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# Long-term Improvements of Neuroplasty and Scalene Muscle Resection in LTN-injured Winged Scapula Patients

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**Background:** Injuries to the long thoracic nerve, which directly branches off of the C6, C7, and C8 brachial plexus nerve roots, can cause scapular winging and affect shoulder movements. Long thoracic nerve injuries resulting from accidents, violence, or overuse can be severe lesions requiring challenging surgeries. We evaluated the long-term functional outcomes of neuroplasty and the scalene muscle resection procedures in patients with long thoracic nerve injury and winging scapula.

**Methods:** All 15 patients who underwent scalene muscle resection with decompression and neurolysis of the long thoracic nerve in a single institution to treat winged scapula and limited shoulder movements between March 2007 and May 2020 with follow-up over 2 years were included in the study.

**Results:** Shoulder abduction and arm flexion improved significantly to 158 ± 52 degrees and 165 ± 53 degrees from a mean of 108 ± 54 degrees and 104 ± 52 degrees ($P < 0.02$) over 2 years after surgery (mean 3.4 years). Overall, there was a significant reduction in the scapular winging, as assessed by estimating the decrease in the angle between the scapular plane and the posterior chest wall. The extent of the score greatly improved post-surgically from a mean of 1.2 ± 0.4 to 3.5 ± 0.9 (range 1–4; 1—severe, 2—moderate, 3—mild, and 4—minimal) ($P < 0.01$).

**Conclusion:** The improvement in shoulder movements and reduced scapular winging was significant and stable over 2 years of surgery in 81% of our study patients.

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## INTRODUCTION

Injuries to the upper brachial plexus and long thoracic and accessory nerves can cause weakness and dysfunction of the shoulder muscles and joints, resulting in limited upper extremity movements, winged scapula, and pain.[1–6] The long thoracic nerve (LTN) is more susceptible to injury because it is superficial, long, and small. The LTN directly branches off of the C6, C7, and C8 brachial plexus nerve roots to innervate the serratus anterior muscle. The function of the serratus anterior is anteversion and protraction of the scapula. LTN injuries resulting from accident, violence, or overuse can be severe lesions requiring challenging surgeries. Affected patients complain of upper extremity weakness and restrictions in their shoulder joint range of motion.[2–4] The compensatory muscle activity required to maintain scapular stability is associated with pain, spasm, and tendonitis around the shoulder joint.[5,6] Non-operative treatments include physical therapy and conservative medical management, such as pain control.[7,8] Operative treatments include nerve decompression, neurolysis, transposition, neurorrhaphy, nerve, muscle, and tendon transfers[9–19] and scapulothoracic fusion.[20]

Along with other investigators, we have previously reported the efficacy of nerve decompression and neurolysis in young athletes and adult patients with upper-extremity disorders.[2,13–19] Andrisevic et al[16] recently demonstrated that neurolysis alone improved shoulder and elbow function in infants with upper trunk obstetric brachial plexus injury (OBPI).

We report an extended long-term functional improvement of neurolysis and decompression of the long thoracic nerve and a partial release of the scalene muscle contractures in all 15 patients with winging scapula and limited shoulder movements and pain.

## METHODS

All 15 patients who underwent scalene muscle resection with decompression and neurolysis of the long

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thoracic nerve in a single institution to treat winged scapula and limited shoulder movements between March 2007 and May 2020 with follow-up over 2 years were included in the study

Fifteen patients had extended long-term (mean: 3.4 years; range: between 2 and 10 years) follow-up evaluations after surgery. Of these 15 patients in this study (mean: age at the time of surgery was 27.5; range: 11.9–55.5) (Table 1), 3 patients had a bilateral shoulder injury. Traumatic brachial plexus injury (TBPI) patients, who underwent the nerve or muscle transfers, were excluded from this study. Patients who underwent other surgeries for new or additional injuries were also excluded.

A detailed history of pain, physical and clinical examination of the extent of the winged scapula and shoulder flexion, and abduction were recorded before and after 2 years of surgery. Nerve conduction velocity (NCV) and electromyography (EMG) examination reports were obtained for our patients' assessment to validate the regional sensory or motor loss of the nerve injury before the operation. All 15 patients in this study underwent the following surgeries.

#### Surgical Technique

Patients were placed in the lawn-chair position with a shoulder roll. A skin incision was created superior and parallel to the clavicle. The incision was sinusoidal and extended 6–8 cm lateral to the palpated lateral clavicular border of the sternocleidomastoid muscle. Dissection was carried through the platysma muscle while protecting the underlying supraclavicular nerves. Resection of the omohyoid muscle allowed access to the scalene fat pad and removal of a potential compressive structure of the brachial plexus.

Inferior to the superior elevation of the scalene fat pad revealed the upper brachial plexus. Exploration of the upper trunk and its trifurcation into the anterior and posterior divisions and the suprascapular nerve typically revealed epineurial scarring. The epineurium was released sharply with microsurgical instruments and technique under high magnification.

The long thoracic nerve (LTN), lateral and posterior to the upper trunk, was identified within the substance of the middle scalene muscle. Partial resection of the middle scalene muscle was performed to reveal the LTN and removed the circumferential muscle fibers. This partial resection of the middle scalene to decompress the LTN released only the most superficial fibers compressing the upper trunk. Thus, resection typically involved 15%–20% of the thickness of the anterior muscle.

A demarcated area of compression was typically apparent toward the point of exit of the LTN from the middle scalene muscle. The site of compression exhibited narrowing and surface neovascularization of the epineurium. External and internal neurolysis of the isolated nerve were performed with microsurgical instruments and the operating microscope in light because of the nerve's small size (diameter: 2–3 mm) and to reduce surgical scar formation. The LTN is multifascicular at this level, and internal neurolysis is required to achieve the goals of the surgery. The platysma and 2 skin layers were reconstructed during the closure with no drains.

Schematic illustrations for decompression, neurolysis of the LTN, and partial resection of the scalene muscle procedures are given in Figure 1.

#### Measurement of the Extent of the Scapular Winging and Shoulder Movements

We have performed both physical and clinical examinations of these patients. The lead author and the surgeon (RKN) performed physical examinations of these patients for scapular winging. Male patients were asked to remove their shirts, and women were asked to wear halter tank tops during the physical examination of the winging scapula of the posterior thorax. We assessed the extent of the scapular winging while the patient forward flexes his/her arms to the horizontal and push on a wall in a push-up motion. We adopted a 4-point numerical scale for determining the extent of scapula winging: 1—severe; 2—moderate; 3—mild; and 4—minimal/normal, as shown in the schematic diagram in our previous publication.[19] No grading systems for the serratus anterior muscle have been established, and therefore we quantified the degree of winging by estimating the angle between the plane of the scapula and the posterior chest wall.[2,12–14]

Patients were asked to send us a short video of the following movements by filming from behind without a shirt (for men) or with a halter tank top (for women) so that the shoulder blade is visible. We also take a video of these patients performing the following movements during the patient's clinics and before and after surgery.

**Movement 1:** Patients were asked to raise their arms straight in front at a right angle to their body and then as high as possible, and then to return them to the resting position in the same way.

**Movement 2:** Patients were asked to raise their arms to the side through a "T position" and then as high as possible, and return them to the resting position through the same "T" position.

**Movement series 3**: Facing a wall, patients were asked to raise their arms to the front at a right angle to their body and continue to raise as high as possible above their head (as in movement 1). And then, they were asked to take them down to the side through a "T" position (as in movement 2) without bringing their arms completely down, and to return them to the front. Then, they were asked to perform a press-up against a wall.

Stills were taken from the video of these patients performing these movements (0 degrees being relaxed at the side and 180 degrees being fully abducted above the head). They were evaluated for 2 distinct motions: shoulder flexion in the sagittal plane and abduction in the frontal plane while videotaped from the posterior and superior views.

All statistical tests were performed using paired Student *t*-test with Analyze-it 2.12 software in Excel 2003 (Analyze-it, Leeds, UK; Microsoft, Redmond, Wash.). $P < 0.05$ was considered statistically significant. Patients were

**Table 1. Demographics**

| Patient | Gender | Side | NCV/EMG/MRI/CT/ Patient Reports | Conservative and Nonsurgical Previous Treatments | Age at Surgery | Follow-up (y) | Cause of the Injury |
|---|---|---|---|---|---|---|---|
| 1 | Woman | R | Normal sensory and motor responses. Acute denervation and neurogenic changes in the pronator and the SA. Labrum tear, undersurface tear of the anterior distal supraspinatus tendon. | Physical therapy and home therapy. Visited a chiropractioner | 50.5 | 3.8 | Motor vehicle accident |
| 2 | Woman | R | Right upper-extremity pinching sensation & pain. Right LTN neuropathy. | Was taking Betamax and Celebrex | 29.7 | 3.0 | Lifting weight at work (work comp); labrum tears; had 2 previous surgeries |
| 3 | Woman | L & R | The absence of activation in the right SA is likely long-standing and complete LTN neuropathy. | Physical therapy | 21.8 | 10.0 | Tennis |
| 4 | Woman | R | NCV and EMG reports given were suggestive and not diagnostics of the injury. | Diclofenac 50 mg bid | 15.4 | 2.5 | Softball player |
| 5 | Man | L & R | 2+ fibrillations in the left SA, and rare fibrillations in the right. Was 1+ scarcity of motor unit recruitment at the left SA. | Pain management | 23.2 | 8.0 | Weightlifting |
| 6 | Woman | | Reduced conduction velocity in the right ulnar motor nerve. Moderately severe right LTN neuropathy, and right ulnar neuropathy. Abnormal study. Right LTN neuropathy Proximal median mononeuropathy. | Creatine monohydrate 5 g daily | 24.5 | 2.2 | Weightlifting |
| 7 | Woman | R | EDX study normal for this age. Clinical correlation and causes of winging scapula were needed. | Was on internal electric device, and taking Coumadin, Lovenox, heparin, and Mestinon | 13.0 | 3.1 | Competitive dancer |
| 8 | Woman | R | Mildly increased signal was seen at the mid and anterior aspect of the supraspinatus tendon. Tendonitis was suspected. | Physical therapy | 11.9 | 2.0 | Soccer |
| 9 | Man | R | Overall, the significant dysfunction of the right BP most prominently affects the right LTN and a significantly lesser extent of the right median nerve. | | 45.0 | 2.5 | Chiropractic visit, cervical traction |
| 10 | Man | R | C6/C7/T1/C8 nerve root laminectomy, C5/C6 fusion. | 2 soft-tissue trigger point procedures | 55.5 | 2.0 | C6/C7/T1/C8 nerve root laminectomy, C5/C6 fusion and pacemaker |
| 11 | Man | R | Chronic LTN injury with 2+/4 denervation with minimal reinnervation. Reversal of the cervical lordosis centered at C5–C6. Limited exam due to the patient's motion and pulsation artifacts. | Physical therapy | 22.8 | 2.1 | Exercise |
| 12 | Woman | R | Chronic appearing LTN neuropathy. The study was limited due to the patient's pain. | Completed 1-y rehabilitation | 14.6 | 3.0 | Cheerleading |
| 13 | Man | L | Abnormal spontaneous activity and high amplitude units in the left C5–C6 innervated muscles, although Paraspinal muscles were spared. Motor units showed a long duration left the upper trunk of BP versus C5–C6 root injury. Involvements of proximal muscles and normal sensory responses suggest root injury. | | 33.3 | | Ulnar and radial nerve tumor excisions in the past |
| 14 | Woman | R | LTN neuropathy, RUE, mild to moderate. | Methadone 5 mg per day, and Lortab as needed | 36.1 | 2.5 | Gall bladder surgery |
| 15 | Man | L & R | Left ulnar, median and radial sensory and motor studies were normal. F-waves studies were normal. Bilateral LTN neuropathy or neuritis. | Lithium ER 1200 mg/day, Wellburtin XR 30 q in AM, Topamax 50 mg i.b.d. Clonazepam 1 mg p.o.q per day p.r.n. Melatonin 4 mg q.h.s. | 24.3 | 3.0 | Intense physical activity |

LTNI, long thoracic nerve injury; SA, serratus anterior; RUE, right upper extremity; EDX, electrodiagnostic studies; NCV, nerve conduction study; EMG, electromyography; MRI, magnetic resonance imaging; CT, Computed tomography.

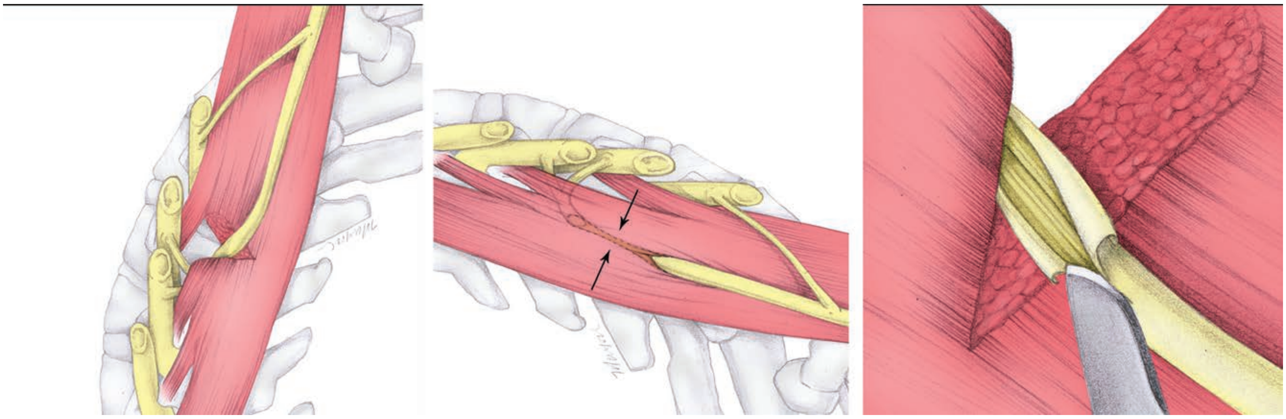

**Fig. 1.** Schematic illustrations of decompression and neurolysis of the long thoracic nerve, and scalene muscle resection procedures.

treated ethically in compliance with the Helsinki declaration. Documented informed consent was obtained for all patients.

## RESULTS

The cause of winging scapula, age at the time of surgery (between 11.9 and 55.5 years), gender (9 women and 6 men), and side of injury (11 right, 3 bilateral, and 1 left) for all 15 patients are given individually in Table 1.

Scapular winging was present on physical examination in all 15 patients in this report, and the winging was severe to moderate in 5 (33%) patients before surgery. Shoulder AROM was poor (<90 degrees) in 8 (53%) of 15 patients before surgery.

Thirteen patients (87%) in this report had short-term follow-up (between 2 weeks and 3 months) evaluations. All 13 patients had improved AROM and decreased winging within 3 months after surgery. We observed recovery in ROM within 24 hours in some of these patients. Two patients (# 1 and # 2 in Tables 1 and 2) reported pain 2 weeks after surgery. Patient # 9 in Tables 1 and 2 were ready to return to work after 3 months of surgery.

We studied if the short-term (<12 months) functional improvements after neurolysis and scalene muscle resection procedures in these patients were maintained and stable for a long time (over 2 years, mean 3.4 years, range 2–10 years). Shoulder abduction and arm flexion improved significantly to 158 ± 52 degrees and 165 ± 53 degrees from a mean of 108 ± 54 degrees and 104 ± 52 degrees ($P < 0.05$) (Table 2) after surgery. Thirteen patients (87%) achieved and maintained full ROM (180 degrees) over 2 years of surgery. Scapular winging was fully recovered in 10 patients (67%) and reduced in the other 5 patients (33%) as observed clinically with improved scapular movement on the thoracic cage in all 15 patients. The extent of the winging scapula score was also significantly improved from a mean of 1.2 ± 0.4 to 3.5 ± 0.9 ($P < 0.01$) (Table 2 and Fig. 2).

Postoperative management is generally restricted to gentle ROM physical therapy, which helps prevent and treat adhesive capsulitis at shoulder girdle joints. We have described the outcome of neurolysis of the LTN and scalene resection procedures individually for all 15 patients in Table 2. Subjective weakness and guarding of the shoulder was reported by 1 patient, which happened after Botox injection at another clinic. There was no improvement in ROM in 1 patient to whom we have indicated repeating the surgery (patient # 13). No infections or other complications occurred.

## DISCUSSION

Patients with LTN injury and winged scapula have considerable difficulty and pain to abduct and flex arm into upward rotation above 90 degrees at the shoulder. Some patients with conservative treatments such as pain control and physical therapy may recover after months or years, and others may not recover.[4] Physical therapy may help preserve the range of motion and prevent potential complications such as adhesive capsulitis of the affected shoulder. Some patients may benefit from botulinum toxin, which is temporary and expensive in the long term.[4] The limited upper-extremity functional movement does not always resolve with conservative medical management. The other treatment options are surgical interventions such as decompression, neurolysis, transposition, neurorrhaphy, nerve, muscle, and tendon transfers,[9–19] and scapulothoracic fusion.[20]

Compression and pressure to the nerve affect neural cell structures impairing precursor molecules' transport and signaling proteins from the soma to the endplate, thereby impede the release of sufficient acetylcholine to stimulate muscle contraction.[21] Decompression and neurolysis of the long thoracic nerve in these cases allow the nerve to resume muscle stimulation rapidly.

Decompression and neurolysis procedures are simpler for continuous nerves, more physiologic, and carry significantly less morbidity than other surgical interventions such as pectoralis to scapula tendon transfers or scapulothoracic fusion.[17] A meta-analysis of our published results of decompression and neurolysis versus the reported outcomes of muscle or tendon transfer procedures shows that these procedures are comparatively effective in the restoration of shoulder functions in winging scapula patients in comparison with muscle or tendon transfer operations.[18]

**Table 2. Stable Long-term Functional Outcomes after Decompression and Neurolysis of the Long Thoracic Nerve, and Scalene Muscle Resection in Patients with Long Thoracic Nerve Injury and Winging Scapula**

| Patient | Preoperative Arm Flexion (Degrees) | Preoperative Shoulder Abduction (Degrees) | Preoperative ESW* | Postoperative Flexion (Degrees) | Postoperative Shoulder Abduction (Degrees) | Postoperative ESW* | Surgical Outcomes |
|---|---|---|---|---|---|---|---|
| 1 | 30 | 30 | 1 | 120 | 120 | 4 | No contracture improved AROM. |
| 2 | 180 | 180 | 1 | 180 | 180 after Botox 30 | 2 | Improved significantly after surgery in strength and AROM. Winging appears decreased. Subjective weakness and guarding of the shoulder by patient's report; happened after Botox injection. |
| 3 | 90 | 90 | 1 | 180 | 180 | 3 | Excellent AROM, Winging present but decreasing. |
| 4 | 30 | 30 | 1 | 180 | 180 | 4 | Normal AROM of both arms, no winging noted. |
| 5 | 180 | 180 | 1 | 180 | 180 | 4 | Excellent result of previous surgery. No current management issues or complaints. |
| 6 | 90 | 90 | 1 | 180 | 180 | 4 | Affected shoulder AROM was stable. |
| 8 | 90 | 90 | 1 | 180 | 180 | 4 | Normal AROM and ongoing close to perfect result of surgery. |
| 8 | 90 | 90 | 2 | 180 | 180 | 4 | Ongoing perfect result of surgery. |
| 9 | 120 | 120 | 1 | 180 | 180 | 4 | Overall stable shoulder strength, with some weakness noted in deltoid. |
| 10 | 120 | 120 | 1 | 180 | 180 | 4 | Continued improvement in winging and full AROM. |
| 11 | 120 | 120 | 1 | 180 | 180 | 2 | AROM and winging appear stable. |
| 12 | 90 | 90 | 1 | 180 | 180 | 4 | Stable and outstanding long-term result of the surgery. |
| 13 | 30 | 90 | 2 | | 30 | 2 | Stable movements of affected upper extremity since the last evaluation: Flexion 90 degrees. Repeat surgery is possible if the patient wants to consider this. |
| 14 | 120 | 120 | 1 | 180 | 180 | 2 | Stable movement status, winging was still present. |
| 15 | 180 | 180 | 2 | 180 | 180 | 4 | Shoulder AROM was normal with no winging of the scapula. |
| Mean | 104 | 108 | 1.2 | 165 | 158 | 3.5 | |
| STD | 52 | 54 | 0.4 | 53 | 52 | 0.9 | |
| *P* | | | | <0.02 | <0.05 | <0.01 | |

LTNI, long thoracic nerve injury; AROM, active range of motion; Extent of the Scapular Winging (ESW): 4—Minimal/Normal, 3—Mild, 2—Moderate, and 1—Severe (Fig. 1).

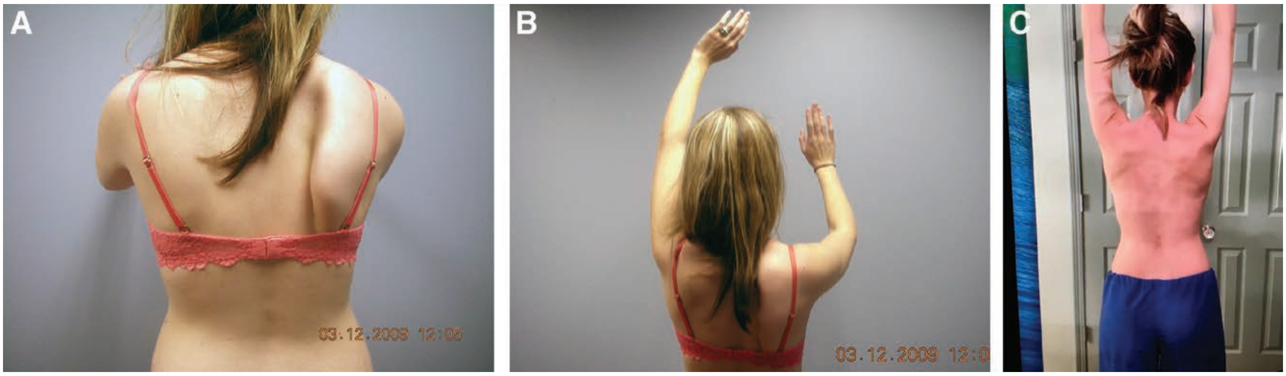


**Fig. 2.** Improvements after neuroplasty and scalene muscle resection. A 22-year-old woman reported to our clinic with a right shoulder injury, severe winging scapula (A), and limited shoulder movements (B) resulting from playing Tennis. C, The same patient 10 years after the decompression and neurolysis of the long thoracic nerve, and a partial release of the scalene muscle contracture procedures. The patient fully regained her shoulder movements (180 degrees), and achieved the healthy normal appearance of the scapula. She was also able to maintain her shoulder stability and functional upper-extremity movements 10 years after surgery.

Other investigators have also shown excellent to good clinical outcomes over 2 years of nerve decompression and neurolysis in both the upper and lower extremities.[22,23] Klifto and Dellon have shown success in relieving pain in the long-term (over 2 years) follow-up of nerve decompression and neurolysis in leprous and diabetic patients.[24,25]

The shoulder injury, pain, and related disability can interfere with activities of daily living and occupation. A third of the upper-extremity injuries occur during sports; it may arise as a consequence of a single acute axial load to the arm resulting in macro-traumatic episodes or multiple repeated (micro-traumatic) activities. The shoulder is anatomically and functionally complex, and the most mobile joint. Its mobility is leveraged in many athletic activities and declines with age and overuse.[26,27]

Overuse, practicing poor sports techniques, and accidents are known to cause these injuries.[28]

Three patients had shoulder injuries and winged scapula resulting from other previous surgeries in the upper-extremity in other clinics. Radical mastectomy and cervical lymph node biopsy or extinction are reported to cause long thoracic and accessory nerve injuries and shoulder disabilities.[28,29] Of these 3 patients, the female patient (# 2 in Table 1) had complained of pain and had decreased muscle tone and bulk on the affected upper extremity before surgery. A male patient (# 10 in Table 1) reported to our clinic with a winged scapula and minimal shoulder range of motion (30 degrees). He had the following multiple previous surgeries in other clinics: C6/C7/T1/C8 Nerve Root Laminectomy, C5/C6 Fusion, and pacemaker. Another male patient, # 13 in Table 1, had ulnar and radial nerve tumor excisions in the past in other clinics, mostly in the right upper extremity, reported with pain and weakness, and reduced shoulder movements.

Three other patients had these injuries from motor vehicle accidents. One of these 3 patients has also been practicing weightlifting. Chronic weightlifting injury is associated with chronic repetitive loading of the shoulder: common in aging athletes.[30] This is due to the trainer focusing on large muscle groups while neglecting to strengthen smaller groups responsible for joint stability. Surgical intervention is often successful and can return the weightlifter to a performance level near their pre-injury level.[30]

Our study included only patients with LTN injury and winged scapula who underwent decompression and neurolysis of the LTN and scalene muscle resection procedures and had a long-term post-surgical follow-up of over 2 years. Therefore, only 15 patients met the inclusion criteria.

## CONCLUSION

The improvement in shoulder function and reduced scapular winging was stable over 2 years of surgery in 81% of our study patients.

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