Primary scapular winging is an under-recognized cause of shoulder dysfunction. It is characterized by abnormal scapulothoracic posturing and dynamic control. Muscle fatigue, rotator cuff weakness, sub-acromial impingement, bicep tendinitis, and gleno-humeral instability symptoms are often associated. For this reason, many patients receive misdiagnoses initially and present with a history of chronic, persistent shoulder complaints. The most common cause of scapular winging is isolated serratus anterior paralysis from long thoracic nerve injury. Causes can be variable and include penetrating, compressive, or stretch injury in the acute traumatic or chronic repetitive injury setting. Collision or overhead athletes, manual laborers, and homemakers are particularly at risk of this condition. Long thoracic nerve palsy typically resolves within 8 to 12 months. In such cases, physical therapy aimed at preventing glenohumeral stiffness and strengthening the scapular stabilizers is the definitive treatment. However, persistent winging and shoulder fatigue can occur in up to 25% of patients after a minimum 1-year course of conservative care. In the absence of clinical or electrodiagnostic evidence of nerve recovery, surgical treatment may be indicated. Options are variable, with distinct advantages and disadvantages associated with each.

Scapulothoracic fusion (STF) has been proposed as a primary definitive surgical treatment, particularly in heavy laborers, patients with combined muscular lesions, and patients in whom prior soft-tissue surgery has failed. Unfortunately, this procedure is characterized by a high complication rate (up to 50%) and modest range-of-motion improvements. Additional options include neurolysis or nerve transfer but are less effective in the chronic setting with irreversible muscle motor endplate degeneration.

Dynamic pectoralis major transfer to the scapula has been shown to be an effective treatment method for this condition. Multiple technical variations exist for this procedure, with little evidence to support one technique over another. The purpose of this article is to introduce and describe our technique for split pectoralis major transfer. To our knowledge, this is the first description of our technique and the first comparison of outcomes for the direct and indirect split transfer methods.
transfer in the treatment of chronic isolated medial scapular winging due to long thoracic nerve palsy.

**Surgical Technique**

**Step 1: Preoperative Workup**

Patients with scapular winging frequently complain of generalized shoulder, neck, and periscapular pain. Additional symptoms include nonspecific fatigue and weakness. The initial workup should include plain radiographs of the chest, cervical spine, shoulder, and scapula. Routine physical examination of the shoulder requires assessment of static and dynamic scapula posturing and movement. Particular attention should be paid to the movement of the inferior angle with humeral forward elevation. Manual stabilization of the scapula during overhead motion may diminish symptoms and improve function, which would support the diagnosis of primary scapular dysfunction. One should also assess for shoulder instability or symptomatic labral tearing, which can produce secondary scapular dysfunction. In many cases, magnetic resonance imaging of the shoulder is warranted to investigate for primary intra-articular pathology. Diagnostic injections are also helpful in localizing potential sources of pain. Neurodiagnostic studies including electromyography and nerve conduction velocity testing are useful adjuncts to confirm the diagnosis and are most helpful no earlier than 6 weeks after a discrete traumatic injury. In cases of more global upper extremity weakness, genetic testing is indicated to rule out facioscapulohumeral dystrophy.

**Step 2: Patient Positioning**

After induction of general anesthesia and administration of a muscle relaxant, the patient is repositioned into the lazy lateral (45° posterior tilt) decubitus position with the assistance of a beanbag. Wide draping to the midline is performed, both anteriorly and posteriorly, to ensure adequate exposure. The ability to manipulate the medial aspect of the scapular body is critical for achieving static reduction of the winged deformity. A SPIDER2 pneumatic arm positioner (Smith & Nephew, Andover, MA) is attached to the proximal third of the operating room table with the central post pointing upward. This positioner allows simultaneous access to the pectoralis major tendon and the inferolateral scapula (Fig 1). Although a long axillary incision may be used, we prefer a 2-incision approach for this procedure. Anteriorly, a 3- to 4-cm vertical skin incision is marked from the coracoid tip to the proximal axillary fold. Posteriorly, a 3- to 4-cm skin incision is drawn in line with the lateral border of the scapula’s inferior angle.

**Step 3: Pectoralis Major Harvest**

The skin is incised, and electrocautery is used to dissect through the subcutaneous tissue layer. The deltopectoral interval is developed, and the cephalic vein is mobilized laterally with the deltoid. Wide subcutaneous tissue flaps are created to optimize visualization. The proximal and distal extent of the pectoralis major musculotendinous junction is identified. The undersurface of the pectoralis is mobilized bluntly with a finger starting at the inferior border and then carried laterally toward the humeral insertion. With assistance from the limb positioner, the arm is brought into slight abduction and external rotation to further expose the muscle belly. Approximately 6 to 8 cm medial to the tendinous insertion, a fibrous raphe, which delineates the sternal head from the more proximal and superciliary clavicular head, can be identified (Fig 2). A pair of hemostats is used to separate the muscle bellies. A Penrose drain is then passed around the sternal head.
and pulled distally to expose the fibrous bands that connect to the clavicular head (Fig 3). These are taken down with Metzenbaum scissors, and the dissection is carried laterally for full exposure of the tendinous portion of the sternal head. With an Army-Navy retractor in place to protect the clavicular head tendon, electrocautery can be used to release the most lateral aspect of the sternal head attachment to the humerus. During tendon release, a finger is placed over the underlying biceps long head tendon to prevent iatrogenic injury. Blunt and sharp release of surrounding fascia and connective tissue is necessary to ensure optimal excursion of the harvested musculotendinous unit (Fig 4). Care is taken to avoid overly aggressive dissection and mobilization, particularly over the muscle undersurface. After harvest, meticulous hemostasis within the anterior wound is performed.

**Step 4: Scapula Exposure**

The arm is repositioned with in-line traction away from the body in approximately 140° of forward elevation to expose the scapula. A skin incision is made, and electrocautery is used to dissect through the subcutaneous tissue. The latissimus dorsi musculature is split in line with its fibers and retracted to expose the deeper teres major muscle layer, which is also split to expose the underlying lateral cortical shelf of the scapula. Electrocautery and a Cobb elevator are used to subperiosteally dissect the subscapularis from the anterior surface and the teres minor from the posterior surface of the scapula for exposure of the inferior angle. By use of digital dissection from the anterior and posterior wounds, a submuscular tissue tunnel is created within the axilla to connect the 2 incisions. Care is taken to bluntly dissect along the chest wall, within the distal aspect of the axilla and below the latissimus muscle, to avoid neurovascular injury. A Penrose drain may be passed back and forth through the tunnel to widen its borders and ensure smooth graft passage (Fig 5).

**Step 5: Preparation for Tendon Transfer and Allograft Augmentation**

Attention is turned toward assessment of the pectoralis major length-to-transfer distance. With the assistance of a Kelly clamp or tonsil hemostat, the pectoralis major sternal head is then passed from anterior to posterior to approximate a direct transfer to the scapula. If the length is inadequate, a semitendinosus allograft augmentation is selected for indirect transfer. Although use of an ipsilateral or contralateral semitendinosus autograft is also an option, we prefer to avoid the additional morbidity and operative time required for autograft tissue harvest. The semitendinosus graft is incorporated into the sternal head by a Pulvertaft tendon weave technique and heavy nonabsorbable suture. The free end of the graft is then whipstitched to assist in tunnel passage (Fig 6). For additional tissue bulk and transfer strength, the semitendinosus may be doubled over onto itself and sutured, after the Pulvertaft weave, for a double-limb indirect transfer. In this case the 6-mm-diameter semitendinosus allograft was believed to be of adequate size and strength for single-limb transfer.

**Step 6: Scapula Tunnel Preparation and Tendon Transfer**

A point-to-point clamp is used to laterally deliver the inferior angle of the scapula into the operative field (Fig 7).
A broad retractor is positioned between the scapula and the chest wall anteriorly. A deeper retractor is necessary to expose the posterior aspect of the scapula as well. With reference to the thickened cortical border and the thinner body, a point approximately 1 cm proximal to the inferior angle and 1 cm medial to the lateral edge is identified for the transosseous tendon transfer site. A 6-mm-diameter drill or reamer is used to create a tunnel, from posterior to anterior. Care is taken to ensure preservation of a 6- to 8-mm bony bridge to the cortical edges to avoid fracture. Once loose osseous debris is removed from the wound, the graft is then passed through the hole, from anterior to posterior, and doubled back over itself for fixation (Fig 8).

An operative assistant is required to manually reduce the...
Scapula against the chest wall and push the inferior angle as laterally as possible while the graft is tensioned to hold reduction and tied to itself with heavy nonabsorbable suture (Fig 9). Excess graft is cut and removed. After tendon transfer, gentle dynamic examination at the shoulder is performed to confirm a stable construct with corrected scapular motion. The wound is thoroughly irrigated, and electrocautery is used to ensure meticulous hemostasis. The teres major and latissimus dorsi muscular layers are reapproximated for wound closure. Anteriorly, the deltopectoral interval is closed in similar fashion. The subcutaneous tissue and skin are closed for both incisions. No drain is usually required. After placement of sterile dressings, the arm is secured in a sling and abduction pillow for postoperative immobilization.

Step 7: Postoperative Rehabilitation
A conservative rehabilitation program is followed to prevent stretching and attenuation of the graft in the early postoperative period. The patient is immobilized in a sling for 6 weeks. During this time, only elbow, wrist, and hand exercises are performed. Between weeks 6 and 8, the patient participates in a passive motion phase. During this period, supine forward elevation and external rotation are progressed to full from 0° to 90° and from 0° to 30°, respectively. Motion is initially in the supine position only, which is important for scapular stabilization. The patient is converted to motion in the upright position slowly, as tolerated. Once upright, the scapula is manually stabilized during passive overhead stretching. Starting in week 9, active range of motion is initiated in the supine position and progressed in all planes. A goal of full overhead motion is set for 12 weeks. Starting in week 13, the resistive and strengthening phase of recovery begins with a focus on periscapular and rotator cuff strengthening. The patient is counseled against strenuous overhead activity, downward or overhead lifting of more than 25 lb, and participation in contact sports for a minimum of 6 months after surgery. Biofeedback training is an important aspect of the rehabilitation program. Attention is paid to reactivation of the pectoralis major musculature through resisted shoulder adduction exercises with the arm in the forward flexed position. Video 1 shows the surgical technique in step-wise fashion.

Discussion
Scapular winging can be a primary or secondary disorder of the shoulder. First described by Velpeau in 1837, isolated serratus anterior palsy producing medial malpositioning of the inferior angle of the scapula is recognized as the most common cause of primary scapular winging. In the setting of long thoracic nerve palsy, initial management is conservative and often successful. In those patients who have persistent symptoms after 12 to 24 months of nonoperative care, surgical treatment may be indicated.

STF offers the theoretical advantage of a durable, static solution to this problem. STF was initially described for the treatment of scapular winging due to facioscapulohumeral muscular dystrophy, but results of STF in the treatment of nondystrophic conditions, such as
isolated serratus anterior or trapezius weakness, have also been reported.\textsuperscript{6,8,9,16} Bizot et al.\textsuperscript{6} were the first authors to publish outcomes of STF in the treatment of serratus anterior paralysis. After a retrospective review of 10 patients with a mean follow-up period of 6.2 years, a 30% nonunion rate was reported. Although 6 patients were able to return to manual labor, mean active abduction and forward flexion were limited to 93° and 101°, respectively. In comparing outcomes of STF for both dystrophic and nondystrophic conditions (42 STFs in 34 patients; mean follow-up period, 5 years), Sewell et al.\textsuperscript{9} reported a 26% clinical failure rate. Overall functional outcome scores were lower for the nondystrophic group. Other authors have noted a similarly high complication rate.\textsuperscript{7,8} Krishnan et al.\textsuperscript{8} published outcomes of STF using a plate and wire construct in 24
Table 2. Advantages and Disadvantages

| Advantages                                      | Disadvantages                                  |
|------------------------------------------------|------------------------------------------------|
| Dynamic solution for dynamic problem           | Inadequate treatment for dystrophic causes of scapular winging |
| Optimizes range of motion                      | Risk of recurrence particularly in young laborers and overhead athletes |
| Added length from graft allows tension-free muscle transfer | Attenuation of graft over time can lead to recurrence |
| Relatively low perioperative morbidity and complication rate compared with scapulohumoral fusion | May cause unacceptable cosmetic deformity of chest |

shoulders with a variety of clinical disorders. More than 50% of patients had complications, which ranged from pneumothorax to pleural effusion, hardware failure, pseudoarthrosis, and persistent pain. In addition to these short-term risks, Atmaca et al.17 used a computer model to demonstrate increased acromioclavicular and glenohumeral joint loads after STF, which may increase the risk of osteoarthritis in the long-term. Finally, in the setting of failed STF, revision surgical options can be limited.

With these issues in mind, the alternative procedure of dynamic muscle transfer to the scapula has gained popularity. A variety of techniques have been described, with results previously published for pectoralis major, pectoralis minor, levator scapulae, and rhomboid transfer.1,3,18-22 The theoretical advantages of this technique over STF include perhaps less technical demand in performing the procedure, less perioperative morbidity, fewer complications, and better shoulder range of motion and function. First described and performed by Tubby24 in 1904, pectoralis major transfer for the treatment of serratus anterior palsy has become the most common surgical treatment method for this condition. Results of both split sternal head transfer1,25 and dual clavicular and sternal head transfer26 have been reported. Other variations include a single- versus 2-incision approach, medial versus lateral scapular tenodesis, direct versus indirect transfer, and augmentation with allograft versus autograft tissue. In an anatomic study, Povacz and Resch27 showed the sternal head direct transfer technique to have the necessary length and excursion for transosseous fixation to the inferior angle of the scapula. The theoretical advantage of this approach is the avoidance of an interposed graft, which may lengthen or attenuate with time. Our preference is to perform a direct tenodesis when possible; however, in our experience, an interposed graft is often required to augment native tendon bulk and to allow for an appropriately tensioned dynamic transfer.23 One should also consider the potential adverse effects of overly aggressive pectoralis mobilization, which may result in traction injury to the medial and lateral pectoral nerves, muscular degeneration, and poorer function.28 To our knowledge, no study has examined the comparative outcomes of autograft versus allograft augmentation with this procedure.

Streit et al.26 reported outcomes of both direct (n = 4) and indirect (n = 22) transfer methods at a mean follow-up of 21.8 months. Contrary to our technique, they used hamstring autograft for augmentation and indirect transfer. Recurrent scapular winging was noted in 19% of shoulders. Final postoperative mean forward flexion and external rotation were 149° and 62.8°, respectively. The mean American Shoulder and Elbow Surgeons score improved from 28 to 67 (P < .001). The mean pain score on a visual analog scale improved from 7.7 to 3.0 (P < .001). No significant clinical difference was noted between the direct and indirect methods, although all 5 failures occurred in the indirect group. With the longest mean follow-up period available in the published literature (92.5 months), Tauber et al.25 showed durable clinical results for direct pectoralis major transfer in the treatment of medial scapular winging. At final follow-up, the mean Constant score increased from 41 to 85.4 points. Mean active forward flexion, abduction, and external rotation were 171°, 161°, and 63°, respectively. The final outcomes were rated as excellent in 10 of 12 patients and good in the remaining 2. Multiple authors, with mean follow-up times ranging from 27 to 70 months, have reported good to excellent outcomes in 67% to 100% of patients by use of the indirect transfer method.3,20,21,23 Chalmers et al.29 retrospectively compared outcomes between patients treated with the indirect (n = 14) and direct (n = 10) transfer techniques. At a mean follow-up of 4.3 years, there were no significant differences in risk of recurrence, range of motion, or American Shoulder and Elbow Surgeons scores.

For cosmetic reasons, split pectoralis major transfer with preservation of the clavicular head anatomy appears to be favored over dual head harvest.26 As an alternative to soft-tissue transfer, sternal head insertional osteotomy with bony reattachment to the scapula can also yield excellent and durable clinical outcomes.25,30 The most frequently reported complications of pectoralis major transfer include transfer failure, infection, unsatisfactory cosmesis, and glenohumeral stiffness, with an incidence ranging from 8% to 22%.3,20-23,25

We present our technique for split pectoralis major transfer to the inferolateral scapula for treatment of chronic medial scapular winging (Table 1). Clinical outcomes are generally better than those of STF, with fewer short-term complications and less surgical morbidity (Table 2). Indirect muscle transfer with allograft tissue augmentation may be required in some instances and can yield reliable results.
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