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Exhibit Selection

Scapular Winging: Evaluation and Treatment

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Abstract: Scapular winging is a rare, underreported, and debilitating disorder that produces abnormal scapulothoracic kinematics, which can lead to shoulder weakness, decreased range of motion, and substantial pain. Although there are numerous underlying etiologies, injuries to the long thoracic nerve or spinal accessory nerve are the most common, with resultant neuromuscular imbalance in the scapulothoracic stabilizing muscles. Early diagnosis followed by initiation of a treatment algorithm is important for successful outcomes. Most cases resolve with nonsurgical management. However, in patients with persistent symptoms despite nonsurgical management, appropriate dynamic muscle transfers can effectively treat the scapular winging, with good clinical outcomes.

Scapular winging is a rare disorder that was originally reported in the published literature by Winslow in 1723[1]. Since its initial description, its pathology has been associated with numerous underlying conditions, with serratus anterior and trapezius palsies being the most commonly encountered etiologies in the clinical setting. This rare disorder may cause pain, compromised shoulder strength, limited range of motion, and cosmetic deformity stemming from abnormal scapulothoracic posture and motion.

Epidemiology

The reported prevalence of scapular winging is exceptionally limited. Johnson and Kendall published the earliest article on the topic that we are aware of, discussing 111 cases, including twenty cases of their own[2]. In 1978, Fardin et al. presented fifteen cases of isolated serratus anterior palsy with clinical and electromyographic follow-up in more than 7000 patients examined[3]. Most notably, a 1940 study by Overpeck and Ghormley at the Mayo Clinic presented only one clinical case of serratus anterior paralysis in 38,500 patients[4].

However, more contemporary clinical case series in the literature suggest that the prevalence of this injury, while still uncommon, is higher than previously believed[5,6]. The diagnosis may be commonly missed as a result of the examining physician's failure to remove the patient's garments and inspect the back during an examination.

Causes

Disruption of the scapulothoracic stabilizers will cause dysfunction in the normal coordinated motion of the scapula. Various etiologies of injury to either the long thoracic or spinal accessory nerve have been reported as a cause of scapular winging. Blunt injuries from trauma or deceleration events during motor vehicle accidents may cause traction-type insults to a nerve[7-10].

Iatrogenic injury to the long thoracic nerve also significantly contributes to the occurrence of scapular winging. Of

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197 cases of isolated serratus anterior palsy evaluated by Vastamäki and Kauppila, 16% were determined to be iatrogenic in origin, with first rib resection being the most common procedure resulting in the injury[11]. The spinal accessory nerve may be iatrogenically damaged during posterior-triangle neck dissections such as a cervical lymph node biopsy or oncologic resection, resulting in trapezius palsy[12].

Reports of scapular winging as a presenting symptom of other atraumatic causes have been published. These other causes include facioscapulohumeral dystrophy, Lyme disease, polio infection, Arnold-Chiari I malformation, Guillain-Barré syndrome, and systemic lupus erythematosus. However, it is uncommon for these conditions to cause scapular winging[7,13-16].

Normal Scapular Biomechanics

The scapula is a triangularly shaped bone that serves as a mobile connection with the thorax and the upper extremity. The scapula is the essential link for coordinated upper-extremity movement and contains either the insertion or the origin point for seventeen separate muscles. The rotator cuff and scapulothoracic and scapulohumeral musculature provide power to the upper extremity to position the hand in space as well as afford stability of the scapula relative to the thorax.

At rest, the scapula is positioned with 30° of anterior rotation and 20° of forward rotation in the sagittal plane relative to the thoracic wall. The inferior angle also deviates away from the spinal column by approximately 3°[17]. Scapulohumeral rhythm, originally described in 1944, is a 2:1 relationship between movements involving glenohumeral elevation and scapular upward tilt[18]. The center of rotation of the scapula migrates proximally and laterally for the first 30° of elevation; for the next 60° it migrates toward the glenoid base, causing an upward and lateral rotation of the inferior pole[19]. This motion may be exaggerated in a throwing athlete, thus making proper scapular kinematics essential to reduce the risk of injury[17].

Serratus Anterior Anatomy

Palsy of the serratus anterior is the most common etiology of scapular winging[5,10,20-22]. This flat muscle originates from the outer surface of the first eight to nine ribs. The course of this muscle follows a posterosuperior direction along the thoracic wall, eventually inserting onto the anterior aspect of the medial margin of the scapula[23]. The long thoracic nerve innervates the serratus anterior[23]. The C5 and C6 nerve roots combine to form the proximal portion of this nerve and initially innervate the upper portion of the serratus anterior. The nerve then passes posterior to the brachial plexus and receives contributions from the C7 nerve root. From this point the nerve branches innervate the intermediate and lower aspects of the serratus muscle. This nerve has a superficial course beneath the clavicle and the first rib, traversing on the lateral chest wall in the midaxillary line. This superficial course causes the long thoracic nerve to be especially susceptible to injury. Repetitive traction may cause serratus anterior palsy, as it has been shown that as little as a 10% increase in nerve length may cause neurapraxia[24].

In general, the serratus anterior muscle serves to protract and stabilize the scapula, orienting the glenoid for effective use of the upper extremity during upward rotation[18]. Bertelli and Ghizoni describe three functional components of this muscle[25]. The upper aspect facilitates lateral rotation of the inferior scapular angle during overhead activities. The intermediate portion acts to protract the scapula. Lastly, the lower portion of the serratus anterior is also responsible for scapular protraction as well as rotation of the inferior angle of the scapula upward and laterally.

Trapezius Anatomy

The trapezius is a very large muscle that has an especially broad origin spanning the external occipital protuberance, the medial nuchal line, and the spinous processes of vertebrae C7 through T12. The innervation of the trapezius comes from the spinal accessory nerve (CN XI). After leaving the skull via the jugular foramen, the spinal accessory nerve penetrates to the deep surface of the sternocleidomastoid muscle, entering the posterior triangle of the neck. It is the only cranial nerve that enters and exits the skull. The spinal accessory nerve is fairly superficial throughout this course and is associated with a chain of five to ten lymph nodes. The sinuous course and superficial nature of this nerve, along with its close association with lymph nodes, place it at risk during surgical dissection of the posterior triangle of the neck during procedures such as lymph node biopsies[26,27]. The insertion of the trapezius muscle is also broad and involves multiple osseous aspects. The superior fibers of this muscle insert onto the posterior aspect of the clavicle, the medial fibers insert onto the medial aspect of the acromion, and the inferior fibers converge onto an aponeurosis that inserts onto the spine of the scapula. The superior and inferior fibers of the trapezius elevate and rotate the scapula laterally. This action moves the glenoid upward to accommodate shoulder abduction. The middle fibers stabilize the scapula during its range of movement. In general this muscle acts to elevate, retract, rotate, and depress the scapula, depending on which portion of the muscle is activated.

Evaluation of the Patient

History

A detailed history should be taken in an attempt to determine the origin of the patient's scapular winging. Although winging may rarely be of spontaneous origin, any history of trauma or iatrogenic injury may provide helpful information in determining the type of winging present and potentially direct further management. Common symptoms reported by patients include pain in the shoulder and/or upper back, stiffness, fatigue, and weakness. A description of hand dominance, occupation, medical history, and surgical history of the shoulder, cervical spine, and breast are essential[10,20,28]. Patients often present with the chief complaint of posterior shoulder pain. Radiation may occur distally down the arm or proximally to the paraspinous cervical area[20,28,29]. The symptoms are sometimes exaggerated with overhead activity such as reaching or throwing. A prominent scapula may also cause excessive discomfort when driving for long periods of time or sitting against a hard surface. Reports of difficulties with activities of daily living may be common but are not a specific finding for scapular winging[19].

Physical Examination

A complete and extensive physical examination should be performed with the patent adequately exposed to allow examination of the entire back as well as the upper extremities bilaterally. With the patient standing with his or her back to the examiner and arms at the side, the examiner should evaluate the patient for any possible muscular atrophy or asymmetry (Fig. 1-A)[20,29,30]. Evaluation of the range of motion may demonstrate and differentiate between dynamic and static deformities of the scapula. Manually stabilizing the scapula to the chest wall will make it easier to detect and differentiate any substantial loss of function when performing range-of-motion movements without the manual stabilization. Glenohumeral pathology can mimic symptoms of scapular winging, but its symptoms are exacerbated with forward elevation and abduction (Fig. 1-B)[6,31].

Testing of the strength and function of individual muscles is performed in an attempt to isolate the deficits to a specific muscle. The wall push-up can be used to detect serratus anterior muscle dysfunction. Patients stand approximately 1 m (3 ft) away from (and facing) a wall, place their hands flat against that surface, and slowly bend their elbows, allowing their body weight to bring them closer to the wall. A patient may require five to ten repetitions of this motion to fatigue the muscle in order to detect scapular winging in cases of incomplete palsy (Fig. 1-C).

The shoulder shrug attempts to isolate a deficit in the trapezius muscle. This is first done without resistance, followed by moderate resistance from the examiner. The examiner should observe for any gross abnormalities of the scapular structure and positioning during each of these maneuvers. The examiner should also evaluate for signs of weakness and fatigue, including asymmetric motor strength, as many scapular winging deformities may not be obvious (Fig. 1-D).

Two types of scapular winging have been described, according to the position of the scapula and the muscular deficiencies

Fig. 1

Fig. 1-A The patient should be adequately exposed to allow proper inspection of the entire back. **Fig. 1-B** Range-of-motion examination will demonstrate dynamic and static deformities. **Fig. 1-C** Wall push-ups are used to evaluate for serratus anterior palsy. **Fig. 1-D** The shoulder shrug evaluates for trapezius palsy.

involved. Medial winging is classically associated with serratus anterior palsy[5,6,20]. Injury to the long thoracic nerve causes functional defects of the serratus anterior and causes superior translation and medial rotation of the inferior pole of the scapula. Pain may radiate to the distal aspect of the arm and toward the scapula. This pain is typically located in the vicinity of the levator scapulae and rhomboid minor; loss of opposition from the serratus anterior may cause these muscles to spasm because of overcompensation[6,8,10,21]. Decreased activation of the serratus anterior during shoulder protraction in this injury pattern causes accentuated winging during wall push-ups as well as during active forward flexion[5,6,10]. Abduction of the affected extremity is typically limited to 110° to 120° unless compression of the scapula to the thorax is applied[5,6].

Lateral winging is classically associated with trapezius palsy. This injury is usually caused by spinal accessory nerve injury and may result in drooping of the shoulder and an asymmetric neckline with prominence of the scapula and diminished trapezial muscle girth[32]. The loss of muscle tone in the trapezius causes the scapula to translate inferiorly, with the inferior angle rotated laterally. In this type of winging, symptoms are centered on the shoulder girdle, especially with overhead activity and on prolonged exertion[23,30,32]. The pain with this type of scapular winging may be severe, with possible spasming of overcompensating periscapular muscles and associated subacromial impingement.

Diagnostic Studies

Shoulder, chest, and cervical spine radiographs can reveal potential osseous anatomic abnormalities such as fractures, mass lesions, or even osteochondromas[10,22,33,34]. Subsequent evaluation with computed tomography or magnetic resonance imaging may be considered for further work-up of these potential pathologies[34,35].

Electromyography (EMG) is the definitive study to evaluate for scapular winging originating from muscular or neurologic abnormalities[3,36]. Analysis of the trapezius, rhomboid, and levator scapulae as well as the corresponding innervating nerves should be performed[6]. Although EMG may be able to determine which structures are malfunctioning, the extent of the injury found during the initial test may not be predictive of the course of recovery[21,37]. There may also be cases of scapular winging in which the EMG result is normal; therefore, clinical suspicion should remain high regardless of the test result[3,38].

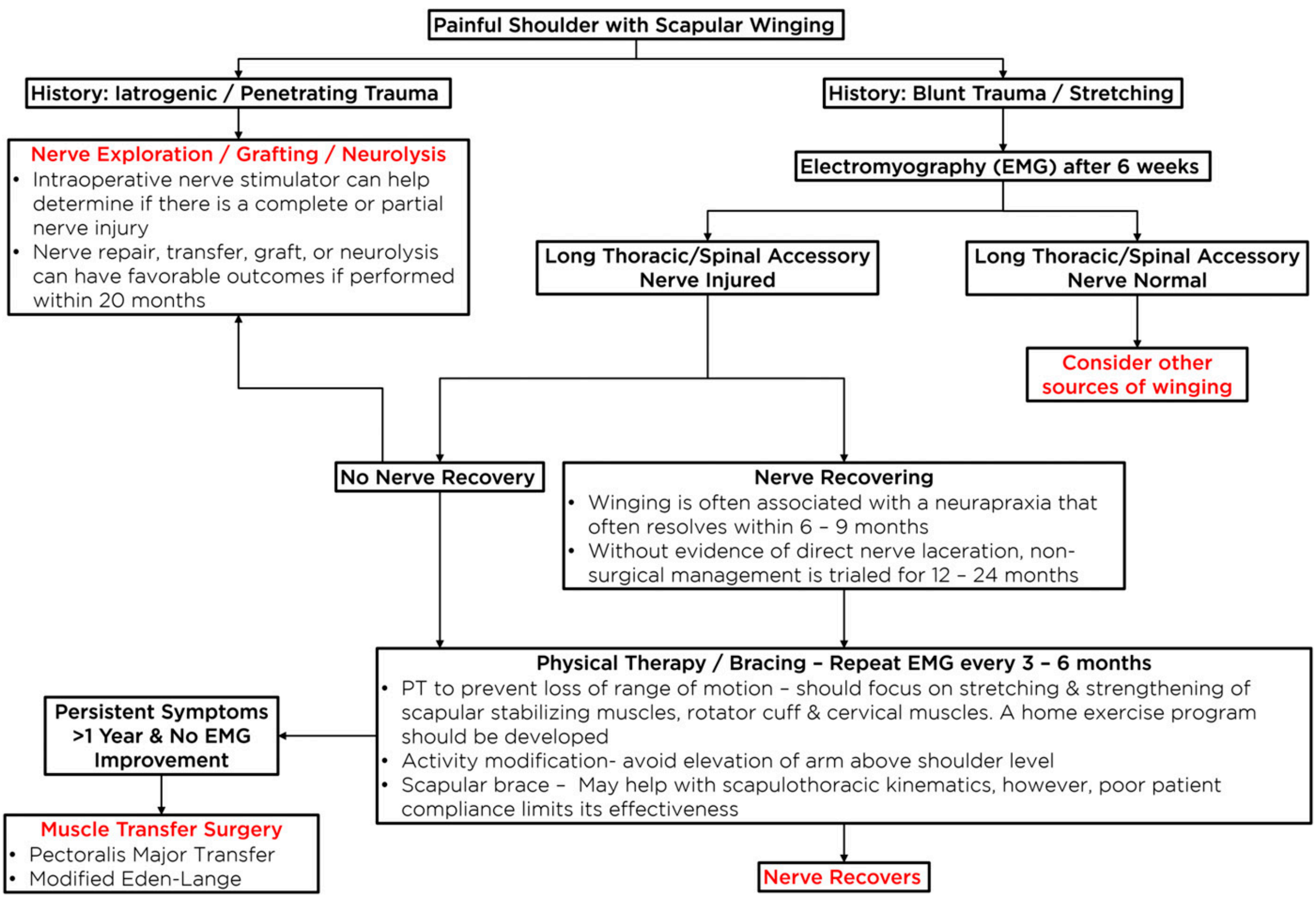

Fig. 2

Decision-making flowchart for management of scapular winging. PT = physical therapy.

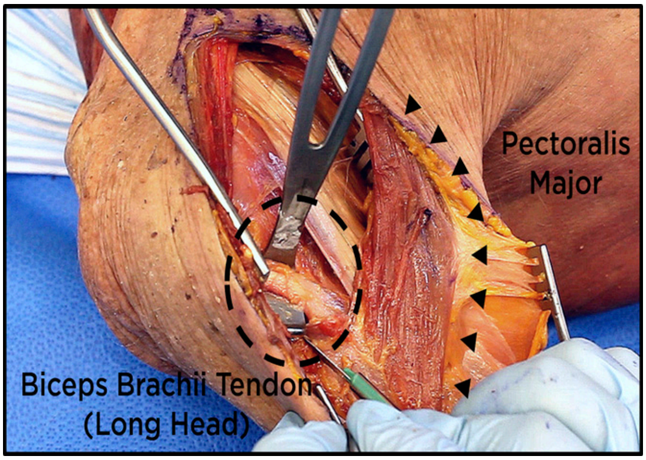

Fig. 3
Identification of the tendon from both heads of the pectoralis major and from the biceps brachii.

Decision-Making and Nonsurgical Management

Appropriate management for scapular winging is critical in achieving positive results and satisfaction. Establishing the etiology of the injury is critical. If either iatrogenic injury (such as lymph node biopsy or posterior-triangle neck dissection) or penetrating trauma is the likely etiology of the patient's scapular winging, the likelihood of substantial nerve injury is high. In this scenario, operative nerve exploration with potential grafting or neurolysis is indicated. An intraoperative nerve stimulator can assist in determining whether there is a complete or partial nerve injury. Nerve repair, transfer, graft, or neurolysis can achieve a favorable outcome if performed within twenty months of the index injury.

If the history more closely suggests a blunt trauma or stretching injury to the nerve, conservative management options are considered the first-line therapy[2,5,6,9,19,21-23,28,39,40]. An EMG of the suspected damaged nerves should be performed six weeks following the index injury. (Prior to six weeks, the EMG may produce a false-negative result.) If the long thoracic nerve or the spinal accessory nerve is confirmed to be injured, the initial step is observation. Scapular winging with a history of blunt trauma or stretching injury is often associated with neurapraxia of the suspected nerve and will often begin to resolve within six to nine months. Repeat EMG should be performed every three to six months to evaluate for nerve function and recovery. Without evidence of any direct nerve laceration injury, nonsurgical management should typically be attempted for twelve to twenty-four months, provided that there is evidence of some progressive nerve recovery (Fig. 2).

Initial nonsurgical management includes a physical therapy program to prevent the loss of range of motion and improve the strength and function of the compensatory muscles. A formal physical therapy regimen as well as an individualized home treatment program should be developed to provide maximum benefit. Activity modification should also be implemented, with a focus on avoiding elevation of the arm above the shoulder level[2,21]. A scapular brace may also be used, as it can improve scapulothoracic kinematics; however, its effectiveness is dependent on patient compliance and body habitus[6,23,41].

After failure of twelve to twenty-four months of conservative management and no substantial improvement as demonstrated by the EMG, dynamic muscle transfer surgery should be considered. Nonoperative treatment options have higher success rates for serratus anterior palsies compared with trapezius palsies[10,20,42-44].

Surgical Technique

Pectoralis Major Transfer with Hamstring Graft

Dynamic transfer of the pectoralis major tendon to the inferior angle of the scapula is the preferred operation for serratus anterior palsy. The patient is placed in the lateral decubitus position with the symptomatic upper extremity and the ipsilateral lower extremity (if choosing to harvest an autograft) prepared and draped free. An anterior deltopectoral approach is used, with the incision following the deltopectoral groove and the cephalic vein mobilized laterally.

The subcutaneous tissue is dissected to expose the inserting tendon of both the sternal and clavicular heads of the pectoralis major as it inserts into the lip of the bicipital groove of the humerus. Utilizing sharp dissection, the tendon from the heads of the pectoralis major is detached from the humerus. It is preferable to harvest and incorporate the tendon from both pectoralis major heads; this method results in improved strength and allows enhanced biofeedback as both heads are contracted simultaneously. In our experience, patients have difficulty independently contracting an individual pectoral head. This method is also technically easier as opposed to single head transfers and provides more muscle mass for the transfer (Fig. 3).

An autograft or allograft hamstring tendon is used to augment the pectoralis major attachment to the scapula. The graft is attached to the pectoralis major tendon by either utilizing a Pulvertaft weave or wrapping the pectoralis major tendon around the graft and securing it with multiple number-2 nonabsorbable sutures (Fig. 4).

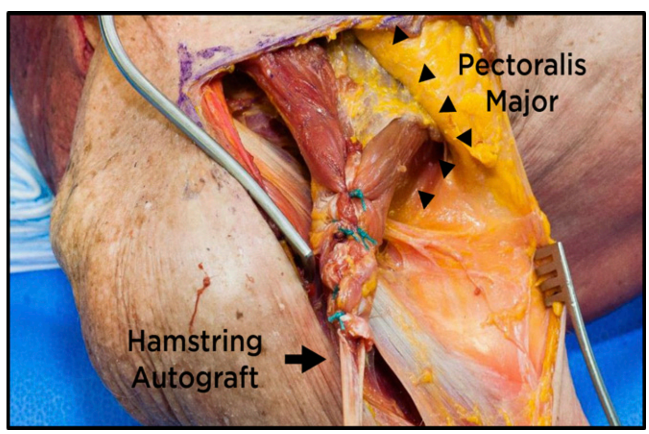

Fig. 4
Hamstring autograft is harvested and attached to the pectoralis major tendon with a Pulvertaft weave and then secured with multiple number-2 nonabsorbable sutures.

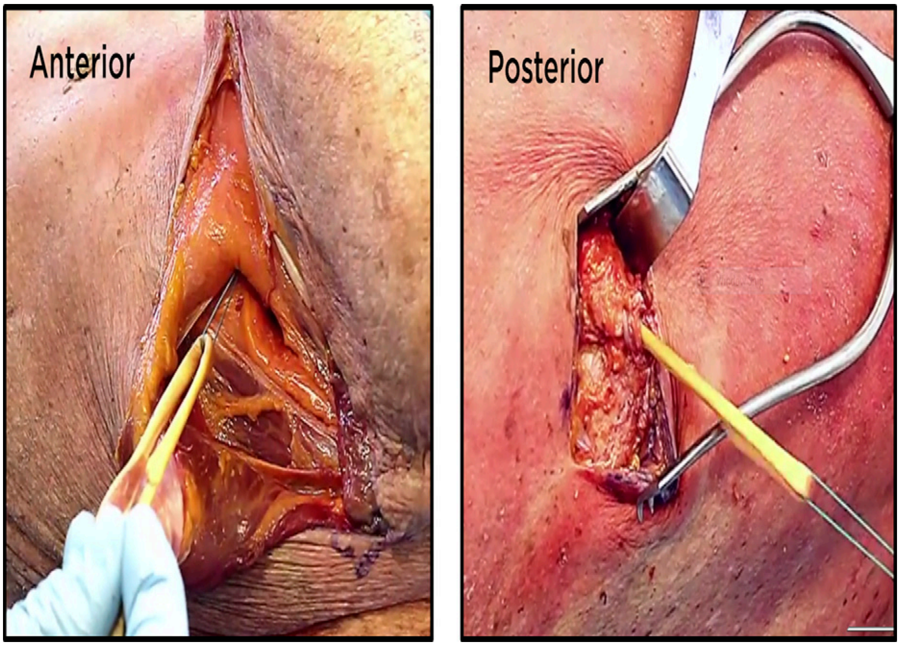

Fig. 5

Blunt dissection with a long curved clamp is used to create a tunnel in the scapulothoracic interval. The inferomedial corner of the scapula is exposed through a posterior incision, and the pectoralis major tendon is retrieved.

Posteriorly, a 3-cm longitudinal incision is made to expose the inferomedial border of the scapula. Once this area is visible, an interval is created from the anterior incision that communicates with the inferomedial border of the scapula. A curved clamp at least 20 cm (8 in) long is used to create a tunnel in the scapulothoracic interval just adjacent to the thoracic wall anteriorly and directed posteriorly toward the inferomedial border of the scapula. The pectoralis major is then brought medial to the conjoined tendon, passed through the scapulothoracic interval, and retrieved posteriorly (Fig. 5).

An 8-mm drill-hole is created 1 cm cephalad and lateral to the inferior angle of the scapula (Fig. 6). The graft is initially passed around the inferior border of the scapula and then passed through the drill-hole from posterior to anterior. The graft is then wrapped around the border of the scapula once more, tensioned, and sewn to itself (Fig. 7). This technique allows the scapula to be abutting against the thoracic wall, allowing maximal tension of the pectoralis major muscle, while enabling easy surgical access and visualization for performing the tendon-to-tendon attachment on the posterior superficial

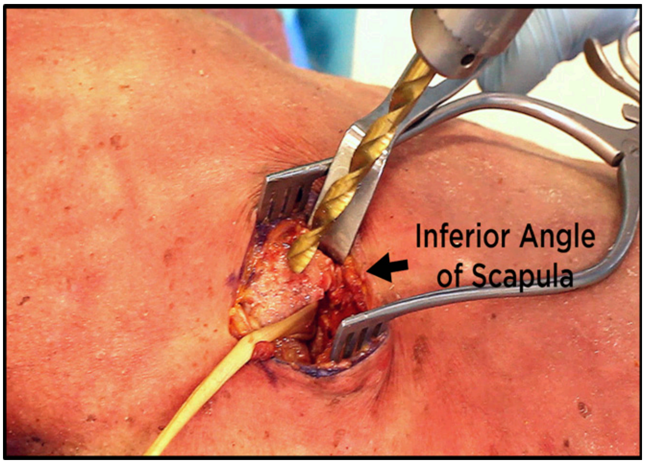

Fig. 6

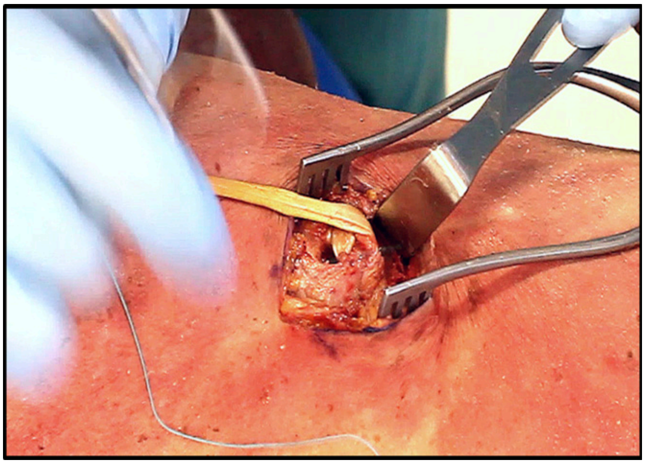

Fig. 7

Fig. 6 The hamstring graft is then passed through a drill-hole 1 cm cephalad to the inferior angle of the scapula and is appropriately tensioned. **Fig. 7** The graft is initially passed around the inferior border, then through the drill-hole from posterior to anterior. The graft is wrapped around the medial border once more, tensioned, and sewn to itself.

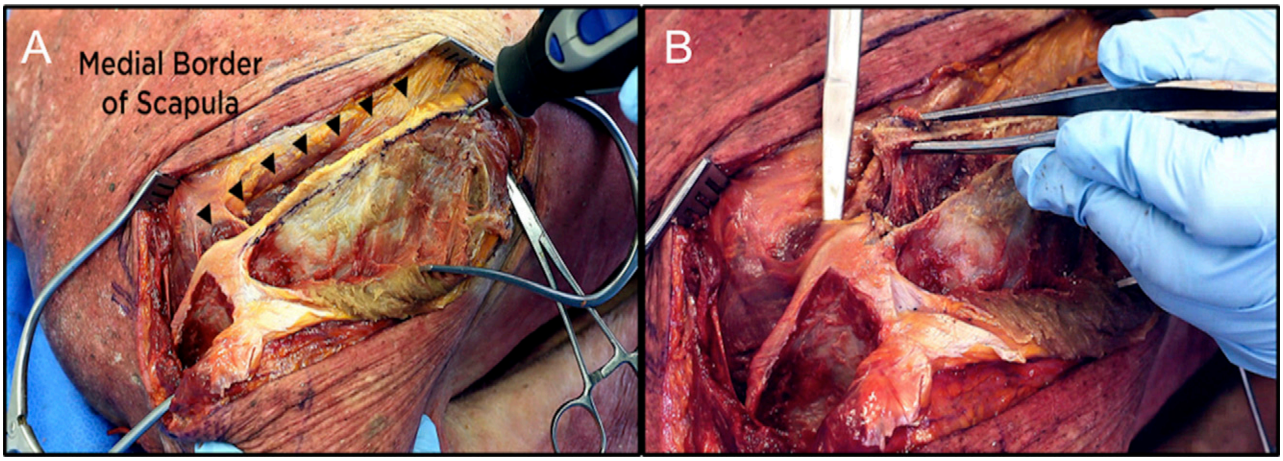

Fig. 8

Fig. 8-A Exposure of the medial border of the scapula is performed with dissection through the atrophic portion of the trapezius. The supraspinatus and the infraspinatus musculature are dissected away from the posteromedial border of the scapula. **Fig. 8-B** The levator scapulae, rhomboid minor, and rhomboid major are detached from the medial aspect of the scapula with 5 mm of bone. This allows secure fixation during the muscle reattachments.

surface of the scapula. Once the hamstring tendon is secured, the remaining length is trimmed and the wounds are closed in a layered fashion.

The pectoralis major transfer for treating long thoracic nerve and serratus anterior deficiency has been the most widely studied with regard to outcome measures. Reported success rates range from 74% to 100%[6,28,39,45-50]. Streit et al. found significant increases in active forward flexion (112° to 149°, $p < 0.001$) and active external rotation (53.8° to 62.8°, $p = 0.045$) as well as improvement in the ASES (American Shoulder and Elbow Surgeons) score (28 to 67.0, $p < 0.001$) and pain (7.7 to 3.0 on a visual analog scale [VAS], $p < 0.001$)[48].

Modified Eden-Lange Procedure

Dynamic transfer of the levator scapulae and rhomboid minor with the Eden-Lange procedure is the preferred operative treatment for trapezius palsy[51]. The patient is placed in the prone position with the entire forequarter draped and prepared. The body of the scapula is marked, and the incision starts 2 cm lateral from the superior angle of the scapula and is extended in a longitudinal direction toward the inferior angle of the scapula. Dissection through the atrophic portion of the trapezius is performed to expose the medial border of the scapula. The supraspinatus and the infraspinatus musculature are identified and dissected away from the posteromedial border of the scapula (Fig. 8-A). A medial osteotomy is performed using a high-speed cutting burr, detaching the levator scapulae and rhomboid musculature from the medial border of the scapula with approximately 5 mm of bone. The osteotomized bone provides a rigid fixation structure to enhance secure reattachment and incorporation of the musculature in the latter

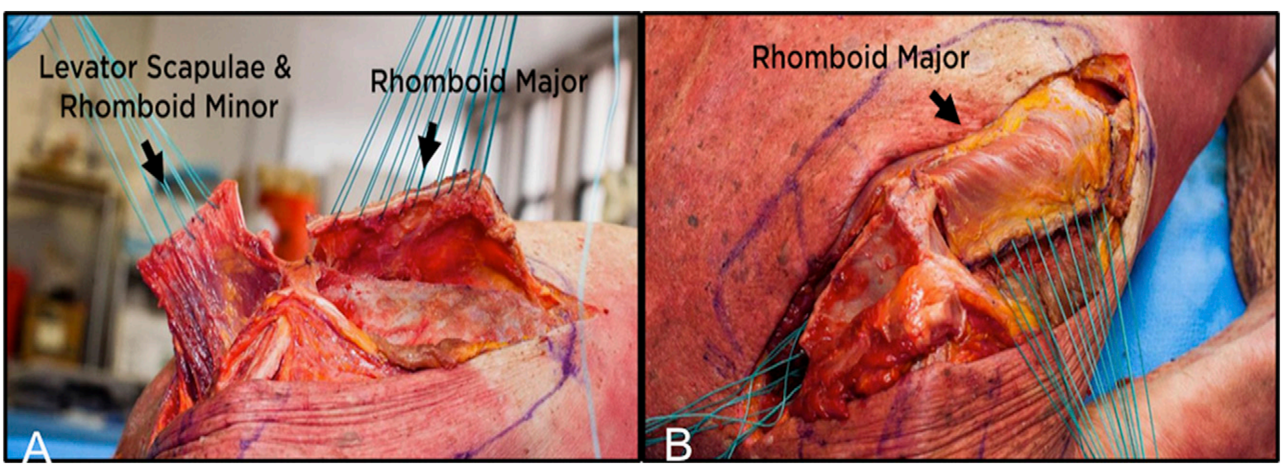

Fig. 9

Fig. 9-A The short tendons of these muscles alone do not hold sutures well, thus making muscle transfers without the osteotomized scapular bone tenuous and prone to failure under tension. **Fig. 9-B** The rhomboid major muscle is lateralized 5 cm onto the infraspinatus fossa.

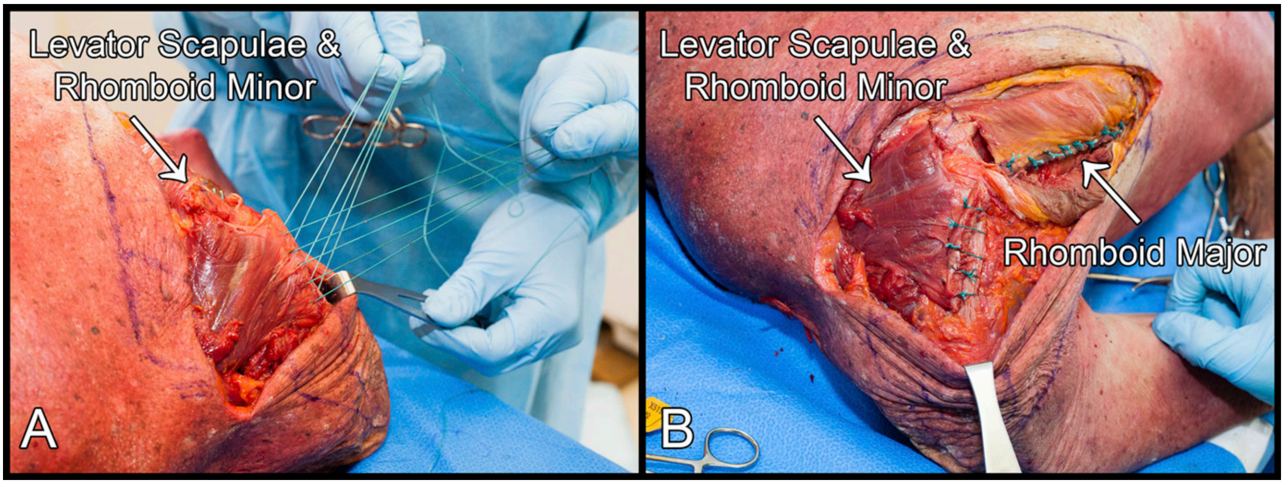

Fig. 10

Fig. 10-A The levator scapulae and rhomboid minor are lateralized and brought inferiorly onto the scapular spine. Simple sutures are placed around the osteotomized bone and through the drill-holes. **Fig. 10-B** All incisions are closed in a layered fashion.

portion of the procedure. In our experience, the short tendons of these muscles alone do not hold sutures well, thus making muscle transfers without the osteotomized scapular bone tenuous and prone to failure under tension (Figs. 8-B, 9-A, and 9-B).

Multiple drill-holes are created approximately 5 cm lateral to the medial border of the scapula and through the scapular spine. As seen in Figures 9-A, 9-B, 10-A, and 10-B, we used nine holes to reattach the rhomboid major and five to reattach the rhomboid minor and levator scapulae. The osteotomized rhomboid major muscle should then be transferred laterally over the drill-holes on the scapular body and secured using number-2 nonabsorbable sutures passed in a mattress suture pattern on the scapula with the suture tails dorsal One suture tail is passed around the osteotomized fragment and tied in a simple fashion (Fig. 9-B). A technical tip is to medially translate the scapula to facilitate lateralization of the muscle transfers and reduction of the scapula, allowing tension-free knot tying. The levator scapulae and rhomboid minor are then pulled 5 cm inferolaterally onto the scapular spine and secured using number-2 nonabsorbable sutures (Fig. 10-B). The incision is closed in a layered fashion.

The Eden-Lange procedure, aimed at managing spinal accessory nerve and trapezius palsy, has been reported to produce good outcomes, with success rates ranging from 71% to 92%[6,28,39,42,51]. For example, Romero and Gerber reported on sixteen consecutive patients undergoing the Eden-Lange procedure with substantial improvement in function and pain[51].

Conclusions

Scapular winging is a rare and potentially debilitating disorder with many causative factors. Diagnosis is largely clinical and relies on a high index of suspicion. Early diagnosis and surgical intervention improve patient outcomes. Dynamic muscle transfers are an effective modality for symptomatic relief from pathology related to scapular winging when conservative management does not result in resolution of the muscle paralysis. The abnormal functionality of affected nerves and muscles creates an uncoordinated kinematic situation, causing substantial pain and loss of function. In younger, more active patients, these operations are the standard of care for the restoration of shoulder function after chronic scapular winging. The use of either the pectoralis major transfer or the Eden-Lange procedure can improve functional outcomes and patient satisfaction. Although most cases of blunt injury to an intact nerve resolve with nonsurgical management, good outcomes for persistent cases are possible with dynamic muscle transfers. ■

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