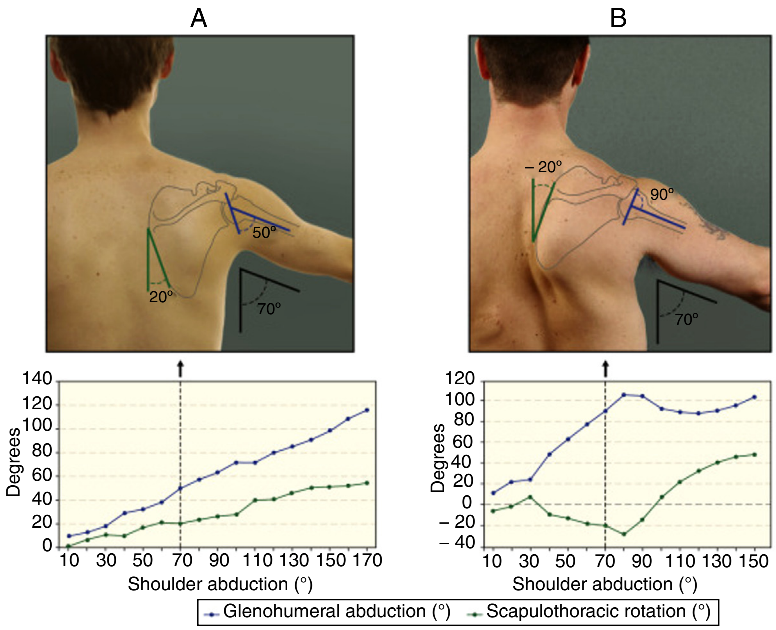
Fig. 7B shows the results of a similar analysis using a person with scapular dyskinesis, which was associated with weakness of the right SA and complaints of anterior shoulder pain with active abduction. The important aspect of the dyskinesis is that the scapula *downwardly* rotates (indicated by negative rotation values) through the first half of shoulder abduction. Because the scapula is downwardly rotated 20° at 70° of shoulder abduction, the angle of glenohumeral joint abduction is assumed to be 90° (i.e., 70° minus −20°). In this situation, *the glenohumeral joint is in greater abduction than the shoulder!* Interestingly and for unknown reasons, the subject's scapula eventually upwardly rotated at shoulder abduction angles greater than 80°. The subject was unable to actively abduct his shoulder beyond 150°.

The excessive downward rotation of the scapula during the first half of shoulder abduction can create stress at the glenohumeral joint, for example, compression of the contents within the subacromial space. Furthermore, the excessive glenohumeral joint abduction caused by the excessive downward rotation of the scapula could unnaturally change the line of force of the rotator cuff muscles, thereby altering their ability to guide the natural arthrokinematics. Also, the excessively downward rotated scapula may alter the length−tension relationship of the scapulohumeral muscles, possibly biasing weakness or fatigue. By being able to visualize the altered pathokinesiology associated with this one example of dyskinesis may help with the diagnosis of the movement impairment and help choose the most effective therapeutic intervention.

Exercises that selectively target activation of the serratus anterior

Several lines of electromyographic research have been published to help determine which exercises create the

Shoulder Abduction (°)	- Scapulothoracic rotation (°)	= Glenohumeral abduction (°)
10	0	10
20	7	13
30	11	19
40	10	30
50	17	33
60	21	39
→ 70	20	50
80	23	57
90	27	63
100	29	71
110	39	71
120	40	80
130	46	84
140	50	90
150	51	99
160	52	108
170	54	116



Shoulder Abduction (°)	- Scapulothoracic rotation (°)	= Glenohumeral abduction (°)
10	-6	16
20	-1	21
30	8	22
40	-9	49
50	-12	62
60	-18	78
→ 70	-20	90
80	-27	107
90	-15	105
100	8	92
110	21	89
120	32	88
130	40	90
140	46	94
150	48	102

Figure 7 Goniometric measurements used to estimate glenohumeral joint abduction (blue) as the difference between shoulder abduction (black; plotted on the horizontal axis of the graphs) and the scapulothoracic rotation position (green). A healthy male (A) and a male with scapular dyskinesis (B) are each shown holding their shoulder abducted to 70 degrees. Upward rotation of the scapula is indicated by positive angles; downward rotation by negative angles.
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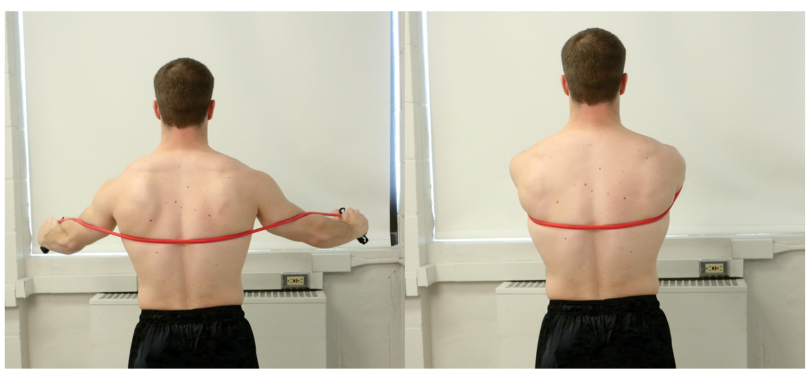

Figure 8 Dynamic hug exercise. Using elastic material as resistance, the subject performs bilateral, maximum scapular protraction.

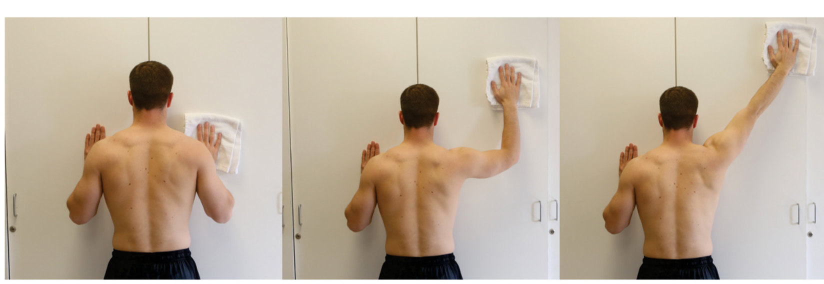

Figure 9 Towel-wall slide. The standing subject slides the towel against a wall, starting in a neutral shoulder position, and ending in combined position of maximal scapular plane abduction and scapular protraction.

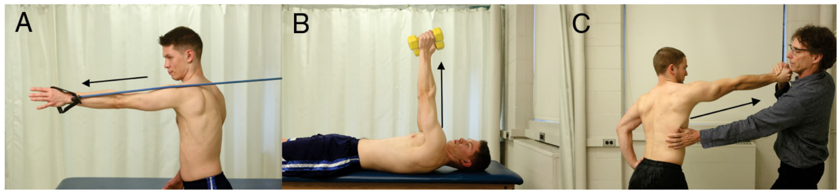

Figure 10 Serratus punches: Exercise performed standing (A) or supine (B) against elastic or weight of dumbbell, or against manual resistance (C) by the examiner.

Figure 11 Push-up plus performed on hands and toes: scapulothoracic protraction (thorax moving on fixed scapulae). Initial position (A) and final position (B). Performed on an unstable surface (C).

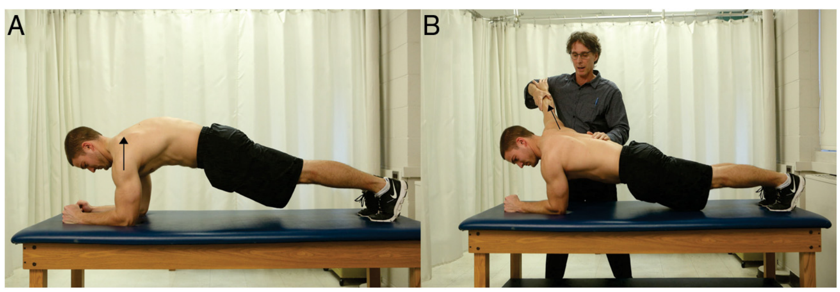

Figure 12 Push-up plus on elbows and toes: (A) bilateral, scapulothoracic protraction (thorax moving on fixed scapulae). (B) Left side shows subject holding relative scapulothoracic protraction; right side shows examiner resisting scapulothoracic protraction (arm and scapula protracting relative to fixed thorax).

greatest (or perhaps the least) activation of muscles in persons with scapular dyskinesis and associated pain or dysfunction.[17,19,20,26–31] Data from these studies help clinicians choose or design exercises that selectively challenge the preferred muscles during an ''ideal'' shoulder scapular plane abduction motion. Ideally, this movement is performed with a near 2:1 scapulohumeral rhythm, incorporating scapular upward rotation with varying amounts of relative external rotation and posterior tilt.[1] Due to the important role of the SA in performing these ideal kinematics, the clinician should know which exercises can selectively challenge this muscle. Furthermore, clinicians may also want to promote optimal muscular *balance* between the SA and other muscles during shoulder abduction. For example, certain exercises have been shown to place large demands on the SA and middle and lower trapezius, while minimizing the demands on the upper trapezius or pectoralis minor. The relative activation of the different parts of trapezius for optimum muscular balance of the scapula is further described in another paper Camargo and Neumann.[1] Figs. 8–12 show common exercises that demonstrate significant activation of the SA, many verified through electromyographic data.

Closing comments

Reduced strength, control, or activation of the SA has been implicated in pathological conditions involving the shoulder complex. These conditions include painful impingement of anatomic tissues, faulty glenohumeral kinematics, and scapular dyskinesis. An understanding of this muscle's anatomy, kinesiology, and pathokinesiology is essential for the clinician to design exercises that specifically target and thereby challenge this muscle in rehabilitation settings.

Several exercises have been identified that selectively target the activation of the SA. This paper describes and illustrates these exercises, as well as provides the literature-based research that justifies their selection. This material is designed to encourage the clinician to prescribe these exercises within their practice and to consider designing other similar-based exercises that likely challenge the SA.

It is suggested that the reader consult the second part of this two-part series entitled: Kinesiologic considerations for targeting activation of scapulothoracic muscles – Part 2: trapezius.[1] This paper describes the kinesiologic and pathokinesiologic relevance of the trapezius during shoulder movements and exercises.

Conflicts of interest

The authors declare no conflicts of interest.

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