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CAUSES OF PERSISTENT AND RECURRENT SYMPTOMS AFTER FIRST-RIB RESECTION FOR NEUROGENIC THORACIC OUTLET SYNDROME: A NARRATIVE REVIEW

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ABSTRACT

Neurogenic thoracic outlet syndrome (NTOS) may persist after surgery or recur after an initial period of improvement. These outcomes are clinically important because reoperation is technically more demanding, the anatomical cause is often uncertain, and symptom relief is less predictable than after primary decompression. This narrative review examines the mechanisms, diagnostic work-up, and treatment of persistent and recurrent symptoms after first-rib resection and related thoracic outlet decompression. A targeted review of clinical series, registry studies, long-term outcome studies, and systematic reviews was performed, with particular emphasis on studies describing reoperative findings and outcomes. The literature consistently identifies several overlapping mechanisms: retained or residual first-rib segments, residual or reattached scalene muscle, perineural fibrosis, unrecognized pectoralis minor syndrome, multilevel compression, mixed neurovascular compression, secondary injury, and an incorrect or incomplete original diagnosis. Importantly, recurrent NTOS may occur even after an anatomically complete primary decompression; in such cases, dense perineural scar tissue encasing the brachial plexus can be the principal operative finding. Dynamic arterial compression may coexist with neurogenic symptoms and should be considered when discoloration, exertional ischemic symptoms, a positional bruit, or marked changes in subclavian artery flow are present. Diagnostic injections add functional information: a positive response to ultrasound-guided botulinum toxin injection of the anterior scalene and pectoralis minor muscles has a high positive predictive value for surgical response, although a negative response does not reliably exclude benefit. Reoperation is most defensible when symptoms, examination, imaging, and injection response converge on a correctable anatomical target. Complete supraclavicular reoperation and isolated reoperative brachial plexus neurolysis can improve disability and symptoms in selected patients, but outcomes remain variable and complications may be underestimated by 30-day reporting. Careful phenotyping, exclusion of mimics, and treatment in experienced multidisciplinary centers are central to avoiding unnecessary repeat surgery and improving long-term results.

KEYWORDS

Neurogenic Thoracic Outlet Syndrome, First-Rib Resection, Recurrent Symptoms, Persistent Symptoms, Brachial Plexus Neurolysis, Perineural Fibrosis, Pectoralis Minor Syndrome, Reoperation

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1. Introduction

Neurogenic thoracic outlet syndrome is a heterogeneous compression neuropathy in which the brachial plexus is irritated or compressed within the interscalene triangle, costoclavicular space, or retropectoralis minor space. The clinical picture may include pain in the neck, shoulder girdle, upper chest, arm, or hand; paresthesia; fatigue; weakness; and positional aggravation during overhead activity. No single examination maneuver, imaging study, or electrodiagnostic test has sufficient sensitivity and specificity to establish the diagnosis in isolation. Consequently, the quality of surgical outcomes depends not only on operative technique but also on the accuracy of diagnosis, the localization of compression, and the exclusion of competing explanations for upper-extremity symptoms.

Surgical treatment generally combines one or more of the following: first-rib resection, anterior and middle scalenectomy, division of fibrous bands, brachial plexus neurolysis, cervical rib resection when present, and pectoralis minor tenotomy in selected patients. Systematic reviews suggest that most carefully selected patients improve after surgery, but the evidence base is dominated by retrospective series with variable diagnostic criteria, surgical methods, follow-up intervals, and outcome definitions [1,2]. A pooled analysis reported meaningful improvement after surgery for NTOS, whereas a Bayesian systematic review found broadly similar pooled success rates for transaxillary first-rib excision and supraclavicular first-rib excision with scalenectomy; supraclavicular release without rib resection also produced favorable results in selected cohorts, with fewer reported complications [1,2]. These findings imply that removal of the first rib is not, by itself, the universal determinant of success. The more relevant question is whether all clinically important sites and structures responsible for compression have been adequately addressed.

Persistent symptoms are generally understood as the absence of clinically meaningful improvement after primary surgery. Recurrent symptoms refer to the return of a characteristic symptom complex after a period of partial or substantial postoperative relief. This distinction matters. Persistent symptoms raise concern for an incorrect diagnosis, incomplete decompression, an untreated second site of compression, or irreversible pain sensitization. Recurrent symptoms more strongly suggest scar-related re-compression, residual anatomy that becomes clinically important over time, recurrent muscle attachment, new injury, or progression of a coexisting disorder. In practice, the categories overlap, and published series frequently use the terms failed, residual, persistent, and recurrent NTOS inconsistently.

Long-term outcome studies show that improvement and complete symptom resolution are not synonymous. In a cohort of patients undergoing first-rib resection and scalenectomy, chronic pain syndromes, opioid use, smoking, neck or shoulder disease, and postoperative complications were associated with worse quality-of-life scores [3]. Conversely, durable benefit has also been reported after supraclavicular decompression without rib resection, with only a small minority later requiring rib excision [4]. These observations reinforce a central theme of this review: poor outcome after first-rib resection is usually multifactorial, and repeat surgery should not be offered merely because symptoms remain after the rib has been removed.

The objective of this narrative review is to synthesize the clinical literature on the causes of persistent and recurrent symptoms after first-rib resection for NTOS, to describe a mechanism-based diagnostic strategy, and to summarize the role, expected benefits, and limitations of reoperative treatment.

2. Methods

A targeted narrative review was performed using the full texts of clinical studies and reviews focused on primary and reoperative surgery for NTOS. The evidence base included retrospective and prospective institutional series, a national registry study, long-term functional outcome studies, and systematic reviews. Particular emphasis was placed on reports that described operative findings during reoperation, distinguished persistent from recurrent symptoms, evaluated pectoralis minor or scalene injections, or reported validated patient-reported outcome measures.

The synthesis was organized around clinically actionable mechanisms rather than by surgical approach alone. Evidence was grouped into incomplete osseous decompression, residual scalene muscle, perineural fibrosis after anatomically complete decompression, pectoralis minor syndrome and multilevel compression, mixed neurovascular compression, diagnostic error and coexisting disorders, and patient-related or post-treatment factors. Because the included literature is heterogeneous and largely nonrandomized, no quantitative meta-analysis was attempted. Numerical results are presented to illustrate the magnitude and consistency of findings rather than to imply direct comparability between cohorts.

3. Scope and Definitions of the Problem

The reported frequency of minimal improvement or later recurrence after NTOS surgery varies from approximately 5% to 30%, depending on patient selection, operative technique, outcome definition, and duration of follow-up [5-9]. Short follow-up can substantially underestimate recurrence because many patients improve initially and return months or years later. In the series of Jammeh and colleagues evaluating recurrence after a previous anatomically complete supraclavicular decompression, the mean interval to reoperation was approximately 30 months; 59% of recurrences developed within two years and 89% within five years [9]. The estimated long-term recurrence rate after primary anatomically complete decompression in that center was 5.6%, providing a useful benchmark but not a universal rate because the cohort was highly selected and treated in a specialized center.

Persistent and recurrent symptoms should also be distinguished from expected postoperative recovery. Early pain, weakness, altered shoulder mechanics, paresthesia, and temporary activity limitation can occur during normal healing. A diagnosis of surgical failure should not be made before adequate wound healing, progressive rehabilitation, and reassessment of the preoperative symptom pattern. Conversely, new objective weakness, progressive atrophy, vascular compromise, severe neuropathic pain, or symptoms clearly different from the preoperative syndrome warrant prompt investigation rather than prolonged observation.

4. Mechanisms of Persistent and Recurrent Symptoms

4.1. Retained or residual first-rib segments and other osseous causes

Incomplete osseous decompression is among the most reproducible findings in reoperative series. A residual anterior or posterior first-rib segment can remain in close proximity to the brachial plexus, subclavian vessels, or residual scalene tissue. The rib remnant may directly narrow the outlet, serve as a fixed point for scar formation, or permit residual muscle to reattach. The clinical significance of a remnant depends on its size, location, relationship to the plexus, and concordance with the patient's symptoms; not every postoperative rib stump is pathological.

In the series by Ambrad-Chalela and colleagues, recurrent NTOS was attributed to incomplete first-rib resection, an intact first or second rib, ectopic bands, pectoralis minor tendon compression, and adherent residual scalene muscle [5]. Carefully selected patients with an identifiable structural cause achieved good or excellent results after targeted reoperation, although the small cohort and retrospective design limit generalizability. More recent data from Jammeh and colleagues provide a broader anatomical picture. Among 90 patients reoperated after procedures performed at other institutions, retained or residual first-rib tissue was common, particularly after transaxillary operations; residual scalene muscle was also frequent [7]. The combination of rib remnants and residual muscle supports the concept that incomplete removal of one structure can facilitate recurrent compression by another.

Goeteyn and colleagues similarly treated patients with persistent or recurrent NTOS using a supraclavicular redo decompression that included cartilage-to-cartilage rib resection, complete anterior and middle scalenectomy, and brachial plexus neurolysis [8]. Patients with an identifiable first-rib remnant appeared to have a more favorable response than those without a clear osseous target, suggesting that a discrete mechanical lesion improves the probability that revision surgery will address the true cause of symptoms.

However, the presence of a rib remnant must not be interpreted in isolation. Long-term improvement after supraclavicular release without rib resection has been reported, and only 5.3% of patients in one long-term cohort later required rib removal [4]. The Bayesian systematic review by Yin and colleagues also found favorable pooled outcomes for supraclavicular release with the first rib left intact [2]. Thus, the literature does not support the simplistic conclusion that every persistent symptom after NTOS surgery requires more extensive rib resection. Osseous revision is most persuasive when cross-sectional imaging demonstrates a substantial remnant or abnormal rib, the physical examination localizes symptoms to the costoclavicular region, and the overall symptom pattern remains compatible with NTOS.

4.2. Residual scalene muscle, muscle reattachment, and fibromuscular bands

Residual anterior or middle scalene muscle is another common cause of persistent or recurrent compression. A transaxillary first-rib resection may provide limited access to the proximal scalene muscles and brachial plexus, leaving muscle fibers or fibrous attachments behind. Even after a supraclavicular procedure, a divided muscle may reattach to residual periosteum, the first-rib stump, or surrounding fascia. With healing, the residual muscle and scar can form a fixed tether around the plexus.

Ambrad-Chalela and colleagues identified adherent residual scalene muscle in most of their reoperated patients with a correctable musculotendinous cause [5]. Jammeh and colleagues found residual scalene muscle in a large proportion of patients referred after previous surgery, with the highest prevalence after transaxillary decompression [7]. These findings are anatomically plausible: first-rib resection alone does not necessarily provide complete decompression of the interscalene triangle, and division without adequate excision may permit reattachment.

The practical implication is that the operative report from the primary procedure should be reviewed in detail. The phrase 'first-rib resection and scalenectomy' does not establish how much rib or muscle was removed, whether the posterior rib was divided near the costotransverse articulation, whether the scalene muscles were excised or merely divided, whether fibrous bands were released, or whether the plexus was externally neurolysed. When available, preoperative and postoperative imaging should be compared to reconstruct the actual anatomy rather than relying on the procedure name.

4.3. Perineural fibrosis after anatomically complete decompression

A major advance in understanding recurrent NTOS is the recognition that symptoms can recur even when the primary decompression was anatomically complete. In this setting, there may be no rib remnant and no residual scalene muscle. The dominant mechanism is dense fibrous scar tissue surrounding, tethering, or encasing the brachial plexus.

Jammeh and colleagues specifically studied 85 patients who underwent reoperative brachial plexus neurolysis after a previous anatomically complete supraclavicular decompression consisting of anterior and middle scalenectomy, first-rib resection, and complete brachial plexus neurolysis [9]. At reoperation, no patient had residual scalene muscle or a first-rib remnant. Instead, the operative finding was dense fibrous scar tissue surrounding or encasing the plexus, often with adherence to the scalene fat pad, extrapleural fascia, and the bed of the resected rib. This series is important because it separates scar-mediated recurrence from technically incomplete primary decompression.

The mean preoperative QuickDASH score before reoperation was 65.2, indicating substantial disability. After reoperative neurolysis, the score improved by 23.3 points, or approximately 34%, during long-term follow-up. Patient-rated outcomes were excellent in 24%, good in 42%, fair in 26%, and poor in 8% [9]. These results show that isolated reoperative neurolysis can provide meaningful benefit, but they also demonstrate that scar-mediated recurrence is not uniformly reversible. Thirteen percent of patients later underwent a third supraclavicular operation for re-recurrent symptoms, a higher recurrence rate than after primary decompression.

The biology of perineural fibrosis remains incompletely understood. Scar may limit nerve excursion, transmit traction during shoulder movement, distort local microvascular supply, and create persistent mechanical sensitivity even without severe static compression. Secondary injury may further disrupt a previously stable scar-nerve interface; in the Jammeh series, an intervening injury precipitated recurrence in 16.5% of patients [9]. This finding is particularly relevant for athletes and patients whose work involves repetitive overhead use, sudden traction, or impact.

Anti-adhesion barriers and nerve wrapping have been used in an attempt to preserve nerve mobility, but high-quality comparative evidence is lacking. In the Jammeh series, the plexus was wrapped with an absorbable polylactide film after neurolysis [9]. The need for further recurrence research is clear: preventing re-scarring may be as important as the technical completeness of the initial decompression.

4.4. Pectoralis minor syndrome and multilevel compression

Compression at the retropectoralis minor space can coexist with supraclavicular NTOS or become the dominant source of symptoms after proximal decompression. Pectoralis minor syndrome is suggested by tenderness near the coracoid process or anterior axilla, reproduction of distal symptoms with local pressure, and aggravation during scapular protraction or overhead activity. Failure to identify this second compression site can produce persistent symptoms even when the interscalene and costoclavicular spaces have been adequately decompressed.

Sanders emphasized the high prevalence of neurogenic pectoralis minor syndrome in patients with recurrent NTOS [6]. In that series, pectoralis minor tenotomy alone produced a good result in 69% of operations, whereas combined pectoralis minor tenotomy and brachial plexus decompression produced a good result in 58%; approximately one fifth of procedures in each group were considered failures [6]. The choice of procedure was guided by the clinical distribution of symptoms and the response to pectoralis minor and scalene muscle blocks.

Pectoralis minor syndrome should therefore be considered both before primary surgery and during reassessment after a failed procedure. A distal compression site may have been missed initially, may have become clinically apparent after proximal decompression, or may reflect altered scapular mechanics during recovery. Reoperation limited to the supraclavicular space is unlikely to succeed when the dominant pain generator lies beneath the pectoralis minor tendon.

4.5. Mixed neurovascular compression and a dynamic arterial component

Some patients classified as having NTOS also exhibit dynamic arterial compression without thrombosis or aneurysm. This does not prove that every positional duplex abnormality is clinically meaningful, because vascular changes can occur in asymptomatic individuals. Nevertheless, a combination of neurological symptoms with exertional pallor or rubor, arm discoloration, coldness, a positional infraclavicular bruit, distal embolic history, or a marked change in subclavian artery velocity should prompt evaluation for mixed neurovascular compression.

Likes and colleagues described 22 patients with NTOS and signs of arterial compromise who underwent first-rib resection and scalenectomy, with additional cervical or second-rib resection when indicated [10]. Twelve patients had a greater than 50% positional change in subclavian artery velocity, and all 22 improved after surgery during relatively short follow-up. The series does not address recurrent NTOS directly, but it has an important diagnostic implication: an apparent failure of conservative treatment or an incomplete response after neurogenic decompression may reflect an unrecognized vascular component. In a patient with recurrent symptoms, dynamic duplex findings should be interpreted together with vascular symptoms, examination, and bony anatomy rather than used as a stand-alone diagnosis.

4.6. Incorrect diagnosis, coexisting disorders, and central pain amplification

The diagnosis of NTOS is one of exclusion, and persistent symptoms after surgery may reveal that the original diagnosis was incomplete or incorrect. Cervical radiculopathy, cervical myelopathy, shoulder instability or rotator-cuff disease, peripheral nerve entrapment, complex regional pain syndrome, inflammatory or systemic neuropathy, and myofascial pain may mimic or coexist with NTOS. A double-crush pattern is particularly relevant: proximal plexus irritation can coexist with ulnar neuropathy at the elbow, carpal tunnel syndrome, or cervical root disease. Treating only one site may produce partial improvement and leave the patient with a symptom pattern that is mistakenly labeled recurrent NTOS.

Persistent pain may also become progressively less dependent on a single anatomical lesion. Chronic opioid use and other chronic pain syndromes were strongly associated with poorer long-term quality-of-life scores after first-rib resection and scalenectomy [3]. This association does not establish causation, but it suggests that central sensitization, psychological distress, sleep disturbance, reduced physical conditioning, and long-standing functional avoidance can modulate outcome independently of decompression. These factors should not be used to dismiss symptoms; rather, they should broaden treatment beyond repeated anatomical surgery.

Patient-related and postoperative factors can also affect recovery. Smoking, neck or shoulder comorbidity, older age in some cohorts, postoperative complications, and repeated injections or operations have been associated with worse outcomes [3]. Recurrent symptoms after a new accident, fall, or sport-related traction injury deserve particular attention because a secondary event may disrupt a previously successful decompression or exacerbate perineural scarring [9].

5. Diagnostic Evaluation After Failed Primary Surgery

5.1. Reconstructing the postoperative course

The first diagnostic task is to determine whether the patient truly had no benefit or whether there was a period of meaningful improvement. A detailed timeline should include the immediate postoperative response, the best level of function achieved, the duration of benefit, the onset and progression of recurrent symptoms, new injuries, changes in work or sport exposure, and the effect of rehabilitation. A symptom pattern identical to the preoperative syndrome after a symptom-free interval supports recurrence. A completely different pattern, new dermatomal pain, focal distal neuropathy, or non-positional constant pain should trigger a wider differential diagnosis.

The original operative report should be obtained whenever possible. Key details include the approach, extent of rib resection, treatment of the rib head and posterior stump, anterior and middle scalene excision, management of a cervical rib or fibrous bands, brachial plexus neurolysis, pectoralis minor tenotomy, vascular procedures, intraoperative complications, and any anti-adhesion material used. Postoperative radiographs or computed tomography should be compared with preoperative studies.

5.2. Physical examination

The examination should localize symptoms rather than simply reproduce them. Palpation over the supraclavicular plexus, scalene triangle, costoclavicular space, and coracoid region should be documented separately. Provocative maneuvers such as the elevated arm stress test and upper limb tension test may support the diagnosis but are not specific. The examiner should assess scapular position and motion, shoulder range of motion, rotator-cuff function, cervical motion, reflexes, objective strength, atrophy, sensory deficits, distal pulses, color changes, swelling, and focal Tinel signs at the cubital and carpal tunnels.

Vascular red flags include exertional pallor or cyanosis, coolness, a positional bruit, significant swelling, venous collateral formation, ischemic digital symptoms, or embolic events. These findings justify targeted vascular imaging. Conversely, isolated loss of pulse during a provocative maneuver is common and should not be equated with clinically important arterial TOS.

5.3. Imaging and electrodiagnostic testing

Plain chest radiography is a practical first step for detecting a cervical rib, abnormal first or second rib, or a large residual rib segment. Computed tomography with multiplanar or three-dimensional reconstruction provides more precise assessment of anterior and posterior first-rib remnants, costotransverse anatomy, heterotopic bone, and the relationship of osseous structures to the clavicle. Imaging should answer a specific anatomical question; the mere presence of postoperative change does not establish causation.

Dynamic duplex ultrasonography is useful when vascular symptoms are present. The Likes series illustrates how substantial positional changes in subclavian artery flow can coexist with neurogenic symptoms [10]. However, dynamic vascular compression must be correlated with symptoms and physical findings because asymptomatic positional changes are common. Cross-sectional angiography may be appropriate when arterial injury, aneurysm, thrombosis, embolization, or severe fixed compression is suspected.

High-resolution ultrasound and magnetic resonance imaging can help identify other pathology, evaluate distal nerve entrapment, and, in selected cases, demonstrate focal scarring, altered nerve course, or muscle abnormalities. Magnetic resonance neurography may provide additional information when a structural plexus lesion is suspected, but evidence supporting its routine use in reoperative NTOS remains limited. Electrodiagnostic studies are valuable for identifying cervical radiculopathy, lower-trunk plexopathy, ulnar neuropathy, carpal tunnel syndrome, or other neuropathies. A normal study does not exclude nonspecific NTOS, but it makes objective progressive nerve injury less likely and can prevent misattribution of symptoms.

5.4. Diagnostic and prognostic injections

Local anesthetic blocks of the anterior scalene and pectoralis minor muscles provide a reversible functional test. A convincing temporary improvement in the patient's characteristic symptoms and provocative tolerance supports the relevance of the injected site. In the recurrent NTOS literature, scalene and pectoralis minor blocks have been used to select the level of reoperation [5,6]. The test is most useful when the response is substantial, anatomically coherent, and assessed with predefined functional tasks rather than by a vague report of feeling better.

Ultrasound-guided botulinum toxin injection provides a longer period of muscle relaxation and may have prognostic value. Donahue and colleagues analyzed 157 patients undergoing 178 injections into both the anterior scalene and pectoralis minor muscles before surgery [11]. Better injection response correlated with better surgical response, and a favorable injection response had a positive predictive value of 99% and specificity of 90% for favorable surgical outcome. Sensitivity was 66%, and the negative predictive value was only 14% [11]. Thus, a strong positive response is useful evidence in favor of a muscle-mediated compression target, whereas a negative response should not be used alone to deny surgery. The study included a selected surgical population and was retrospective, so its performance characteristics should not be generalized to all patients evaluated for NTOS.

6. Management

6.1. Nonoperative management and timing of reoperation

Unless there is progressive objective neurological deficit, vascular injury, thrombosis, or another urgent structural problem, most patients should undergo a renewed course of mechanism-specific nonoperative treatment before revision surgery. Rehabilitation should address scapular control, posture, breathing mechanics, neural mobility, gradual overhead tolerance, and avoidance of repetitive provocative loading. Pain management may include neuropathic agents, sleep optimization, and treatment of coexisting cervical, shoulder, or distal nerve disorders. The purpose is not merely to repeat generic physical therapy, but to determine whether symptoms remain sufficiently severe, anatomically coherent, and resistant to targeted treatment to justify reoperation.

Reoperation should be considered when the diagnosis remains sound, disability is substantial, conservative management has failed, and the evaluation identifies a plausible correctable mechanism. The strongest indications are a substantial rib remnant or abnormal rib, residual or reattached scalene muscle, a positive and concordant scalene or pectoralis minor block, clear pectoralis minor syndrome, or dense scar-mediated recurrent NTOS after a previously successful complete decompression. Nonspecific pain without a localized target is a weak indication.

6.2. Mechanism-based reoperative strategies

When incomplete decompression is present, an anatomically complete supraclavicular revision allows direct visualization of the brachial plexus, residual scalene muscle, rib remnants, fibrous bands, and the subclavian artery. Jammeh and colleagues used complete supraclavicular reoperation to remove retained or residual first-rib and cervical-rib tissue, excise residual anterior and middle scalene muscle, and perform external neurolysis [7]. At a mean follow-up of more than five years, QuickDASH improved by 21 points; outcomes were rated excellent in 10%, good in 36%, fair in 43%, and poor in 11% [7]. The high proportion of fair outcomes is clinically important: most patients improved, but complete or near-complete recovery was not the usual result.

Goeteyn and colleagues reported significant improvement in DASH, Cervical Brachial Symptom Questionnaire, and TOS Disability scores after supraclavicular redo decompression [8]. Complications occurred in approximately 18%, including chyle leak, transient phrenic nerve palsy, and Horner syndrome; one Horner syndrome was permanent. These data support the effectiveness of revision in selected patients but also show why redo surgery should be concentrated in experienced centers.

When the primary decompression was anatomically complete and dense perineural scar is the dominant finding, reoperative external neurolysis is the principal procedure. In the Jammeh neurolysis series, no intraoperative nerve injury occurred, the mean hospital stay was 3.6 days, and QuickDASH improved by 23.3 points over long-term follow-up [9]. Nevertheless, 8% rated the result poor and 12.9% later underwent a third operation. Surgeons and patients should therefore understand that neurolysis can improve function without eliminating the biological tendency to re-scar.

When symptoms localize to the retropectoralis minor space, pectoralis minor tenotomy may be performed alone or with supraclavicular revision. Sanders' results suggest that isolated pectoralis minor tenotomy can be effective in patients whose diagnostic block and symptom distribution support a distal compression site [6]. A combined procedure is more appropriate when both supraclavicular and subcoracoid compression are present.

6.3. Expected outcomes and complications

Outcome counseling should distinguish partial improvement from complete relief. Across primary surgical series, approximately three quarters to nine tenths of selected patients report some benefit, but complete symptom resolution is less common [1,2,12]. Reoperative cohorts generally begin with greater disability and have more modest, less predictable outcomes. A 20- to 23-point improvement in QuickDASH is clinically meaningful, yet many patients remain functionally impaired after revision [7-9].

Complication rates are difficult to compare because studies use different definitions and follow-up intervals. The national Finnish registry study of 699 first-rib resections found registry-coded complications in 9.8% within 30 days and 18.8% within one year; vascular complications increased from 5.9% to 10.3% and neural complications from 0.7% to 2.7% over the same interval [13]. These figures include a broad national

population and may not map directly onto specialized NTOS cohorts, but they demonstrate that 30-day reporting can underestimate clinically relevant morbidity. Potential complications of primary or revision surgery include pneumothorax, hemothorax, chyle leak, vascular injury, phrenic or long thoracic nerve injury, Horner syndrome, brachial plexus injury, infection, chronic neuropathic pain, and recurrent scar formation.

Table 1. Key studies informing the evaluation of persistent and recurrent symptoms

Study	Population / design	Principal finding	Clinical relevance
Ambrad-Chalela et al. [5]	17 patients; 20 reoperations for recurrent NTOS	Correctable causes included incomplete or intact ribs, ectopic bands, pectoralis minor tendon compression, and adherent residual scalene muscle.	Supports mechanism-specific reoperation when a discrete structural lesion is identified.
Sanders [6]	86 patients; 104 operations for recurrent NTOS	Pectoralis minor tenotomy alone produced 69% good results; combined tenotomy and plexus decompression produced 58% good results.	Highlights pectoralis minor syndrome and multilevel compression.
Jammeh et al. [7]	90 patients after previous operations at other centers	Residual scalene muscle and retained or residual first-rib tissue were common; QuickDASH improved by 21 points after complete revision.	Demonstrates the frequency of incomplete primary decompression and the potential of complete supraclavicular revision.
Goeteyn et al. [8]	45 patients with persistent or recurrent NTOS	Validated disability scores improved after redo supraclavicular decompression; complications occurred in about 18%.	Shows both benefit and nontrivial risk of redo surgery.
Jammeh et al. [9]	85 patients after previous anatomically complete decompression	Dense perineural scar encased the plexus; QuickDASH improved by 23.3 points after isolated reoperative neurolysis.	Proves that recurrence can occur despite complete rib and scalene removal.
Likes et al. [10]	22 patients with NTOS and dynamic arterial compromise	Neurological and arterial symptoms improved after first-rib resection and scalenectomy.	Mixed neurovascular compression should be sought when vascular features accompany recurrent symptoms.
Donahue et al. [11]	157 patients; 178 ultrasound-guided botulinum toxin injections before surgery	A positive response predicted favorable surgery with 99% PPV and 90% specificity; NPV was only 14%.	A strong positive injection response supports surgery, but a negative response does not exclude benefit.
Rochlin et al. [3]	162 primary FRRS patients; long-term quality-of-life analysis	Chronic pain, opioid use, smoking, neck/shoulder disease, and complications predicted poorer outcomes.	Patient factors and coexisting disorders influence persistent disability.
Ruopsa et al. [4]	94 patients after supraclavicular release without rib resection	Long-term symptom reduction was common; 5.3% later underwent rib resection.	The first rib is not the sole determinant of successful decompression.
Pääkkönen et al. [13]	National registry; 699 first-rib resections	Complications rose from 9.8% at 30 days to 18.8% at one year.	Longer surveillance is needed to capture morbidity.

7. Discussion

The literature supports a mechanism-based rather than procedure-based model of surgical failure. A patient does not have recurrent NTOS simply because symptoms returned after first-rib resection, and the fact that the rib has been removed does not identify the current pain generator. The most defensible explanations fall into three broad categories: incomplete primary decompression, recurrent compression caused by scar or secondary injury, and symptoms arising from a different or additional diagnosis.

Incomplete decompression is the most surgically intuitive category. Rib remnants, residual scalene muscle, and untreated pectoralis minor compression are repeatedly documented in reoperative series [5-8]. These patients often have a visible target and may experience meaningful improvement after complete revision. Yet the long-term results of rib-sparing decompression caution against treating the first rib as the only relevant structure [2,4]. A small rib stump on imaging is not, by itself, an indication for surgery; causality requires concordant clinical localization and exclusion of competing disorders.

Scar-mediated recurrence after a truly complete decompression is more difficult. The Jammeh neurolysis series demonstrates that dense perineural fibrosis can be sufficient to reproduce NTOS without residual rib or scalene muscle [9]. It also reveals the limits of revision: although two thirds of patients rated the outcome good or excellent and disability improved substantially, re-recurrence remained more common than after primary surgery. These findings should temper expectations and motivate research into nerve mobility, anti-adhesion strategies, rehabilitation after neurolysis, and the biological determinants of excessive scar formation.

The new evidence on diagnostic injections provides a useful bridge between anatomy and symptoms. An imaging abnormality is static, whereas NTOS is often dynamic. A positive, muscle-specific anesthetic or botulinum toxin response indicates that reducing tension or volume at a proposed compression site changes the patient's characteristic symptoms. Donahue and colleagues found a particularly high positive predictive value for surgery after ultrasound-guided botulinum toxin injection of both anterior scalene and pectoralis minor muscles [11]. The low negative predictive value is equally important: nonresponse may reflect incomplete chemodenervation, incorrect dose or target, severe fixed compression, scar rather than muscle-mediated compression, or limitations in outcome assessment. Therefore, injection response should modify probability, not function as a binary gatekeeper.

Mixed neurovascular compression deserves greater attention during reassessment. The study by Likes and colleagues shows that a subset of patients with neurogenic symptoms also has clinically relevant dynamic arterial compromise [10]. In recurrent cases, a vascular component may have been missed before primary surgery, may persist because of incomplete osseous decompression, or may arise from an abnormal rib-clavicle relationship. Dynamic duplex should be reserved for patients with vascular features and interpreted cautiously, but it can materially change management when findings are concordant.

Patient selection remains the decisive variable. Reoperation is more likely to help when there was an initial response to the primary operation, the recurrent symptom pattern remains characteristic, disability is substantial, conservative care has failed, and a correctable anatomical or functional target is demonstrated. It is less likely to help when pain is diffuse and constant, examination findings are inconsistent, no target is identified, or untreated cervical, shoulder, distal nerve, systemic, or centralized pain conditions dominate the presentation. In these patients, additional surgery can compound scar formation and reinforce disability without addressing the underlying problem.

This review has limitations. Most available studies are retrospective, originate from high-volume referral centers, and include highly selected patients. Definitions of success, recurrence, complications, and follow-up differ. Some cohorts combine surgical approaches or include vascular forms of TOS. Diagnostic blocks and botulinum toxin injections are not standardized across institutions. The reported outcomes therefore cannot be directly compared as if they arose from randomized trials. Nonetheless, the convergence of operative findings across several independent series provides a coherent clinical framework for evaluating patients after failed NTOS surgery.

8. Conclusions

Persistent and recurrent symptoms after first-rib resection for NTOS are usually multifactorial. The principal correctable mechanisms are retained or residual first-rib tissue, residual or reattached scalene muscle, untreated pectoralis minor syndrome, multilevel compression, and perineural fibrosis. Recurrent NTOS can also occur after an anatomically complete decompression, with dense scar encasing the brachial plexus as the only major operative finding. Mixed arterial compression, distal entrapment neuropathies, cervical or shoulder pathology, secondary injury, and chronic pain amplification must be actively considered.

The decision to reoperate should be based on convergence of the clinical timeline, focused examination, review of the original operation, targeted imaging, exclusion of mimics, and, when appropriate, a concordant response to scalene or pectoralis minor injection. A positive botulinum toxin response can strongly support the likelihood of surgical benefit, but nonresponse does not reliably exclude it. Complete supraclavicular revision and isolated reoperative brachial plexus neurolysis can produce clinically meaningful improvement in carefully selected patients, although complete relief is uncommon and recurrence remains possible. Because revision surgery carries nontrivial neurological, vascular, lymphatic, and pleural risks, treatment should be undertaken in experienced multidisciplinary centers with realistic outcome counseling and long-term follow-up.

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