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Arthroscopic Pectoralis Minor Release and Infraclavicular Brachial Plexus Decompression for Neurogenic Thoracic Outlet Syndrome

A Novel Treatment for an Old Problem

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Background: Neurogenic thoracic outlet syndrome (nTOS) of infraclavicular etiology is a complex condition involving the compression of the brachial plexus through the interscalene triangle and costoclavicular, infraclavicular, and pectoralis minor space. New insight into nTOS of infraclavicular etiology and its association with scapular dyskinesia has enabled minimally invasive treatments: endoscopic pectoralis minor release (PMR) and infraclavicular brachial plexus neurolysis. The purpose of this study was to analyze clinical outcomes of this technique compared with historically published outcomes for open first rib resection (FRR) and/or scalenectomy.

Methods: All patients who underwent endoscopic surgical decompression for nTOS of infraclavicular etiology were retrospectively reviewed at a single institution. Surgical treatment included endoscopic PMR, subclavius release, and neurolysis of the infraclavicular brachial plexus. Patient-reported outcomes were collected prospectively and compared with prior research on FRR and scalenectomy. A subgroup analysis was performed on patients with prior open FRR or anterior cervical discectomy and fusion (ACDF).

Results: Fifty-eight shoulders among 55 patients were included, with an average follow-up of 25.8 months (range: 12-52). Patients showed significant improvement in visual analog scale pain (7.0-2.1) and single alpha-numeric evaluation scores (37% to 84%). Overall, 90% of patients experienced good or excellent outcomes according to the Derkash classification. There were no major complications and only 2 minor ones (one wound infection and one case of adhesive capsulitis). Satisfaction and Derkash scores among patients undergoing endoscopic surgery were comparable with previously published studies on open FRR and scalenectomy, with lower rates of major complications and equivalent or improved clinical outcomes. Patients with prior ACDF or open FRR had worse postoperative American Shoulder and Elbow Surgeons; Quick Disabilities of the Arm, Shoulder, and Hand; and Derkash scores than the subgroup with no prior intervention.

Conclusions: Endoscopic PMR and infraclavicular brachial plexus decompression is a viable and effective treatment option for nTOS of infraclavicular etiology driven by the pectoralis minor and associated scapular girdle dyskinesia. This cohort demonstrates improvements in clinical outcomes comparable with open scalenectomy and FRR with high patient satisfaction and no major neurologic, vascular, or thoracic complications.

Level of Evidence: Therapeutic Level IV–Case Series. See Instructions for Authors for a complete description of levels of evidence.

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Emory University Institutional Review Board approved this study. Study 00004054.

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A746).

Introduction

Thoracic outlet syndrome (TOS) represents a group of compressive pathologies of the vessels and nerves affecting the supraclavicular and infraclavicular fossa, with up to 90% to 95% of these pathologies being neurogenic in nature[1,2]. Neurogenic thoracic outlet syndrome (nTOS) of infraclavicular etiology, distinct from vascular TOS, is a dynamic compressive neuropathy either supraclavicularly associated with scalenes and first or cervical rib, or infraclavicularly associated with the pectoralis minor, subclavius, and scapular girdle[3,4]. Infraclavicular predominant nTOS likely begins with pectoralis minor overactivity causing scapular protraction, producing a dynamic subcoracoid compression of the infraclavicular brachial plexus, manifesting as pain and paresthesia, often alongside repetitive strain or overuse[3-13].

Unlike vascular TOS, which has reliable surgical options, outcomes for infraclavicular predominant nTOS are less predictable[14]. Surgical management for nTOS of infraclavicular origin has included open scalenectomy, FRR, or both combined[14-21], and the optimal treatment algorithm remains controversial[22-24]. Although combined scalenectomy and FRR may produce the lowest recurrence rate, higher associated recovery times, morbidity, and risks for major complications (e.g., vascular, lymphatic, or neurologic) make these decisions challenging[14-16,25,26].

In the last 2 decades, open pectoralis minor release (PMR) for patients with nTOS driven by pectoralis minor hyperactivity and associated scapular girdle pathology has been found to be effective[7,9,27-31]. Recently, endoscopic options have emerged, with the goal of specifically targeting compressive pathology in the subcoracoid and infraclavicular spaces, as well as improving scapular kinematics[3,4,30,32,33]. Two prior case series of 21 and 10 patients demonstrated promising short-term results[34,35], although many patients were excluded from the final analysis. Consequently, the role of endoscopic treatment in infraclavicular predominant nTOS with PMR and brachial plexus decompression has been poorly elucidated in large series.

The purpose of this study was to analyze the success of endoscopic management using the Derkash classification[20,21,36,37], percentage improvement[15,20,26,38], and patient-reported outcome measures (PROMs), while also examining the safety and reproducibility of the procedure. We hypothesize that an endoscopic approach for selected patients yields sustained improvements in clinical outcomes comparable with FRR, with fewer complications.

TABLE I NCS/EMG Data on Surgical Patients With Neurogenic TOS*

Muscle	Total With Abnormal Result
Suprascapular nerve	19%
Median nerve at carpal tunnel	12%
Other	39%

*NCS = nerve conduction study, EMG = electromyography, and TOS = thoracic outlet syndrome. Other nerves tested with noted abnormalities include the ulnar nerve at the cubital tunnel, axillary nerve, C5, and radial nerve.

Materials and Methods

Patient Selection

After Institutional Review Board approval, all patients who underwent an endoscopic PMR, subclavius release, and decompression of the infraclavicular brachial plexus for nTOS of infraclavicular origin were retrospectively reviewed. All patients underwent a standardized workup to rule out other pathologies

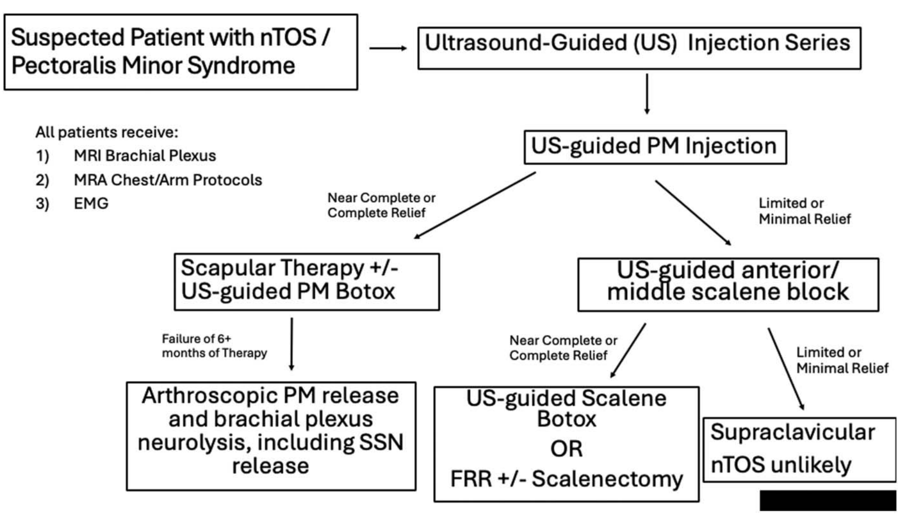

Fig. 1

Diagnostic algorithm for neurogenic thoracic outlet syndrome. MRI = magnetic resonance imaging, EMG = electromyogram, SSN = suprascapular nerve, PM = pectoralis minor, MRA = magnetic resonance angiography.

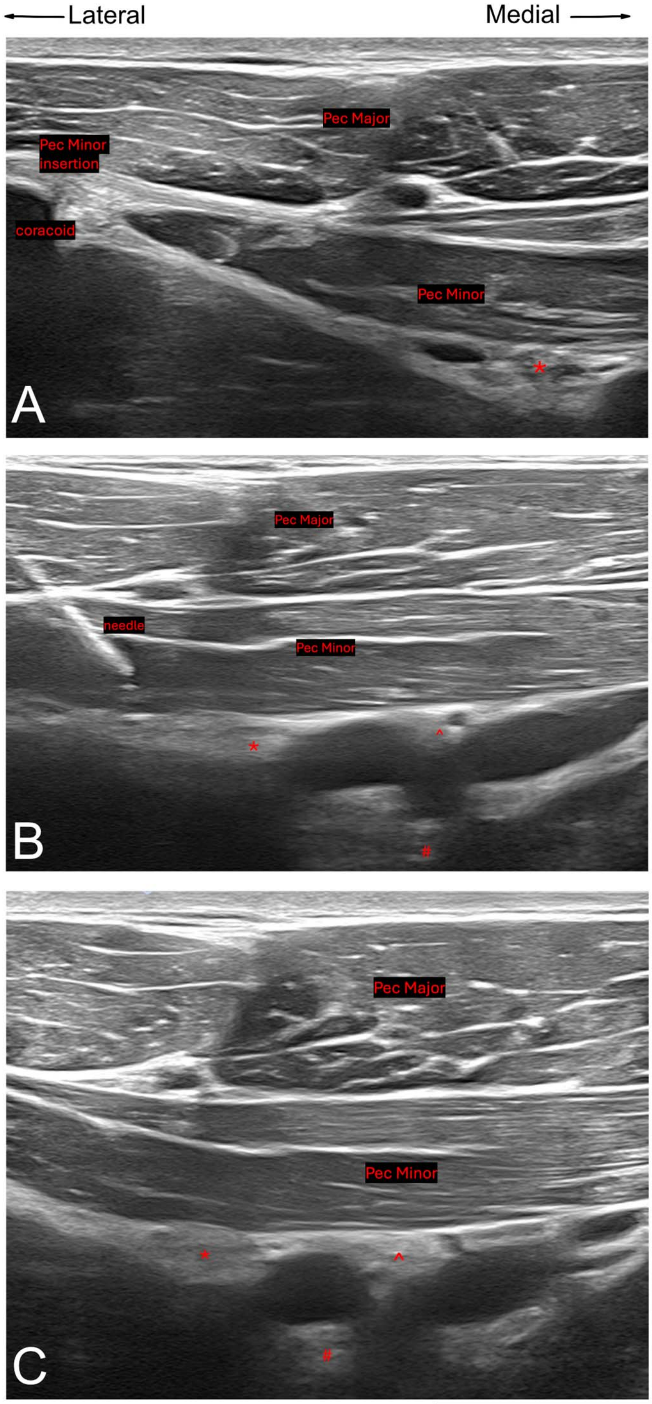

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Fig. 2

Ultrasound-guided pectoralis minor injection series. The pectoralis minor insertion at the coracoid is clearly visualized (**Fig. 2-A**). Botulinum toxin is administered into the pectoralis minor through a needle (**Fig. 2-B**), avoiding the deep neurovascular structures, including the lateral cord (*), medial cord, (^) and posterior cord (#) in the retro/subpectoralis minor space (**Fig. 2-C**).

and diagnose nTOS, primarily by an infraclavicular mechanism[21,39,40]. This included a thorough physical examination[11,39,41-44], imaging workup consisting of brachial plexus magnetic resonance imaging neurography and an arms up/down MR angiography, electromyography, and ultrasound-guided injections[45-48] of local anesthetic (Table I, Fig. 1). Physical examination included palpation and Tinel of the scalene triangle and medial to the pectoralis minor insertion on the coracoid, the Adson test[41], the upper limb tension (ULTT)[42,43] and elevated arm stress (EAST) tests[44], evaluation for scapular dyskinesia or protraction[3,4,12,13,28,29], shoulder examination maneuvers, and peripheral nerve compression provocative maneuvers. As an objective measure of scapular protraction, the pectoralis minor length, defined as the distance from the medial aspect of the coracoid to the inferior margin of the fourth rib at the sternocostal junction with the patient upright, and Pectoralis Minor Index (PMI) ([pectoralis minor length {cm}/patient height {cm}] × 100) were recorded for the involved and contralateral sides using previously validated techniques[11,49]. Magnetic resonance imaging (MRI) neurography was used to rule out any brachial plexus pathology, while stress angiography was used to rule out vascular abnormalities, including vascular TOS. Diagnostic injections were used to help confirm an nTOS diagnosis—either supraclavicularly in the scalene triangle associated with first rib compression or infraclavicularly from pectoralis minor overactivity and associated scapulothoracic abnormal motion.

Patients were included even if they had a prior FRR or ACDF that failed to resolve their symptoms. Patients with evidence of vascular compression on MRI/magnetic resonance angiography, signs of ischemia on examination, or those with a cervical rib were deemed to have predominant vascular TOS and recommended to undergo open FRR[40]. Furthermore, patients with a positive response to diagnostic scalene injections and without a response to pectoralis minor injections were deemed to have supraclavicular-driven nTOS pathology and were excluded from this study. The ultimate diagnosis of infraclavicular-driven nTOS was made according to the Society for Vascular Surgery's standardized recommendations[40]: (1) local findings: history and physical examination indicating infraclavicular compression potentially associated with scapular dyskinesia, with scapular protraction and a PMI difference of >1 point compared with the other side[47]; (2) peripheral findings: provocative symptoms from repetitive overhead elevation or shoulder extension and positive provocative maneuvers such as arm elevation or extension, scapular retraction, or positive ULTT and/or EAST tests; (3) absence of other pathologies: predominant symptoms from cervical disease, carpal/cubital tunnel syndrome, brachial plexus pathology, or vascular TOS; and (4) positive response to local anesthetic or botulinum toxin administration to the pectoralis minor muscle belly with >50% relief (Fig. 2). Furthermore, patients had to have undergone 6 months of a scapula-directed physical therapy protocol with a figure-of-eight brace without sufficient improvement.

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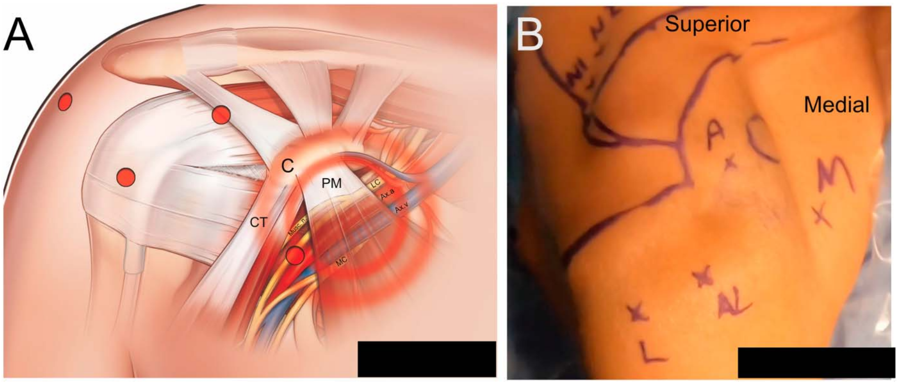

Fig. 3
Schematic (**Fig. 3-A**) and clinical photograph (**Fig. 3-B**) of portal placement in arthroscopic pectoralis minor release and infraclavicular brachial plexus decompression. Six portals are used: lateral, anterolateral, anterior, medial, and 2 Neviaser portals. Red circles in A indicate portals. Ax. V = axillary vein, Ax.a = axillary artery, C = coracoid, CT = conjoint tendon, LC = lateral cord, MC = medial cord, Musc. n = musculocutaneous nerve, and PM = pectoralis minor.

Surgical Technique

Endoscopic PMR was performed based on the technique of Lafosse et al.[32,34] as modified by the lead author[3,4]. Using a lateral viewing portal, anterolateral working portal, and 2 Nevaiser portals (Fig. 3), the suprascapular nerve was released at the suprascapular notch and neurolysed toward its origin on the upper trunk. Next, the coracoid was exposed, revealing the pectoralis minor, conjoint tendon, and coracoclavicular ligament (Fig. 4). The pectoralis minor insertion was then released directly off the coracoid (Fig. 5). The infraclavicular brachial plexus was exposed and neurolysed, following the musculocutaneous and median branches to the lateral cord and axillary nerve to the posterior cord. The cords were then neurolysed, releasing additional possible compressive lesions including fibrotic adhesions–the clinical significance of which was unclear. This was performed up to and under the clavicle, releasing dividing the subclavius muscle vertically with electrocautery over the lateral cord (Fig. 6). The brachial plexus decompression was finished when the suprascapular nerve was seen coming from the upper trunk posterior to the subclavius, as previously described[32,34]. Given the complexity in the diagnosis and the likelihood of concomitant pathologies, our goal was to avoid any residual symptoms and need for revision surgery. Therefore, we believe this to be necessary and this was done routinely for all cases. A sling was placed for comfort, and a 3 to 4-month scapular retraining physical therapy protocol focusing on stretching and strengthening was started with a figure-of-eight brace to resist resting scapular protraction[45]. Return to overhead sports and all other activities starts at 3 months.

Outcomes Measures and Statistical Analysis

PROMs were collected, including the visual analog scale (VAS) pain, shoulder single alpha-numeric evaluation (SANE), American Shoulder and Elbow Surgeons (ASES), and Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) scores. Derkash classification, primarily used in vascular and thoracic surgery

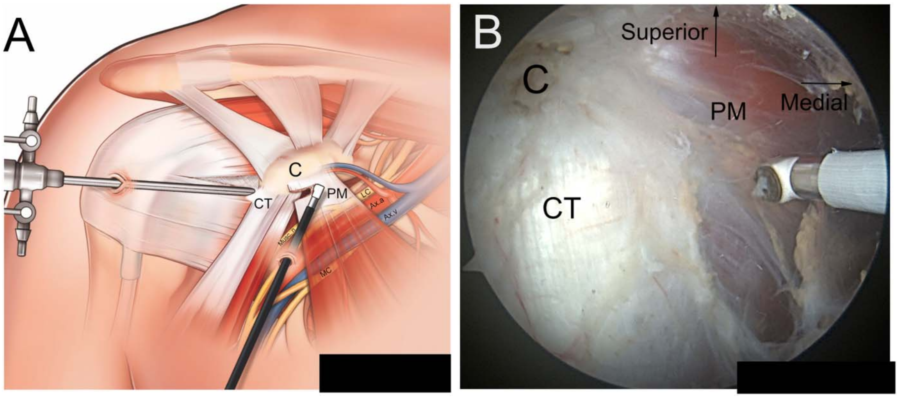

Fig. 4
Schematic (**Fig. 4-A**) and arthroscopic photograph (**Fig. 4-B**) of arthroscopic pectoralis minor release and infraclavicular brachial plexus decompression. The pectoralis minor insertion is fully visualized and released with a radiofrequency ablation probe. Ax. V = axillary vein, Ax.a = axillary artery, C = coracoid, CT = conjoint tendon, LC = lateral cord, MC = medial cord, Musc. n = musculocutaneous nerve, and PM = pectoralis minor.

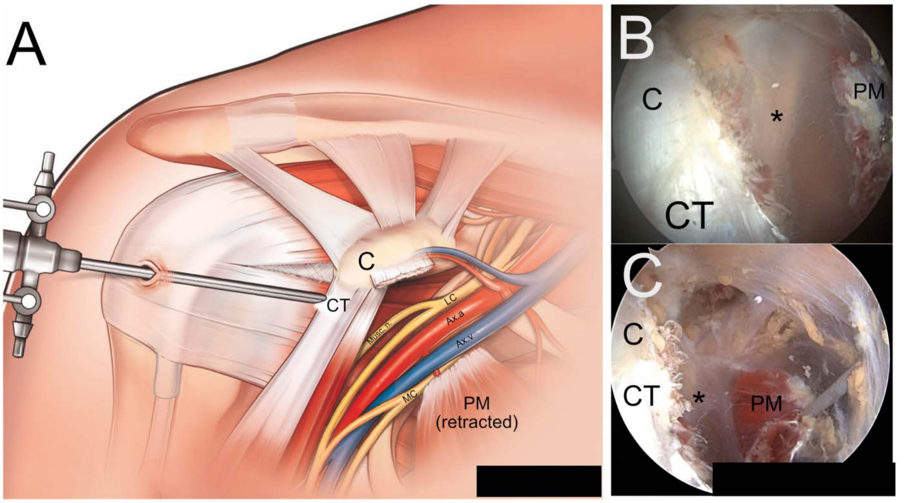

Fig. 5

Schematic (**Fig. 5-A**) and arthroscopic photographs (**Figs. 5-B and 5-C**) of infraclavicular brachial plexus decompression after pectoralis minor release. The pectoralis minor is seen to retract medially, exposing the underlying neurovascular structures (*). Ax. V = axillary vein, Ax.a = axillary artery, C = coracoid, CT = conjoint tendon, LC = lateral cord, MC = medial cord, Musc. n = musculocutaneous nerve, and PM = pectoralis minor.

literature, was also calculated to provide a basis for direct comparison to prior studies[14,20,21,36,37]. Derkash classification is an ordinal scale measuring outcomes as "excellent," "good," "fair," and "poor," with most studies of FRR considering treatment successful if outcomes are "good" or "excellent"[38]. Patients were also assessed on their "percentage improvement," being asked if their symptoms improved by >75%, 50% to 75%, 25% to 50%, or <25% compared with preoperatively[15,20,26,38]. PROMs were collected at a minimum of 1 year postoperatively, as prior literature indicates that results after TOS decompression plateau after 6 months[21]. *T*-tests, χ^2, and Mann-Whitney *U* tests were used to compare cohorts. A priori power analysis was performed, with at least 20 patients needing complete follow-up data to determine a VAS score difference of 2. Subgroup analysis was performed among patients with prior ACDF/FRR or no prior intervention.

Results

Fifty-eight patients with 61 affected shoulders were retrospectively enrolled from 2019 to 2022. Three patients were excluded due to incomplete follow-up of <1 year, given prior

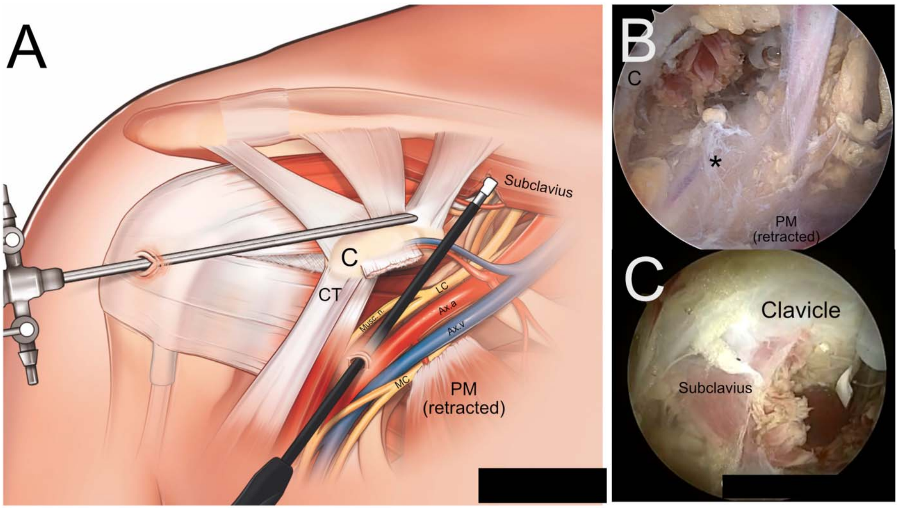

Fig. 6

Schematic (**Fig. 6-A**) and arthroscopic photographs (**Figs. 6-B and 6-C**) of infraclavicular brachial plexus decompression after pectoralis minor release. The infraclavicular brachial plexus (*) is exposed and neurolysed, following the musculocutaneous and median branches to the lateral cord and axillary nerve to the posterior cord. The cords are then neurolysed up to and under the clavicle, dividing the subclavius muscle (**Fig. 6-C**). The decompression is finished when the suprascapular nerve is seen coming from the upper trunk posterior to the subclavius. Ax. V = axillary vein, Ax.a = axillary artery, C = coracoid, CT = conjoint tendon, LC = lateral cord, MC = medial cord, Musc. n = musculocutaneous nerve, and PM = pectoralis minor.

TABLE II Demographics*

Total Patients	55
Shoulders	58
Female	37 (63.8%)
Average age	34.4 (16-78)
Race (White)	43 (78.2%)
Right-sided procedure	34 (61.8%)
Patient history	
Diabetes	1 (1.8%)
Inflammatory arthritis	0 (0%)
Smoking	5 (8.6%)
Athlete	24 (41.4%)
Prior ACDF	9 (15.5%)
Prior FRR	6 (10.3%)
Prior surgery	22 (37.9%)

*ACDF = anterior cervical decompression and fusion, and FRR = first rib resection. Prior surgery included all patients with ACDF, FRR, or other surgeries for compressive neuropathy including carpal tunnel and cubital tunnel release.

studies show outcomes can change 6 to 12 months postoperatively before plateauing[14,21]. Ultimately, 58 shoulders among 55 patients were included, with an average follow-up of 25.8 months (12-52). Patient demographics are depicted in Table II. Many were competitive overhead athletes (41%), and many underwent previous surgeries (38%) including ACDF, FRR, or surgery for compressive neuropathy (carpal and/or cubital tunnel release). Preoperative PMI was significantly different from the contralateral side ($p < 0.001$). There was significant improvement between preoperative and postoperative pectoralis minor length and indices (Table III). Being a competitive athlete was the only demographic variable associated with preoperative or postoperative outcomes (Table IV), with improved outcomes among this cohort.

After undergoing shoulder endoscopy, PMR, and brachial plexus decompression, there was sustained improvement in VAS pain and SANE scores at the most recent follow-up (Tables V and VI). Patient satisfaction was high, with patients reporting excellent (68.6%) and good (21.6%) satisfaction and none reporting dissatisfaction. When asked if they would have surgery again, 88% of patients said yes, 10% were undecided, and only 2% said they would not. There were no major neurological, thoracic, lymphatic, or vascular complications noted postoperatively. There were 2 minor complications noted: one superficial endoscopic portal site infection requiring superficial irrigation and debridement, and one case of adhesive capsulitis that responded to conservative measures alone. No patients reported new paresthesia or tingling early or late postoperatively. Subgroup analysis demonstrated that postoperative PROMs, including ASES and QuickDASH scores, were worse among those with prior intervention (Table V).

The 2 most common methods to measure success include the Derkash score and percentage of symptom improvement. Derkash scores demonstrated 90% of patients had successful outcomes (good or excellent): 65% excellent results, 25% good, 10% fair, and no poor results. Patients with prior FRR or ACDFs had worse Derkash scores than those with no prior surgery (Table V). Furthermore, 94% of patients reported >50% symptom improvement compared with preoperatively, including 65% with complete symptom relief. Although 6% of patients reported no change, none reported worsening of symptoms postoperatively. The endoscopic approach demonstrated overall fewer complications than FRR with similar or improved PROMs (VAS or SANE) in cases of isolated nTOS.

Discussion

As our understanding of the pathophysiology underlying infraclavicular predominant nTOS evolves, so do our diagnostic and therapeutic treatment algorithms (Fig. 1)[4,7]. The dynamic interplay between the scapular girdle, first rib, and clavicle and their roles in brachial plexus compression continues to be elucidated. While the scalenes were traditionally implicated in narrowing the thoracic outlet, the role of the pectoralis minor is now emerging. When overactive, it protracts the scapula and is associated with scapulothoracic abnormal motion, leading to suprascapular nerve (SSN) tethering at the suprascapular notch and narrowing of the retropectoralis and subclavius space[3,12,13,28,29,34,50]. With the morbidity of open FRR, including major complications such as brachial plexopathies, subclavian artery or vein injuries, pneumothorax or hemothorax, and persistent lymph node leakage[14-16,22,23,26,38], open PMR has shown promise in treating nTOS[7,9,27,30]. Furthermore, in recent years, novel endoscopic approaches have emerged[34,35],

TABLE III Average Preoperative and Postoperative Pectoralis Minor Lengths and Indices*

Pec Minor Measurements	Preoperative Values Mean (SD)	Postoperative Values Mean (SD)	p
Length affected side	**12.9 (1.5)****	**14.6 (1.3)****	**0.02**
Length contralateral side	14.9 (1.5)	14.8 (1.2)	0.250
Index affected side	**7.5 (0.8)****	**8.6 (0.7)****	**<0.01**
Index contralateral side	8.7 (0.6)	8.7 (0.7)	0.182

*Pec minor index calculated as (pec minor length [cm]/height [cm] × 100). Bold text and ** designate a statistically significant change from preoperative means to postoperative means.

TABLE IV Patient-Reported Outcomes, Bivariate Analysis*

	VAS		SANE		DASH	ASES
	Preoperative	Postoperative	Preoperative	Postoperative	Postoperative	Postoperative
Age						
Under 30	7.0 ± 2.5	1.7 ± 2.2	40 ± 18	85 ± 22	12.6 ± 19.3	85.7 ± 18.7
30 and over	6.9 ± 2.5	2.4 ± 2.5	35 ± 21	84 ± 15	18.3 ± 17.1	79.0 ± 20.3
Sex						
Female	7.0 ± 2.4	1.9 ± 2.2	37 ± 18	84 ± 18	17.0 ± 19.7	82.3 ± 19.2
Male	6.9 ± 2.2	2.3 ± 2.7	38 ± 23	86 ± 19	12.7 ± 15.6	81.6 ± 21.1
BMI						
Under 30	6.9 ± 2.5	1.8 ± 2.1	36 ± 20	83 ± 19	17.0 ± 19.3	82.7 ± 18.5
30 and over	7.3 ± 2.1	2.9 ± 2.9	41 ± 19	86 ± 16	12.9 ± 6.7	78.8 ± 23.4
Comorbidities						
Diabetes mellitus	7.0 ± 0	6.0 ± 0	40 ± 0	60 ± 0	29.5 ± 0	62 ± 0
Inflammatory arthritis	—	—	—	—	—	—
History of smoking	7.6 ± 2.3	1.2 ± 2.2	43 ± 30	86 ± 15	12.0 ± 14.4	85.8 ± 16.3
History of surgery						
Prior FRR	7.0 ± 2.0	1.7 ± 1.6	35 ± 17	82 ± 18	25.4 ± 15.2	77.8 ± 22.4
Prior ACDF	7.1 ± 1.2	2.8 ± 3.2	39 ± 20	81 ± 17	21.5 ± 17.9	72.8 ± 28.2
Competitive athlete						
Athlete	7.0 ± 2.5	1.6 ± 2.3	43 ± 21	87 ± 23	10.9 ± 19.3	**88.0 ± 18.3****
Nonathlete	7.0 ± 2.3	2.4 ± 2.4	33 ± 18	82 ± 14	**19.3 ± 16.8****	78.1 ± 19.9
Totals	7.0 ± 2.4	2.1 ± 2.4	37 ± 20	84 ± 18	15.4 ± 18.3	82.1 ± 19.7

*All statistical testing was done within demographic subgroups. ACDF = anterior cervical discectomy and fusion, ASES = American Shoulder and Elbow Surgeons, DASH = Disabilities of Hand, Arm, and Shoulder Index, FRR = first rib resection, SANE = single alpha-numeric evaluation, and VAS = visual analog scale. Statistical significance was set as $p < 0.05$ and is denoted by ** and bold text. Competitive athletes were those currently participating in a high, collegiate, or professional sport.

with the advantage of improved visualization, more extensive decompression, and potentially improved overall safety. This series sought to evaluate the outcomes of endoscopic treatment of nTOS in a large retrospective case series.

In this study, patients who underwent endoscopic decompression of infraclavicular predominant nTOS had significant improvement in pain and extremity function. The main factors that affected outcomes included a history of open FRR or cervical spine surgery. When compared with the published literature on open FRR, patients had comparable PROMs and satisfaction rates while having a much lower incidence of major and minor complications (Tables VII and VIII). In comparison with outcomes published in a recent meta-analysis[22], VAS pain scores in our study improved from 7.0 to 2.1, compared with 7.5 to 2.3 for transaxillary FRR and 5.4 to 2.4 for supraclavicular FRR. Furthermore, if success is defined by a Derkash score of "excellent," "good," or "fair" outcomes, there was a 100% success rate in our series, compared with success rates of FRR (transaxillary or supraclavicular) and open scalenectomy of 93.4%, 87.9%, or 97.4%. If success is defined as greater than 50% improvement in symptom relief, our success rate was 94%, compared with 76%, 77%, and 85% for transaxillary FRR, supraclavicular FRR, and isolated scalenectomy, respectively[26]. Finally, the postoperative Disabilities of Hand, Arm, and Shoulder Index (DASH) score of 15.6 was comparable with the DASH scores of 23.6, 27.9, and 13.4 for supraclavicular and transaxillary FRR and open scalenectomy, respectively[22]. With a minimum follow-up of 1 year and a mean follow-up over 2 years, these results should be maintained over long-term follow-up, as most failures of nTOS surgery occur within the first 12 months[20,21].

When interpreting the literature regarding open FRR, it is critical to differentiate between vascular and neurogenic TOS. Although systematic reviews have demonstrated high success rates in most patients undergoing FRR for vascular TOS[26,27,38], outcomes for nTOS are much more variable[14-16,25,26,38], with one study reporting failure rates as high as 68%[15]. Furthermore, the morbidity of FRR and scalenectomy is also relevant. In recent meta-analyses, major complication rates for transaxillary FRR, supraclavicular FRR, and isolated scalenectomy were 14.5% to 22.5%, 8.7% to 22.5%, and 3.6% to 12.6%, respectively[22,26]. These complications include brachial plexopathies, subclavian artery or vein injuries, pneumothorax or hemothorax, pleural effusion, thoracic duct injury, and lymphatic leakage[14-16,26,38]. Conversely, in our series, there were no major complications. The only minor complications included one superficial portal site infection and one case of adhesive capsulitis.

TABLE V Postoperative Patient-Reported Outcomes, Satisfaction, and Derkash Scores*

	No Prior Surgery n = 36	Prior FRR n = 6	Prior ACDF n = 9	All Patients
VAS				
Preoperative	6.6 ± 2.6	7.0 ± 2.0	7.1 ± 1.2	7.0 ± 2.3
Postoperative	1.6 ± 1.9	1.7 ± 1.6	2.8 ± 3.2	2.1 ± 2.4
Change	5.0 ± 3.1	5.3 ± 2.3	4.3 ± 3.4	4.9 ± 3.1
SANE				
Preoperative	39 ± 20	35 ± 17	39 ± 20	37 ± 20
Postoperative	86 ± 17	82 ± 18	81 ± 17	84 ± 18
Change	44 ± 32	47 ± 8.8	33 ± 31	43 ± 30
DASH				
Postoperative	13.1 ± 18.2	25.4 ± 15.2	21.5 ± 17.9	15.4 ± 18.3
ASES				
Postoperative	85.1 ± 16.5	77.8 ± 22.4	72.8 ± 28.2	82.1 ± 19.7
Derkash		**	**	
Excellent	22	**0**	**3**	33
Good	8	**5**	**5**	13
Fair	2	**0**	**0**	5
Poor	0	**0**	**0**	0
Satisfaction				
Very satisfied	23	2	5	35
Satisfied	6	3	3	11
Neither	3	0	0	5
Slightly dissatisfied	0	0	0	0
Not satisfied	0	0	0	0

*All statistical comparison tests were done within subgroups based on surgical history. ACDF = anterior cervical discectomy and fusion, ASES = American Shoulder and Elbow Surgeons, DASH = Disabilities of Hand, Arm, and Shoulder Index, FRR = first rib resection, SANE = single alpha-numeric evaluation, and VAS = visual analog scale. Statistical significance was set as $p < 0.05$ and is denoted by ** and bold text.

The role of the pectoralis minor is important to understand when interpreting outcomes associated with its surgical release. We believe infraclavicular predominant nTOS occurs along a spectrum, starting with pectoralis minor syndrome and progressing to more significant degrees of morbidity. Overactivity of this muscle leads to scapular protraction and narrowing of the retropectoralis minor space[3,12,13,28,29,32,50]. This is exacerbated by shoulder extension, overhead activities, or attempts at scapular retraction, leading to radiating pain and paresthesia. Furthermore, it leads to scapular dyskinesia during active shoulder motion, compressing the underlying brachial plexus. The pectoralis minor is thought to be a reason for failure of open FRR in the treatment of SGD-nTOS[28,31,51]. This was consistent with our study, as patients with a prior open FRR experienced significant improvements

TABLE VI Change in VAS Pain Scores and SANE*

	VAS			SANE		
	Preoperative	Postoperative	p	Preoperative	Postoperative	p
No prior surgery	6.6 ± 2.6	1.6 ± 1.9	**<0.001****	39 ± 20	86 ± 17	**<0.001****
Prior FRR	7.0 ± 2.0	1.7 ± 1.6	**0.027****	35 ± 17	82 ± 18	**0.027****
Prior ACDF	7.1 ± 1.2	2.8 ± 3.2	**0.015****	39 ± 20	81 ± 17	**0.017****
Overall	7.0 ± 2.3	2.1 ± 2.4	**<0.001****	37 ± 20	84 ± 18	**<0.001****

*ACDF = anterior cervical discectomy and fusion, FRR = first rib resection, SANE = single alpha-numeric evaluation, and VAS = visual analog scale. Wilcoxon signed-rank test was used for paired data. Statistical significance was set as $p < 0.05$ and is denoted by ** and bold text.

TABLE VII Comparison w/Blondin et al.[22], Systematic Review and Meta-Analysis of Neurogenic Thoracic Outlet Syndrome Approaches*

	FRR–TA	FRR–SC	Scalenectomy	Endoscopic PMR, Neurolysis (This Cohort)	p
Preoperative VAS	7.5	5.4	NA	7	
Postoperative VAS	2.3	2.4	NA	2.1	
Postoperative DASH	27.9	23.6	13.4	15.4	
Postoperative Derkash†	87.9%	93.2%	97.4%	100%	
Major complications‡	6.8%	7.8%	1.1%	0%	**<0.001****
All complications§	14.5%	8.7%	3.6%	3.3%	**<0.00001****

*DASH = Disabilities of Hand, Arm, and Shoulder Index, FFR = first rib resection, PM = pectoralis minor, SC = supraclavicular, TA = transaxillary, and VAS = visual analog scale. †Derkash success classified as "Excellent, Good, or Fair" outcomes per Blondin et al.[22] ‡Major complications: pneumothorax, hematoma/hemothorax, lymphatic leak/thoracic duct injury, subclavian artery/vein thrombosis or laceration, pleural effusion, pneumonia, Horner syndrome, readmission. §Minor complications: swelling, reinjury, stitch granuloma, temporary phrenic nerve injury, wound infection, excessive scar, temporary phrenic nerve injury, stitch granuloma, swelling. Statistical significance was set as $p < 0.05$ and is denoted by ** and bold text.

preoperatively to postoperatively, despite worse outcomes compared with those without prior surgery. Open PMR has demonstrated promising outcomes overall and relatively few complications, with success rates up to 90%[7,9,27,30,52]. Poor visualization with open PMR, however, limits possible decompression without a more extensive muscle compromising dissection.

Open[7,9,14-16,25,26,30,38,53] and endoscopic[32,34,35,50,54,55] PMR have both demonstrated success. Over the last few decades, however, shoulder endoscopy has seen many innovations in instability[56,57], rotator cuff repair[58], and tendon transfers[59,60] and offers many advantages. These include the following: (1) improved visualization of critical anatomy; (2) the ability to perform a more extensive decompression of the SSN, release the pectoralis minor and subclavius, and decompress the retropectoralis and infraclavicular brachial plexus; and (3) potentially improved safety given the easier visualization and lack of retractors. This is supported by the lack of major complications and symptom relief scores greater than 90% in this series.

This study has several limitations. Our analysis compares postoperative DASH scores to previously described literature, and there may be differences in the diagnostic criteria for nTOS of infraclavicular etiology, as well as in patient selection. PROMs for TOS are often combined based on primary arterial, venous, or neurogenic etiology. Older literature on FRR and scalenectomy cohorts may include patients with more severe or combined pathologies, whose symptoms may have been more severe to justify the added risk and morbidity, negatively biasing previously published results and influencing comparisons. We would emphasize that a deliberate diagnostic evaluation is essential in the accurate diagnosis of infraclavicular predominant nTOS and indication for surgery, including positive response to staged local anesthetic or botulinum toxin administration to the pectoralis minor and anterior/middle scalenes[3,46]. Despite some data suggesting outcomes after decompression plateau after 12 months, these interventions were more invasive; therefore, recurrence data beyond 2 years would be beneficial, especially in a high-risk

TABLE VIII Comparison w/Yin et al. (2019), Outcomes of Surgical Management of Neurogenic Thoracic Outlet Syndrome: A Systematic Review and Bayesian Perspective*

	FRR–TA	FRR–SC	Scalenectomy	Arthroscopic PMR, Neurolysis (This Cohort)
Success†	76%	77%	85%	94%
Symptom relief >50%	67%	71%	69%	94%
Complete symptom relief (100%)	53%	57%	61%	65%
Complications‡	22.5%	25.9%	12.6%	3.3%

*FFR = first rib resection, PMR = pectoralis minor release, SC = supraclavicular, and TA = transaxillary. †Success defined as greater than 50% improvement in symptoms, no significant residual symptoms, and no reoperation per Yin et al. ‡Complications: pneumothorax, hematoma/hemothorax, chylothorax, lymphatic leak/thoracic duct injury, subclavian artery/vein injury, pleural effusion, pneumonia, brachial plexus injury, infection, shoulder stiffness, readmission, death.

cohort[21]. Finally, some authors distinguish neurogenic pectoralis minor syndrome as distinct from nTOS, with positive Tinel at the scalene triangle being a differentiator[7]. We group these as a single entity with 2 possible primary dynamic compression locations: (1) mixed vascular and brachial plexus compression at the interscalene triangle and first rib, or (2) retropectoralis compression of the brachial plexus by the pectoralis minor and secondarily the subclavius and/or the suprascapular notch[4].

Conclusion

Endoscopic PMR and infraclavicular brachial plexus decompression is a viable and effective treatment option for nTOS of infraclavicular origin driven by the pectoralis minor and associated scapular girdle dyskinesia. This cohort demonstrates improved clinical outcomes, comparable with open scalenectomy and FRR, with high patient satisfaction and no major complications. Long-term studies and large multicenter trials will help further define diagnostic and treatment algorithms. ■

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