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SHOULDER

The role of the scapula in preventing and treating shoulder instability

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Abstract The shoulder is a closed-chain mechanism that balances the mobility required by the ranges of motion in normal activities with the stability required to act as a stable ball and socket base for those activities. The scapula plays key roles in the closed-chain mechanism by being mobile enough to place the glenoid in optimal relation to the humerus to facilitate concavity/compression and by being a stable base for coordinated muscle activation to compress the humerus into the glenoid. Scapular dyskinesis alters these roles and is frequently present in many types of glenohumeral instability. It may create or exacerbate the abnormal glenohumeral kinematics in instability. Clinical evaluation methods can demonstrate scapular dyskinesis, and if dyskinesis is present, rehabilitation for the dyskinesis should be included in the non-operative, preoperative, or post-operative treatment. Rehabilitation for scapular dyskinesis can be performed by specific protocols and is more successful in muscle-predominant instabilities such as multidirectional instability and repetitive microtrauma instability.

Level of evidence V.

Keywords Scapula · Scapular dyskinesis · Scapula evaluation · Shoulder injury prevention

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Introduction: scapular roles in stability and instability

From a biomechanical perspective, the glenohumeral (GH) joint is a closed-chain mechanism comprised of bones, ligaments, and muscles that balances stability against excessive translations with mobility necessary to achieve positions and motions of the arm and hand to accomplish specific tasks [53]. For almost all normal shoulder/arm functions, GH kinematics that results from this balance resembles a ball and socket arrangement. The scapula, as the "G" of GH, is a key element in the closed-chain mechanism. The scapula plays multiple roles in creating and maintaining the ball and socket kinematics. This paper will describe the scapular roles in shoulder function and their association with shoulder dysfunction, will describe the causative factors and clinical evaluation for scapular dyskinesis, and will outline rehabilitation guidelines. These descriptions are applicable for clinical situations in which there is no glenoid bone loss compromising the capability of restoring scapular roles. Glenoid bone loss is a separate subject relating more to GH joint anatomy than to scapular kinematics in association with instability. The GH bone loss must be restored before scapular evaluation and treatment can be instituted.

The first scapular role is the glenoid must be dynamically positioned in three-dimensional space to maintain the "glenohumeral angle"—the orientation of the glenoid cavity and the long axis of the humerus from humeral head to elbow—in a "safe zone" that minimizes glenohumeral shear [54], maximizes concavity/compression [28, 31], and minimizes muscular activation [11]. This angle has been estimated clinically by Jobe to be ±30°. This clinical observation has been verified by a biomechanical study

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that showed that muscle activation was most efficient in maintaining joint stability when the glenohumeral angle measured ±29.3° [11]. If the angle is maintained within these parameters, the resultant force vectors are directed within the glenoid cavity, shear forces are minimized, tension on the ligaments is minimized, and the muscle activation requirements are minimized, creating the most efficient joint conditions for stability. In this position, all of the intrinsic shoulder muscles of the rotator cuff can pull in relatively straight lines to maximize concavity/compression into the joint. Achievement of this scapular position requires that the scapula be positioned in anticipation of arm and shoulder movements.

The dynamic stabilization is important due to the lack of adequate static stabilization from the bony and ligamentous anatomy. The curvature of the humeral head is larger than the curvature of the glenoid, minimizing joint stability, and the ligaments are only taut at the end ranges of motion. This dynamic positioning to stabilize the GH joint in all positions and motions is part of an integrated coordination of multiple segments throughout the entire kinetic chain in an anticipated response to the required demands and loads of a specific task. The muscular activation sequences that allow this anticipatory bony positioning are task-specific patterns [11, 36] that integrate multiple muscles to move multiple joints [37, 44, 58].

Typical muscle activation patterns involve stabilization of the contralateral hip and trunk extension as a base for scapular activity [57], anterior and posterior core stabilization for force development at the shoulder [22], sequential activation of contralateral, then ipsilateral abdominals before rotator cuff activation [12], and activation of scapular stabilizers before rotator cuff activation [18].

The functional and observable result of the muscle activations producing dynamic positioning is scapulohumeral rhythm (SHR), the coupled synchronous movement of the arm and scapula. SHR has been likened to a "ball on a sea-lion's nose" (Carter Rowe Personal Communication), describing the dynamic nature of the nose (the glenoid) actively moving in anticipation and response to movement of the ball (humerus) to keep the ball centred on the nose.

Second, the scapula is the point of origin for all of the intrinsic and extrinsic muscles that dynamically stabilize the GH joint in almost all ranges of motion. Muscles are responsible for GH stability through about 90 % of the motions in all planes [53]. The rotator cuff acts as a compressor cuff through force couples, helping to centre the humerus on the glenoid and decreasing translations [28]. A stable base is a requirement for maximal activation of all the rotator cuff and deltoid muscles [15, 23, 43, 45]. Demonstrated muscle strength can be improved by as much as 24 % off a stabilized scapula [23, 45]. Maximal rotator cuff activation increases the compression of the humerus into the joint.

Third, optimal scapular position and motion are required to limit loads on the ligaments and other passive constraints in the joint. Increased scapular protraction creates excessive tensile loads on the anterior inferior GH ligament [55], increasing the risk of GH instability. Also, increased glenoid antetilting in protraction increases compression and shear loads on the posterior superior glenoid labrum, creating injury and decreasing the effectiveness of the labrum as a washer and a gasket to maximize GH stability [4, 53].

In summary, the scapula's roles in GH stability are directed towards developing the maximal dynamic efficiency to maintain the rather minimal static ball and socket kinematics in the face of the large loads, forces, and strains imposed by athletic and industrial demands on the shoulder. Alteration of the scapular roles may decrease this efficiency, leading to increased loads and increased dysfunction, and may make treatment more difficult.

Alterations of the scapula associated with glenohumeral instability

Alterations of static scapular position or dynamic scapular motion, collectively termed scapular dyskinesis, are frequent in patients with demonstrated GH instability occurring in between 67 and 80 % of patients [5, 39, 54]. Scapular dyskinesis appears to alter normal shoulder biomechanics and joint stability by altering normal scapular kinematics.

Dyskinesis results in scapular positions of increased anterior tilt, increased internal rotation, decreased upward rotation, and increased protraction. These positions have the effect of increasing the glenohumeral angle beyond the "safe zone", of increasing anterior shear, and of increasing tensile loads on the anterior band of the inferior glenohumeral ligament [25, 55]. Excessive scapular protraction also decreases maximum rotator cuff activation, decreasing the "compressor cuff" muscle function that establishes dynamic stability.

Dyskinesis is not a specific injury, nor is it associated directly with a specific instability. It is an alteration of resting scapular position and/or dynamic scapular motion and is considered to be an impairment of optimal or efficient SHR [20]. In this situation, dyskinesis can create or exacerbate the symptoms and dysfunction of the instability and if present, should be addressed as part of the treatment.

Dyskinesis has multiple causative factors. In patients with instability, the most common factors include inhibition of coordinated muscle activation, from joint pain or joint internal derangement (labral, biceps, etc.), muscle fatigue, muscle inflexibility, altered joint mechanics due to deficits in glenohumeral rotation (GIRD), and learned compensation patterns from chronic instability [20]. These factors combine with the bony or ligamentous anatomic lesions to create or exacerbate the clinical symptoms and need to be addressed during treatment.

The type of instability may play a major factor in the causation of the dyskinesis, the relative importance of the dyskinesis to overall dysfunction, and the effectiveness of treatment for dyskinesis. Traumatic anterior or posterior instability with resulting Bankart lesions, reverse Bankart lesions and labral injuries, results in dyskinesis due to pain, muscle alteration(s), or altered joint mechanics. Dyskinesis is frequently associated with symptoms in these patients, but dyskinesis can rarely be completely resolved in the presence of the anatomic lesion, and a scapular-based rehabilitation programme is infrequently successful in resolving the dysfunction, but is more commonly used to minimize recurrence during a competitive season until definitive treatment is performed [8]. However, once the anatomic lesion is stabilized, scapular rehabilitation should be one of the primary areas of focus during the early phases of postoperative treatment [16].

The altered muscle function may result from actual muscle weakness, atrophy from disuse, inhibition of individual muscle activation or coordinated patterns of activation, or from fatigue [9, 49–51]. Symptoms in many other types of instability are more related to alterations of muscle function, which then create dyskinesis, and treatment of dyskinesis has been shown to have a more central effect on symptom resolution and functional restoration [7, 16, 56].

In patients with instability due to repetitive microtrauma or superior labral injury, both frequently due to a process over time, weakness and inhibition of the lower trapezius and serratus anterior, coupled with inflexibility of the pectoralis minor, appear to be the main causative factors for the dyskinesis [5, 30]. Dyskinesis is present in almost all of these patients most commonly due to serratus anterior and lower trapezius muscles weakness. Several reports have suggested that a scapular-based rehabilitation programme, focused on kinetic chain restoration, scapular stabilization in retraction, and normalization of glenohumeral rotation, can reduce symptoms and improve function so that a significant percentage of patients could return to activity [6, 8, 10, 27].

In patients with instability symptoms related to multidirectional instability, dyskinesis and altered muscle activations play a large role. Studies have demonstrated that inhibition and weakness of subscapularis, supraspinatus, serratus anterior, and lower trapezius, coupled with increased activation of pectoralis minor and latissimus dorsi, place the scapula in a protracted, downward rotated position with decreased humeral head compression [3, 13, 14, 30, 38]. Latissimus dorsi activation then becomes the destabilizing force, pulling the humeral head inferiorly over the downwardly facing glenoid. Rehabilitation programmes focusing on scapular retraction, increased serratus anterior and lower trapezius strength, and flexibility of the pectoralis minor and latissimus dorsi are advocated for restoring function.

In summary, scapular dyskinesis is commonly associated with all types of GH instability. The dyskinetic positions and motions create and exacerbate altered GH kinematics and muscle activations by decreasing the "sea lion's" ability to maintain "the ball" on its nose. This increases the dysfunction of the instability and can decrease the effectiveness of non-operative or post-operative rehabilitation protocols. Because dyskinesis is so prevalent in patients with instability, evaluation for the presence or absence of scapular dyskinesis should be included as part of a comprehensive examination of the unstable shoulder.

Scapular evaluation in glenohumeral instability

Patients with scapular dyskinesis associated with microtraumatic instability have a high frequency of alterations in other parts of the kinetic chain, so a comprehensive evaluation is indicated. Patients with traumatic instability will rarely have associated kinetic chain alterations but will frequently have scapular dyskinesis. The scapular examination in these individuals can be more focused on the scapula itself. The evaluation for scapular dyskinesis should be the same for both groups. Direct evaluation of scapular position and motion should be proceeded in the proper patients by a screening kinetic chain examination, to discover proximal deficits in flexibility and strength that can affect scapular muscle activation and scapular position [41]. This would include one-leg stability evaluation for hip muscle weakness, hip range of motion, hamstring flexibility, and core strength [22].

Clinical evaluation of scapular position and motion is often difficult due to the overlying musculature and the lack of objective reproducible tests to measure the scapula. The examination may be made more reproducible by examining in a specific sequence involving position, motion, strength, and dynamic motion and stabilization-related corrective manoeuvres.

Static scapular position may be evaluated by observing the resting posture of both scapulae. Marking the superior and inferior medial borders with a marker is a good help. Scapular dyskinesis patterns can often be demonstrated by observing the resting position of the scapula. The altered position at rest has been termed the Scapula malposition/Inferior medial border prominence/Coracoid pain/scapular dysKinesis (SICK) scapula [5] and is characterized by apparent inferior drooping, which is actually due to anterior scapular tilting.

Palpation of tender areas in the upper and lower trapezius and palpation of tender areas in the pectoralis minor can identify areas of pain that cause muscle inflexibility and inhibition of muscle activation that may need to be treated as part of the clinical problem.

Since precise clinical identification of scapular motion is frequently difficult, multiple methods have been described to accurately identify markers for evaluation. Static measurements of scapular position are imprecise [42], and plain radiographs, Moire topographic analysis [54], biplanar fluoroscopic evaluation, and 3-dimensional motion analysis [52] are not easily performed in the clinical setting. An observational definition for dyskinesis was determined from a consensus meeting of scapular research experts. The definition of dyskinesis is the alteration of normal scapular kinematics [21]. "Dys" (alteration of) "kinesis" (motion) is a general term that reflects the loss of normal control of scapular motion [20]. Clinical research using this definition showed that dynamic examination of scapular motion could be the best method to identify dyskinesis and that this examination can be reliably performed by clinical observation of the motion as the arm elevates and descends [32, 35, 46]. This motion requires activation of the muscles to maintain the closed-chain mechanism and scapulohumeral rhythm. Failure to maintain this control results in medial border prominence, in either static position, upward/downward motion, or altered dyssynchronous motion and is considered to be the hallmark clinical identifier of dyskinesis [25, 29]. This clinical observation of medial border prominence in symptomatic patients has been correlated with biomechanically determined dyskinesis [52], and this method is clinically reliable enough (sensitivity and positive predictive value between 0.64 and 0.84) to be used as the basis for the determination of the presence or absence of dyskinesis. The examination is conducted by having the patients raise the arms in forward flexion to maximum elevation, and then lower them 3–5 times, with a 3–5 pound weight in each hand [32, 46]. Medial border prominence on the symptomatic side due to alteration of position, motion, or dyssynchronous motion is recorded as "yes" (prominence detected) or "no" (prominence not detected).

Scapular stabilizer strength may be clinically estimated by several methods. Scapular pinch estimates scapular retraction ability. The scapulae should be retracted and held in an isometric manner for 10 s. Weak muscles will exhibit spasm within that time span. Wall push-ups estimate serratus anterior strength, especially if done in a "plus" (hyperprotraction) position. Dyskinesis will be exhibited as the muscles fatigue [9, 49–51].

The scapular assistance test (SAT) and scapular retraction test (SRT) are stabilization-related corrective manoeuvres that can alter the injury symptoms and provide information about the role of scapular dyskinesis in the total picture of dysfunction that accompanies shoulder instability and needs to be restored [17, 23]. The corrective manoeuvres may be more relevant in microtraumatic instability, in that they give information to help comprehensive rehabilitation that may be more effective in these cases. However, they are also helpful in the traumatic instabilities to help guide the post-operative rehabilitation to restore maximum function, and in patients for whom non-operative treatment may be favoured. The SAT helps evaluate scapular contributions to impingement and elevation strength, and the SRT evaluates contributions to elevation and rotator cuff strength and labral symptoms. In the SAT, the examiner applies gentle pressure to assist scapular upward rotation and posterior tilt as the patient elevates the arm (Fig. 1) [17]. A positive result occurs when the painful arc of impingement symptoms is relieved and the arc of motion is increased. In the SRT, the examiner grades the elevation muscle strength following standard manual muscle testing procedures or evaluates labral injury with the dynamic labral shear (DLS) test [23]. The clinician then places and stabilizes the scapula in a retracted position (Fig. 2). A positive test occurs when the demonstrated elevation strength is increased or the symptoms of internal impingement in the labral injury are relieved in the retracted position. Although these tests are not capable of

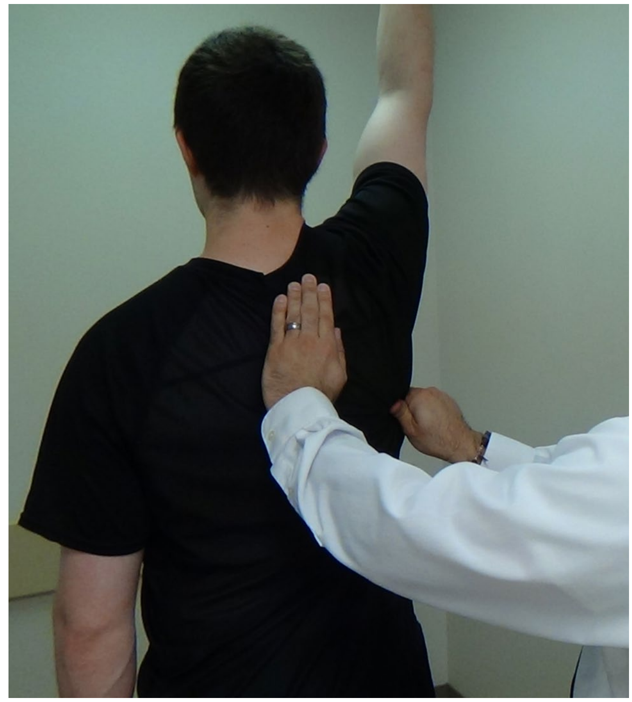

Fig. 1 Increased arm elevation during application of the scapular assistance test demonstrates the dysfunctional scapula to the patient and examiner

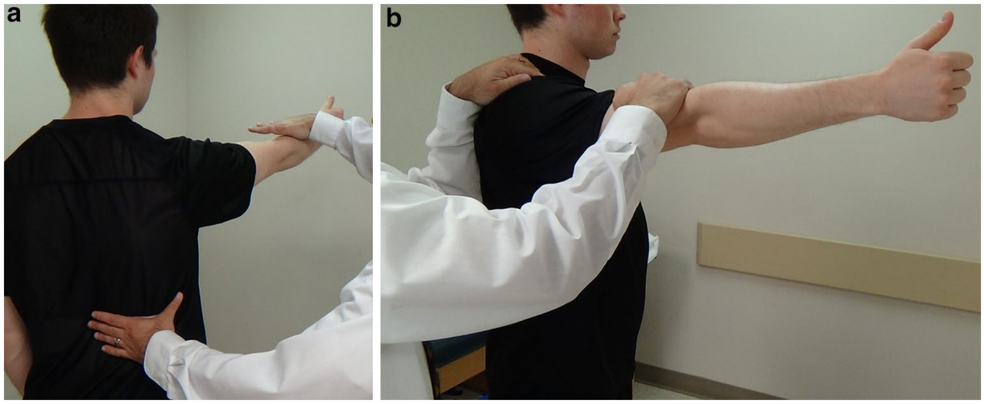

Fig. 2 The first component of the scapular retraction test is to manual-muscle-test the arm in elevation (**a**) followed by re-testing with the application of manual stabilization of the scapula (**b**)

diagnosing a specific form of shoulder pathology, a positive SAT or SRT shows that scapular dyskinesis is directly involved in producing the symptoms and indicates the need for inclusion of early scapular rehabilitation exercises to improve scapular control.

Rehabilitation of the scapula in glenohumeral instability

The success of a scapular-based rehabilitation programme in instability will be mainly determined on restoring SHR and compensating for the soft tissue anatomic injury. In general, instability derived from atraumatic origins can be more effectively managed with rehabilitation compared to traumatically caused instability [6, 26, 47]. Burkhead and Rockwood reported that only 16 % of patients with traumatic dislocations had good to excellent outcomes which was in stark contrast to the 80 % of good to excellent outcomes which occurred in the atraumatic group [6]. Although there is a lack of strong evidence supporting the use of rehabilitation as a viable treatment option following traumatic shoulder dislocations, a recent value analysis comparing the value of operative and non-operative treatment for primary traumatic anterior dislocations identified scenarios where one method of treatment would be advocated over the other [1]. Non-operative treatment may be favoured for the following groups: (1) in-season athletes who are willing to risk further episodes of instability in order to continue playing; (2) patients who have extraneous concerns about the risks associated with surgery; and (3) patient populations known to have lower recurrence rates such as those over the age of 50 years of age [1].

Scapular rehabilitation may be used in preoperative, non-operative, and post-operative contexts [33, 40]. Preoperative scapular rehabilitation is directed towards re-establishing kinetic chain activation patterns to maximize scapular stabilizer activation and controlling scapular retraction capability and is addressed towards flexibility and strength deficits discovered on the kinetic chain examination. Post-operative scapular rehabilitation may be started very early in the post-operative period. Kinetic chain exercises for trunk and hip strengthening and scapular retraction exercises may be started, while the arm is still in the sling or other post-operative protection. These exercises establish a stable base for more advanced and shoulder-specific exercises. As healing proceeds and as the arm may be moved into abduction and rotation, closed-chain axial load exercises strengthen scapular stabilizers while minimizing loads on the repair site [19]. When rotator cuff exercises are indicated in the progressions, integrated scapular stability/humeral head depression exercises re-establish the compressor cuff activation function off a stabilized scapular.

The results of scapular rehabilitation as part of a non-operative treatment of GH instability are primarily related to the underlying pathology. Patients with post-traumatic instability frequently have ligament and/or bone injury that will not allow ball and socket kinematics. Patients with instability due to microtrauma or labral injuries can regain function by re-establishing the coupled SHR to maximize concavity/compression and ball and socket kinematics. Since MDI is a very muscle-dependent problem, effective scapular control and resulting muscle activation through rehabilitation are frequently successful in resolving symptoms.

Specific scapular rehabilitation exercises

Rehabilitation exercises for scapular control can be broken down into three groups—proximal kinetic chain exercises

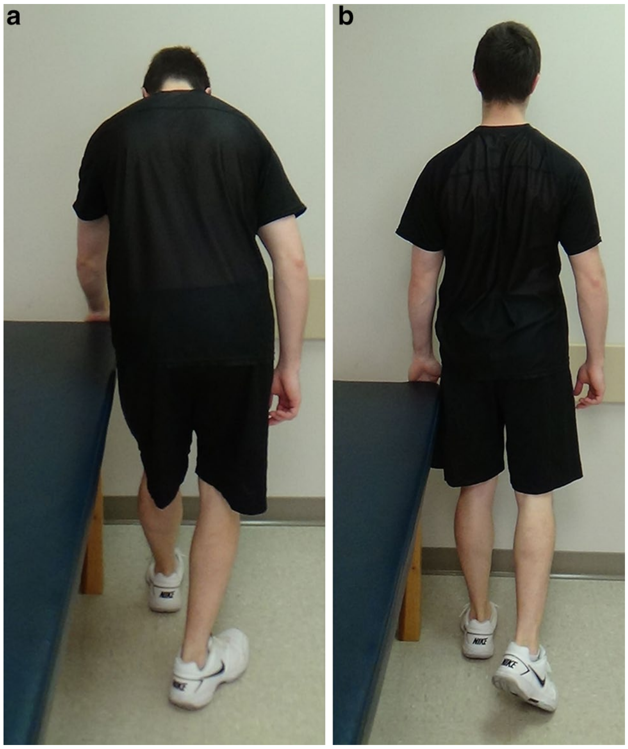

Fig. 3 Starting position for the low row (**a**). The patient should be instructed to extend the hips and trunk to facilitate scapular retraction (**b**)

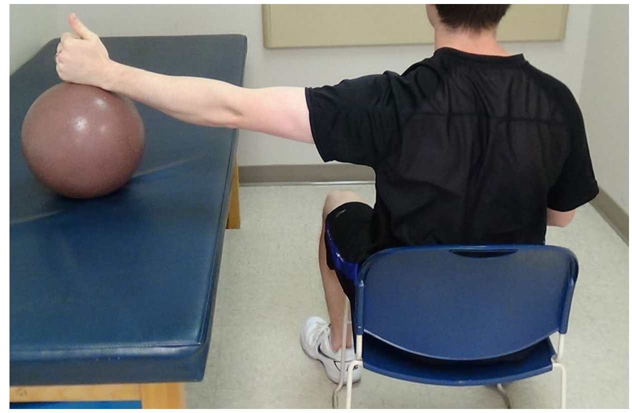

Fig. 4 Inferior glide, also used to strengthen the lower trapezius and serratus anterior, is performed by isometrically pushing arm down into adduction

Fig. 5 Lawnmower exercise begins with the trunk and hips/arm flexed (**a**). The manoeuvre utilizes trunk rotation to help facilitate scapular retraction (**b**)

to facilitate scapular muscle strength, flexibility exercises to minimize traction on scapular posture, and exercises specific for peri-scapular activation.

Kinetic chain exercises for trunk and hip start from and end at the "ideal position" of hip extension/trunk extension. They include trunk/hip flexion/extension, rotation, and diagonal motions. Progressions include step up/down and increased weights.

Specific areas to be addressed for flexibility include the anterior coracoid (pectoralis minor and biceps short head) and shoulder rotation. Tightness in these areas increases scapular protraction. Exercises include the open book and corner stretch for coracoid muscles and cross-body stretch for shoulder rotation.

Peri-scapular strengthening should emphasize achieving a position of scapular retraction, as this is the most effective position to maximize scapular roles. Scapular retraction exercises may be done in a standing position to simulate normal activation sequences and allow kinetic chain sequencing. Scapular pinch and trunk extension/scapular retraction exercises may be started early in rehabilitation to start the integrated activation.

Several specific exercises have been shown to be very effective to activate the key scapular stabilizers—the lower trapezius and serratus anterior [24]. They are the low row (Fig. 3) and inferior glide (Fig. 4), both isometric exercises, and the lawnmower (Fig. 5).

Closed-chain exercises should also be emphasized, to restore the normal activations of the closed-chain mechanism. These exercises are characterized by supporting the hand on a stable or movable surface and loading the arm and scapula from distal to proximal [19]. Examples include rhythmic stabilization and wall washes.

Once scapular control is achieved, traditional rotator cuff exercises such as open chain elevation, scaption, external rotation, and horizontal abduction that stimulate rotator cuff activation off a stabilized scapula are added [2, 34, 48]. They may be done in various planes of abduction and flexion, with different amounts or types of resistance, and may be modified to be sport specific.

Conclusions

The scapula plays several key roles in helping to establish dynamic GH stability throughout the ranges of motions, variable loads, and variable tasks the shoulder experiences. Scapular dyskinesis, or alteration of the normal scapular static position or components of dynamic scapular motion, is commonly detected in patients with microtraumatic or traumatic GH instability. A heightened awareness of the possibility of scapular dyskinesis, a comprehensive clinical evaluation for the presence or absence of dyskinesis based on published guidelines, and inclusion of scapula stabilization in the functional shoulder rehabilitation will help the clinician to optimize functional outcomes. In general, although dyskinesis can be associated with microtraumatic and traumatic instability, non-operative scapular-based rehabilitation has been found to be more effective in improving function without surgery in the microtraumatic group. For most traumatic instability patients, scapular-based rehabilitation will be beneficial in maximizing post-operative outcomes.

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