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ORIGINAL ARTICLE

Neurogenic Thoracic Outlet Syndrome: Comparison of early Versus late Surgical Intervention in terms of Improvement in Clinical Symptoms

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ABSTRACT
Background: Neurogenic thoracic outlet syndrome is a condition with unpredictable response to conservative management, and the optimal timing of surgical intervention remains debated.
Objectives: To determine the impact of surgical intervention on clinical, electrophysiological, and functional outcomes in patients with neurogenic thoracic outlet syndrome in Pakistan.
Methods: This was a prospective study which included diagnosed patients of neurogenic thoracic outlet syndrome with surgical treatment and were followed for six months postoperatively. Patients were divided into two groups based on timing of surgery, i.e. delayed surgery after failure of conservative management and early surgery following diagnosis. Preoperative assessment included clinical evaluation of patients, electrophysiological studies, and functional disability assessment using the Disability of the Arm, Shoulder, and Hand questionnaire. Postoperative outcomes were determined by using the same parameters to compare recovery between two groups of patients.
Results: Radiological findings highlighted 75% of respondents with cervical rib, 15% with elongated C7 transverse process, and 10% with anomalous first thoracic rib . Preoperatively, 90% of respondents had paraesthesia and 85% had pain, with greater functional impairment and electrophysiological abnormalities observed in patients undergoing delayed surgery (Group I) compared to early surgery (Group II). Postoperatively, both groups showed improvement; significant functional recovery was observed only in the early surgery group (Group II: 27.3 ± 10.5 preoperative vs. 10.5 ± 5.7 postoperative, $p < 0.001$); whereas the improvement in delayed surgery patients was not statistically significant (Group I: 34.2 ± 13.3 vs. 23.5 ± 13.9, $P = 0.07$).
Conclusion: Surgical decompression is an effective treatment for neurogenic thoracic outlet syndrome; however, early surgical intervention yields superior clinical and functional outcomes compared with delayed treatment.
Keywords: Neurogenic thoracic outlet syndrome, Surgical decompression, Timing of surgery, Functional outcome, Electrophysiological studies, DASH score

INTRODUCTION
Neurogenic thoracic outlet syndrome (NTOS) is chronic compression and irritation of the brachial plexus as it passes through the space enclosed by the anterior and middle scalene muscles and the first rib (i.e., the "scalene triangle")[1]. Additional sites of compression may occur at the costoclavicular space and laterally in the subcoracoid region, directly behind the pectoralis minor tendon[2,3]. This cycle of compression and irritation is often driven by repetitive microtrauma, leading to fibrosis, hypertrophy, and spasm of the scalene and/or pectoralis minor muscles[4]. Progressive scar formation may involve the brachial plexus itself, contributing to chronic neural compromise. Predisposing anatomic factors, such as cervical ribs, elongated transverse processes, or musculofascial bands also known as "Roos bands", may be observed at the time of surgical decompression[5,6].

NTOS is primarily diagnosed on the basis of clinical signs and symptoms which may overlap with other cervical or peripheral nerve disorders, making it challenging for healthcare professionals to reach exact diagnosis. Patients typically present with pain and sensory disruptions mainly affecting the ulnar portion of the forearm and hand; the condition is often aggravated by continuous use of the affected limb or overhead activities[7,8]. In chronic cases, motor weakness and wasting of the intrinsic hand muscles may be observed, reflecting chronic brachial plexus involvement[8,9]. Neurophysiological studies support the diagnosis of NTOS by establishing features of chronic postganglionic axonal loss, while facilitating excluding alternative diagnoses such as cervical radiculopathy or focal mononeuropathies.

The management of neurogenic TOS remains challenging, mainly due to variations in diagnostic criteria, heterogeneity of patients, and differences in reported treatment outcomes. Although conservative management of NTOS, including physical therapy and activity alteration, is widely recommended as first-line treatment, several studies have reported suboptimal or unpredictable long-term results, with a good number of patients remaining symptomatic despite prolonged nonoperative curative therapy[10,11]. Surgical management is therefore considered in specific patients; however, reported success rate of cure and development of complications also vary significantly, contributing to argument regarding patient selection for surgery and optimal timing of surgical intervention.

Surgical decompression for NTOS may include various approaches, each with its own risks and benefits. Early identification of patients for surgical intervention could prevent patients from long-term nerve damage and functional deterioration. In contrast, unnecessary delays in the management of NTOS may lead to permanent damage, affecting patient quality of life. Understanding the role of time to influence both clinical and electrophysiological recovery is therefore essential. Furthermore, limited evidence exists regarding the effect of timing of surgery on functional and neurophysiological outcomes. Especially it is unclear whether early surgical decompression can prevent irreversible neural degenerative changes and result in superior functional recovery when compared with delayed surgery following extended conservative NOTS management. Therefore, this study is conducted with an aim to compare the functional outcomes of patients undergoing early surgical intervention with those undergoing delayed surgical treatment after six months of medical and physical therapy for neurogenic thoracic outlet syndrome.

METHODOLOGY
Study Design and Setting: This study was a prospective comparative cohort study conducted at a tertiary care hospital, over a period of twelve-months from the month of May 2022 to April 2023.

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Ethical Considerations: The study was conducted in accordance with the Declaration of Helsinki and written informed consent was obtained from all NTOS patients before their enrollment in the study and surgical intervention. Furthermore, patients were also informed regarding the nature of the disease, available treatment options, potential benefits of treatment, and possible complications of surgery.

Study Population and Group Allocation: The study sample comprised of twenty patients, who were diagnosed with NTOS, and the sample included 10 women and 10 men, with an age range of 20 years to 52 years. Furthermore, patients were enrolled in the study consecutively after fulfilling standardized diagnostic criteria for NTOS. Based on the timing of surgical intervention, the selected participants of the study were divided into two groups, group I with 10 patients who underwent surgical decompression within three months of symptom onset due to inadequate response to initial conservative management. Group II with 10 patients who underwent surgical decompression after at least six months of structured medical and physical therapy with persistent or progressive symptoms. However, patients with other peripheral nerve entrapment syndromes, cervical disc disease, traumatic thoracic outlet syndrome, or associated vascular thoracic outlet syndrome were excluded from the study.

Adequate History: The first and most critical step was to obtain a detailed and structured clinical history to ensure that patients fulfilled the diagnostic protocols for NTOS. Only patients meeting standardized diagnostic requirements were included in the study. More recently, the Society for Vascular Surgery (SVS) developed reporting standards for thoracic outlet syndrome. According to the most recent definition proposed in 2016 by Illig et al., the diagnosis of NTOS requires the presence of at least three of the following four criteria [12,13]:

1. Local symptoms in an area of compression, for example, chest wall, trapezius, or neck region, which is confirmed by reproducible pain on palpation in the specific anatomical region.
2. Peripheral symptoms involving the upper or lower limbs, as reported in patient history, and confirmed by stimulating maneuvers that reproduce or exacerbate the symptoms.
3. Absence of other likely diagnoses of conditions, including cervical spine pathology, shoulder disorders, or other peripheral nerve entrapment syndromes among patients.
4. Positive response to diagnostic scalene muscle injection using a local anesthetic.

Physical Examination: A comprehensive physical examination was performed for all patients to support the clinical diagnosis and to exclude alternative causes of upper limb symptoms. This included a detailed vascular, neurological, and motor examination, as well as assessment of patient posture, muscle bulk, symmetry, and tone of the ipsilateral muscles of shoulder, arm, and hand. Application of gentle but firm thumb pressure over the brachial plexus in the supraclavicular fossa or over the scalene muscles for a brief duration was performed. Reproduction of the patient's characteristic neck, shoulder, or ipsilateral arm pain was considered supportive of NTOS. Standard provocative tests, including Adson's test, Wright's test, elevated arm stress test (EAST), and costoclavicular maneuver, were used to further assess thoracic outlet compression.

Investigations: As part of further diagnostic evaluation, plain radiographs (X-rays) of the thorax and cervical spine were obtained in all patients to identify possible anatomical anomalies, for example as cervical ribs or elongated transverse processes. Magnetic resonance imaging (MRI) of the cervical spine and thoracic outlet was performed in all patients to support the diagnosis and to rule out cervical disc disease or other compressive pathologies [14,15].

Imaging techniques are believed to be potentially useful diagnostic modality for NTOS; however, diagnostic utility is highly dependent on type of imaging technique. Previous studies have reported Magnetic Resonance Imaging (MRI) sensitivity and specificity of approximately 33% and 41%, respectively, based on cohorts that included thoracic outlet syndrome but not exclusively NTOS. In contrast, magnetic resonance neurography (MRN) may offer improved visualization of brachial plexus abnormalities. High-resolution 3.0-Tesla MRI scanners utilizing Short Tau Inversion Recovery (STIR) sequences and Spectral Adiabatic Inversion Recovery (SPAIR) modules offer superior anatomical delineation of neural structures, although MRN was not routinely available in the present study.

Electrodiagnostic studies (EDS) were performed in all patients preoperatively to objectively support the diagnosis of NTOS, exclude other neuropathies, polyneuropathy, or motor neuron disease, and to establish a baseline for postoperative comparison.

Postoperative Assessment: Postoperative evaluation was conducted six months after surgery and included the following:

1. Clinical reassessment of presenting symptoms and physical signs,
2. Repeat EDS to assess neurophysiological changes,
3. Functional assessment using the DASH questionnaire.

DASH Questionnaire: The DASH questionnaire as a validated tool was used to assess functional disability among NTOS patients, and score was calculated by summing responses to the 30 items of the questionnaire, dividing by the number of completed items, subtracting one, and multiplying by 25, which results in a final score with a range from 0, indicating no disability, to 100 indicating maximum disability among patinets [16].

Scalene Block Trial: A local anesthetic injection, usually into the scalene muscles, is another diagnostic procedure that may be even more useful in light of the current 2016 guidelines and since its initial description in 1939, this method has been used as a supporting diagnostic procedure for NTOS. The intramuscular anterior scalene block is thought to work by momentarily paralyzing or blocking the muscle in spasm, which permits the first rib to fall and decompress the thoracic outlet [17].

Indications for Surgical Treatment: Surgical intervention was indicated in patients with NTOS who met one or more of the following criteria [17]:

1. Documented neurological deficit due to brachial plexus compression triggered by anatomical abnormalities, or refractory and intractable pain despite conservative treatment with a positive response to scalene block,
2. Severe limitations in daily life activities and significant reductions in quality of life.

Operative Technique: At our center, a supraclavicular surgical approach was routinely employed in preference to the transaxillary approach, as it allows accurate intraoperative diagnosis, complete removal of anomalous structures, including the first rib, cervical rib, or elongated transverse process, and excellent visualization of neurovascular structures, with a relatively low risk to surrounding tissues. Patients were positioned supine with a supportive roll beneath the cervical and thoracic spine, and the head turned away from the operative side. The thoracic outlet was exposed through an S-shaped supraclavicular incision measuring approximately 5–7 cm, allowing visualization of the subclavian artery, first rib, brachial plexus, and scalene muscles.

Following detection of the supraclavicular nerve, the phrenic nerve and subclavian artery were carefully identified, and anterior scalene muscle was divided, and the brachial plexus was mobilized using an atraumatic technique. The first rib was then divided and excised along with associated fibrous and soft tissue attachments with limited exposure of the subclavian vein. Based on institutional experience, the supraclavicular approach was favored for its safety and superior access to neurovascular structures.

Data Analysis: Data was analyzed using the Statistical Package for the Social Sciences (SPSS), version 24.0; means and standard deviations summarize numerical variables. Paired-sample t-test was applied to compare parametric variables between two groups, while the Chi-square (χ^2) test was used to compare frequencies and proportions among groups. A P value ≤ 0.05 was considered statistically significant.

RESULTS

Patient Demographics and Anatomical Findings: Twenty patients who had been prospectively followed 6 months after surgical treatment for NTOS including 10 women (50%) and 10 men (50%) with a mean age of 34.51 ± 8.6 years. The age of particpants ranged from 20 to 52 years. After radiological studies cervical ribs were diagnosed in 15 participants (75%), an elongated C7 transverse process in 3 patients (15%), and a large anomalous first thoracic rib in two patients (10%).

Preoperative Assessment of Patient: The most common preoperative symptom among patients was paraesthesia, present in 18 participants (90%), which worsened with physical activity (10 in Group I, 8 in Group II). Pain was reported in 17 participants (85%). Weakness of intrinsic hand muscles or flexor digitorum profundus was observed in 6 participants (30%), predominantly in Group I (n = 4).; atrophy of the hypothenar muscles was observed in 3 participants (8.6%), all in Group I.

Electrophysiological assessment showed abnormalities in both groups including reduced or absent ulnar sensory nerve action potential (SNAP) was observed in 16 participants (80%; 10 in Group I and 6 in Group II), while denervation on EMG was observed in 7 participants (35%), all from Group I. Prolonged F-wave latency was noted in 5 patients (25%; 1 in Group I and 4 in Group II). Preoperative DASH scores were higher in Group I (34.2 ± 13.3) compared to Group II (27.3 ± 10.5), indicating greater functional impairment.

Post Operative Outcome in Both Groups: At six months post-surgery, both groups showed improvement in clinical symptoms and functional scores. Paraesthesia persisted in 50% of Group I and 20% of Group II. Pain was present in 40% of Group I and 30% of Group II. Muscle weakness and wasting were more frequent in Group I (30% each) than Group II (10% and 0%, respectively). Electrophysiological improvements were observed predominantly in Group II, with resolution of ulnar SNAP abnormalities, EMG derivation, and prolonged F-wave latency in all patients. DASH scores improved in both groups; however, the improvement was significant only in Group II. Postoperative DASH scores were 23.5 ± 13.9 in Group I (P = 0.07) and 10.5 ± 5.7 in Group II (P < 0.001).

Table1. Preoperative Clinical and Electrophysiological Assessment of Patients by Group

Clinical presentation	Group I (late surgical treatment) n = 10	Group II (early surgical treatment) n = 10
Paraesthesia	10 (100%)	8 (80%)
Pain	9 (90%)	8 (80%)
Muscle weakness	4 (40%)	2 (20%)
Muscle wasting	3 (30%)	0 (0%)
Positive provocative tests	6 (60%)	8 (80%)
Reduced or absent SNAP of ulnar nerve	10 (100%)	6 (60%)
Denervation in EMG	7 (35%)	0 (0%)
Prolonged F latency	4 (40%)	1 (10%)
DASH	34.2 ± 13.3	27.3 ± 10.5

Table 2. Postoperative Clinical and Electrophysiological Outcomes by Group

Clinical presentation	Group I (n = 10)	Group II (n = 10)
Paraesthesia	5 (50%)	2 (20%)
Pain	4 (40%)	3 (30%)
Muscle weakness	3 (30%)	(10%)
Muscle wasting	3 (30%)	0 (0%)
Reduced SNAP of ulnar nerve	6 (60%)	0 (0%)
Denervation in EMG	5 (50%)	0 (0%)
Prolonged F latency	2 (20%)	0 (0%)
DASH score	23.5 ± 13.9	10.5 ± 5.7

Table 3. Comparison of Functional Disability (DASH Scores) Pre- and Postoperatively

Group	Preoperative	Postoperative	P
Group I (n = 10)	34.2 ± 13.3	23.5 ± 13.9	0.07
Group II (n = 10)	27.3 ± 10.5	10.5 ± 5.7	0.001**

Functional Disability: Pre- vs. Postoperative DASH Scores: The postoperative score in group I partcipants was recorded to be 23.5 ± 13.9, and the improvement was not significant compared to the preoperative score 34.2 ± 13.3. Whereas, in group II the postoperative score among participants was recorded to be10.5 ± 5.7 and improvement was significant compared to their preoperative score 27.3 ± 10.5. The postoperative DASH score among participants improved in both groups, but it was not statistically significant in group I compared to group 11 (p < .07 in group 1 and p < .001 in group 2)

DISCUSSIONS

The study showed that patients who underwent early surgical treatment experienced more pronounced relief of sensory symptoms, including paraesthesia and pain, and demonstrated greater recovery of neurological function compared with those who underwent surgery after a prolonged period of conservative management. Early intervention was also associated with a lower frequency of residual muscle weakness and an absence of persistent muscle wasting following surgery, suggesting a protective effect against progressive neural injury. In contrast, NTOS patients who were managed with surgical intervention showed partial improvement in symptoms; however, sensory instability and motor function deficits were more likely to persist among patients. Incomplete neurophysiological recovery in this group was observed, demonstrating prolonged compression may result in partially irreversible changes. Functional outcomes of NTOS management improved in both groups, with early surgery patients achieved a greater restoration of upper-limb function and better performance in daily life activity.

Nonoperative or non-surgical management of NTOS includes modification of behavior by avoiding provocative activities and arm positions, in addition to individually tailored physical therapy programs[17]. The indications for surgical management of NTOS and the choice of the correct type of operative procedure are still a subject for debate because of the frequency of recurrence and complications among patients. Currently, the most frequently used method for decompression of the thoracic outlet (inlet) is transaxillary first rib resection[18,19]. However, different publications suggest that this method alone results in a recurrence rate of approximately 20– 30% in experienced hands[20,21].

Supraclavicular approach for thoracic outlet decompression is less popular than the transaxillary approach but has been advocated by several authors[22,23]. Supraclavicular approach is considered as the surgery of choice in NTOS patients mandating surgical management only. It gives the best coverage of the neurovascular bundle, cervical ribs, and fibrous bands to the surgeon, and can be applied for the first rib resection. In this study, early surgical treatment for neurogenic TOS has reported significant surgical outcomes compared to late surgical treatment. Pain and sensory disturbance improved significantly in group 2 compared to group 1, whereas improved muscle strength was nonsignificant in group 2 compared to group 1. Muscle wasting never resolved in patients had late surgery, which suggests that early surgery may prevent irreversible denervation of hand muscles. This result is in agreement with the results of previous studies like Hashel et all which also concluded that early surgical treatment for neurogenic TOS has reported significant surgical outcome compared to late surgical treatment[24].

Functional prognosis of NTOS is the main factor in determining the outcome of surgical management. However, most studies have declined to use an objective measure for determination of functional outcome. We used the DASH questionnaire as its questions encompass a very broad clinical spectrum[25]. Early surgical management of the patients with NTOS demonstrated a highly significant improvement in their DASH scale compared to improvement of patients with late surgical treatment who also improved at later stages, but less significant than in patients with early surgical intervention. The result of postoperative improvement in DASH questionnaire is similar to the result of other authors who reported more improvement in early surgical intervention of NTOS[26,27]. However, lack of improvement in symptoms after surgery is usually triggered by irreversible degenerative pathological changes of the brachial plexus as revealed by the electrophysiological studies. Another challenge which is usually observed in cases of NTOS is recurrence of symptoms after few months to years as reposted in adolescent population by ShaKarchi et al. in his study focusing on young population. However, no such recurrence was observed after surgical interventions, and recorded surgical complications in 2 out of 20 patients but these did not give rise to long-term or permanent symptoms or disability[28,29,30].

The strengths of this study include its prospective design, standardized clinical and electrophysiological assessment, and use of a validated functional outcome measure to evaluate surgical results. The direct comparison between early and delayed surgical intervention provides clinically relevant insight into the impact of timing on outcomes in neurogenic thoracic outlet syndrome. However, the study is limited by a relatively small sample size of participants, short follow-up interval, and single-center design of the study, which may restrict the generalizability of the findings. Additionally, the non-randomized grouping of patients may introduce selection bias.

CONCLUSION

Surgical decompression is an effective treatment for neurogenic thoracic outlet syndrome and results in improvement of symptoms and functional capacity. While both early and delayed surgical interventions provide clinical benefit, early surgical treatment is associated with more favorable outcomes, including greater relief of sensory symptoms, better preservation of muscle strength, and more complete neurological recovery. Patients undertaking delayed surgery demonstrated improvement mainly in pain and functional limitation of the limb, but residual sensory deficits and muscle wasting were more likely to persist, indicating partially irreversible neural changes.

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