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OPERATIVE TREATMENT OF NEUROGENIC THORACIC OUTLET SYNDROME

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Henrik Nuutinen

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ABSTRACT

In neurogenic thoracic outlet syndrome (NTOS), the brachial plexus is compressed and causes pain, numbness, and motor nerve disturbances, typically in the upper limb or shoulder region. Compression can occur in three different areas: in the area of the scalene muscles in the so-called scalene triangle, between the first rib and the clavicle in the costoclavicular space, or between the pectoralis minor muscle and the chest wall in the pectoralis minor space. NTOS can be acquired, for example, as a result of an injury. It can also be congenital, for example, due to an extra rib or bony anomalies.

This study includes the short- and long-term results of operative treatment of NTOS. The short-term results are based on the clinician's assessment at the short-term outpatient clinical follow-up visit. Standardized patient-reported outcome measures were used in the long-term follow-up. These queries were the Cervical Brachial Symptom Questionnaire (CBSQ) and the Quick Disability of the Arm, Shoulder, and Hand Questionnaire (QuickDASH). The patients included in the long-term follow-up were evaluated by a physiatrist and underwent X-ray imaging focused on the first rib, from which a radiology specialist assessed the length of the first rib stump.

The short- and long-term results after the surgical treatment were correlated with each other. The surgical results of patients operated on with the open transaxillary or video-assisted technique were similar in both the short- and long-term follow-up. Approximately 65% of the patients had a good or excellent surgical result at the 3-month follow-up. In the long-term follow-up, about 80% had a good or excellent outcome.

The CBSQ indicated that after surgery, the patients had only mild or moderate symptoms, and their functional performance measured by QuickDASH was only mildly limited at the long-term follow-up. The patients' ability to function improved, and a large proportion would have gone through the procedure again if given the choice now. A first rib stump length of more or less than 3 cm long had no correlation with the long-term outcomes. The first rib stump length was similar after open and video-assisted surgery.

In conclusion, it is possible to achieve good long-term results with both open and video-assisted technology. These findings also support the most recent publications that it is worth offering operative treatment as an alternative to patients with troublesome NTOS symptoms if they do not respond to conservative treatment. The functional performance and symptom questionnaire results support this view and are in line with the previously published articles.

Keywords: video-assisted, operative treatment, thoracic outlet syndrome, surgery, long-term outcome, first rib resection

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TIIVISTELMÄ

Hermoperäisessä eli neurogeenisessä thoracic outlet syndroomassa olkahermopunos jää puristuksiin aiheuttaen kipua, tunnottomuutta sekä liikehermojen häiriöitä tyypillisesti yläraajan tai hartian seutuun. Olkahermopunos voi jäädä puristuksiin kolmella alueella; Scalenus lihasten alueella niin sanotussa scalenus triangelissa, 1. kylkiluun ja solisluun välissä tai pectoralis minor lihaksen ja rintakehän seinämän välissä. Rintakehän yläaukeaman ahtauma voi olla seurausta esimerkiksi vammasta, ahtaus voi olla myös synnynnäistä esimerkiksi ylimääräisestä kylkiluusta tai anomalioista johtuvaa.

Tässä tutkimuksessa selvitettiin neurogeenisen thoracic outlet syndrooman operatiivisen hoidon lyhyt- ja pitkäaikaistuloksia. Lyhytaikaistulokset perustuvat kliinikon arvioon seurantakäynnillä. Pitkäaikaisseurannassa hyödynnettiin potilaille lähetettyjä standardoituja oire- ja toimintakykykyselyitä (CBSQ, QuickDASH). Pitkäaikaisseurantaan kuuluvat potilaat arvioi fysiatrian erikoislääkäri, samalla he kävivät 1. kylkiluun kohdennetussa röntgen kuvassa, josta radiologian erikoislääkäri arvioi 1. kylkiluun tyngän pituuden.

Tuloksemme osoittivat, että leikkaushoidon lyhytaikaistulokset sekä pitkäaikaistulokset korreloivat keskenään. Videoavusteisella tekniikalla ja avoimella tekniikalla leikattujen potilaiden leikkaustulokset olivat samanlaiset niin pitkäaikaisseurannassa kuin lyhytaikaisseurannassa. Lyhytaikaistulokset osoittivat, että noin 65 %:lla oli hyvä tai erinomainen leikkaustulos seurantakäynnillä kolmen kuukauden kohdalla. Pitkäaikaisseurannassa, noin 80 %:lla oli hyvä tai erinomainen lopputulos.

Oire ja toimintakykykyselyillä mitaten potilaiden oireet olivat lieviä tai kohtalaisia, ja toimintakyky vain lievästi rajoittunutta pitkäaikaisseurannassa. Potilaiden toimintakyky parani ja suuri osa olisi mennyt toimenpiteeseen uudelleen, jos saisi nyt valita uudelleen. Ensimmäisen kylkiluun tyngän pituudella (yli tai alle 3 senttimetriä) ei ollut tutkimuksessamme korrelaatiota potilaan leikkauksen onnistumiseen. Ensimmäisen kylkiluun tyngän pituus oli samanlainen avoimen sekä videoavusteisen leikkauksen jälkeen.

Tutkimustuloksemme osoittavat, että hyvät pitkäaikaistulokset on mahdollista saavuttaa sekä avoimella että videoavusteisella tekniikalla. Tutkimuksemme tukee myös aiempia julkaisuja siitä, että hankalaoireisille neurogeenista thoracic outlet syndroomaa sairastaville potilaille kannattaa tarjota operatiivista hoitoa vaihtoehdoksi, jos konservatiivisella hoidolla ei saada vastetta. Toimintakykykysely sekä oirekysely tuloksemme tukevat tätä ja ovat samassa linjassa aiemmin julkaistujen artikkelien kanssa.

Avainsanat: videoavusteinen, leikkaushoito, olkahermopunos, puristus, toimintakyky, kirurgia

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ABBREVIATIONS

ATOS	Arterial thoracic outlet syndrome
BDI	Beck's Depression Inventory
CBSQ	Cervical Brachial Symptom Questionnaire
EANS	European Association of Neurosurgical Societies
DASH	Disabilities of the Arm, Shoulder, and Hand Questionnaire
EAST	One-Minute Elevated Arm Stress Test (Roos-test)
FRR	First rib resection
NDI	Neck Disability Index
NTOS	Neurogenic thoracic outlet syndrome
PROMs	Patient-reported outcome measures
PSS	Paget-Schroetter syndrome
RCT	Randomized controlled trial
SCV	Subclavian vein
TOS	Thoracic outlet syndrome
ULTT	Upper Limb Tension Test
VAS	Visual analog (pain) scale
VATS	Video-assisted thoracoscopic surgery
VTOS	Venous thoracic outlet syndrome

1 INTRODUCTION

Thoracic outlet syndrome (TOS) is the result of compression in the upper thoracic region, just above the first rib and behind the clavicle. Compression is applied to the neurovascular bundle and thus the symptoms can be manifold. Peet et al. (1956) gave this syndrome the name TOS in 1956; it had previously been referred to as scalenus anticus syndrome and Adson syndrome. Neurogenic thoracic outlet syndrome (NTOS) is the most common manifestation, representing more than 90% of all patients with TOS (Sanders et al. 2007). Venous thoracic outlet (VTOS) syndrome is the second most common, and arterial thoracic outlet syndrome (ATOS) is the rarest (Sanders et al. 2007). ATOS and VTOS may overlap with NTOS (Illig et al. 2016).

Diagnosis of NTOS is challenging, and there is not a single diagnostic test (Sanders et al. 2004). The TOS reporting standards of the Society for Vascular Surgery demand that three of four criteria be present for the NTOS diagnosis: (a) signs and symptoms of pathology occurring at the thoracic outlet (pain, tenderness, or both); (b) signs and symptoms of nerve compression (distal neurologic changes, often worse with arms overhead or dangling); (c) absence of other pathology potentially explaining the symptoms; and (d) positive response to duly performed scalene muscle injection (Illig et al. 2016, Jordan et al. 1998).

NTOS treatment is primarily conservative (Doneddu et al. 2017). It includes physiotherapy, painkillers, and ergonomic changes at home and at work (Illig et al. 2016). Surgical treatment is considered in severely symptomatic cases. The most common approach to surgical decompression is transaxillary first rib resection (FRR), which is most often combined with scalenotomy (Roos 1966). Other decompression techniques are supraclavicular, infraclavicular, and video-assisted FRR with scalenotomy (George et al. 2017, Hempel et al. 1981). A mere scalenotomy is also an option.

Standardized patient-reported outcome measures (PROMs) should be used to assess patient recovery (Illig et al. 2016). These PROMS include the Quick Disabilities of the Arm, Shoulder, and Hand Questionnaire (QuickDASH), the Cervical Brachial Symptom Questionnaire (CBSQ), and the TOS disability scale (Illig et al. 2016). These outcomes should be reported after any treatment, including conservative treatment. This would make it easier to compare the effectiveness of different therapies (Illig et al. 2016). In a recent systematic review including 32 studies with 3683 pooled patients who had undergone NTOS operation, 76% of

patients reported success after transaxillary FRR, 77% after supraclavicular FRR, and 85% after supraclavicular release leaving the first rib intact (Yin et al. 2019). However, it is difficult to compare among studies because standardized PROMs have not been widely used in publications. Moreover, the variability of different surgical techniques makes comparison difficult.

This dissertation focuses on the surgical outcomes of patients with NTOS. Surveys according to the reporting standards of NTOS were used (Illig et al. 2016). PROMs and outpatient clinic visits measured the patient's performance and quality of life. The goal was also to compare the surgical outcome of transaxillary FRR and mini-invasive video-assisted FRR. The correlation between the residual stump length and residual symptoms was also evaluated.

2 REVIEW OF THE LITERATURE

2.1 ANATOMY OF THE THORACIC OUTLET

TOS is due to compression of neurovascular structures in the thoracic outlet area. Compression may involve the brachial plexus, the subclavian vein (SCV), or the subclavian artery. The brachial plexus and the subclavian artery travel together through the costoclavicular space, posterior to the anterior scalene muscle (**Figure 1**). The SCV travels anterior to the scalene muscle. The clavicle is anterior to the thoracic outlet space and posterior to the first rib. The insertion on the pectoralis muscle is on the coracoid process of the humerus, lateral to the thoracic outlet space. The sternum is medial to the thoracic outlet space.

Compression of these neurovascular structures may occur in three different places: the scalene triangle, the costoclavicular space, and the pectoralis minor space (**Figure 2**) (Klaassen et al. 2014). Compression is the most common in the scalene triangle; when compressed, the brachial plexus is usually also under compression. The anterior scalene muscle borders the scalene triangle anteriorly and the middle scalene muscle posteriorly. The superior border of the first rib is the inferior boundary of the scalene triangle. The costoclavicular space is located between the clavicle and the first rib. The SCV, the brachial plexus, and the subclavian artery travel through this space. In the costoclavicular space, the SCV is most likely to get pinched. The pectoralis minor space is bordered posteriorly by the chest wall and anteriorly by the pectoralis minor muscle. The brachial plexus, the SCV, and the subclavian artery pass to the upper arm through this space.

In addition to the above-mentioned causes, TOS may develop due to congenital anomalies such as a cervical rib or congenital cervical fibro-cartilaginous bands (Pollack 1980). A cervical rib significantly increases the occurrence of TOS (Henry et al. 2018). Weber et al. (2014) found that up to 29% of patients with TOS who received an operation had a bone anomaly such as cervical rib, clavicular anomalies, or first rib aberrations. Most patients with cervical ribs are women (Sanders et al. 2007). The syndrome may also be acquired. In these cases, it may be due to age related shoulder sagging, a whiplash injury, a strong increase in muscle mass in shoulder or chest area, or a bony fracture of the first rib or clavicle (Baumer et al. 2014, Casbas et al. 2005, Sanders et al. 2007). Muscle mass may increase due to exercise or repetitive workload.

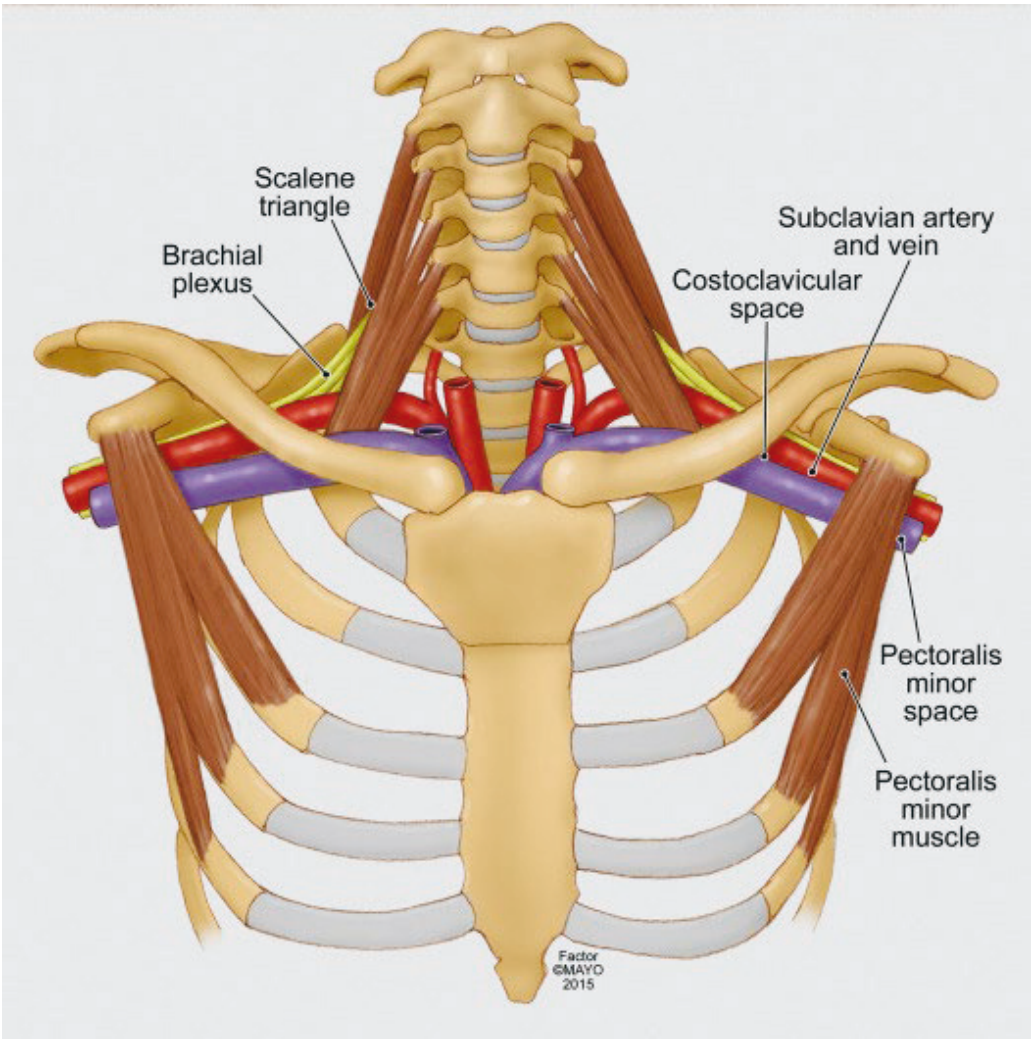


Figure 1. Anatomy of the thoracic outlet. Reproduced with permission of the Mayo Foundation for Medical Education and Research.

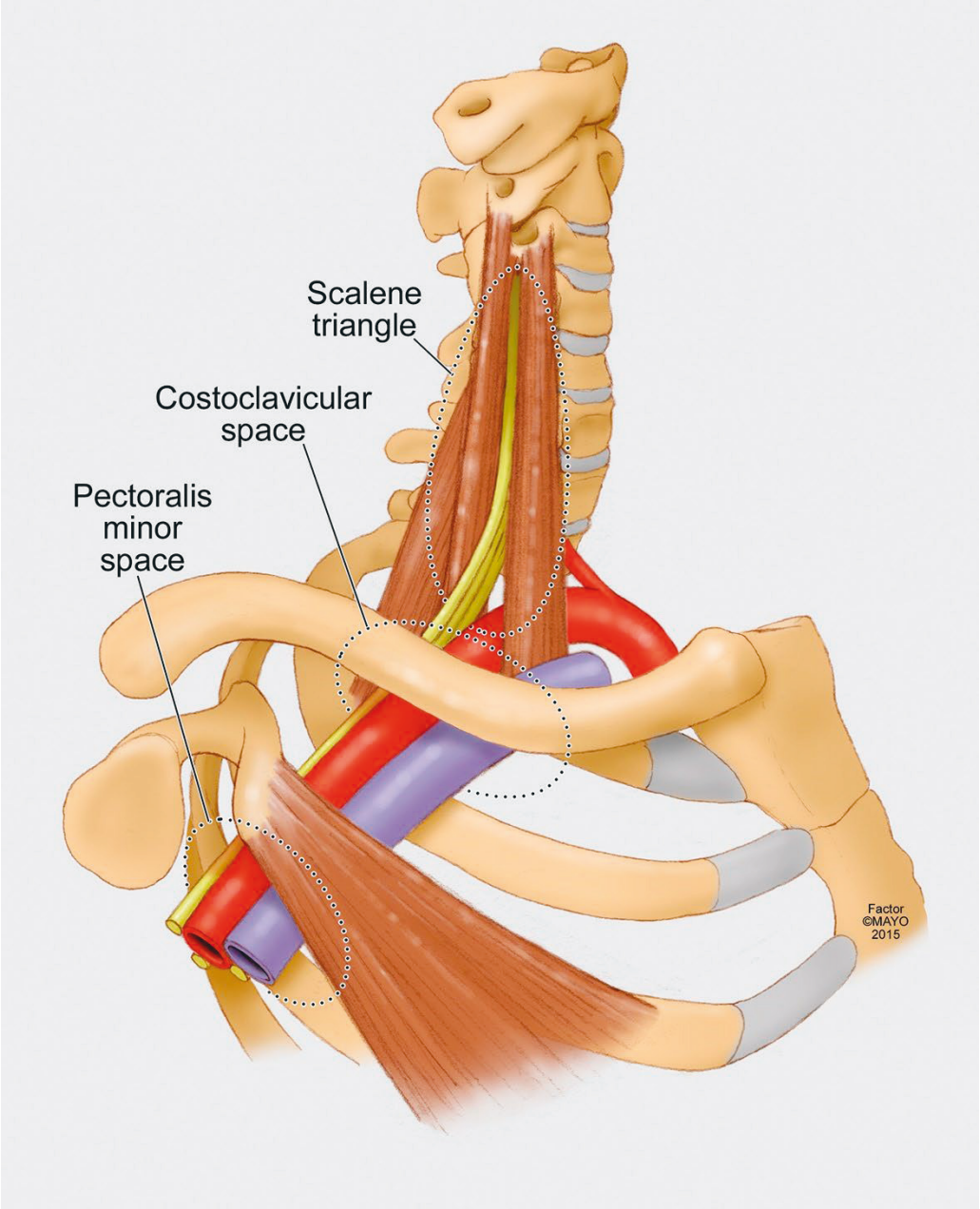


Figure 2. Compression sites of thoracic outlet syndrome. Reproduced with permission from the Mayo Foundation for Medical Education and Research.

2.2 DEFINITION AND CLASSIFICATION OF THORACIC OUTLET SYNDROME

TOS comprises three main categories that differ in their presentation and treatment: NTOS, VTOS (or Paget-Schroetter syndrome [PSS]), and ATOS.

2.2.1 Neurogenic thoracic outlet syndrome

NTOS is the most common type of TOS (Gockel 1996, Sanders et al. 2007). The symptoms of NTOS are the results of a compression of the brachial plexus in the scalene triangle, the costoclavicular space, or the pectoralis minor space (Klaassen et al. 2014). The most common place for brachial plexus compression is the scalene triangle. Compression causes symptoms that impair quality of life (Panda et al. 2021). According to the reporting standards of NTOS, compression of the brachial plexus in the scalene triangle is termed NTOS while compression of the pectoralis minor space is called neurogenic pectoralis minor syndrome (Illig et al. 2016). However, these terms have not been used routinely in the literature. The costoclavicular space is a third site for compression. Standardized terminology would facilitate comparison among studies.

2.2.2 Venous thoracic outlet syndrome (Paget-Schroetter syndrome)

VTOS is the second most common type of TOS. It typically manifests as an acute thrombosis in the subclavian or axillary vein (sometimes referred to as idiopathic or primary upper extremity deep vein thrombosis). This condition is due to compression in the area of the first rib, the clavicle, and the anterior scalene muscle (Illig et al. 2010, Molina et al. 2009). This costoclavicular space narrows when the arms are raised. Continuous or repeated compression can cause scar tissue to form in the SCV and thus also constrict the vein (Cook et al. 2021). Axillary vein or SCV thrombosis caused by TOS is referred to as PSS.

PSS typically causes acute upper limb swelling, cyanosis, or upper limb pain (Molina et al. 2009). The patients are typically young, and the upper limbs are subjected to repetitive strain due to either sport or work (Molina et al. 2009). Prolonged repeated compression to the SCV causes a collateral venous network in the SCV area. The rate of pulmonary embolism in PSS has been reported as very low (1%) in some studies, whereas a recent study from the University of Eastern Finland reported an 18% incidence rate (Karaolanis et al. 2021, Kärkkäinen et al. 2016).

There should be suspicion of PSS if the patient has a typical history and sudden swelling or cyanosis of the upper limb. Duplex ultrasound imaging is the gold standard for diagnosis (Chin et al. 2005). If the duplex ultrasound finding remains negative and there is still a strong clinical suspicion, conventional venography, magnetic resonance venography or upper extremity computed tomography should be performed (Cook et al. 2021).

If a strong suspicion of VTOS arises, therapeutic anticoagulation should be initiated (Cook et al. 2021). In addition, venous thrombolysis is often performed with an intravenous catheter (Kärkkäinen et al. 2016). PSS should be treated within about 2 weeks to prevent the situation from becoming chronic (Molina et al. 2009). Treatment options after thrombolysis are surgical decompression or anticoagulation (Karaolanis et al. 2021, Lee et al. 2006, Thompson 2012). Cook et al. (2021) recommend surgical treatment for almost all patients 4-6 weeks after thrombolysis. Transaxillary FRR with scalenotomy is the most common approach, but the infraclavicular, paraclavicular, and video-assisted thoracoscopic surgery (VATS) techniques are also used (Desai et al. 2014, Kärkkäinen et al. 2016, Mahmoud et al. 2018, Molina 1998a, Molina et al. 2009, Roos 1966, 1976). Intraoperative or postoperative venography is also recommended; at that time, balloon angioplasty may be performed, or in rare occasions, a stent may be placed in the SCV after decompression and reconstruction (Chang et al. 2012).

As with other forms of TOS, guided physiotherapy is an integral part of VTOS treatment. Typically, recovery from surgery lasts 12 weeks (Cook et al. 2021), and 75%-95% of patients are asymptomatic after surgery (Vemuri et al. 2016). Moreover, 20%-25% of operated patients require long-term anticoagulation (Vemuri et al. 2016).

2.2.3 Arterial thoracic outlet syndrome

ATOS is the rarest form of TOS (Sanders et al. 2007). As early as 1831, Mayo (1831) described a patient suffering from external compression of the subclavian artery caused by cervical rib. At the population level, less than 2% have cervical ribs, which are known to cause ATOS and subclavian artery aneurysm (White et al. 1945). The cervical ribs may also be bilateral. Typically, ATOS is caused by external compression in the scalene triangle region due to a cervical rib or other anomalous structure such as congenital cervical fibro-cartilaginous bands (Pollack 1980). ATOS is rare in adults. Due to the anomalous structures mentioned above, the syndrome is more common in children and teenagers (Chang et al. 2011).

The typical symptoms of ATOS include ischemic pain, pale color, coldness of the hands, or numbness or weakness of the upper limbs (Illig et al. 2016). Acute upper extremity embolism is possible. ATOS can also be asymptomatic. Cerebellar ischemic stroke may be a rare manifestation in patients with ATOS (Palmer et al. 2015). This is due to a retrograde embolism originating from the thrombus of the subclavian artery aneurysm. According to Likes et al. (2014), patients with a mixed type of TOS (NTOS and ATOS) should be operated on early if physiotherapy does not achieve a response. They justify the operation on the grounds that no thrombosis or stenosis develops in the subclavian artery (Likes et al. 2014).

When ATOS is suspected, clinical examination should pay attention to classical signs of ischemia such as rest pain, numbness, coldness, and discoloration (Illig et al. 2016). The pulse status should also be checked, as well as listening for a possible subclavian artery whiz (Illig et al. 2016). The patient should be asked about their history, especially possible clavicle and rib fractures. Chest radiography is part of routine imaging studies in patients with ATOS (Illig et al. 2016). Duplex ultrasound, arteriography, computed tomography arteriography, magnetic resonance arteriography, and hemodynamic testing including finger plethysmography may be included in ATOS imaging (Illig et al. 2016). Duplex ultrasound can be used to assess arterial blood flow at rest as well as in a provocative position to detect possible narrowing. Duplex ultrasound is a sensitive but not a specific imaging study. Arterial obstruction may also occur in healthy patients (Gergoudis et al. 1980).

Surgery is recommended for symptomatic patients. If the subclavian artery is damaged, it should be repaired or replaced (Illig et al. 2016). The indications for subclavian artery replacement are aneurysmal dilation greater than two times the normal size, the presence of intramural thrombus, or a history of thromboembolism (Nguyen et al. 2021). TOS decompression may also be involved, typically performed with the supraclavicular technique (Nguyen et al. 2021). Any distal emboli should also be treated as necessary (Illig et al. 2016).

If a patient has acute ischemia, open thrombectomy or catheter-assisted thrombolysis is performed (Illig et al. 2016). In addition, systemic anticoagulation is recommended after thrombectomy (Nguyen et al. 2021).

2.3 EPIDEMIOLOGY OF THORACIC OUTLET SYNDROME

TOS was first described in the early 1900s (Roos 1996). Although it has been known over a century, the variable diagnostics have made it difficult to determine

the prevalence or the incidence of the different manifestations of TOS. The above-mentioned situation is especially true for NTOS. Indeed, the entire NTOS diagnosis has been challenged in the literature (Roos 1990, Wilbourn 1990)

In the late 1980s, Roos (1989) published that the prevalence of TOS is between 0.3% and 2% of the population aged 25-40 years. ATOS is the least common accounting for no more than 1% of patients (Sanders et al. 2007). Subsequently, 80%-90% of all patients with TOS are estimated to have NTOS (Illig et al. 2021a). Of all patients with TOS who undergo operation, > 95% of them have NTOS (Sanders et al. 2007). There may be a large difference in the number of operations between different centers, especially between NTOS and VTOS (Illig et al. 2021a). Illig et al. (2021a, 2021b) have estimated the overall incidence of different forms of TOS in the United States population: 3 per 100 000 people per year for NTOS, 1 per 100 000 people per year for VTOS, and 0.2 per 100 000 people per year for ATOS. TOS may be even more common in athletes (Chandra et al. 2014).

2.4 NEUROGENIC THORACIC OUTLET SYNDROME

Hereafter, this thesis focuses exclusively on NTOS, a very controversial entity in clinical medicine. Besides diagnostic criteria and optimal treatment, there has been debate about its very existence (Lederman 1987, Lindgren et al. 1995, Molina et al. 2009, Porter et al. 1982). The subjective assessment of the improvement by the operating surgeon is not the most reliable or the best method (Porter et al. 1982). Until 2016, the problem was the lack of uniform diagnostic criteria (Illig et al. 2016).

There are thousands of publications about NTOS. However, there are only a few randomized controlled trials (RCTs) (Finlayson et al. 2011, Goeteyn et al. 2022b, Iwuagwu et al. 2005, Kim et al. 2016, Ortac et al. 2020, Plewa et al. 1998, Sheth et al. 2005). Ortac et al. (2020) compared kinesiotaping with placebo taping. Kim et al. (2016) evaluated the effect of a steroid injection on a patient's pain compared with a stretching exercise group. Plewa et al. (1998) investigated the incidence of false-positive findings in diagnostic tests of TOS. Finlayson et al. (2011) compared botulinum toxin injections to a control group of patients who received a placebo injection into the scalenus muscle. Iwuagwu et al. (2005) investigated electrodiagnostic neurophysiological test in patients with no symptoms of TOS in which one group underwent early reduction mammoplasty surgery and the other group underwent delayed reduction mammoplasty. Sheth et al. (2005) compared long-term operative outcomes of transaxillary FRR and supraclavicular

scalenotomy. The latest RCT from Goeteyn et al. (2022b) compared the differences between transaxillary FRR and conservative treatment in a short-term follow-up.

There are five treatment guidelines for NTOS. The most cited is the reporting standards of the Society for Vascular Surgery for thoracic outlet syndrome (Illig et al. 2016). This report aims to produce consistency in the diagnosis, treatment description, and evaluation of the results (Illig et al. 2016). The European community of peripheral nerve surgeons has recently published their own recommendation (Dengler et al. 2022). Other guidelines focus on imaging (Moriarty et al. 2015, Zurkiya et al. 2020). Scher et al. (1984) aimed to classify and guide treatment in subclavian artery compression caused by a cervical rib.

Over the decades, NTOS has been both overdiagnosed and underdiagnosed. However, according to current knowledge, it is a real group of disorders, and diagnosis requires familiarity with the subject (Brantigan et al. 2004, Jones et al. 2019).

2.5 DIAGNOSIS OF NEUROGENIC THORACIC OUTLET SYNDROME

The diagnosis of NTOS relies heavily on patient history and physical examination. Imaging and other tests are used mainly to exclude differential diagnoses. Diagnostics are confused by other conditions that cause similar symptoms, such as carpal tunnel syndrome, rotator cuff laceration, or cervical prolapse/ radiculopathy. Other differential diagnostic conditions are fibromyalgia, myofascial pain, and chronic headache (Panda et al. 2021). Patients with NTOS may also have some overlap with VTOS (Illig et al. 2016).

According to the reporting standards of the Society for Vascular Surgery, patients should match three of the four criteria for the diagnosis of NTOS (Illig et al. 2016). The four criteria are: (a) local findings in the thoracic outlet, including pain and tenderness; (b) peripheral findings due to nerve compression, including distal neurologic changes that are usually worse when the arms are placed overhead or dangling; (c) absence of other probable diagnoses; and (d) a positive response to scalene muscle injections. The European community of peripheral nerve surgeons does not totally agree with the American Society for Vascular Surgery criteria for the diagnosis of NTOS (Dengler et al. 2022). According to the European Association of Neurosurgical Societies (EANS), NTOS should be subclassified as follows: hypotrophic NTOS (NTOS1), includes patients with weakness, hypotrophy, or atrophy of upper extremity muscles; irritative NTOS with anatomic abnormality (NTOS2); and irritative NTOS without anatomic abnormality

(NTOS3). NTOS2 contains subcategories depending on symptom distribution, namely (a) radicular, (b) cervicoscapular, and (c) diffuse (Dengler et al. 2022).

2.5.1 Symptoms

When evaluating a potential patient with NTOS, the symptom onset and what provokes the symptoms should be determined. The patient's occupation should be clarified, and they should be asked how the symptoms affect them at work. Typically, working above the head exacerbates symptoms. A possible history of trauma should also be clarified. The characteristics of NTOS pain, including its location, can vary (Panda et al. 2021). Patients may also report numbness or loss of sensation in the upper limb, chest wall, or hand. Motor weakness or fatigue in the upper arm may also occur. Skin color and temperature changes in the upper arm may also be present, but these are less common (Panda et al. 2021). Chronic compression of the inferior trunk of the brachial plexus can cause pain and progressive atrophy and weakness in the forearm and hand area; this is also called Gilliat-Summer hand in the literature (Gilliatt 1983, Goeteyn et al. 2022c, Tender et al. 2004).

2.5.2 Clinical examination

The clinical examination should pay attention to possible differences between the shoulders and upper limbs. Possible atrophies of the thenar, hypothenar, and interosseous muscles should be evaluated (Illig et al. 2016). Vascular examination should also be done (temperature, color, pulses, swelling, and capillary filling). The neurological status of the shoulder and upper limb is included to the clinical examination. Palpation and possible tenderness of thoracic outlet should also be classified. At this point, attention should be paid to whether the pain is localized to the pectoralis minor space or the scalene triangle (Illig et al. 2016). In the supraclavicular pressure test, the brachial plexus is deeply palpated; a positive finding is deep pain (Dengler et al. 2022). Provocative tests—the One-Minute Elevated Arm Stress Test (EAST (Roos-test)) and the Upper Limb Tension Test (ULTT)—should be done (Illig et al. 2016). These tests provoke symptoms by either narrowing the anatomical structures in the thoracic outlet area or stretching the brachial plexus. Pesser et al. (2022) reported that the EAST has low diagnostic value in isolation; however, standardization of the EAST leads to significant improvements in test-retest reliability. The Adson, Halstead, and costoclavicular maneuver tests are also used in clinical research. In their RCT, Plewa et al. (1998)

showed that TOS shoulder maneuvers have moderately low false-positive rates when pain occurs in the same arm for more than two of the following maneuvers: The Adson test, costoclavicular maneuver, or supraclavicular pressure test, or discontinuation of the EAST secondary to pain (Plewa et al. 1998). Also, if other symptoms besides pain occurred in more than three of these maneuvers, the results were the same.

2.5.3 Radiological examinations

There are no machine-driven tests to detect NTOS with certainty. The only routine imaging study for NTOS diagnosis is chest and cervical spine radiography (Illig et al. 2016). The purpose of this imaging is to find a possible cervical rib or another bony abnormality. The differential diagnostic examination may include computed tomography or magnetic resonance imaging of the thoracic wall (Sanders et al. 2007). Magnetic resonance imaging of the brachial plexus may be recommended if NTOS is suspected (Baumer et al. 2014, Dengler et al. 2022). Most neurosurgeons also perform magnetic resonance imaging of the cervical spine to investigate the nerve root or other spinal pathologies (Aramaslak 2012, Dengler et al. 2022, McGillicuddy 2004). Previous studies have indicated that high-resolution ultrasound and nerve conduction studies may help identify Gilliatt-Sumner hand (Goeteyn et al. 2022c, Pesser et al. 2020).

2.5.4 Neurophysiological examinations

Electrophysiological studies may help to diagnose NTOS and perform differential diagnosis such as carpal tunnel syndrome and cubital tunnel syndrome (Dengler et al. 2022, McGillicuddy 2004). Electromyography and nerve conduction velocity tests are normal in the majority of patients with NTOS (Sanders et al. 2007). Machanic et al. (2008) published earlier that medial antebrachial cutaneous nerve measurements showed increased latency and decreased amplitude on electromyography.

2.5.5 Scalene muscle injections

Injecting local anesthetic, botulinum toxin, or steroids into the scalene muscles is a good diagnostic test (Illig et al. 2016). This also predicts what would occur after FRR and scalenotomy (Donahue et al. 2020, Finlayson et al. 2011, Jordan et al. 2000, Kim et al. 2016, Torriani et al. 2009, 2010). However, botulinum toxin injection does

not seem to improve the symptom situation more than placebo injections with saline (Finlayson et al. 2011). Botulinum toxin is most often injected into the anterior scalene muscle under ultrasound guidance (Khalilzadeh et al. 2021).

2.6 CONSERVATIVE TREATMENT OF NEUROGENIC THORACIC OUTLET SYNDROME

NTOS treatment is primarily conservative (Arokoski et al. 2017, Doneddu et al. 2017, Povlsen et al. 2014). Indeed, conservative treatment should always be attempted before operative treatment (Doneddu et al. 2017). Peet et al. (1956) were the first to favor conservative treatment for TOS. They were also the first to describe conservative treatment: massage, strengthening of the levator scapularis muscle, stretching of the pectoralis muscles, moist heat, and postural correction exercises. Since then, other authors have refined and added to the conservative treatment protocol. These included mobility exercises, coordination exercises, and muscle relaxation and painkillers (Sällström et al. 1983, Smith 1979, Walsh 1994). Weight loss may also be beneficial (Panther et al. 2022). There is only one published RCT showing that conservative treatment is not better for NTOS than transaxillary thoracic outlet decompression (Goeteyn et al. 2022b).

The goal of conservative treatment is to strengthen the muscles of the shoulder area as well as improve posture (Lindgren 1997, Vanti et al. 2007). The patient's understanding of the causes of the syndrome plays a key role. In this way, the workload can be reduced and instructions for self-training and pain medication can be given (Franklin 2015). The QuickDASH questionnaire makes it easier assess performance and set goals for conservative treatment (Balderman et al. 2019). The success of conservative treatment ultimately depends on the good compliance of the patient (Vanti et al. 2007). According to their review, Jones et al. (2019) reported that rehabilitation should include patient education (weight, postural mechanics, and relaxation techniques), functional changes, and TOS-focused physiotherapy. If conservative treatment has been tried and the patient still has severe symptoms, operative treatment can be considered.

2.7 SURGICAL TREATMENT OF NEUROGENIC THORACIC OUTLET SYNDROME

All previous treatments and changes in life should be documented before beginning operative care (Illig et al. 2016). This includes changes in work and

leisure activities, possible physiotherapeutic treatments, as well as pain therapies. According to the reporting standards of NTOS, PROMs (QuickDASH, CBSQ, and the TOS disability scale) should be included in the evaluation of the treatment effect in patients with NTOS. Multidisciplinarity is essential for the diagnosis and treatment of patients with NTOS.

There is no single indication for surgical treatment in NTOS. Surgical treatment should be considered if conservative treatment does not provide an adequate response. Surgery can be divided into rib-sparing techniques and FRR techniques. The aim of surgery is to decompress the thoracic outlet.

2.7.1 Rib-sparing techniques

Adson et al. (1927) was the first to describe a scalenotomy without FRR to treat TOS-like syndromes nearly a century ago. Trauma caused by physical stress or a sudden stretch has been reported to cause changes in the scalenus muscles and thereby lead to NTOS (Roos 1996, Sanders et al. 2008, Yoshizumi et al. 2021). Yoshizumi et al. (2021) treated post-traumatic patients with NTOS with scalenotomy and brachial plexus neurolysis.

Scalenotomy and neurolysis of the brachial plexus are normally performed via supraclavicular approach (Sanders et al. 2004, Yoshizumi et al. 2021). The incision is made 2-3 cm above the clavicle. This is followed by splitting or retracting the sternocleidomastoid muscle, with transection into the subcutaneous layer as well as the platysma muscle (Sanders et al. 2004, Yoshizumi et al. 2021). The jugular vein and the omohyoid muscle are retracted medially or laterally. A scalenotomy is then performed on the anterior scalenus muscle below the fat layer. The phrenic nerve should be gently set aside before scalenotomy because it is located on the muscle (Sanders et al. 2004, Yoshizumi et al. 2021). If the middle scalene muscle is prominent and causing compression of the brachial plexus, it is partially dissected. Finally, neurolysis of the brachial plexus is performed as much as possible (Yoshizumi et al. 2021).

Ruopsa et al. (2021) considered that intraoperative compression between the clavicle and the first rib may be sign of the need for the FRR operation. The authors also found that consistent paleness during the Roos test may be a sign of severe compression in that area. Therefore, they have referred these patients for FRR operation instead of supraclavicular scalenotomy (Ruopsa et al. 2021).

2.7.2 First rib resection

FRR is currently the most common surgical treatment of NTOS (Yin et al. 2019), although the initial treatment of NTOS is conservative (Arokoski et al. 2017, Doneddu et al. 2017, Povlsen et al. 2014). Patients with severe symptoms who do not respond to conservative therapy may be referred for evaluation for surgical intervention. FRR is combined with scalenotomy (Roos 1966). The most common surgical technique for FRR is the open supraclavicular or transaxillary approach (Hempel et al. 1981, Roos 1966). In addition, mini-invasive techniques such as VATS or robot-assisted surgery are emerging (Burt et al. 2020, George et al. 2017, Gharagozloo et al. 2012, Mahmoud et al. 2018, Martinez et al. 2021, Ohtsuka et al. 1999). An infraclavicular approach can also be used in ATOS or VTOS operations (Bozzay et al. 2020). Good operative results can be achieved with all the above-mentioned techniques. The operator's preference influences the choice of surgical method.

Transaxillary technique

Transaxillary FRR was first described by Roos (1996). Since then, it has been the most common approach to FRR. Traditionally, an incision is made inferior to the axillary hairline. Soft tissues are moved to the side. Monopolar electrosurgery is used to expose the first rib. The anterior and medial scalene muscles are cut at their insertions of first rib. Then, using a rib cutter instrument, the first rib is cut as posteriorly as possible and, at the anterior end, as close to the costal cartilage as possible (Roos 1996, Stilo et al. 2020). A pleural drain is placed if needed. Chest radiography is performed after the surgery. The transaxillary approach to thoracic outlet decompression does not allow reconstruction of blood vessels but gives good visibility to the rib. However, a posterior rib stump may remain (Mingoli et al. 1995). Molina (1998b) suggested that subtotal removal of the first rib via the transaxillary approach may be acceptable if attempting complete removal would risk neurogenic or vascular injury.

Supraclavicular technique

Using the supraclavicular technique, excellent visibility is achieved in the operation area (vessels and first rib) (Hempel et al. 1981, Sanders et al. 2004). The supraclavicular FRR technique was first described by Sanders et al. (1985). It allows many more options than the transaxillary route, and the same incision can be

made for scalenotomy, neurolysis, and removal of the cervical rib (Sanders et al. 2004). The benefits of supraclavicular incision are a greater portion of the anterior and middle scalene muscles can be removed, the spinal nerves and trunks of the brachial plexus can be fully exposed, large-scale neurolysis can be achieved, it provides complete exposure of the entire rib, it allows for exposure of cervical ribs and elongated C7 transverse process, and vascular reconstructions are available if necessary (Aboul Hosn et al. 2020, Broussard et al. 2021, Illig 2013).

The supraclavicular skin incision is typically 4-6 cm long and it is placed 1-2 cm above the clavicle. The incision is centered on the lateral border of the sternocleidomastoid muscle (Broussard et al. 2021). Electrocautery is used when going through the platysma. The scalene fat pad is mobilized (Broussard et al. 2021). The anterior scalene muscle should be identified and dissected with caution because the phrenic nerve runs just on its surface (Broussard et al. 2021). The anterior scalene and middle scalene muscles are cut away (Broussard et al. 2021). The posterior part of the first rib lies under the middle scalene muscle. The first rib is exposed and divided first posteriorly and the anteriorly (Broussard et al. 2021).

Video-assisted and robot-assisted techniques

Video-assisted and robot-assisted FRR are new alternative approaches to decompression of the thoracic outlet. Partial resection of the first rib, especially posteriorly, can be attributed to the operative technique as well as trouble with insufficient exposure, this is where video-assisted technology is considered to bring an advantage (Burt 2018, Costantino et al. 2021). It may be difficult to treat patients with obesity by using the traditional surgical techniques (Burt 2018). In VATS, 2-3 thoracoscopic ports are normally used (Costantino et al. 2021, Mahmoud et al. 2018). Anatomical structures are identified, and then the parietal pleura of the first rib is opened by electrocautery. The first rib is dissected from the intercostal muscle anteriorly and posteriorly from the costovertebral junction (Costantino et al. 2021). A rongeur is used to trim the sharp edges of the first rib stump (Costantino et al. 2021). A pleural drain is left in the operation area. There is no need to manipulate or stretch the brachial plexus or subclavian artery when operating with the video-assisted or robot-assisted technique (Burt 2018). This reduces the risk of complications. In case of bleeding, VATS may need to be converted to open surgery because there are no suitable (wristed) instruments (Costantino et al. 2021).

2.8 TREATMENT OUTCOMES OF NEUROGENIC THORACIC OUTLET SYNDROME

Standardized PROMs should be obtained before and after any treatment to allow clinicians and researchers to compare the effects of different therapies. According to TOS reporting standards of the Society for Vascular Surgery, the severity of the symptoms, the duration of physiotherapy, current medication, physical examination, and PROM scores (QuickDASH, CBSQ, and the TOS disability scale) should be reported during the follow-up (Illig et al. 2016). The results should be obtained at 3, 6, 12, and 24 months after any treatment (Illig et al. 2016). Vastamäki et al. (2020) published the thoracic outlet syndrome index that is specifically aimed at measuring the quality of life of patients with TOS.

2.8.1 Patient-reported outcome measures

Baseline PROM scores are important to assess the success of treatments. QuickDASH (maximum score 100) focuses on functional disability of the upper extremities. The 11-item QuickDASH is based on the 30-item DASH survey (maximum score 100) (Beaton et al. 2005, Gummesson et al. 2006). DASH has been assessed regarding reliability, cross-sectional validity, and longitudinal validity in a number of upper extremity disorders (Beaton et al. 2001, Davis et al. 1999, Hudak et al. 1996). A QuickDASH score of 0 means no difficulty, 25 indicates mild difficulty, 50 indicates moderate difficulty, 75 indicates severe difficulty, and 100 means unable. QuickDASH does not consider which upper extremity is in question, or both. The score is for the overall performance.

CBSQ (maximum score 120) focuses on symptoms. CBSQ was developed to evaluate the success of the treatment of patients with TOS (Jordan et al. 2007). The instrument contains 12 questions that are scored 0-10, with 0 meaning that it did not happen in the past week and 10 meaning that it did happen all the time in the past week. A CBSQ total score of 0 means that no symptoms occurred during the last week, 60 means that there were symptoms half of the time during the last week, and 120 means that the symptoms were present for the entire week. In addition, CBSQ contains two verbal questions, where the symptoms can be explained by coloring the hand diagram. With the TOS disability scale, the patient is asked to rate global overall disability, not just pain, related to thoracic outlet symptoms from 0 (no disability) to 10 (maximum disability) (Illig et al. 2016).

The Neck Disability Index (NDI) is a 10-item questionnaire (maximum score 50), that measures patient's self-reported neck pain and disability (Vernon et al. 1991). NDI validity has been ensured through peer review and patient feedback. NDI was developed in patients who had a whiplash injury (Vernon et al. 1991).

The Beck Depression Inventory (BDI) is a 21-item self-report questionnaire (maximum score 63) that measures characteristic attitudes and symptoms of depression (Beck et al. 1961)

2.8.2 Outcomes after conservative treatment

There are only a few publications on the efficacy of conservative treatment of NTOS (Kenny et al. 1993, Vanti et al. 2007). In their review, Vanti et al. (2007) found that conservative treatment achieved a good or very good short-term outcome (1 month) in 76%-100% of patients. After at least 1 year, 58%-88% of patients showed a good or very good outcome. Balderman et al. (2019) reported that 27% of 150 patients with NTOS responded well to conservative treatment. Obesity, prolonged symptoms, and psychoemotional disturbances are predictors of a negative outcome (Lindgren 1997, Mailis et al. 1995, Novak et al. 1995, Sällström et al. 1983).

One RCT compared kinesiotaping and placebo taping at the 12-month follow-up (Ortac et al. 2020). The study showed that pain and DASH decreased significantly more in the kinesiotaping group during the follow-up. In their RCT, Kim et al. (2016) compared ultrasound-guided steroid injection and stretching exercise of the scalene muscle. The patients were suspected to have NTOS, and the main complaint was upper extremity paresthesia. After 2 weeks, there was significant decrease in the visual analog scale (VAS) in both groups; however, injection caused a larger decrease in the VAS. In another RCT, botulinum toxin injection did not lead to better function or less paresthesia or pain compared with placebo (saline) injection (Finlayson et al. 2011)

A few studies have used PROMs (**Table 1**). One study compared the results of physiotherapy and surgical (supraclavicular FRR) treatment based on QuickDASH; the score was 37 at the 20-month follow-up (Balderman et al. 2019). Goeteyn et al. (2022b) reported a DASH score of 65, a CBSQ score of 82, and a TOS disability score of 7 at 3 months after conservative treatment.

Conservative treatment has been shown to reduce symptoms, improve function, and facilitate return to work (Vanti et al. 2007). However, it is not possible to say what kind of conservative treatment is the best (Vanti et al. 2007).

2.8.3 Outcomes after rib-sparing surgery

In a systematic review of 40 studies including 3683 pooled patients, Yin et al. (2019) found that in the long-term follow-up, the surgical success rate after scalenotomy was 85%. Complete relief occurred in 61% of patients. It was concluded that FRR may not be necessary in the treatment of patients with NTOS, however, it should be noted that the lack of standard diagnostic criteria and different surgical indications may affect the result (Yin et al. 2019). The low QuickDASH/CBSQ scores in the study by Ransom et al. (2022) are explained by the fact that they evaluated adolescents.

According to the systematic review by Yin et al. (2019), the complication rate after scalenotomy was 12.6%. Opened pleura and pneumothorax were the most frequently reported complications. The reported rate of temporary brachial plexus injury was 5.0%, although no permeant injury occurred. Wound infection and hematoma/seroma occurred in 0.2% of patients. In other studies, the reported rate of transient phrenic nerve injury after scalenotomy was 1.1%-4.4% (Ruopsa et al. 2021, Sanders et al. 1989). No permanent phrenic nerve injuries have been reported (Ruopsa et al. 2021, Sanders et al. 1989; Yoshizumi et al. 2021).

2.8.4 Outcomes after supraclavicular first rib resections

In the long-term follow-up, the surgical success rate of supraclavicular FRR has been reported as 77%, with a complete symptom relief rate of 57% (Yin et al. 2019). Baldermann et al. (2019) compared the outcomes of physiotherapy and supraclavicular FRR in 130 patients with NTOS. The QuickDASH scores decreased more in the operative group than in the physiotherapy group (**Table 1**). Of note, in that study the final QuickDASH scores of the operative group were lower, but the initial scores were higher than in the physiotherapy group (Balderman et al. 2019). The high QuickDASH scores in the study by Jammeh et al. (2021) in **Table 1** could be explained by the fact that the data are from reoperated patients.

Yin et al. (2019) also reported on complications after supraclavicular FRR. The complication rate was 25.9%, which is slightly greater than in transaxillary surgery. Similar to transaxillary surgery, opened pleura and pneumothorax were the most frequently reported complications. Neurological injury occurred after 3.3% of supraclavicular FRR operations. Permanent brachial plexus injury occurred in only 0.1% of supraclavicular operations. The reoperation rate was 0.8%, which is slightly higher than in transaxillary surgery. Finally, 0.07% of patients died after supraclavicular surgery, although the cause of death was not reported.

2.8.5 Outcomes after transaxillary first rib resections

There have been numerous reports of short-term results after transaxillary FRR (Gelabert et al. 2018, Goeteyn et al. 2022b, Lepäntalo et al. 1989, Lum et al. 2012). However, according to the literature, short-term results may not be permanent, and symptoms may return. Typically, this occurs 2 years after treatment (Altobelli et al. 2005). Therefore, long-term (> 2 years) outcomes play an important role in assessing the effectiveness of different treatments. In their RCT, Goeteyn et al. (2022b) reported a DASH score of 34, a CBSQ score of 36, and a TOS disability score of 3 at the 12-month follow-up (**Table 1**).

The long-term surgical success rate after transaxillary FRR was 76% (Yin et al. 2019). Lepäntalo et al. (1989) reported a 37% permanent success rate after a 6-year follow-up. The complete relief rate was 53% in a systematic review of 2326 patients in 17 studies by Yin et al. (Yin et al. 2019). The worse final outcome was the result of poor patient selection to the operation in one study (Lepäntalo et al. 1989). The QuickDASH and CBSQ scores after different treatments in the midterm/long-term follow-up are presented in **Table 1**. After transaxillary FRR, QuickDASH/DASH scores were 32-35 (**Table 1**) (Gelabert et al. 2018, Goeteyn et al. 2022b, Pesser et al. 2021). After the transaxillary FRR, the CBSQ scores were 36-37 (Goeteyn et al. 2022b, Pesser et al. 2021, Rochlin et al. 2013). In a recent RCT including 50 patients, 3 months after transaxillary FRR, the DASH and CBSQ scores were significantly lower than in the conservative treatment group (Goeteyn et al. 2022b). In that study, the patients in the conservative treatment group were operated on after a 3-month follow-up. In another RCT, 75% of patients who received a transaxillary FRR reported a good or excellent outcome that was significantly better compared with 48% of patients who underwent supraclavicular scalenotomy (Sheth et al. 2005).

Table 1. Midterm/long-term follow-up studies of patients with neurogenic thoracic outlet syndrome evaluated with patient-reported outcome measures.

Reference	Number of patients	Follow-up time (months)	QuickDASH score	CBSQ score
Physiotherapy				
Balderman et al. 2019	40	20	37	NA
Scalenotomy without FRR				
Ransom et al. 2022	16	70	14	30
Ruopsa et al. 2021	89	155	37	52
Supraclavicular FRR				
Balderman et al. 2019	90	12	30	NA
Chandra et al. 2011	14	12	21	NA
Chandra et al. 2014	18	37	12	NA
Jammeh et al. 2021	90	67	44	NA
Ransom et al. 2022	8	70	6	23
Li et al. 2021	30	27	21*	30
Transaxillary FRR				
Rochlin et al. 2013	87	45	NA	36
Gelabert et al. 2018	62	21	35	NA
Pesser et al. 2021	45	24	32*	37
Goeteyn et al. 2022b	25	12	34*	36

* used the DASH (30-item questionnaire).

CBSQ, Cervical Brachial Symptom Questionnaire; FRR, first rib resection; NA, not available; QuickDASH, Quick Disability of the Arm, Shoulder, and Hand Questionnaire.

Complications after transaxillary first rib resections

Yin et al. (2019) described the complications after transaxillary FRR in a systematic review. The complication rate was 22.5%. Opened pleura and pneumothorax were the most frequently reported complications. Neurological injury occurred after 4.9% of the operations. However, the reported rate of permanent brachial plexus injury was only 0.1%. The reoperation rate was 0.15% and 0.04% died of postoperative bleeding. Yi et al. (2017) reported that Horner's syndrome occurred in 0.89% of patients after transaxillary FRR.

Recurrence after transaxillary first rib resection

According to Mingoli et al. (1995), a posterior rib stump > 3 cm may correlate with residual symptoms. By definition, recurrent TOS is defined as when a patient shows symptom improvement for at least 3 months, followed by symptoms returning (Illig et al. 2016). Typically, recurrence occurs 12-18 months after surgery (Phillips et al. 2021). Rochlin et al. (2012) reported that reoperated patients were slightly older (over 40 years), had had preoperative symptoms for a longer time, had suffered from chronic pain syndrome, or were active smokers. Lindgren et al. (1991) concluded that monotonous work could cause kinesiological abnormalities in the thoracic aperture. Kinesiological abnormalities can cause the recurrence of TOS symptoms even after FRR. Persistent TOS means that symptoms never significantly improve after treatment (Illig et al. 2016). Preoperative injection of local anesthetic into the pectoralis minor or scalenus anterior muscle that does not relieve symptoms predicts a poor surgical outcome (Jordan et al. 1998). The initial treatment for recurrence or persistence includes 4-6 weeks of physiotherapy aimed at softening scar tissue and mobilizing the brachial plexus. This includes stretching as well as massage therapy. Rochlin et al. (2012) found that > 90% of patients with recurrent or persistent NTOS recovered by multimodal treatment, local injections, and physical therapy. The exception was patients subjected to incomplete primary FRR.

Those with severe recurrent or residual symptoms may be considered for reoperation, which includes resection of unaddressed anatomical points of brachial plexus compression (Goeteyn et al. 2022a, Phillips et al. 2021). The cause of reoperation may be the anterior or middle scalene muscle; residual scar tissue adjacent to the brachial plexus; or a bony abnormality such as an elongated C7 transverse process, a cervical rib, or the residual posterior first rib stump (Phillips et al. 2021). Residual scalene muscle has been found in 83% of reoperated patients

(Jammeh et al. 2021). In the same study, the frequency of a posterior rib stump was significantly higher (74%) in patients who had had previous transaxillary surgery compared with those who had had previous supraclavicular surgery (21%). Cheng et al. (1994) reported 38 supraclavicular reoperations after initial supraclavicular, infraclavicular or transaxillary FRR with a 45% success rate after an 18-month follow-up. Goeteyn et al. (2022a) reported a DASH score of 42 and a CBSQ score of 56 after a 12-month follow-up. Jammeh et al. (2021) reported a QuickDASH score of 44 at 67 months after the surgery.

In the study by Cheng et al. (1994), 59% of symptoms were explained by scar tissue around the brachial plexus and 41% were explained by a long first rib stump of a missed cervical rib. They also reported that the first rib stump itself does not cause symptoms, but the growth of fibrotic tissue, bone, or cartilage from the stump can cause compression of the brachial plexus. Phillips et al. (2021) reported that the length of the posterior first rib stump beyond the first thoracic transverse process did not correlate with functional improvement.

Due to scar tissue, the reoperation is always more complicated. Cheng et al. (1994) reported that brachial plexus injury occurred in 5% of reoperated patients, and phrenic nerve injury occurred in 5% of cases. The occurrence of long thoracic nerve palsy (3%) and recurrent laryngeal nerve palsy (3%) were slightly lower. Goeteyn et al. (2022a) reported an 18% complication rate. Moreover, after supraclavicular FRR reoperations, one patient (2%) had permanent postoperative Horner syndrome and one (2%) had transient Horner syndrome. The complications are the same as in primary surgeries: wound infections, plexus injuries, phrenic nerve injuries, long thoracic nerve injuries, thoracic duct injuries, and vascular injuries (Camporese et al. 2022).

The same approach can be used in the reoperation as in the primary operation. However, reoperation for a transaxillary FRR via the same transaxillary approach can be tricky due to the scar of the primary operation (Cikrit et al. 1989). According to Phillips et al. (2021), the supraclavicular procedure provides better visibility and allows for possible additional procedures better than the transaxillary approach. The location of nerve compression affects the approach, especially compression in the subcoracoid region favors the transaxillary approach.

2.8.6 Outcomes after video-assisted first rib resections

Authors have reported an 89%-90% success at the short-term follow-up for mini-invasive surgical techniques (George et al. 2017, Soukiasian et al. 2015). Long-term results from these mini-invasive techniques are not available. Hwang et al. (2017)

provided a series of 8 TOS patients operated with VATS, however only one patient had NTOS. In addition, Martinez et al. (2021) published 16 years of results from 412 patients undergoing transaxillary robot-assisted FRR, but the results did not address success rates or used PROMs.

Gharagozloo et al. (2020) discussed robot-assisted FRR in 39 patients. The QuickDASH score was 4 at the 6-month follow-up. Palivela et al. (2021) published short-term results from a series of 40 robot-assisted FRR operations. At 15 weeks, the mean DASH score was 30.

In VATS and robot-assisted techniques, intercostal incisions may result in postoperative pain (Costantino et al. 2021). Soukiasian et al. (2015) reported a complication rate of 12.1% after 66 thoracoscopically assisted FRRs. Specifically, 3.0% of patients had pneumothorax. The most common complication was wound infection, which occurred in 4.5% of patients. There were no nerve injuries reported (Soukiasian et al. 2015).

3 AIMS OF THE STUDY

The general aim of this thesis was to evaluate the results of surgical treatment of patients with NTOS at Kuopio University Hospital. The specific aims were:

1. to compare short-term outcomes of the thoracoscopic technique and traditional transaxillary FRR (study I);

2. to compare long-term outcomes of the thoracoscopic technique and traditional transaxillary FRR (study II);

3. to investigate long-term outcomes over a decade after transaxillary FRR in patients with NTOS (study III);

4. to evaluate the association of the length of the first rib stump with residual symptoms after FRR in patients with NTOS (studies II and III).

4 SUBJECTS AND METHODS

These studies have been approved by the North-Savo institutional review board (ethical committee). Study I was entirely retrospective whereas studies II and III included both retrospective collection of the operative data and prospective follow-up setting to collect long-term data. Patients participating in prospective studies II and III gave their informed consent. The retrospective study I did not require informed consent.

4.1 SUBJECTS AND METHODS IN STUDY I AND II

4.1.1 Study population

The study I population consisted of 47 consecutive patients with NTOS treated with FRR at the Department of Vascular Surgery at our academic teaching hospital between July 2009 and October 2016. The total number of operations was 60 (13 bilateral). The first 30 procedures were done using the transaxillary approach, and the following 30 were done using a fully thoracoscopic technique. All patients had their initial diagnostic work-up, examinations, and conservative treatment provided by physical medicine and rehabilitation physicians (i.e., physiatrists). Patients with prolonged (> 6 months in duration) and severe symptoms were referred for surgical treatment. In addition, a good result from previous FRR on the contralateral side subjected to operative consideration. All surgical candidates were referred to and evaluated by one senior consultant cardiovascular surgeon.

In study II, the 47 above-mentioned patients were invited to participate in a prospective follow-up survey study via a letter, and those willing to participate were included. Thus, the patient population was the same as in study I. Altogether, 33 patients (with 40 operations) participated in study II. This comprised 18 of 30 transaxillary procedures and 22 of 30 video-assisted FRRs of the original 60 procedures included in study I.

4.1.2 Data acquisition and methods

In study I, all data were collected and analyzed retrospectively. All transaxillary FRRs were performed by a single senior vascular surgeon, and all VATS procedures were performed by a different senior cardiovascular surgeon. Thoracic radiographs were taken postoperatively, and the drains were removed according

to the clinical situation. All patients received personal postoperative training instructions by a physiotherapist.

In study I, the need for analgesics during the first 24 hours after surgery and the need for hospitalization in days as well as the duration of the drainage and the amount of drainage secretion were collected during the ward care period. All patients were examined approximately 3 months postoperatively at the outpatient clinic by a senior cardiovascular surgeon.

In the study II, data were collected retrospectively from the patients' medical records, including the diagnostic workup, the index procedure, and short-term (3-month) outcomes. PROM questionnaires were sent with the invitation letter to evaluate long-term outcomes and patient satisfaction. The questionnaires included QuickDASH and CBSQ, both of which are recommended in the TOS reporting standards of the Society for Vascular Surgery. In addition, BDI and NDI were used to identify possible factors that may confound the surgical outcomes. Patients also underwent a physical examination at the outpatient clinic, including the Adson, Spurling, and Roos tests, and a thorough examination of the upper limb neurological status, including reflex, skin sensation, and muscle strength tests. The patients also reported their TOS disability scale and pain scale scores. The patient's ability to work was estimated using questions covering subjective assessment of their current ability to work (yes/no) and whether the procedure had improved their working ability (yes/no). All clinical examinations were performed by the same senior physiatrist. The same grading of symptom improvement as in the 3-month follow-up visit was used. A chest X-ray, limited to a clavicular projection, was taken. The residual first rib length was measured by a senior radiologist.

4.1.3 Outcome endpoints and definitions

The patients' recovery at the 3-month (study I) and the long-term (study II) follow-ups was graded as no improvement, partial recovery, good recovery, or excellent recovery. In the long-term follow-up, the degree of the patient's symptoms was assessed with the CBSQ score and functional disability was evaluated with the QuickDASH score. A chest X-ray was taken at the time of the long-term follow-up (study II) to determine the potential posterior first rib remnant.

4.2 SUBJECTS AND METHODS IN STUDY III

4.2.1 Study population

The study population comprised patients with NTOS treated with FRR at Kuopio University Hospital between 1998 and 2007. During the study period, a total 47 (36 patients) transaxillary FRRs were performed for NTOS. A patient who had died during the follow-up (n = 1) and a patient who had moved abroad (n = 1) were excluded. The other patients received an invitation letter, and those willing to participate were included. Ultimately, 20 patients who underwent 27 FRR operations (27 operated arms) participated in the study.

The diagnostic criteria were pain and tenderness at the area of compression (scalene triangle, pectoral minor insertion site, or both), evidence of nerve compression by distal symptomatology, and the absence of another potentially causative problem. Scalene block testing was not used. Imaging studies and electroneuromyography were performed selectively. Initially, all patients underwent a diagnostic workup and a conservative physical rehabilitation period initiated by a physiatrist and lasting for a minimum of 6 months. The conservative treatment consisted of manual physical therapy, therapeutic exercises, and pain medication. Patients who failed to achieve satisfactory symptom resolution were referred to a senior vascular surgeon for the consideration of operative treatment.

4.2.2 Data acquisition and methods

The diagnostic workup, index procedure, and short-term (3-month) outcomes were extracted retrospectively from the patients' medical records. The long-term outcomes and patient satisfaction were determined using PROM questionnaires sent along with the invitation letter. These questionnaires included QuickDASH and CBSQ, both of which are recommended in the TOS reporting standards of the Society for Vascular Surgery. In addition, BDI and NDI were used to screen for factors that could confound the surgery results. In the outpatient clinic, the patients underwent a physical examination, which included the Adson, Spurling, and Roos tests, as well as a thorough upper limb neurological status examination, including reflex, skin sensation, and upper limb force tests. They also answered questionnaires to determine their TOS disability scale and pain scale scores. The patients' ability to work was estimated with a question, where they subjectively assessed their current ability to work (yes/no) and whether the procedure had

improved their working ability (yes/no). The clinical examination was performed by a senior physiatrist. A chest X-ray, limited to a clavicular projection, was taken.

4.2.3 Outcome endpoints and definitions

The clinical outcome at the 3-month and long-term follow-ups was graded as no improvement, or partial, good, or excellent recovery. In the long-term follow-up, the degree of the patient's symptoms was assessed with the CBSQ score, and functional disability was evaluated with the QuickDASH score. A chest X-ray was obtained to identify a potential posterior first rib remnant; the residual first rib length was measured by a senior radiologist.

4.3 STATISTICAL ANALYSES

SPSS statistics versions 21, 25, and 27 were used for statistical analyses. Continuous variables are expressed as mean ± standard deviation (SD). Fisher's exact test was used to compare nominal data, and the Mann-Whitney U test was used to compared nonparametric data. When analyzing dependent samples, the McNevar-Bowker test was used. For all tests, $p < 0.05$ was considered statistically significant.

5 RESULTS

5.1 SHORT-TERM OUTCOMES AFTER TRANSAXILLARY VERSUS THORACOSCOPIC FIRST RIB RESECTION IN PATIENTS WITH NEUROGENIC THORACIC OUTLET SYNDROME (STUDY I)

The mean age of all patients was 44 ± 11 years, and 63% were female. The preoperative characteristics and comorbidities were similar between the study groups (transaxillary and thoracoscopic). The mean operation time in the thoracoscopic group was 83 ± 27 minutes versus 48 ± 12 minutes in the transaxillary group ($p < 0.001$). However, there was a clear learning curve in the thoracoscopic group: After 10-20 procedures, the operation time stabilized to around 60 minutes. At the 3-month follow-up, 20 patients (67%) in the VATS group were fully asymptomatic or had only minor residual symptoms; in the transaxillary group, 19 patients (63%) reported similar improvement (**Table 2**).

Table 2. Follow-up data after 30 thoracoscopic and 30 transaxillary first rib resections.

Follow-up status at approximately 3 months	Transaxillary group (n = 30)	Thoracoscopic group (n = 30)	p
0. No significant improvement (%)	5 (17)	4 (13)	ND
1. Partial recovery (moderate residual symptoms) (%)	6 (20)	6 (20)	ND
2. Good recovery (minor residual symptoms) (%)	12 (40)	9 (30)	ND
3. Excellent recovery (fully asymptomatic) (%)	7 (23)	11 (37)	ND
Good or excellent recovery (2 + 3) (%)	19 (63)	20 (67)	1.000

All data are expressed as n (%) unless otherwise stated.

SD, standard deviation.

ND, not determined

5.2 LONG-TERM OUTCOMES AFTER TRANSAXILLARY VERSUS THORACOSCOPIC FIRST RIB RESECTION IN PATIENTS WITH NEUROGENIC THORACIC OUTLET SYNDROME (STUDY II)

The mean age was 45 ± 13 years in the transaxillary group and 43 ± 12 years in the VATS group ($p = 0.798$). The majority of patients in both groups were female (67% and 59%, respectively). The mean follow-up time was 70 ± 27 months overall, specifically 95 ± 19 months in the transaxillary group and 50 ± 12 months in the VATS group ($p < 0.001$).

The patients reported that their working ability had improved after 15 (83%) transaxillary procedures and after 15 (68%) video-assisted FRR ($p = 0.464$). The surgical outcome was considered good or excellent after 15 (83%) procedures in the transaxillary group and after 17 (77%) procedures in the VATS group ($p = 0.709$)

(**Table 3**). The mean CBSQ scores (maximum of 120) were 43 ± 29 (transaxillary group) versus 38 ± 25 (VATS group) (p = 0.819). The mean QuickDASH scores (maximum of 100) were 26 ± 17 (transaxillary group) versus 34 ± 19 (VATS group), (p = 0.180). The patients were asked whether they would undergo surgery again if they were given the choice (on scale of 0-10, where 0 is absolutely not and 10 is absolutely yes). The mean scores were 8 ± 4 (transaxillary group) and 8 ± 4 (VATS group) (p = 0.657). Minor symptoms returned during the follow-up period after 12 (67%) procedures in the transaxillary group and after 12 (55%) procedures in the VATS group (p = 0.526).

One patient in the transaxillary group required reoperation as symptoms recurred several years after index procedureIn this procedure, the patient developed persistent iatrogenic Horner syndrome, which did not improve during the follow-up. One patient in the VATS group reported numbness of the operated chest.

Table 3. Short- and long-term outcomes of 40 first rib resections in patients with neurogenic thoracic outlet syndrome.

Early follow-up status at 3 months	**Transaxillary**	**Thoracoscopic**	**p**
0. No significant improvement (%)	0 (0)	2 (9)	ND
1. Partial recovery (moderate residual symptoms) (%)	4 (22)	4 (18)	ND
2. Good recovery (minor residual symptoms) (%)	9 (50)	8 (36)	ND
3. Excellent recovery (fully asymptomatic) (%)	5 (28)	8 (36)	0.737
Good or excellent recovery (2 + 3) (%)	14 (78)	16 (73)	1.000
Late follow-up status, > 50 months after surgery			
0. No significant improvement (%)	3 (17)	2 (9)	ND
1. Partial recovery (moderate residual symptoms) (%)	0 (0)	3 (14)	ND
2. Good recovery (minor residual symptoms) (%)	14 (78)	10 (45)	ND
3. Excellent recovery (fully asymptomatic) (%)	1 (6)	7 (32)	0.054
Good or excellent recovery (2 + 3) (%)	15 (83)	17 (77)	0.709

ND, not determined

5.3 LONG-TERM OUTCOMES AFTER TRANSAXILLARY FIRST RIB RESECTION IN PATIENTS WITH NEUROGENIC THORACIC OUTLET SYNDROME (STUDY III)

The mean age of the patients was 42 ± 10 years, and 21 (78%) were female. The mean hospital stay was 2.4 ± 0.7 days. At the first follow-up visit, approximately 3 months after the index surgery, 16 patients (59%) reported excellent or good recovery after surgery.

The mean follow-up time was 15 ± 4 years (range 11-21 years). There was excellent or good recovery after 22 (81%) operations, with no difference between short- and long-term recovery in the same patients (p = 0.278) (**Table 4**). There were no cases of late symptom recurrence in patients who experienced initial symptom resolution. Twenty-three patients (85%) reported long-term improvement in their working capacity. The QuickDASH score was 21 ± 18 and the CBSQ score was 27 ± 28 at the time of the long-term follow-up. The patients were asked whether if given the choice they would still undergo surgery, rated from 0 (absolutely not) to 10 (absolutely yes). The mean score for the answers was 9 ± 2.

Table 4. Symptom relief and outcome at 3 months and 15 ± 4 years of 27 operated arms of patients with neurogenic thoracic outlet syndrome who underwent first rib resections.

Follow-up status	**At 3 months**	**At 15 ± 4 years**
0. No significant improvement, number (%)	2 (7)	2 (7)
1. Partial recovery, moderate residual symptoms, number (%)	9 (33)	3 (11)
2. Good recovery, minor residual symptoms, number (%)	7 (26)	9 (33)
3. Excellent recovery, number (fully asymptomatic) (%)	9 (33)	13 (48)
Excellent or good recovery, number (%)	16 (59)	22 (81)

5.4 CORRELATION OF THE FIRST RIB STUMP LENGHT WITH OUTCOMES AFTER FIRST RIB RESECTION IN PATIENTS WITH NEUROGENIC THORACIC OUTLET SYNDROME (STUDY II AND III)

In study II, the mean length of the residual stump of the operated first rib was 31 ± 7 mm in the transaxillary group and 28 ± 9 mm in the VATS group. There was no significant difference between the groups in the mean length of the rib stump (p = 0.286). The stump length was > 30 mm in 9 (50%) cases in the transaxillary group and in 9 (41%) cases in the VATS group (p = 0.750). A residual stump > 30 mm long had no association with the symptom status during the follow-up (**Table 5**).

Table 5. The first rib stump correlation to the long-term outcome for 40 first rib resections in patients with neurogenic thoracic outlet syndrome.

Late follow-up status, > 50 months after surgery	**Stump length > 30 mm (18 operations)**	**Stump length ≤ 30mm (22 operations)**	**p**
0. No significant improvement (%)	3 (17)	2 (9)	0.642
1. Partial recovery (moderate residual symptoms) (%)	1 (6)	2 (9)	ND
2. Good recovery (minor residual symptoms) (%)	9 (50)	15 (68)	ND
3. Excellent recovery (fully asymptomatic) (%)	5 (28)	3 (14)	0.430
Good or excellent recovery (2 + 3) (%)	14 (78)	18 (82)	1.000

ND, not determined

In study III, out of the 27 operated arms, 26 (96%) had a residual first rib stump visible in the long-term follow-up X-ray. The mean length of the residual first rib was 29 ± 10 mm. The length was < 30 mm after 13 (48%) and ≥ 30 mm after 14 (52%) operations. A stump > 30 mm long had no association with worse long-term outcome or residual symptoms (p = 1.000) (**Table 6**). No reoperations were performed during the follow-up period.

Table 6. Long-term outcomes of 27 first rib resections in patients with neurogenic thoracic outlet syndrome and the length of first rib stump.

Long-term follow-up status at 15 ± 4 years	**First rib stump < 30 mm**	**First rib stump ≥ 30 mm**
0. No significant improvement (%)	1 (4)	1 (4)
1. Partial recovery (moderate residual symptoms) (%)	1 (4)	2 (7)
2. Good recovery, minor residual symptoms (%)	4 (15)	5 (19)
3. Excellent recovery (%)	7 (26)	6 (22)

6 DISCUSSION

6.1 OPERATION TIME, COMPLICATIONS, AND SHORT-TERM RESULTS OF THORACOSCOPIC AND TRANSAXILLARY FIRST RIB RESECTIONS (STUDY I)

The most important findings of study I were that FRR could be performed safely using VATS and with early results similar to what was achieved using the transaxillary technique. There were no immediate complications in either group. Three patients (10%) had surgical wound infections after transaxillary FRR, defined as late complications, although all were managed conservatively. Previously, Orlando et al. (2015) reported an infection rate of 1.3% after transaxillary FRR. The difference between these numbers may be explained by variable diagnostic criteria for infection, and perhaps, by the fact that in our study the health care centers were able to prescribe an antibiotic for wound infection even if it was normal inflammatory reaction that is part of the wound healing process leading to a higher rate of wound infection diagnoses. In addition, data from a small number of patients could lead to a higher occurrence of wound infections that what would occur with a larger number of patients. One patient developed plexus neuralgia 3 weeks after VATS, which left us baffled because the patient was asymptomatic immediately after surgery. The symptoms in this patient resolved completely with physiotherapy during the long-term follow-up.

The mean thoracoscopic operation time was significantly higher than the operation time in the transaxillary group. The first thoracoscopic FRR were 2-hour procedures, but they now take around 60 minutes. This procedure time is nearly similar to the transaxillary procedure time. The median operation time in the VATS group was nearly the same as George et al. (2017). The short-term success outcomes of 63%-67% are comparable to other studies (Yin et al. 2019). However, short-term results may not be permanent, and symptoms may return (Altobelli et al. 2005). In addition, the problem with comparing previously published case series against each other is that, inevitably, the diagnostic criteria and indications for intervention rely greatly on each physician's judgment that the threshold for surgery varies significantly among institutions. Therefore, a comparison of short-term results among studies is not reliable. In the literature of NTOS, there is also no consensus on what time exactly short-term and long-term mean.

Based on these short-term results, we cannot say that either surgical method is significantly better. The surgeon's preference affects the chosen surgical method. However, traditional open surgery must always be another option if a thoracoscopic procedure is not possible—for example, due to pleural adhesions.

6.2 LONG-TERM OUTCOMES AFTER FIRST RIB RESECTIONS IN PATIENTS WITH NEUROGENIC THORACIC OUTLET SYNDROME (STUDIES II AND III)

A lot of operative results based on subjective evaluation have been published in the literature. However, not many long-term results in line with the reporting standards of NTOS have been published. Previous articles have mainly included series published using traditional open techniques.

The mean characteristics of our study populations are the same as have been reported in previous studies. Most of the patients were female and without other comorbidities (Mingoli et al. 1995). In study III, at a mean of 15 years after the surgery, up to 80%-90% of patients reported sustained recovery with minor or no residual symptoms and a normal working ability. The results from study II are similar. These findings are comparable to the latest systematic review article of patients with NTOS who underwent transaxillary surgery; the authors reported a success rate of 76% (Yin et al. 2018).

In study III, the long-term outcomes more than a decade after the initial surgery were also comparable to the short-term outcomes, and there was no recurrence of symptoms during this very long follow-up period. However, the patients were not completely asymptomatic: Half of them had some level of residual symptoms. Nevertheless, most patients reported that they would be willing to undergo surgery again if given the choice. In some ways, this also reflects the improvement in the patient's quality of life. Altobelli et al. (2005) indicated that a good surgical outcome generally means an improvement in symptoms, but not necessarily a total cure.

In prior studies, the operative results were worse when symptoms had lasted for > 2 years (Altobelli et al. 2005, Rochlin et al. 2013), but we did not observe the same phenomenon. The mean long-term QuickDASH score, which focuses on functional disability, is slightly lower than or at the same level as reported in previous studies (Balderman et al. 2019, Gelabert et al. 2018, Pesser et al. 2021). The mean postoperative QuickDASH scores in our studies were 21 and 26 in the transaxillary groups and 34 in the VATS group. The other recommended measure

in the Society for Vascular Surgery reporting standards document CBSQ focuses on the symptoms. The mean CBSQ scores in our studies were 27 and 43 in the transaxillary groups and 38 in the VATS group, also similar to the previous studies (Pesser et al. 2021, Rochlin et al. 2013). In a supraclavicular study of adolescent patients, Ransom et al. (2022) reported lower CBSQ scores. The QuickDASH and CBSQ scores in our studies provide a good description of the status of patients at the long-term follow-up; specifically, very few were completely asymptomatic.

Operative treatment for patients with severe NTOS symptoms is justified. It would be useful to use PROMs to measure the severity of symptoms. Operative treatment seems to improve the patients' quality of life. However, complete absence of symptoms after the surgery is rare. This should be discussed with the patient before committing to surgery.

6.3 RESIDUAL FIRST RIB STUMP LENGTH AFTER FIRST RIB RESECTIONS IN PATIENTS WITH NEUROGENIC THORACIC OUTLET SYNDROME (STUDIES II AND III)

The lengths of the residual stumps were fairly similar between the groups. We found no correlation between stump length and clinical outcome or residual symptoms. In the literature, stump length > 3 cm has been associated with residual symptoms, although this finding is based on limited data (Mingoli et al. 1995). There are only a few publications describing the stump length in patients with NTOS who had undergone transaxillary surgery. Altobelli et al. (2005) published a series of 254 patients subjected to a transaxillary operation, each with a rib stump < 1 cm long. Of these patients, up to 80 underwent reoperation because their symptoms were not sufficiently relieved. On the other hand, in the effort to completely resect the first rib, the risks of complications increase (Molina 1998b).

In our opinion, VATS provides better visual control for FRR. The first rib stump was shorter in the VATS group than in the transaxillary group, although the difference was not significant. The importance of the rib stump in the return of symptoms should be investigated in more detail in the future. It is also possible that the rib stump grows over the years (Gelabert et al. 2014).

6.4 STRENGTHS AND LIMITATIONS

The retrospective nature of these studies represents a limitation. In particular, it would have been helpful to assess PROMs at the time of diagnosis to gauge changes after surgery. Indeed, we might expect to see decreases in the QuickDASH and CBSQ scores after surgery. In addition, an issue with comparing previously published case series against each other is that, inevitably, the diagnostic criteria and indications for intervention vary greatly. Another limitation is the relatively small number of patients. Although, the participation rate was good, the reluctance of symptomatic patients to participate in the study might have caused selection bias. Selecting which patients are suitable for surgical treatment is particularly difficult for patients with NTOS. This may also cause bias in a small study.

The strengths of the studies are their multidisciplinary assessment using standardized, objective metrics at the long-term follow-up. The values of these studies are the long follow-up of patients. In previous studies involving PROMs recommended by the reporting standards, follow-up times have been relatively short.

6.5 FUTURE DIRECTIONS

The TOS reporting standards of the Society for Vascular Surgery will play an important role in future studies. They will make the diagnostic criteria for the measures as similar as possible, enabling comparison among studies. Collecting PROM scores for both pre- and postoperative periods and for ≥ 2 years of follow-up are needed. More long-term results and RCT comparing operative techniques are needed. In addition, new studies are needed assessing the newer VATS and robot-assisted surgical techniques.

7 CONCLUSIONS

1. NTOS operation can be done safely with VATS in experienced hands. There is a significant learning curve to this procedure, which has to be taken into account.

2. The transaxillary and VATS approaches achieved favorable outcomes based on the long-term follow-up.

3. Operative treatment using FRR for NTOS is associated with marked improvement in symptom relief—and thus quality of life—after a long follow-up period.

4. The residual rib stump length had no association with treatment outcome in our studies. However, a comparative prospective trial with a long-term follow-up and conservative treatment group, together with strict adherence to the reporting standards, is warranted.

REFERENCES

Aboul Hosn M, Goffredo P, Man J, Nicholson R, Kresowik T, Sharafuddin M, Sharp WJ, Pascarella L. Supraclavicular Versus Transaxillary First Rib Resection for Thoracic Outlet Syndrome. J Laparoendosc Adv Surg Tech A. 2020 Jul;30(7):737-741.

Adson A, Coffey JR. Cervical Rib: A Method of Anterior Approach for Relief of Symptoms by Division of the Scalenus Anticus. Annals of Surgery 1927;85:839.

Altobelli GG, Kudo T, Haas BT, Chandra FA, Moy JL, Ahn SS. Thoracic outlet syndrome: pattern of clinical success after operative decompression. J Vasc Surg. 2005 Jul;42(1):122-8.

Aralasmak A, Cevikol C, Karaali K, Senol U, Sharifov R, Kilicarslan R, Alkan A. MRI findings in thoracic outlet syndrome. Skeletal Radiol. 2012 Nov;41(11):1365-74.

Arokoski J, Karppinen J, Lindgren KA, Vastamäki H, Vastamäki M, Ristolainen L, Laimi K. Thoracic outlet syndrome. Duodecim. 2017;133(11):1043-51.

Balderman J, Abuirqeba AA, Eichaker L, Pate C, Earley JA, Bottros MM, Jayarajan SN, Thompson RW. Physical therapy management, surgical treatment, and patient-reported outcomes measures in a prospective observational cohort of patients with neurogenic thoracic outlet syndrome. J Vasc Surg. 2019 Sep;70(3):832-841.

Baumer P, Kele H, Kretschmer T, Koenig R, Pedro M, Bendszus M, Pham M. Thoracic outlet syndrome in 3T MR neurography-fibrous bands causing discernible lesions of the lower brachial plexus. Eur Radiol. 2014 Mar;24(3):756-61.

Beaton DE, Katz JN, Fossel AH, Wright JG, Tarasuk V, Bombardier C. Measuring the whole or the parts? Validity, reliability, and responsiveness of the Disabilities of the Arm, Shoulder and Hand outcome measure in different regions of the upper extremity. J Hand Ther. 2001 Apr-Jun;14(2):128-46.

Beaton DE, Wright JG, Katz JN; Upper Extremity Collaborative Group. Development of the QuickDASH: comparison of three item-reduction approaches. J Bone Joint Surg Am. 2005 May;87(5):1038-46.

Beck AT, Ward CH, Mendelson M, Mock J, Erbaugh J. An inventory for measuring depression. Arch Gen Psychiatry. 1961;4(6):561-571.

Bozzay JD, Walker PF, Ronaldi AE, Patel JA, Koelling EE, White PW, Rasmussen TE, Golarz SR, White JM. Infraclavicular Thoracic Outlet Decompression Compared to Supraclavicular Thoracic Outlet Decompression for the Management of Venous Thoracic Outlet Syndrome. Ann Vasc Surg. 2020 May;65:90-99.

Brantigan CO, Roos DB. Etiology of neurogenic thoracic outlet syndrome. Hand Clin. 2004 Feb;20(1):17-22.

Broussard BL, Donahue DM. Surgical Technique: Supraclavicular First Rib Resection. Thorac Surg Clin. 2021 Feb;31(1):71-79.

Burt BM. Thoracic outlet syndrome for thoracic surgeons. J Thorac Cardiovasc Surg. 2018 Sep;156(3):1318-1323.e1.

Burt BM, Palivela N, Cekmecelioglu D, Paily P, Najafi B, Lee HS, Montero M. Safety of robotic first rib resection for thoracic outlet syndrome. J Thorac Cardiovasc Surg. 2020 Sep 3:S0022-5223(20)32561-7.

Camporese G, Bernardi E, Venturin A, Pellizzaro A, Schiavon A, Caneva F, Strullato A, Toninato D, Forcato B, Zuin A, Squizzato F, Piazza M, Stramare R, Tonello C, Di Micco P, Masiero S, Rea F, Grego F, Simioni P. Diagnostic and Therapeutic Management of the Thoracic Outlet Syndrome. Review of the Literature and Report of an Italian Experience. Front Cardiovasc Med. 2022 Mar 22;9:802183.

Casbas L, Chauffour X, Cau J, Bossavy JP, Midy D, Baste JC, Barret A. Post-traumatic thoracic outlet syndromes. Ann Vasc Surg. 2005 Jan;19(1):25-8.

Chandra V, Little C, Lee JT. Thoracic outlet syndrome in high-performance athletes. J Vasc Surg. 2014 Oct;60(4):1012-7.

Chandra V, Olcott C 4th, Lee JT. Early results of a highly selective algorithm for surgery on patients with neurogenic thoracic outlet syndrome. J Vasc Surg. 2011 Dec;54(6):1698-705.

Chang K, Graf E, Davis K, Demos J, Roethle T, Freischlag JA. Spectrum of thoracic outlet syndrome presentation in adolescents. Arch Surg. 2011 Dec;146(12):1383-7.

Chang KZ, Likes K, Demos J, Black JH 3rd, Freischlag JA. Routine venography following transaxillary first rib resection and scalenectomy (FRRS) for chronic subclavian vein thrombosis ensures excellent outcomes and vein patency. Vasc Endovascular Surg. 2012 Jan;46(1):15-20.

Cheng SW, Stoney RJ. Supraclavicular reoperation for neurogenic thoracic outlet syndrome. J Vasc Surg. 1994 Apr;19(4):565-72. doi: 10.1016/s0741-5214(94)70027-3.

Chin EE, Zimmerman PT, Grant EG. Sonographic evaluation of upper extremity deep venous thrombosis. J Ultrasound Med. 2005 Jun;24(6):829-38; quiz 839-40.

Cikrit DF, Haefner R, Nichols WK, Silver D. Transaxillary or supraclavicular decompression for the thoracic outlet syndrome. A comparison of the risks and benefits. Am Surg. 1989 Jun;55(6):347-52.

Cook JR, Thompson RW. Evaluation and Management of Venous Thoracic Outlet Syndrome. Thorac Surg Clin. 2021 Feb;31(1):27-44.

Costantino CL, Schumacher LY. Surgical Technique: Minimally Invasive First-Rib Resection. Thorac Surg Clin. 2021 Feb;31(1):81-87.

Davis AM, Beaton DE, Hudak P, Amadio P, Bombardier C, Cole D, Hawker G, Katz JN, Makela M, Marx RG, Punnett L, Wright JG. Measuring disability of the upper extremity: a rationale supporting the use of a regional outcome measure. J Hand Ther. 1999 Oct-Dec;12(4):269-74.

Dengler NF, Ferraresi S, Rochkind S, Denisova N, Garozzo D, Heinen C, Alimehmeti R, Capone C, Barone DG, Zdunczyk A, Pedro MT, Antoniadis G, Kaiser R, Dubuisson A, Kretschmer T, Rasulic L. Thoracic Outlet Syndrome Part I: Systematic Review of the Literature and Consensus on Anatomy, Diagnosis, and Classification of Thoracic Outlet Syndrome by the European Association of Neurosurgical Societies' Section of Peripheral Nerve Surgery. Neurosurgery. 2022 Jun 1;90(6):653-667.

Desai SS, Toliyat M, Dua A, Charlton-Ouw KM, Hossain M, Estrera AL, Safi HJ, Azizzadeh A. Outcomes of surgical paraclavicular thoracic outlet decompression. Ann Vasc Surg. 2014 Feb;28(2):457-64.

Donahue DM, Godoy IRB, Gupta R, Donahue JA, Torriani M. Sonographically guided botulinum toxin injections in patients with neurogenic thoracic outlet syndrome: correlation with surgical outcomes. Skeletal Radiol. 2020 May;49(5):715-722.

Doneddu PE, Coraci D, De Franco P, Paolasso I, Caliandro P, Padua L. Thoracic outlet syndrome:Wide literature for few cases. status of the art. Neurological Sciences 2017;38:383-8.

Finlayson HC, O'Connor RJ, Brasher PMA, Travlos A. Botulinum toxin injection

for management of thoracic outlet syndrome: a double-blind, randomized, controlled trial. Pain. 2011;152(9):2023-2028.

Franklin GM. Work-related neurogenic thoracic outlet syndrome: diagnosis and treatment. Phys Med Rehabil Clin North Am 2015;26:551-61.

Gelabert HA, Jabori S, Barleben A, Kiang S, O'Connell J, Jimenez JC, Derubertis B, Rigberg D. Regrown first rib in patients with recurrent thoracic outlet syndrome. Ann Vasc Surg. 2014 May;28(4):933-8.

Gelabert HA, Rigberg DA, O'Connell JB, Jabori S, Jimenez JC, Farley S. Transaxillary decompression of thoracic outlet syndrome patients presenting with cervical ribs. J Vasc Surg. 2018 Oct;68(4):1143-1149.

George RS, Milton R, Chaudhuri N, Kefaloyannis E, Papagiannopoulos K. Totally endoscopic (VATS)First Rib Resection for Thoracic Outlet Syndrome. *Ann Thorac Surg*. 2017;103(1): 241-245.

Gergoudis R, Barnes RW. Thoracic outlet arterial compression: prevalence in normal persons. Angiology. 1980 Aug;31(8):538-41.

Gharagozloo F, Meyer M, Tempesta BJ, Margolis M, Strother ET, Tummala S. Robotic en bloc first-rib resection for Paget-Schroetter disease, a form of thoracic outlet syndrome: technique and initial results. Innovations (Phila). 2012 Jan-Feb;7(1):39-44.

Gharagozloo F, Meyer M, Tempesta B, Werden S. Robotic First Rib Resection for Thoracic Outlet Syndrome. Surg Technol Int. 2020 May 28;36:239-244.

Gilliatt RW. Thoracic outlet syndrome. Br Med J (Clin Res Ed). 1983 Sep 10;287(6394):764.

Gockel M. Operative treatment of thoracic outlet syndrome in Finland. Ann Chir Gynaecol. 1996;85(1):59-61.

Goeteyn J, Pesser N, Houterman S, van Sambeek MRHM, van Nuenen BFL, Teijink JAW. Surgery versus continued conservative treatment for neurogenic thoracic outlet syndrome: the first randomised clinical trial (STOPNTOS-trial). Eur J Vasc Endovasc Surg. 2022 May 7:S1078-5884(22)00295-7. B

Goeteyn J, Pesser N, van Sambeek MRHM, Vervaart K, van Nuenen BFL, Teijink JAW. Thoracic outlet decompression surgery for Gilliatt-Sumner hand as a presentation of neurogenic thoracic outlet syndrome. J Vasc Surg. 2022 Jun;75(6):1985-1992. C

Goeteyn J, Van Der Sanden L, Pesser N, Houterman S, van Sambeek MRHM, van Nuenen BFL, Teijink JAW. Redo surgery for neurogenic thoracic outlet syndrome is useful. J Vasc Surg. 2022 Mar 31:S0741-5214(22)01357-X. A

Gummesson C, Ward MM, Atroshi I. The shortened disabilities of the arm, shoulder and hand questionnaire (QuickDASH): validity and reliability based on responses within the full-length DASH. BMC Musculoskelet Disord. 2006 May 18;7:44.

Hempel GK, Rusher Jr AH, Wheeler CG, Hunt DG, Bukhari HI. Supraclavicular resection of the first rib for thoracic outlet syndrome. *Am J Surg*. 1981;141(2): 213-215.

Henry BM, Vikse J, Sanna B, Taterra D, Gomulska M, Pękala PA, Tubbs RS, Tomaszewski KA. Cervical Rib Prevalence and its Association with Thoracic Outlet Syndrome: A Meta-Analysis of 141 Studies with Surgical Considerations. World Neurosurg. 2018 Feb;110:e965-e978.

Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). Am J Ind Med. 1996 Jun;29(6):602-8.

Hwang J, Min BJ, Jo WM, Shin JS. Video-assisted thoracoscopic surgery for intrathoracic first rib resection in thoracic outlet syndrome. J Thorac Dis. 2017 Jul;9(7):2022-2028.

Illig KA. Surgical techniques: operative decompression using the supraclavicular approach for NTOS. In: Illig KA, Thompson RW, Freischlag JA et al, editors. Thoracic outlet syndrome. 1st edition. London: Springer;2013. p. 209-16.

Illig KA, Donahue D, Duncan A, Freischlag J, Gelabert H, Johansen K et al. Reporting standards of the Society for Vascular Surgery for thoracic outlet syndrome: Executive summary. J Vasc Surg. 2016;64(3):797-802.

Illig KA, Doyle AJ. A comprehensive review of Paget-Schroetter syndrome. J Vasc Surg. 2010 Jun;51(6):1538-47.

Illig KA, Rodriguez-Zoppi E. How Common Is Thoracic Outlet Syndrome? Thorac Surg Clin. 2021 Feb;31(1):11-17. A

Illig KA, Rodriguez-Zoppi E, Bland T, Muftah M, Jospitre E. The Incidence of Thoracic Outlet Syndrome. Ann Vasc Surg. 2021 Jan;70:263-272. B

Iwuagwu OC, Bajalan AA, Platt AJ, Stanley PR, Drew PJ. Effects of reduction mammoplasty on upper-limb nerve conduction across the thoracic outlet in women with macromastia: a prospective randomized study. Ann Plast Surg. 2005;55(5):445-448.

Jammeh ML, Ohman JW, Vemuri C, Abuirqeba AA, Thompson RW. Anatomically Complete Supraclavicular Reoperation for Recurrent Neurogenic Thoracic Outlet Syndrome: Clinical Characteristics, Operative Findings, and Long-term Outcomes. Hand (N Y). 2021 Jan 27:1558944720988079.

Jones MR, Prabhakar A, Viswanath O, Urits I, Green JB, Kendrick JB, Brunk AJ, Eng MR, Orhurhu V, Cornett EM, Kaye AD. Thoracic Outlet Syndrome: A Comprehensive Review of Pathophysiology, Diagnosis, and Treatment. Pain Ther. 2019 Jun;8(1):5-18.

Jordan SE, Ahn SS, Freischlag JA, Gelabert HA, Machleder HI. Selective botulinum chemodenervation of the scalene muscles for treatment of neurogenic thoracic outlet syndrome. Ann Vasc Surg. 2000 Jul;14(4):365-9.

Jordan SE, Ahn SS, Gelabert HA. Differentiation of thoracic outlet syndrome from treatment-resistant cervical brachial pain syndromes: development and utilization of a questionnaire, clinical examination and ultrasound evaluation. Pain Physician. 2007 May;10(3):441-52.

Jordan SE, Machleder HI. Diagnosis of thoracic outlet syndrome using electrophysiologically guided anterior scalene blocks. Ann Vasc Surg. 1998;12(3):260-264.

Karaolanis G, Antonopoulos CN, Koutsias SG, Giosdekos A, Metaxas EK, Tzimas P, de Borst GJ, Geroulakos G. A systematic review and meta-analysis for the management of Paget-Schroetter syndrome. J Vasc Surg Venous Lymphat Disord. 2021 May;9(3):801-810.e5.

Kenny RA, Traynor GB, Withington D, Keegan DJ. Thoracic outlet syndrome: a useful exercise treatment option. Am J Surg. 1993 Feb;165(2):282-4.

Khalilzadeh O, Glover M, Torriani M, Gupta R. Imaging Assessment of Thoracic Outlet Syndrome. Thorac Surg Clin. 2021 Feb;31(1):19-25.

Kim YW, Yoon SY, Park Y, Chang WH, Lee SC. Comparison between steroid

injection and stretching exercise on the scalene of patients with upper extremity paresthesia: randomized cross-over study. Yonsei Med J. 2016;57(2):490-495.

Klaassen Z, Sorenson E, Tubbs RS, Arya R, Meloy P, Shah M, Shirk S, Loukas M. Thoracic outlet syndrome: a neurological and vascular disorder. Clin Anat. 2014;27:724-32.

Kärkkäinen JM, Nuutinen H, Riekkinen T, Sihvo E, Turtiainen J, Saari P, Mäkinen K, Manninen H. Pharmacomechanical Thrombectomy in Paget-Schroetter Syndrome. Cardiovasc Intervent Radiol. 2016 Sep;39(9):1272-9.

Lederman RJ. Thoracic outlet compression syndromes; review of the controversies and a report of 17 instrumental musicians. Med Probl Perfor Art. 1987;2:87-91.

Lee JT, Karwowski JK, Harris EJ, Haukoos JS, Olcott C 4th. Long-term thrombotic recurrence after nonoperative management of Paget-Schroetter syndrome. J Vasc Surg. 2006 Jun;43(6):1236-43.

Lepäntalo M, Lindgren KA, Leino E, Lindfors O, von Smitten K, Nuutinen E, Tötterman S. Long term outcome after resection of the first rib for thoracic outlet syndrome. Br J Surg. 1989 Dec;76(12):1255-6.

Li Y, Liu Y, Zhang Z, Gao X, Cui S. A Novel Approach to First-Rib Resection in Neurogenic Thoracic Outlet Syndrome. Front Surg. 2021 Nov 12;8:775403.

Likes K, Rochlin DH, Call D, Freischlag JA. Coexistence of arterial compression in patients with neurogenic thoracic outlet syndrome. JAMA Surg. 2014 Dec;149(12):1240-3.

Lindgren KA. Conservative treatment of thoracic outlet syndrome: a 2-year follow-up. Arch Phys Med Rehabil 1997; 78:373-8.

Lindgren KA, Leino E, Lepäntalo M, Paukku P. Recurrent thoracic outlet syndrome after first rib resection. Arch Phys Med Rehabil. 1991 Mar;72(3):208-10.

Lindgren KA, Oksala I. Long-term outcome of surgery for thoracic outlet syndrome. Am J Surg. 1995 Mar;169(3):358-60.

Lum YW, Brooke BS, Likes K, Modi M, Grunebach H, Christo PJ, Freischlag JA. Impact of anterior scalene lidocaine blocks on predicting surgical success in older patients with neurogenic thoracic outlet syndrome. J Vasc Surg. 2012 May;55(5):1370-5.

Machanic BI, Sanders RJ. Medial antebrachial cutaneous nerve measurements to diagnose neurogenic thoracic outlet syndrome. Ann Vasc Surg. 2008 Mar;22(2):248-54.

Mahmoud O, Sihvo E, Räsänen J, Vikatmaa L, Vikatmaa P, Venermo M. Treatment of Paget-Schroetter syndrome with a three-stage approach including thoracoscopic rib resection at the second stage. J Vasc Surg Venous Lymphat Disord. 2018 Jan;6(1):75-82.

Mailis A, Papagapiou M, Vanderlinden RG, Campbell V, Taylor A. Thoracic outlet syndrome after motor vehicle accidents in a Canadian pain clinic population. Clin J Pain. 1995 Dec;11(4):316-24.

Martinez BD, Albeshri H, Chulkov M, Alharthi S, Nazzal MMS, Sferra J. Development and evolution of a robotic surgical technique for the treatment of thoracic outlet syndrome. J Vasc Surg. 2021 Sep;74(3):938-945.e1.

Mayo H. Exotosis of the first rib with strong pulsations of the subclavian artery. Lond Med Phy J.1831;11:40.

McGillicuddy JE. Cervical radiculopathy, entrapment neuropathy, and thoracic outlet syndrome: how to differentiate? Invited submission from the Joint Section Meeting on Disorders of the Spine and Peripheral Nerves, March 2004. J Neurosurg Spine. 2004 Sep;1(2):179-87.

Mingoli A, Feldhaus RJ, Farina C, Cavallari N, Sapienza P, di Marzo L, Cavallaro A. Long-term outcome after transaxillary approach for thoracic outlet syndrome. Surgery. 1995 Nov;118(5):840-4.

Molina JE. A new surgical approach to the innominate and subclavian vein. J Vasc Surg. 1998 Mar;27(3):576-81. A

Molina JE. Combined posterior and transaxillary approach for neurogenic thoracic outlet syndrome. J Am Coll Surg. 1998 Jul;187(1):39-45. B

Molina JE, Hunter DW, Dietz CA. Protocols for Paget-Schroetter syndrome and late treatment of chronic subclavian vein obstruction. Ann Thorac Surg. 2009 Feb;87(2):416-22.

Moriarty JM, Bandyk DF, Broderick DF, Cornelius RS, Dill KE, Francois CJ, Gerhard-Herman MD, Ginsburg ME, Hanley M, Kalva SP, Kanne JP, Ketai LH, Majdalany BS, Ravenel JG, Roth CJ, Saleh AG, Schenker MP, Mohammed TL, Rybicki FJ. ACR

Appropriateness Criteria Imaging in the Diagnosis of Thoracic Outlet Syndrome. J Am Coll Radiol. 2015 May;12(5):438-43.

Nguyen LL, Soo Hoo AJ. Evaluation and Management of Arterial Thoracic Outlet Syndrome. Thorac Surg Clin. 2021 Feb;31(1):45-54.

Novak CB, Collins ED, Mackinnon SE. Outcome following conservative management of thoracic outlet syndrome. J Hand Surg Am. 1995 Jul;20(4):542-8.

Ohtsuka T, Wolf RK, Dunsker SB. Port-access first-rib resection. Surg Endosc. 1999 Sep;13(9):940-2.

Orlando MS, Likes KC, Mirza S, et al. A decade of excellent outcomes after surgical intervention in 538 patients with thoracic outlet syndrome. J Am Coll Surg 2015;220:934-9.

Ortac EA, Sarpel T, Benlidayi IC. Effects of kinesio taping on pain, paresthesia, functional status, and overall health status in patients with symptomatic thoracic outlet syndrome: a single-blind, randomized, placebo-controlled study. Acta Orthop Traumatol Turc. 2020;54(4):394-401.

Palivela N, Lee HS, Jang HJ, Paily P, Montero M, Najafi B, Burt BM. Improvement of disability in neurogenic thoracic outlet syndrome by robotic first rib resection. Ann Thorac Surg. 2021 Aug 19:S0003-4975(21)01443-0.

Palmer OP, Weaver FA. Bilateral cervical ribs causing cerebellar stroke and arterial thoracic outlet syndrome: a case report and review of the literature. Ann Vasc Surg. 2015 May;29(4):840.e1-4.

Panda N, Donahue DM. Evaluation of Patients with Neurogenic Thoracic Outlet Syndrome. Thorac Surg Clin. 2021 Feb;31(1):55-59.

Panther EJ, Reintgen CD, Cueto RJ, Hao KA, Chim H, King JJ. Thoracic Outlet Syndrome: A review. J Shoulder Elbow Surg. 2022 Aug 10:S1058-2746(22)00609-7.

Peet RM, Henriksen JD, Anderson TP, Martin GM. Thoracic-outlet syndrome: evaluation of a therapeutic exercise program. Proc Staff Meet Mayo Clin. 1956 May 2;31(9):281-7.

Pesser N, de Bruijn BI, Goeteyn J, Houterman S, van Sambeek MRHM, Thompson RW, Teijink JAW, van Nuenen BFL. Reliability and validity of the elevated arm stress test in the diagnosis of neurogenic thoracic outlet syndrome. J Vasc Surg. 2022 Sep;76(3):814-820.

Pesser N, Goeteyn J, van der Sanden L, Houterman S, van Alfen N, van Sambeek MRHM, van Nuenen BFL, Teijink JAW. Feasibility and Outcomes of a Multidisciplinary Care Pathway for Neurogenic Thoracic Outlet Syndrome: A Prospective Observational Cohort Study. Eur J Vasc Endovasc Surg. 2021 Jun;61(6):1017-1024.

Pesser N, Teijink JAW, Vervaart K, Goeteyn J, Gons RAR, van Sambeek MRHM, van Nuenen BFL. Value of Ultrasound in the Diagnosis of Neurogenic Thoracic Outlet Syndrome. Eur J Vasc Endovasc Surg. 2020 May;59(5):852-853.

Phillips WW, Donahue DM. Reoperation for Persistent or Recurrent Neurogenic Thoracic Outlet Syndrome. Thorac Surg Clin. 2021 Feb;31(1):89-96.

Plewa MC, Delinger M. The false-positive rate of thoracic outlet syndrome shoulder maneuvers in healthy subjects. Acad Emerg Med. 1998;5(4):337-342.

Pollack EW. Surgical anatomy of the thoracic outlet syndrome. Surgery, Gynecology & Obstetrics. 1980 Jan;150(1):97-103.

Porter JM, Rivers SP, Coull BM, Baur GM. Thoracic outlet syndrome: a conservative approach. Vasc Diagn Ther. 1982;2:35-42.

Povlsen B, Hansson T, Povlsen SD. Treatment for thoracic outlet syndrome. Cochrane Database Syst Rev 2014:CD007218.

Ransom EF, Minton HL, Young BL, He JK, Ponce BA, McGwin G, Meyer RD, Brabston EW 3rd. Intermediate and Long-term Outcomes Following Surgical Decompression of Neurogenic Thoracic Outlet Syndrome in an Adolescent Patient Population. Hand (N Y). 2022 Jan;17(1):43-49.

Rochlin DH, Gilson MM, Likes KC, Graf E, Ford N, Christo PJ, Freischlag JA. Quality-of-life scores in neurogenic thoracic outlet syndrome patients undergoing first rib resection and scalenectomy. J Vasc Surg. 2013 Feb;57(2):436-43.

Rochlin DH, Likes KC, Gilson MM, Christo PJ, Freischlag JA. Management of unresolved, recurrent, and/or contralateral neurogenic symptoms in patients following first rib resection and scalenectomy. J Vasc Surg. 2012 Oct;56(4):1061-7; discussion 1068.

Roos DB. Congenital anomalies associated with thoracic outlet syndrome. Anatomy, symptoms, diagnosis, and treatment. Am J Surg. 1976 Dec;132(6):771-8.

Roos DB. Historical perspectives and anatomic considerations. Thoracic outlet syndrome. Semin Thorac Cardiovasc Surg. 1996 Apr;8(2):183-9.

Roos D. Review of thoracic outlet syndrome. In: Machleder, editor. Vascular diseases of the upper extremity. New York: Mt Kisco; 1989. p. 155-77.

Roos DB. The thoracic outlet syndrome is underrated. Arch Neurol. 1990 Mar;47(3):327-8.

Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg1966;163:354-8.

Ruopsa N, Ristolainen L, Vastamäki M, Vastamäki H. Neurogenic Thoracic Outlet Syndrome with Supraclavicular Release: Long-Term Outcome without Rib Resection. Diagnostics (Basel). 2021 Mar 5;11(3):450. doi: 10.3390/diagnostics11030450.

Scher LA, Veith FJ, Haimovici H, et al. Staging of arterial complications of cervical rib: guidelines for surgical management. Surgery. 1984;95(6):644-649.

Sanders RJ, Hammond SL. Supraclavicular first rib resection and total scalenotomy: technique and results. Hand Clin. 2004;20(1):61-70.

Sanders RJ, Hammond SL, Rao NM. Diagnosis of thoracic outlet syndrome. Journal of vascular surgery2007;46:601-4.

Sanders RJ, Hammond SL, Rao NM. Thoracic outlet syndrome: a review. Neurologist. 2008 Nov;14(6):365-73.

Sanders RJ, Pearce WH. The treatment of thoracic outlet syndrome: a comparison of different operations. J Vasc Surg. 1989 Dec;10(6):626-34.

Sanders RJ, Raymer S. The supraclavicular approach to scalenectomy and first rib resection: description of technique. J Vasc Surg. 1985 Sep;2(5):751-6.

Sheth RN, Campbell JN. Surgical treatment of thoracic outlet syndrome: a randomized trial comparing two operations. J Neurosurg Spine. 2005;3(5):355-363.

Smith KF. The thoracic outlet syndrome: a protocol of treatment *. J Orthop Sports Phys Ther. 1979;1(2):89-99.

Soukiasian HJ, Shouhed D, Serna-Gallgos D, McKenna R 3rd, Bairamian VJ, McKenna RJ Jr. A video-assisted thoracoscopic approach to transaxillary first rib resection. Innovations (Phila). 2015 Jan-Feb;10(1):21-6.

Stilo F, Montelione N, Benedetto F, Spinelli D, Vigliotti RC, Spinelli F. Thirty-year experience of transaxillary resection of first rib for thoracic outlet syndrome. Int Angiol. 2020 Feb;39(1):82-88.

Sällström J, Celegin Z. Physiotherapy in patients with thoracic outlet syndrome. Vasa. 1983;12(3):257-61.

Tender GC, Thomas AJ, Thomas N, Kline DG. Gilliatt-Sumner hand revisited: a 25-year experience. Neurosurgery. 2004 Oct;55(4):883-90; discussion 890.

Thompson RW. Comprehensive management of subclavian vein effort thrombosis. Semin Intervent Radiol. 2012 Mar;29(1):44-51.

Torriani M, Gupta R, Donahue DM. Botulinum toxin injection in neurogenic thoracic outlet syndrome: results and experience using a ultrasound-guided approach. Skeletal Radiol. 2010 Oct;39(10):973-80.

Torriani M, Gupta R, Donahue DM. Sonographically guided anesthetic injection of anterior scalene muscle for investigation of neurogenic thoracic outlet syndrome. Skeletal Radiol. 2009 Nov;38(11):1083-7.

Vanti C, Natalini L, Romeo A, Tosarelli D, Pillastrini P. Conservative treatment of thoracic outlet syndrome. A review of the literature. Eura Medicophys. 2007 Mar;43(1):55-70.

Vastamäki M, Ruopsa N, Vastamäki H, Laimi K, Ristolainen L, Saltychev M. Validity and internal consistency of the thoracic outlet syndrome index for patients with thoracic outlet syndrome. J Shoulder Elbow Surg. 2020 Jan;29(1):150-156.

Vemuri C, Salehi P, Benarroch-Gampel J, McLaughlin LN, Thompson RW. Diagnosis and treatment of effort-induced thrombosis of the axillary subclavian vein due to venous thoracic outlet syndrome. J Vasc Surg Venous Lymphat Disord. 2016 Oct;4(4):485-500.

Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. J Manipulative Physiol Ther. 1991 Sep;14(7):409-15.

Walsh MT. Therapist management of thoracic outlet syndrome. J Hand Ther. 1994 Apr-Jun;7(2):131-44.

Weber AE, Criado E. Relevance of bone anomalies in patients with thoracic outlet syndrome. Ann Vasc Surg. 2014 May;28(4):924-32.

White JC, Poppel MH, Adams R. Congenital malformations of the first thoracic rib; a cause of brachial neuralgia which simulates the cervical rib syndrome. Surg Gynecol Obstet. 1945 Dec;81:643-59

Wilbourn AJ. The thoracic outlet syndrome is overdiagnosed. Arch Neurol. 1990 Mar;47(3):328-30

Yi JA, Johnston RJ, Nehler MR, Gibula DR, Alix K, Glebova NO, Brantigan CO. A Fourteen-Year Experience with Vascular Anomalies Encountered during Transaxillary Rib Resection for Thoracic Outlet Syndrome. Ann Vasc Surg. 2017 Apr;40:105-111.

Yin ZG, Gong KT, Zhang JB. Outcomes of Surgical Management of Neurogenic Thoracic Outlet Syndrome: A Systematic Review and Bayesian Perspective. J Hand Surg Am. 2019 May;44(5):416.e1-416.e17. Epub 2018 Aug 16.

Yoshizumi T, Murata H, Kanno H, Shinonaga M. Efficacy of Supraclavicular Scalenotomy Followed by External Neurolysis without Rib Resection for Post-traumatic Neurogenic Thoracic Outlet Syndrome. Spine (Phila Pa 1976). 2021 Jun 1;46(11):E632-E638.

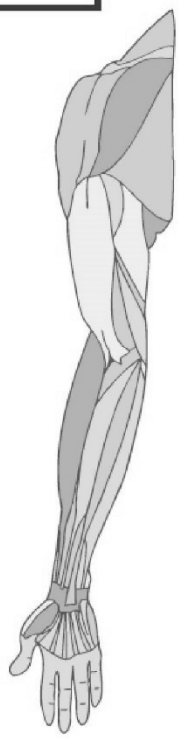
Zurkiya O, Ganguli S, Kalva SP, Chung JH, Shsh LM, Majdalany BS, Bykowski J, Carter BW, Chandra A, Collins JD, Gunn AJ, Kendi AT, Khaja MS, Liebeskind DS, Maldonado F, Obara P, Sutphin PD, Tong BC, Vijay K, Corey AS, Kanne JP, Dill KE. Expert Panels on Vascular Imaging, Thoracic Imaging, and Neurological Imaging. ACR appropriateness criteria thoracic outlet syndrome. J Am Coll Radiol. 2020;17(5S):S323-S334.

APPENDICES

APPENDIX 1

THE QuickDASH OUTCOME MEASURE

SUOMI



OHJEET

Tämä kysely kartoittaa oireitanne ja kykyänne suoriutua tietyistä tehtävistä.

Vastatkaa kaikkiin kysymyksiin ympyröimällä vaihtoehto, joka kuvastaa parhaiten viime viikon toimintakykyänne.

Jos ette tehneet joitain tehtävistä viime viikolla, arvioikaa miten olisitte suoriutuneet niistä. Vastatkaa sen mukaan miten suoriuduitte tehtävästä huolimatta siitä miten se toteutui.

Ei ole väliä kumpaa kättä, kyynärvartta tai olkavartta käytätte suoriutuaksenne tehtävistä. Vastatkaa sen mukaan miten suoriuduitte tehtävästä huolimatta siitä miten se toteutui.

QuickDASH

Arvioikaa miten suoriuduitte viime viikolla seuraavista tehtävistä ympyröimällä sopiva vaihtoehto.

	EI VAIKEUKSIA	VÄHÄN VAIKEUKSIA	KOHTALAISIA VAIKEUKSIA	SUURIA VAIKEUKSIA	EN PYSTYNYT
1. Purkin tai tiukan kannen avaaminen.	1	2	3	4	5
2. Raskaiden kotitöiden tekeminen (esim. ikkunoiden pesu, lattioiden pesu).	1	2	3	4	5
3. Ostoskassin tai salkun kantaminen.	1	2	3	4	5
4. Selän peseminen.	1	2	3	4	5
5. Veitsen käyttö ruoan pilkkomiseen.	1	2	3	4	5
6. Vapaa-ajan harrasteet, jotka aiheuttavat iskun tai kuormituksen olkapäähän, olkavarteen, kyynärvarteen tai käteen(esim. golf, vasarointi, tennis jne.).	1	2	3	4	5

	EI OLLENKAAN	VÄHÄN	KOHTALAISESTI	PALJON	ERITTÄIN PALJON
7. Kuinka paljon olkapään, olkavarren, kyynärvarren tai käden ongelmat ovat rajoittaneet normaalia sosiaalista kanssakäymistänne perheen, ystävien tai muiden tuttavien kanssa viime viikon aikana?	1	2	3	4	5

	EI OLLENKAAN	VÄHÄN	KOHTALAISESTI	PALJON	EN PYSTYNYT
8. Rajoittivatko olkapään, olkavarren, kyynärvarren tai käden ongelmat töitänne tai muita päivittäisiä toimianne viime viikon aikana?	1	2	3	4	5

	EI OLLENKAAN	VÄHÄN	KOHTALAISESTI	PALJON	ERITTÄIN PALJON
9. Olkapään, olkavarren, kyynärvarren tai käden kipua.	1	2	3	4	5
10. Pistelyä olkapäässä, olkavarressa, kyynärvarressa tai kädessä.	1	2	3	4	5

	EI VAIKEUKSIA	VÄHÄN VAIKEUKSIA	KOHTALAISIA VAIKEUKSIA	SUURIA VAIKEUKSIA	NIIN PALJON ETTEN SAANUT NUKUTUKSI
11. Onko teillä ollut nukkumisvaikeuksia olkapään, olkavarren, kyynärvarren tai käden kivun vuoksi viime viikon aikana?	1	2	3	4	5

QuickDASH

TYÖOSIO (VALINNAINEN)

Seuraavat kysymykset kartoittavat olkavarren, olkapään tai käden ongelmien vaikutusta kykyynne työskennellä (kodinhoito mukaan lukien mikäli se on päätyönne).

Mitä teette työksenne:_____

__ En ole töissä. (Voitte siirtyä seuraavan osioon.)

Ympyröikää vaihtoehto, joka parhaiten kuvaa fyysistä suoriutumiskykyänne viime viikolla. Oliko teillä vaikeuksia:

	EI VAIKEUKSIA	VÄHÄN VAIKEUKSIA	KOHTALAISIA VAIKEUKSIA	SUURIA VAIKEUKSIA	EN PYSTYNYT
1. Käyttää tavanomaisia työmenetelmiä?	1	2	3	4	5
2. Työskennellä olkapään, olkavarren, kyynärvarren tai käden kivun vuoksi?	1	2	3	4	5
3. Työskennellä niin hyvin kuin olisitte halunneet?	1	2	3	4	5
4. Käyttää yhtä paljon aikaa työntekoon kuin tavallisesti?	1	2	3	4	5

HAASTAVAT TOIMINNOT URHEILU/MUSIIKKIOSIO (VALINNAINEN)

Seuraavat kysymykset kartoittavat olkavarren, olkapään tai käden ongelmien vaikutusta soittamiseen, urheiluun tai molempiin.

Jos harrastatte montaa lajia tai soitatte useampaa soitinta, vastatkaa teille tärkeimmän harrastuksen mukaisesti.

Tärkein lajinne tai soittimenne:_____

__ En urheile enkä soita mitään soitinta. (Voitte olla vastaamatta seuraaviin kysymyksiin.)

Ympyröikää vaihtoehto, joka parhaiten kuvaa fyysistä suoriutumiskykyänne viime viikolla. Oliko teillä vaikeuksia:

	EI VAIKEUKSIA	VÄHÄN VAIKEUKSIA	KOHTALAISIA VAIKEUKSIA	SUURIA VAIKEUKSIA	EN PYSTYNYT
1. Käyttää tavanomaista tekniikkaa urheillessa tai soittaessa?	1	2	3	4	5
2. Soittaa tai urheilla olkapään, olkavarren, kyynärvarren tai käden kivun vuoksi	1	2	3	4	5
3. Soittaa tai urheilla niin hyvin kuin olisitte halunneet?	1	2	3	4	5
4. Käyttää yhtä paljon aikaa soittamiseen ja urheilemiseen kuin tavallisesti?	1	2	3	4	5

APPENDIX 2

Cervical Brachial Symptom Questionnaire ("CBSQ")

NAME_____ DATE_____

READ INSTRUCTIONS FIRST. This form is important for measuring the outcome of treatment.
Based on your experiences in the PAST WEEK, answer the following questions regarding how often symptoms would be likely to increase if you were to engage in certain activities.
Circle the number corresponding to how likely it would be for symptoms to increase during an activity so much that you would have to stop or modify the activity.
DO NOT LEAVE ANY BLANKS.
If a CONSTANT ongoing symptom would not be more noticeable during the activity, mark the answer "0."
If a symptom would increase during half of the instances of the activity, mark the answer "5."
Only mark "10" if your symptoms would increase during EVERY instance of the activity.

1. Pain going down the arm increases with neck movement, as in turning, flexing or extending the neck.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week — This past week, it would happen ALWAYS

2. Pain in the arm or shoulder increases instantly with brief shoulder movement as in throwing something or in reaching behind the body.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week — This past week, it would happen ALWAYS

3. Hand or arm aches or fatigues with arm exercise, particularly with overhead or outstretched positioning.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week — This past week, it would happen ALWAYS

4. Hand or arm swells after arm exercise, including after any activities that require repetitive arm movements.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week — This past week, it would happen ALWAYS

5. Sensations of tingling or numbness in the hand or arm increase when reaching overhead or outwards. Examples include brushing hair or blow-drying hair, reaching for an overhead shelf, or working with arms overhead as in painting a ceiling or screwing in light bulbs.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week — This past week, it would happen ALWAYS

6. Sensations of tingling or numbness increase in the hand or arm when awakening from sleep.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week — This past week, it would happen ALWAYS

7. Sensations of tingling or numbness increase in the hand or arm with repetitive finger movements as in writing, typing, sewing, playing musical instruments or assembling objects.

0 1 2 3 4 5 6 7 8 9 1 0
It would NEVER happen this past week This past week, it would happen ALWAYS

8. Sensations of tingling or numbness increase with prolonged or forceful grasping as in holding a steering wheel to drive, using tools, handling office instruments or controlling industrial equipment.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week This past week, it would happen ALWAYS

9. Sensations of tingling or numbness increase while bending elbow or leaning on elbow, for example, while holding telephone receiver or leaning on a desk.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week This past week, it would happen ALWAYS

10. Hand is clumsy or weak while trying to hold onto objects or while attempting to open jars, use keys to open a lock, pull zippers or button clothing.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week This past week, it would happen ALWAYS

11. Pain is caused by experiences that ordinarily are not painful. Examples include a light touch to the hand, arm, or neck, such as a light draft, the rub and tug of clothing, or the touch of something moderately hot or cold.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week This past week, it would happen ALWAYS

12. Disabling pain that can last into the next day is caused by activities that ordinarily produce only mild discomfort. Examples include a light exercise session, a physical therapy treatment or a physical examination.

0 1 2 3 4 5 6 7 8 9 10
It would NEVER happen this past week This past week, it would happen ALWAYS

13. Symptoms have occurred with the above activities in the past without recurrence in the past week.

yes no (circle your answer) If the answer is "yes", please list by number and explain on back.

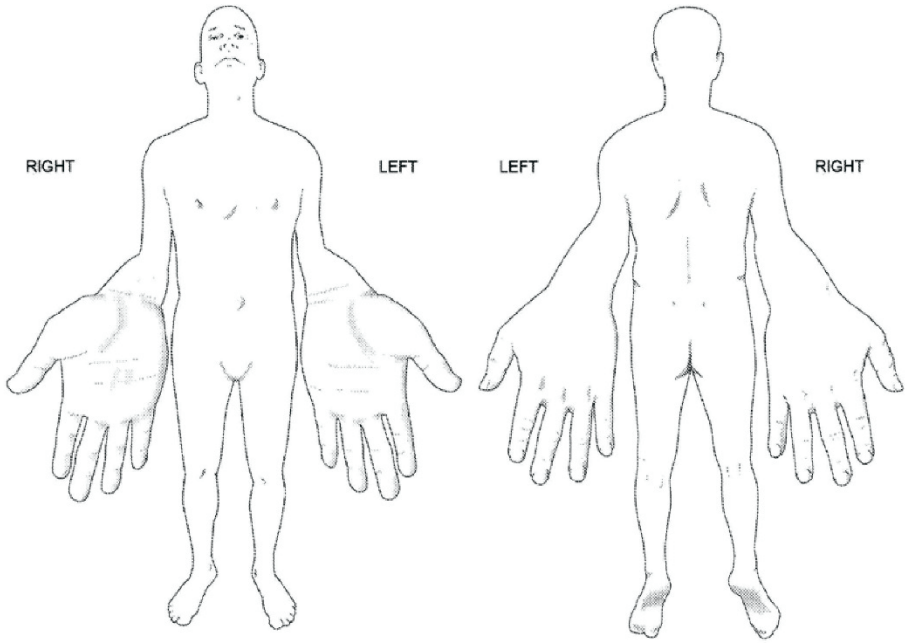
14. Hand becomes blue, red, swollen, sweaty or hot. Yes No (circle answer) If "yes" explain on back.

CERVICAL BRACHIAL SYMPTOM QUESTIONNAIRE

Mark where you feel pain with horizontal or vertical lines. Mark sensory changes with diagonal lines. If different pains or sensory changes are caused by specific items in the questionnaire, then indicate by the question number.
Use next page if necessary.

NAME_____

_____



or Mark pain

or Mark numbness or sensory disturbance including tingling

ORIGINAL PUBLICATIONS (I – III)

I

Thoracoscopic versus Transaxillary Approach to First Rib Resection in Thoracic Outlet Syndrome

Nuutinen H, Riekkinen T, Aittola V, Mäkinen K, Kärkkäinen JM

Annals of Thoracic Surgery 2018 Mar;105(3):937-942.

II

Long-term outcomes of transaxillary versus video assisted first rib resection for neurogenic thoracic outlet syndrome

Nuutinen H, Kärkkäinen JM, Mäkinen K, Aittola V, Riekkinen T, Saari P, Pesonen J

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Long-term outcomes of transaxillary versus video-assisted first rib resection for neurogenic thoracic outlet syndrome

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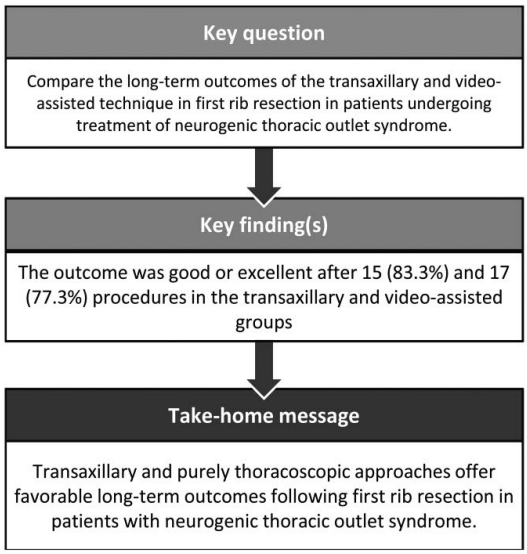

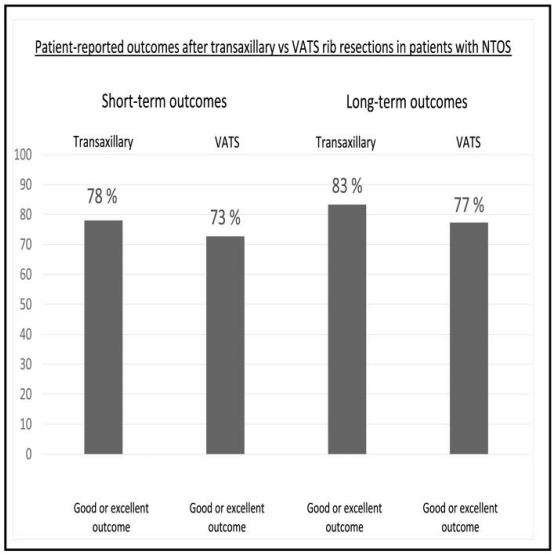

Abstract

OBJECTIVES: This study compared the long-term outcomes in terms of clinical examinations and patient-reported outcome measures, between transaxillary and video-assisted thoracoscopic techniques for first rib resection in patients with neurogenic thoracic outlet syndrome.

METHODS: The study population comprised patients who underwent first rib resection for neurogenic thoracic outlet syndrome at our institution between 2009 and 2016. All patients were recruited in a follow-up assessment in 2019, and those who agreed to participate were included in this study. Outcomes included examinations at the outpatient clinic and patient-reported outcome measures: Disabilities of Arm Shoulder and Hand Score and Cervical Brachial Symptom Questionnaire. The completeness of the rib resection was assessed on chest X-rays.

RESULTS: :A total of 60 first rib resections (30 transaxillary + 30 video-assisted fully thoracoscopic approaches) were performed for neurogenic thoracic outlet syndrome in 47 patients between 2009 and 2016. Of these, 32 patients participated in the study including 18 who had transaxillary and 22 who had video-assisted thoracoscopic procedures. The mean follow-up was 5.9 (standard deviation: 2.2) years. The outcome was good or excellent after 15 (83.3%) and 17 (77.3%) procedures in the transaxillary and video-assisted thoracoscopic surgery groups, respectively (P = 0.709). There were no differences in patient-reported outcome measures between the 2 groups. Furthermore, the length of the residual first rib stump was similar in both groups.

CONCLUSIONS: We found no differences in the long-term outcomes between the study groups. These results indicate that both transaxillary and purely thoracoscopic approaches offer favourable long-term outcomes following first rib resection in patients with neurogenic thoracic outlet syndrome.

Keywords: Neurogenic thoracic outlet syndrome • quality of life • video-assisted • transaxillary • long-term outcome • QuickDASH

ABBREVIATIONS

BDI	Beck's Depression Inventory
CBSQ	Cervical Brachial Symptom Questionnaire
FRR	first rib resection
NDI	Neck Disability Index
NTOS	neurogenic thoracic outlet syndrome
PROMs	patient-reported outcome measures
QuickDASH	shortened version of the Disability of the Arm, Shoulder, and Hand Outcome Measure
SD	standard deviation
TOS	thoracic outlet syndrome

INTRODUCTION

Neurogenic thoracic outlet syndrome (NTOS) is the most common manifestation of thoracic outlet syndrome [1]. Its symptoms are due to compression and irritation of the brachial plexus. Patients should meet 3 of 4 criteria for the diagnosis of NTOS according to the reporting standards of the Society for Vascular Surgery [2]. The 4 criteria are (i) local findings in the thoracic outlet, including pain and tenderness; (ii) peripheral findings due to nerve compression, including distal neurological changes, which are usually worse when the arms are placed overhead or dangling; (iii) absence of other probable diagnoses; and (iv) a positive response to scalene muscle injections. It is difficult to reach a definite diagnosis of NTOS, making it challenging to determine which patients are candidates for surgery.

The treatment of NTOS is primarily conservative, involving ergonomic changes to the patient's work and daily life, together with physiotherapy and painkillers [2]. Surgery should be considered if the patient does not respond to conservative therapy. If surgery is selected, it involves first rib resection (FRR), which is often combined with scalenotomy [3]. The most common surgical techniques involve open transaxillary and supraclavicular approaches [3, 4]. However, with ongoing trends favouring minimally invasive surgery, a new resection technique based on video-assisted thoracoscopic surgery (VATS) has been introduced [5–7]. Although the thoracoscopic techniques described in the literature differ greatly, the technique used at our hospital is fully thoracoscopic. The VATS technique also provides better visibility of the surgical field, especially the posterior part of the rib compared to transaxillary FRR [8].To date, only 1 study has published long-term results (> 2 years) of patients with NTOS operated on with a thoracoscopic technique: Hwang published long-term outcomes from a series of 8 patients, but only 1 patient had NTOS [9].

The goal of this study was to compare the long-term outcomes of the transaxillary technique and VATS in FRR in consecutive patients undergoing surgical treatment of NTOS. We evaluated the long-term outcomes in terms of patient-reported outcome measures (PROMs) and clinical examinations performed in outpatient clinics. We also measured the residual first rib stump to evaluate the correlation between stump length and any residual symptoms.

PATIENTS AND METHODS

Study design and ethics statement

This ambispective (i.e. data collected both retrospectively and prospectively from each patient) comparative cross-sectional cohort study was approved by the North-Savo institutional review board (ID : 342/2015). All patients provided written consent to participate in the study. All consecutive patients who underwent FRR for NTOS at a single academic teaching hospital between 2009 and 2016 were asked to participate in the study. The postoperative, short-term outcomes of these patients have been published All patients were invited to participate via a letter, and those willing to participate were included [5]in this follow-up study.

Diagnostic criteria and workup

The diagnostic criteria for thoracic outlet syndrome (TOS) were pain and tenderness in the area of compression (scalene triangle, pectoral minor insertion site or both), evidence of nerve compression from distal symptoms and the absence of another potential cause. We did not perform scalene block testing. All patients underwent a diagnostic workup and received conservative physical rehabilitation for at least 6 months that was provided by a physiotherapist. Conservative therapy comprised manual physical therapy, therapeutic exercises and pain medication. Patients who failed to achieve satisfactory symptom resolution were referred to a senior vascular surgeon to be considered for surgery. Transaxillary FRR was performed using a standard approach originally described by Roos *et al.* [3]. VATS comprised complete FRR and division of the anterior and middle scalenus muscles via a fully thoracoscopic approach with a standard three-port technique. The transaxillary procedures were performed by a single senior vascular surgeon. The transition to the VATS approach occurred between 2012 and 2014, and the VATS procedures were performed by a single experienced thoracic

surgeon. The operative techniques are described in detail in our prior publication [5].

Data collection and outcome measures

We collected data retrospectively from the patients' medical records, including diagnostic workup, index procedure and short-term outcomes at the 3-month follow-up. The clinical outcome at 3 months was graded as (i) no improvement or as (ii) partial, (iii) good or (iv) excellent recovery. Partial recovery was defined as some improvement with moderate residual symptoms. Good recovery was defined as minor residual symptoms. Excellent recovery was defined as the complete absence of symptoms. In the prospective part of the study, PROM questionnaires were sent with the invitation letter to evaluate long-term outcomes and patient satisfaction. The questionnaires included the shortened version of the Disabilities of Arm, Shoulder, and Hand (QuickDASH) Outcomes Measure and Cervical Brachial Symptom Questionnaire (CBSQ), both of which are recommended in the reporting standards of the Society for Vascular Surgery for TOS [2]. In addition, we used Beck's Depression Inventory (BDI) and the Neck Disability Index (NDI) to identify possible factors that may confound the surgical outcomes. Patients also underwent a physical examination at the outpatient clinic, including the Adson, Spurling and Roos tests, and a thorough examination of the upper limb neurological status, including reflex, skin sensation and muscle strength tests. The patients also reported the TOS disability scale and pain scale scores [2]. The patient's ability to work was estimated using questions covering a subjective assessment of their current ability to work (yes/no) and whether the procedure improved their working ability (yes/no). All clinical examinations were performed by the same senior physiatrist. During the examination, the patients were also interviewed regarding their reported outcomes. We used the same grading of symptom improvement as was used during the 3-month follow-up visit. A chest X-ray, limited to a clavicular projection, was taken to determine the potential posterior first rib remnant. The residual first rib length was measured by a senior radiologist.

Table 1: Preoperative characteristics of 32 patients with neurogenic thoracic outlet syndrome who underwent first rib resection (40 procedures)

Variable	Transaxillary procedure	Thoracoscopic procedure	*P*-value
Operations in the follow-up study	18	22	
Number of patients*	15	18	
Age, mean ± SD, years	44.8 ± 12.5	43.4 ± 10.8	0.798
Sex, female (%)	12 (66.7)	13 (59.1)	0.747
Operated arm: right (%)	9 (50.0)	11 (50.0)	1.000
Both sides operated (%)*	4 (22.2)	4 (18.2)	0.705
BMI, mean ±SD, kg/m^2	27.3 ± 4.0	27.1 ± 3.9	0.778
Comorbidities			
Overweight (BMI > 30) (%)	7 (38.9)	5 (22.7)	0.315
Smoker (%)	3 (16.7)	2 (9.1)	0.745
Diabetes (%)	0 (0.0)	2 (9.1)	0.492
Hypertension (%)	3 (16.7)	8 (36.4)	0.286
Coronary artery disease (%)	1 (5.6)	1 (4.5)	1.000

Values are *n* (%) or mean ± SD.

*One patient underwent a transaxillary procedure and subsequent thoracoscopic surgery of the contralateral arm.

BMI: body mass index; SD: standard deviation.

Statistical analysis

We used IBM SPSS Statistics, version 27 (IBM-SPSS Inc., Armonk, NY, USA) for all statistical analyses. Categorical variables are presented as the numbers and percentages of patients or procedures, as appropriate. Continuous variables are expressed as mean and standard deviation (SD). We used the Fisher exact test to compare categorical variables and the Mann–Whitney U test for nonparametric continuous variables. Results were considered statistically significant at *P*-values < 0.05.

RESULTS

A total of 60 FRRs were performed for NTOS during the study period in 47 patients, of whom 13 underwent bilateral procedures. The first 30 underwent the transaxillary procedure and the latter 30 underwent VATS with a fully thoracoscopic approach. Of the 47 patients, 32 patients (68.1%) participated in the study, comprising 18 of 30 (60.0%) transaxillary procedures and 22 of 30 (73.3%) VATS procedures ($P = 0.412$). Both groups were comparable in terms of their general and clinical characteristics (Table 1). The mean age was 44.8 (SD: 12.5) years in the transaxillary group and 43.4 (SD: 10.8) years in the VATS group ($P = 0.798$). Most patients in both groups were female and had no other diseases.

Long-term outcomes

The mean follow-up time was 70.2 (SD: 26.9) months overall, 94.5 (SD: 18.9) months in the transaxillary group and 50.4 (SD: 11.7) months in the VATS group ($P < 0.001$) (Table 2). At the long-term follow-up examination, the patients reported a normal working ability after 16 (88.9%) procedures in the transaxillary group and after 18 (81.8%) procedures in the VATS group ($P = 0.673$). The patients reported that their working ability had improved after surgery: 15/18 (83.3%) in the transaxillary group and 15/22 (68.2%) in the VATS group ($P = 0.464$). For most patients, the use of painkillers decreased after surgery compared with their preoperative situation. Two patients in both groups reported increased use of painkillers after surgery (Table 2).

The surgical outcome was considered good or excellent after 15/18 (83.3%) operations in the transaxillary group and after 17/22 (77.3%) operations in the VATS group ($P = 0.709$; Table 3) Total symptom relief was achieved after 1 transaxillary operation (5.6%) and after 7 VATS procedures (31.8%) ($P = 0.054$). In both groups, the proportion of procedures with good and excellent outcomes was greater at the long-term follow-up than at the short-term follow-up, with values of 83.3% versus 77.8%, respectively, in the transaxillary group and 77.3% versus 72.7%, respectively, in the VATS group (Table 3). The symptoms were unchanged after 3 procedures (16.7%) in the transaxillary group and after 2 procedures (9.1%) in the VATS group. Minor symptoms returned during the follow-up period after 12 (66.7%) procedures in the transaxillary group and after 12 (54.5%) procedures in the VATS group ($P = 0.526$). For 6 (50.0%) procedures in the transaxillary group and 8 (66.7%) in the VATS group, the symptoms returned more than 2 years after the initial procedure ($P = 0.327$; Table 3).

Table 2: Long-term follow-up data for 40 first rib resections in patients with neurogenic thoracic outlet syndrome

Variable	Transaxillary procedure	Thoracoscopic procedure	*P*-value
Follow-up time, months	94.5 ± 18.9	50.4 ± 11.7	< 0.001
Normal working ability, number (%)	16 (88.9)	18 (81.8)	0.673
Working capacity improved with surgery, number (%)	15 (83.3)	15 (68.2)	0.464
Usage of painkiller decreased after surgery, number (%)	12 (66.7)	14 (63.6)	0.580
Usage of painkiller increased after surgery, number (%)	2 (11.1)	2 (9.1)	0.706
Queries			
Neck Disability Index , mean ± SD, score	11.6 ± 8.0	13.5 ± 9.9	0.619
Beck's Depression Inventory , mean ± SD, score	6.4 ± 6.9	8.4 ± 10.8	0.737
Cervical Brachial Symptom Questionnaire , mean ± SD, score	43.0 ± 28.5	38.0 ± 24.6	0.819
Disabilities of Arm, Shoulder, and Hand Score (QuickDASH), mean ± SD, score	25.7 ± 16.5	33.6 ± 19.0	0.180
Would you go for surgery again?, mean ± SD, score 0-10, 0 = no, 10 = absolutely yes	7.8 ± 3.6	8.0 ± 3.7	0.657
Thoracic outlet syndrome disability scale, mean ± SD, score 0-10, 0= none, 10 = complete	2.6 ± 1.2	3.0 ± 2.0	0.527
Pain scale, mean ± SD, score 0-10, 0 = none, 10 = intolerable	3.3 ± 2.2	3.5 ± 2.9	0.925
Operated hand grip strength, mean ± SD, kg	33.6 ± 13.2	33.2 ± 9.2	0.946
Contralateral hand grip strength, mean ± SD, kg	33.8 ± 13.3	30.2 ± 10.0	0.527
Length of residual stump of operated first rib, mean ± SD, mm	30.9 ± 6.7	28.0 ± 9.3	0.286
Residual stump length more than 30 mm	9 (50.0)	9 (40.9)	0.750

Values are n (%) or mean ± SD.
SD: standard deviation.

Table 3: Short-term and long-term outcomes of 40 first rib resections in patients with neurogenic thoracic outlet syndrome

Variable	Transaxillary procedure	Thoracoscopic procedure	*P*-value
Early follow-up status at approximately 3 months			
0. No significant improvement	0 (0.0)	2 (9.1)	
1. Partial recovery (residual symptoms)	4 (22.2)	4 (18.2)	
2. Good recovery (minor residual symptoms)	9 (50.0)	8 (36.4)	
3. Excellent recovery (fully asymptomatic)	5 (27.8)	8 (36.4)	0.737
Good or excellent recovery (2 + 3)	14 (77.8)	16 (72.7)	1.000
Late follow-up status, more than 50 months after surgery			
0. No significant improvement	3 (16.7)	2 (9.1)	
1. Partial recovery (residual symptoms)	0 (0.0)	3 (13.6)	
2. Good recovery (minor residual symptoms)	14 (77.8)	10 (45.5)	
3. Excellent recovery (fully asymptomatic)	1 (5.6)	7 (31.8)	0.054
Good or excellent recovery (2 + 3)	15 (83.3)	17 (77.3)	0.709
Whether the symptoms have come back over the years even a little?	12 (66.7)	12 (54.5)	0.526
Residual symptoms (n = 12 in both groups) have come back over 2 years after the operation	6 (50.9)	8 (66.7)	0.327
Reoperations	1 (5.6)	0 (0.0)	

Values are n (%).

Patient-reported outcomes at the long-term follow-up

The mean NDI scores (maximum: 50) were 11.6 (SD: 8.0) in the transaxillary group versus 13.5 (SD: 9.9) in the VATS group (P = 0.619). The BDI scores (maximum: 63) were 6.4 (SD: 6.9) in the transaxillary group versus 8.4 (SD: 10.8) in the VATS group (P = 0.737). The mean CBSQ scores (maximum: 120) were 43.0 (SD: 28.5) in the transaxillary group versus 38.0 (SD: 24.6) in the VATS group (P = 0.819). The mean QuickDASH scores (maximum: 100) were 25.7 (SD: 16.5) in the transaxillary group versus 33.6 (SD: 19.0) in the VATS group, respectively (P = 0.180; Table 2). The mean TOS disability scale scores (maximum: 10) were 2.6 (SD: 1.2) in the transaxillary group versus 3.0 (SD: 2.0) in the VATS group, respectively (P = 0.527). The mean pain scale scores (maximum: 10) were 3.3 (SD : 2.2) in the transaxillary group versus 3.5 (SD: 2.9) in the VATS group (P = 0.925). The mean grip strengths were 33.6 (SD: 13.2) kg in the transaxillary group versus 33.3 (SD: 9.2) kg in the VATS group for the treated hand (P = 0.946) and were 33.8 (SD: 13.3) in the transaxillary group versus 30.2 (SD: 10.0) kg in the VATS group for the contralateral hand (P = 0.527). The patients were also asked whether they would undergo surgery again if they were given the choice (on scale of 0–10, where 0 = absolutely not and 10 = absolutely yes). The mean scores were 7.8 (SD: 3.6) in the transaxillary and 8.0 (SD: 3.7) in the VATS group (P = 0.657). The response score was 10 after 27 (out of 40) operations, and 6 responses were between 5 and 9. The response was between 0 to 2 after 7 operations, which is interpreted that these patients would not have undergone the surgery again.

Residual stump and long-term complications

The length of the residual stump of the operated first rib was 30.9 (SD : 6.7) mm in the transaxillary group and 28.0 (SD: 9.3) mm in the VATS group and was not significantly different between the 2 groups (P = 0.286; Table 2). The stump length was >30 mm in 9 (50.0%) cases in the transaxillary group and in 9 (40.9%) cases in the VATS group (P = 0.750). The length of the residual stump over 30 mm had no correlation with the symptoms during the follow-

Table 4: The first rib stump correlation with the long-term outcome for 40 first rib resections in patients with neurogenic thoracic outlet syndrome

Variable	Stump length > 30 mm (18 operations)	Stump length < 30 mm (22 operations)	*P*-value
Late follow-up status, more than 50 months after surgery			
0. No significant improvement	3 (16.7)	2 (9.1)	0.642
1. Partial recovery (residual symptoms)	1 (5.6)	2 (9.1)	
2. Good recovery (minor residual symptoms)	9 (50.0)	15 (68.2)	
3. Excellent recovery (fully asymptomatic)	5 (27.8)	3 (13.6)	0.430
Good or excellent recovery (2 + 3)	14 (77.8)	18 (81.8)	1.000

Values are n (%).

up (Table 4). As short-term outcomes, we previously reported brachial plexus injury in 1 case [5]. The symptoms in this patient resolved completely with physiotherapy during the long-term follow-up. During the follow-up, 1 patient in the transaxillary group required reoperation because symptoms recurred several years after the index procedure. The patient underwent tenotomy of the pectoralis minor muscle as the secondary procedure (pectoralis minor compression syndrome). In this operation, the patient developed persistent iatrogenic Horner syndrome. One patient in the VATS group reported numbness of the operated chest.

DISCUSSION

Although there are plenty of publications on the treatment of NTOS, the literature on the long-term outcomes is scant. Moreover, there are no previous publications comparing long-term results and PROMs between the traditional transaxillary FRR and the fully thoracoscopic VATS approach. In this long-term follow-up study of patients who underwent surgical treatment of NTOS, we found no statistically significant outcome differences between the 2 approaches. After a mean follow-up of 4–8 years, 81.8%–88.9% of patients reported a normal working ability, and 68.2%–83.3% of the patients reported that surgery improved their ability to work. In addition, the use of painkillers decreased significantly after surgery in both groups. Furthermore, the PROMs indicated an objective improvement in quality of life.

The patients' responses to whether they would undergo surgery again also demonstrated patient satisfaction at the long-term follow-up. This observation is supported by the low incidence of reoperation, which was necessary in only 1 patient. Furthermore, 77.3%–83.3% of the patients reported only minor or no residual symptoms at the long-term follow-up. This response is similar to the value in the study by Yin *et al.*, in which the success rate was 76% following transaxillary FRR for NTOS [10]. In the present study, 54.5%–66.7% of patients also reported that the symptoms returned to some extent during the follow-up period, as reported in previous studies [11, 12]. Approximately 20% of operated patients reported only partial recovery or no improvement after surgery. There can be several explanations for the "less than good" outcome in one-fifth of the patients. First is the diagnostic challenge of NTOS; it is possible that some patients who were operated on did not actually have NTOS because there is no definitive diagnostic test for this condition. Second is the recurrence of symptoms over time, perhaps, because of the formation of scar tissue that may accumulate around the brachial plexus. The third possibility is the incomplete decompression of the brachial plexus formation in the thoracic outlet. The fourth reason may be that some patients could have developed chronic pain that persisted even after decompression of the nerve. Altobelli *et al.* also stated that a good outcome of surgery generally means an improvement in symptoms, but not a total cure [11]. In the present study, most patients reported that their symptoms returned more than 2 years after surgery. This period is slightly longer that the 18 months reported in the study by Ambrad-Chalela *et al.* in 2004 [13]. The number of completely asymptomatic patients was numerically greater in the VATS group, although this did not reach statistical significance due to the small sample size. A shorter follow-up time may also contribute to this finding because symptoms often return over several years.

Using VATS, FRR can be performed under visual control. The first rib stump was shorter in the VATS group than in the transaxillary group, although the difference was not statistically significant. The first rib stump length was not correlated with the long-term outcomes. There is no consensus among experts regarding the length of the stump. Mingoli *et al.* previously reported that a stump greater than 3 cm is associated with residual symptoms [14]. In the present study, the stump was >3 cm in 40.9% of patients in the VATS group and in 50.0% of patients in the transaxillary group. In 1998, Molina *et al.* reported that subtotal removal of the first rib via a transaxillary approach may be acceptable to reduce the risk of neurogenic problems or vascular injury [15]. Video-assisted techniques may avoid this compromise because surgery is done under visual control. Therefore, the clinical significance of the stump length should be investigated in the future, especially in patients with NTOS.

PROMs are standardized, validated questionnaires and are therefore suitable for objective patient evaluation. We measured functional disability using QuickDASH. The mean score was slightly lower in the transaxillary group than in the VATS group, although the scores were similar to those in prior studies [16, 17]. By contrast, Gharagozloo *et al.* reported that the QuickDASH scores were significantly lower with robot-assisted techniques than in our study [18]. Symptoms were assessed using the CBSQ, and mean scores were lower in the VATS group than in the transaxillary group. These results were similar to those reported by Rochlin *et al.* in 2013 [19]. The NDI scores showed that the patients experienced a slight decrease in their ability to perform daily activities. The TOS disability scale indicated that our patients had mild disabilities. Using a pain scale, the patients reported occasional mild to moderate pain. The patients also completed the BDI to exclude other factors that may contribute to the symptoms. The results indicated that our patients were not depressed. Furthermore, we found no significant difference in the hand grip strength between the operated and contralateral sides.

Overall, 72.7%–77.8% of patients reported good or excellent results at the short-term follow-up, and 77.3%–83.3% of patients

reported good or excellent results at the long-term follow-up. Thus, the present results suggest that the short-term outcome may predict the long-term outcome. Nevertheless, the symptoms returned during the long-term follow-up period, which was apparent as a decrease in the percentage of patients who reported an excellent result. Similarly, Altobelli *et al.* previously published that the outcomes of surgery deteriorate over time [11].

The retrospective nature of this study represents a limitation. In particular, the assessment of PROMs at the time of diagnosis would have been particularly helpful to gauge changes after surgery. Indeed, we might expect to see decreases in QuickDASH and CBSQ scores after surgery. The number of patients was relatively low. Although the participation rate was good, the reluctance of symptomatic patients to participate in the study might have caused selection bias. Selecting which patients are suitable for surgical treatment is particularly difficult for patients with NTOS. In addition, due to the study design, there was a statistically significant difference in the mean follow-up time between the 2 groups that may also cause bias in a small study.

The strength of the study was its multidisciplinary assessment using standardized, objective metrics at the long-term follow-up. Therefore, we believe that objective evaluations should be included in future studies involving patients with NTOS. The unique value of this study is the long follow-up of patients who underwent purely thoracoscopic techniques.

CONCLUSIONS

Our results indicate that the outcomes of surgery did not differ between transaxillary and VATS for FRR in patients with NTOS, suggesting that both approaches provide favourable outcomes. The surgical techniques also resulted in satisfactory quality of life of patients in both groups. Surgeons should also be very judicious and critical when choosing on whom to operate.

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Author contributions

H.N. contributed to the data acquisition, analysis and interpretation of data. All authors contributed to study design, interpretation of data and critical revision of the manuscript.

Data availability

Data are available from the authors subject to certain legal restrictions.

REFERENCES

[1] Sanders RJ, Hammond SL, Rao NM. Diagnosis of thoracic outlet syndrome. J Vasc Surg 2007;46:601–4.
[2] Illig KA, Donahue D, Duncan A, Freischlag J, Gelabert H, Johansen K *et al.* Reporting standards of the Society for Vascular Surgery for thoracic outlet syndrome: executive summary. J Vasc Surg 2016;64:797–802.
[3] Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354–8.
[4] Hempel GK, Rusher AH, Jr, Wheeler CG, Hunt DG, Bukhari HI. Supraclavicular resection of the first rib for thoracic outlet syndrome. Am J Surg 1981;141:213–5.
[5] Nuutinen H, Riekkinen T, Aittola V, Mäkinen K, Kärkkäinen JM. Thoracoscopic Versus Transaxillary Approach to First Rib Resection in Thoracic Outlet Syndrome. Ann Thorac Surg 2018;105:937–42.
[6] George RS, Milton R, Chaudhuri N, Kefaloyannis E, Papagiannopoulos K. Totally endoscopic (VATS) First Rib Resection for Thoracic Outlet Syndrome. Ann Thorac Surg 2017;103:241–5.
[7] Abdellaoui A, Atwan M, Reid F, Wilson P. Endoscopic assisted transaxillary first 386 rib resection. Interact CardioVasc Thorac Surg 2007;6:644–6.
[8] Chan YC, Gelabert HA. High-definition video-assisted transaxillary first rib resection for thoracic outlet syndrome. J Vasc Surg 2013;57:1155–8.
[9] Hwang J, Min BJ, Jo WM, Shin JS. Video-assisted thoracoscopic surgery for intrathoracic first rib resection in thoracic outlet syndrome. J Thorac Dis 2017;9:2022–8.
[10] Yin ZG, Gong KT, Zhang JB. Outcomes of Surgical Management of Neurogenic Thoracic Outlet Syndrome: a Systematic Review and Bayesian Perspective. J Hand Surg Am 2019;44:416.e1–416.e17.
[11] Altobelli GG, Kudo T, Haas BT, Chandra FA, Moy JL, Ahn SS. Thoracic outlet syndrome: pattern of clinical success after operative decompression. J Vasc Surg 2005;42:122–8.
[12] Nuutinen H, Kärkkäinen JM, Mäkinen K, Aittola V, Saari P, Pesonen J. Long-term outcome over a decade after first rib resection for neurogenic thoracic outlet syndrome. Interact CardioVasc Thorac Surg 2021 29;33:734–40.
[13] Ambrad-Chalela E, Thomas GI, Johansen KJ. Recurrent neurogenic thoracic outlet syndrome. Am J Surg 2004;187:505–10.
[14] Mingoli A, Feldhaus RJ, Farina C, Cavallari N, Sapienza P, di Marzo L *et al.* Long-term outcome after transaxillary approach for thoracic outlet syndrome. Surgery 1995;118:840–4.
[15] Molina JE. Combined posterior and transaxillary approach for neurogenic thoracic outlet syndrome. J Am Coll Surg 1998;187:39–45.
[16] Gelabert HA, Rigberg DA, O'Connell JB, Jabori S, Jimenez JC, Farley S. Transaxillary decompression of thoracic outlet syndrome patients presenting with cervical ribs. J Vasc Surg 2018;68:1143–9.
[17] Balderman J, Abuirqeba AA, Eichaker L, Pate C, Earley JA, Bottros MM *et al.* Physical therapy management, surgical treatment, and patient-reported outcomes measures in a prospective observational cohort of patients with neurogenic thoracic outlet syndrome. J Vasc Surg 2019;70:832–41.
[18] Gharagozloo F, Meyer M, Tempesta B, Werden S. Robotic First Rib Resection for Thoracic Outlet Syndrome. Surg Technol Int 2019;36:239–44.
[19] Rochlin DH, Gilson MM, Likes CK, Graf E, Ford N, Christo PJ *et al.* Quality-of-life scores in neurogenic thoracic outlet syndrome patients undergoing first rib resection and scalenectomy. J Vasc Surg 2013;57:436–43.

III

Long-term outcome over a decade after first rib resection for neurogenic thoracic outlet syndrome

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The treatment of neurogenic thoracic outlet syndrome is controversial. The present study investigated the results of operative treatment of neurogenic thoracic outlet syndrome. In the present study majority of the patients benefited from the operation. If results are not achieved with conservative treatment, operative treatment should be considered.

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