Arthroscopy-assisted First Rib Resection and Brachial Plexus Neurolysis for Thoracic Outlet Syndrome

Hiroshi Satake (hsatake@med.id.yamagata-u.ac.jp)  
Yamagata University

Ryusuke Honma  
Yamagata University

Toshiya Nito  
Yamagata University

Yasushi Naganuma  
Yamagata University

Junichiro Shibuya  
Yamagata University

Masahiro Maruyama  
Yamagata University

Tomohiro Uno  
Yamagata University

Tomoyuki Kazama  
Yamagata University

Michiaki Takagi  
Yamagata University

Research Article

Keywords: thoracic outlet syndrome (TOS), visualization, middle interscalene muscles, blood loss, operation time, preoperative and postoperative QuickDASH, patient satisfaction

Posted Date: March 17th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-294089/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

The present study included 27 consecutive patients (30 limbs) undergoing arthroscopy-assisted transaxillary first rib resection and brachial plexus neurolysis for thoracic outlet syndrome (TOS). To improve visualization, we changed the intraoperative limb position in three stages. We assessed the intraoperative parameters, including the scalene interval width between the anterior and middle interscalene muscles (interscalene base), blood loss, operation time, preoperative and postoperative QuickDASH, patient satisfaction, and complications. The mean intraoperatively measured interscalene base width was 6.2 mm. Appropriate visualization could be obtained at zero-position in the late phase. Intraoperative blood loss and operation time were significantly less in the late phase ($p<0.001$). The QuickDASH score was significantly improved (42 before surgery vs. 9 at final follow-up, $p<0.001$), especially in athletes relative to non-athletes (0.2 vs 14, $p<0.001$). The outcome was excellent in 43.3% of cases, good in 43.3%, fair in 13.3%, and poor in none. The present approach achieved complete relief in 43% of cases overall (91% in athletes and 16% in non-athletes). Pneumothorax was present at the early phase in 3.3%. There were no other complications and no recurrences. Arthroscopic surgery is useful for TOS, especially in athletes.

Introduction

Surgical treatment for thoracic outlet syndrome (TOS) associated with a cervical rib was first described by Coote in 1861\(^1\). Morley described that brachial pressure neuritis occurred in the absence of a cervical rib, and that resection of a normal rib yielded very satisfactory results\(^2\). Rogers was first to describe pain in the upper limb due to lesions of the 'thoracic outlet' \(^3\). Several surgical treatments for TOS have been reported, including supraclavicular scalenectomy leaving the first rib intact\(^4\), supraclavicular first rib resection with scalenectomy\(^5\), transaxillary first rib resection\(^6\), and endoscopic brachial plexus neurolysis\(^7\). Transaxillary first rib resection has become the most common procedure for TOS. However, it is usually difficult to obtain satisfactory visualization under direct vision, and it is sometime difficult to control bleeding. Therefore, this procedure is associated with recurrence and complications to some degree\(^8\)–\(^12\). Endoscopically assisted first rib resection and robotically assisted thoracoscopic first rib resection have reduced the incidence of these complications\(^13\)–\(^19\).

We hypothesized that an arthroscopically assisted transaxillary approach would be able to improve visualization and allow safe surgery for both vascular and neurogenic TOS, and that the position of the upper limb would be important for transaxillary insertion of the arthroscope. The purpose of the present study was to evaluate the results of arthroscopic transaxillary first rib resection with scalenectomy and brachial plexus neurolysis for TOS in different limb positions.

Results

Indications and imaging.

We performed surgery only for patients with certain objective findings, including blood flow disruption (Video 1), low blood flow (Fig. 1a, affected limb; Fig. 1b, contralateral side), and accelerated blood flow (Fig. 1c, affected limb; Fig. 1d, contralateral side) in the subclavian artery demonstrated using Doppler sonography, narrowing of the interscalene base or costoclavicular space demonstrated using Duplex ultrasonography set at an ABER position or CT, or narrowing of the subclavian artery demonstrated by CT angiography (Fig. 2a, preoperative; Fig. 2b, six days after surgery). The mean blood flow was 83.2 cm/s (range, 48–120 cm/s) at rest and 144.1 cm/s (range, 32–301 cm/s) at an ABER position sitting in a chair demonstrated by Doppler sonography (Table 1). The mean interscalene base width was 8.7 mm (range, 5.1–16.3 mm) at rest and 8.1 mm (range, 0-14.7 mm) at an ABER position sitting in a chair demonstrated by Duplex ultrasonography (Table 1). The mean costoclavicular space demonstrated by Duplex ultrasonography was 9.6 mm (range, 4.7–13.1 mm) at an ABER position sitting on a chair and the mean costoclavicular space demonstrated by CT was 11.3 mm (range, 6.2–18.1 mm) with the shoulder at full abduction (Table 1).
Surgical procedure and intraoperative measurements.

Appropriate visualization could not be obtained simply by inserting the arthroscope at 150 degrees of limb abduction (Fig. 3a) nor at 90 degrees of limb abduction with the arm pulled upwards (Fig. 3b). Therefore, we needed to improve the visualization using some large retractors. However, better
visualization was obtained simply by inserting the arthroscope without any retractors at a subordinate pivotal position\textsuperscript{20} where the deltoid, the supraspinatus and the infraspinatus were relaxed (Fig. 3c, Video 2, 3). Appropriate visualization was also obtained by applying antifog to the arthroscope and attaching suction to the side of the arthroscope (Fig. 4), thus significantly decreasing the amount of intraoperative blood pooling. The mean intraoperative blood loss was 25 mL (range, 3–126 mL): 47 mL (range, 7–126 mL) in the early phase, 33 mL (range 6–101 mL) in the middle phase, and 10 mL (range, 3–20 mL) in the late phase (Table 1). Intraoperative blood loss was significantly lower in the late phase ($p<0.001$). The mean intraoperative measured width of the interscalene base was 6.15 mm (range, 2–12 mm). The mean operation time was 135 min (range, 60–307 min), being 244 min (range, 166–307 min) in the early phase, 152 min (range, 86–272 min) in the middle phase, and 87 min (range, 60–132 min) in the late phase (Table 1). Operation time was also significantly shorter in the late phase ($p<0.001$).

**Clinical assessments.**

The mean Quick Disability of the Arm, Shoulder and Hand (QuickDASH) score was 42 (range, 11–96) before surgery and 9 (range, 0–48) at final follow-up ($p<0.001$), demonstrating a significant improvement (Table 2, 3). The mean QuickDASH score at final follow-up was 0.2 (range, 0–2) in athletes and 14 (range, 0–48) in non-athletes (Table 3). The QuickDASH score was significantly better in athletes ($p<0.001$, Table 3). All of the patients were satisfied with their surgical outcomes and were happy with the improvement seen in their limbs. The rating was excellent in 13 patients (43.3%), good in 13 (43.3%), fair in 4 (13.3%), and poor in none (Table 2). Complete relief with the present methods was achieved in 43% of the patients (91% in athletes and 16% in non-athletes). There was one case (3.3%) of slight parietal pleura damage in the early phase with no complaint, and healing was achieved without any additional treatment. There were no other complications and no cases of recurrence.
| Patients | Sports  | Preoperative QuickDASH | Postoperative QuickDASH | Differences of QuickDASH | Patient Satisfaction |
|----------|---------|------------------------|-------------------------|--------------------------|---------------------|
|          |         | D/S  | Sports | D/S  | Sports | D/S  | Sports |          |                     |
| 1        | Baseball| 27   | 100    | 0    | 0      | 27   | 100    | Excellent |
| 2        |         | 19   | 0      | 0    | 0      | 19   | 0      | Excellent |
| 3        | Baseball| 30   | 75     | 0    | 0      | 30   | 75     | Excellent |
| 4        | Baseball| 68   | 75     | 0    | 0      | 68   | 75     | Excellent |
| 5        |         | 27   | 18     | 9    | 0      | 27   | 18     | Good      |
| 6        |         | 45   | 34     | 11   | 0      | 45   | 34     | Good      |
| 7        |         | 89   | 11     | 78   | 0      | 89   | 11     | Fair      |
| 8        |         | 52   | 5      | 47   | 0      | 52   | 5      | Good      |
| 9        |         | 95   | 48     | 47   | 0      | 95   | 48     | Fair      |
| 10       | Baseball| 32   | 75     | 2    | 0      | 30   | 75     | Good      |
| 11       |         | 84   | 11     | 73   | 0      | 84   | 11     | Good      |
| 12       |         | 66   | 25     | 41   | 0      | 66   | 25     | Good      |
| 13       |         | 75   | 16     | 59   | 0      | 75   | 16     | Good      |
| 14       | Baseball| 27   | 100    | 0    | 13     | 27   | 87     | Good      |
| 15       |         | 11   | 0      | 11   | 0      | 11   | 0      | Excellent |
| 16       |         | 64   | 9      | 55   | 0      | 64   | 9      | Good      |
| 17       |         | 23   | 7      | 16   | 0      | 23   | 7      | Good      |
| 18       | Baseball| 30   | 50     | 0    | 0      | 30   | 50     | Excellent |
| 19       |         | 11   | 0      | 11   | 0      | 11   | 0      | Excellent |
| 20       |         | 89   | 9      | 80   | 0      | 89   | 9      | Good      |
| 21       |         | 50   | 16     | 34   | 0      | 50   | 16     | Good      |
| 22       |         | 52   | 23     | 29   | 0      | 52   | 23     | Good      |
| 23       | FH      | 18   | 100    | 0    | 0      | 18   | 100    | Excellent |
| 24       |         | 27   | 11     | 16   | 0      | 27   | 11     | Fair      |
| 25       | Baseball| 30   | 88     | 0    | 0      | 30   | 88     | Excellent |
| 26       | Baseball| 27   | 63     | 0    | 0      | 27   | 63     | Excellent |
| 27       | Baseball| 16   | 88     | 0    | 0      | 16   | 88     | Excellent |
| 28       |         | 11   | 0      | 11   | 0      | 11   | 0      | Excellent |
| 29       |         | 20   | 18     | 2    | 0      | 20   | 18     | Fair      |
| 30       | Baseball| 32   | 75     | 0    | 0      | 32   | 75     | Excellent |
| Mean     |         | 42   | 81     | 9    | 1      | 33   | 80     | Excellent |

QuickDASH, Quick Disability of the Arm, Shoulder and Hand; D/S, disability/symptom; FH, field hockey
Discussion

Vascular TOS cases can be diagnosed by Color Doppler and Duplex ultrasonography\textsuperscript{21,22} or CT angiography\textsuperscript{23–25}. We evaluated patients with vascular TOS using similar methods. Blood flow disruption, low blood flow, and accelerated blood flow of the subclavian artery were measured using Doppler sonography in an ABER position. Neurogenic TOS cases can also be diagnosed by Duplex ultrasonography\textsuperscript{26,27}. In cadaver studies, the mean interscalene base width and mean costoclavicular space have been reported to be 10.7 mm and 13.5 mm, respectively\textsuperscript{28}. The mean costoclavicular space measured by CT was 12.5 mm\textsuperscript{29}. Preoperative and intraoperative measures of the interscalene base can predict disorders due to scalene triangular stenosis. In the presence of clinical TOS, the scalene muscles compress the structures of the brachial plexus in the thoracic outlet between the anterior and middle scalene muscles. Therefore, both scalenectomy and first rib resection provide significant functional improvements in patients with TOS.

Arthroscopic surgery requires appropriate visualization, especially when inserting an arthroscope in a place other than a joint. Therefore, we changed the upper arm position in three phases. Better visualization was obtained at the subordinate pivotal position\textsuperscript{20}/zero-position\textsuperscript{30}. The relationship between the neurovascular bundle and the scalene muscles could be observed clearly using an arthroscope in the zero-position. Furthermore, arthroscopic neurolysis was possible when the brachial plexus and subclavian artery were adherent. Arthroscopically assisted surgery allowed decompression for both vascular and neurogenic TOS.

There are three major procedures for TOS in the absence of a cervical rib: transaxillary first rib resection\textsuperscript{8,31–33}, supraclavicular first rib resection\textsuperscript{2,5,11,34–36}, and supraclavicular release of the anterior and middle scalene muscles leaving the first rib intact\textsuperscript{37–39}. Statistically there is no significant difference in outcome between the three procedures, fair results being reported in 4–8% of each group\textsuperscript{11}. A systematic literature search revealed that both supraclavicular scalenectomy and transaxillary first rib resection had a high probability of success\textsuperscript{12}. In the present study, arthroscopically assisted surgery achieved some degree of improvement in all patients. The mean improvement of QuickDASH was 33, and the complete relief was obtained 43% of the patients. TOS sometimes occurs in throwing athletes\textsuperscript{40,41}. Athletes show better improvement than non-athletes after first rib resection and scalenectomy\textsuperscript{42}. Here, complete relief was observed significantly more often in athletes than in non-athletes (91% vs 16%).

Transaxillary first rib resection has a higher incidence of complications than supraclavicular scalenectomy, being 22.5% and 12.6% respectively\textsuperscript{12}. Among 594 cases of TOS treated by transaxillary first rib resection, there were 138 (23%) cases of intraoperative pneumothorax\textsuperscript{9}. In the present study, intraoperative pneumothorax occurred in only one case (3.3%) and no other complications or recurrences were observed after arthroscopic surgery. Ohtsuka et al. have reported thoracoscopic first rib resection\textsuperscript{43}. However, as this procedure poses a significant potential risk to the neurovascular bundle, modified techniques with appropriate instrumentation have been developed\textsuperscript{15,18}. Furthermore, endoscopically assisted transaxillary first rib resection using a 10-mm endoscope has resulted in a lower incidence of complications\textsuperscript{13,14}. In the present study, arthroscopically assisted transaxillary first rib resection and brachial plexus neurolysis using a 4-mm arthroscope also achieved good results with a lower incidence of complications.

Limitations

The present study had several limitations. First, it was based on a retrospective review with a small number of patients and lacked a control group. Second, most cases of TOS can be cured by conservative therapy. Therefore, there are relatively few cases requiring surgery in our department, and for this reason we accepted TOS patients from other institutions who had not responded to conservative therapy and needed surgery. Because the sample size was limited, a controlled trial would have taken much more time, delaying the publication of the preliminary outcomes. Arthroscopically assisted transaxillary first rib resection and brachial plexus neurolysis allowed us to obtain satisfactory results and was a safe procedure for TOS. In particular, athletes showed significantly better improvement than non-athletes. Third, the diagnosis of TOS is well known to be controversial\textsuperscript{44,45}. In the present study we excluded one patient with ‘true neurogenic TOS’\textsuperscript{22,46,47} associated with a cervical rib. We diagnosed TOS using Doppler sonography adopting an ABER method or CT angiography.

Materials And Methods

Study design.
Twenty-eight consecutive patients (32 limbs) with TOS who underwent surgery in our department between April 2016 and February 2020 were evaluated. We excluded one patient (2 limbs) with ‘true neurogenic TOS’ on the basis of Gilliatt-Sumner hand associated with bilateral cervical ribs, which were excised by the supraclavicular approach. Among the remaining 27 patients, 30 limbs were included in the present study. There were 14 males and 13 females, and the mean age at surgery was 28.1 years (range, 15–50 years).

**Diagnosis.**

The diagnosis of TOS is controversial, and no specific set of diagnostic criteria has yet been established. We diagnosed patients as having TOS on the basis of symptomatic presentation, physical examination maneuvers including the Roos test, Wright test and Moley test, and lack of any evidence of a more likely cause. Patients with traumatic TOS were excluded. Color Doppler and Duplex ultrasonography are useful diagnostic modalities in this context. The measures assessed included blood flow disruption, low blood flow, and accelerated blood flow in the subclavian artery demonstrated by Doppler sonography, the scalene interval width between the anterior and middle interscalene muscles (interscalene base), and the costocervical space demonstrated by Duplex ultrasonography in a resting position with the shoulder in abduction and in the external rotation (ABER) position sitting on a chair (Fig. 5) by a medical technologist (T.K.). Furthermore, enhanced computed tomography (CT) was performed with the shoulder in full abduction to confirm the presence of stenosis of the subclavian artery and the costocervical space. If peripheral neuropathy such as ulnar and median neuropathy could not be ruled out, nerve conduction studies were also performed.

**Surgical technique.**

The patient was placed in a lateral position with the arm elevated to expose the axilla using a limb positioner (SPIDER2, Smith & Nephew, Memphis, TN) for the upper extremity and operated on under general anesthesia. The upper limb position was set at 150 degrees of abduction in the early phase (n = 3, Fig. 3a), 90 degrees of abduction with the arm pulled upwards according to Roos in the middle phase (n = 15, Fig. 3b), and in the subordinate pivotal position in the late phase (n = 12, Fig. 3c). At the beginning, it was difficult to obtain appropriate visualization. Therefore, we changed the position in three stages to improve visualization (Videos 2, 3).

A transverse 4-cm skin incision was made over the third rib between the pectoralis major and the latissimus dorsi muscles at the axillary hairline level (Fig. 3d). Careful dissection was performed to allow confirmation of subclavian artery pulsation with a finger. An arthroscopic incision was made more superior and posterior at the third rib level (Fig. 3d). We used a 4.0-mm 30-degree arthroscope, detached both the anterior and middle inter-scalene muscles from the first rib, excised the first rib piecemeal using bone cutting rongeurs, and neurolysis of the brachial plexus was performed with arthroscopic assistance (Fig. 6, Video 4).

Informed consent was obtained from all included patients and/or a parent (age blow 18).

**Postoperative care.**

Range of motion exercise for shoulder abduction up to 90 degrees was allowed immediately after surgery, and unlimited shoulder motion was allowed after four weeks. The patients returned to full activities, such as sports, between two and three months after surgery.

**Evaluation of clinical data and definitions of outcome variables.**

A comprehensive review of medical records was conducted by one observer (H.S.). Demographic and surgical data collected included the following: securing visualization in each upper limb position; intraoperative measurement of the interscalene base; intraoperative blood loss; operation time; preoperative and postoperative QuickDASH; patient satisfaction; and complications at a mean of 25.6 months (range, 12–56 months) after surgery. Patient satisfaction was divided into four categories according to Derkash et al.: excellent, complete relief; good, almost complete relief; fair, partial relief; poor, no improvement. We compared the clinical results among these patients according to whether they were athletes or not.

**Statistical analysis.**

The QuickDASH was compared using Wilcoxon test and Fisher’s exact test, while intraoperative blood loss and operation time were compared using Kruskal-Wallis test. Differences at $P < 0.05$ were regarded as statistically significant. All statistical analyses were performed with the EZR software program (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria, version 3.6.3).

**Declarations**

**Ethical statements.**
This study was approved by the ethics committee of Yamagata University (No. 2020-358), and was conducted in accordance with the ethical standards described in the latest revision of the Declaration of Helsinki.

**Patient consent for participation and publication.**

Informed consent for patient participation and publication was received in the form of an opt-out in-hospital notice.

**Data availability**

All data relevant to the study are included in the article.

**Acknowledgement**

The authors thank Dr. Kozo Furushima at Keiyu Orthopaedic Hospital, for technical assistance.

**Author contributions**

H.S. performed all surgery and wrote the main manuscript. R.H. aided with statistical analysis and fitting of equations. T.N. researched the literature and conceived the study. Y.N. aided with statistical analysis and fitting of equations. J.S. assisted surgery. M.M. researched the literature and conceived the study. T.U. assisted surgery. T.K. performed Doppler sonography and Duplex ultrasonography. M.T. wrote the main manuscript. All authors reviewed and edited the manuscript and approved the final version.

**Funding**

None to report.

**Competing interests**

The authors have no competing interests to declare.

**Additional information**

Correspondence and requests for materials should be addressed to H.S.

**References**

1. Coote, H. Exostosis of the left transverse process of the seventh cervical vertebra surrounded by blood vessels and nerves: successful removal. *Lancet*, 360–361 (1861).
2. Morley, J. Brachial pressure neuritis due to a normal first thoracic rib: its diagnosis and treatment by excision of rib. *J. 42*, 461-464 (1913).
3. Rogers, L. Upper-limb pain due to lesions of the thoracic outlet, the scalenus syndrome, cervical rib, and costoclavicular compression. *Med. J. 2*, 956-958 (1949).
4. Adson, A.W. & Coffey, J.R. Cervical rib: a method of anterior approach for relief of symptoms by division of the scalenus anticus. *Surg. 85*, 839-857 (1927).
5. Falconer, M.A. & Li, F.W. Resection of the first rib in costoclavicular compression of the brachial plexus. *Lancet 1*, 59-63 (1962).
6. Roos, D.B. & Owens, J.C. Thoracic outlet syndrome. *Surg. 93*, 71-74 (1966).
7. Lafosse, T., Hanneur, M.L. & Lafosse, L. All-endoscopic brachial plexus complete neurolysis for idiopathic neurogenic thoracic outlet syndrome: a prospective case series. *Arthroscopy* 33, 1449-1457 (2017).
8. Orlando, M.S., et al. A decade of excellent outcomes after surgical intervention in 538 patients with thoracic outlet syndrome. *Am. Coll. Surg. 220*, 934-939 (2015).
9. Roos, D.B. The place for scalenectomy and first-rib resection in thoracic outlet syndrome. *Surgery 92*, 1077-1085 (1982).
10. Sanders, R.J., Monsour, J.W., Gerber, W.F., Adams, W.B. & Thompson, N. Scalenectomy versus first rib resection for treatment of the thoracic outlet syndrome. *Surgery 85*, 109-121 (1979).
11. Sanders, R.J. & Peace, W.H. The treatment of thoracic outlet syndrome: a comparison of different operations. *Vasc. Surg. 10*, 626-634 (1989).
12. Yin, Z.G., Gong, K.T. & Zhang, J.B. Outcomes of surgical management of neurogenic thoracic outlet syndrome: a systematic review and Bayesian perspective. *Hand Surg. Am. 44*, 416.e1-416.e17 (2019).
13. Abdellaoui, A., Atwan, M., Reid, F. & Wilson, P. **Endoscopic assisted transaxillary first rib resection.** Interact Cardiovasc Surg. **6**, 644-646 (2007).

14. Chan, Y.C. & Gelabert, H.A. High-definition video-assisted transaxillary first rib resection for thoracic outlet syndrome. Vasc. Surg. **57**, 1155-1158 (2013).

15. Furushima, K. & Funakoshi, T. Endoscopic-assisted transaxillary approach for first-rib resection and neurolysis in thoracic outlet syndrome. **Tech. Orthop.** **10**, e235-e240 (2021).

16. George, R.S., Milton, R., Chaudhuri, N., Kefaloyannis, E. & Papagiannopoulos, K. Totally endoscopic (VATS) first rib resection for thoracic outlet syndrome. **Thorac. Surg.** **103**, 241-245 (2017).

17. Kocher, G.J., Zehnder, A., Lutz, J.A., Schmidli, J. & Schmid, R.A. First rib resection for thoracic outlet syndrome: the robotic approach. **World J. Surg.** **42**, 3250-3255 (2018).

18. Martinez, B.D., Wiegand, C.S., Evans, P., Gerhardinger, A. & Mendez, J. Computer-assisted instrumentation during endoscopic transaxillary first rib resection for thoracic outlet syndrome: a safe alternate approach. **Neurosurgery** **58**, ONS-287-290; discussion ONS-290-291 (2006).

19. Soukiasian, H.J. et al. A video-assisted thoracoscopic approach to transaxillary first rib resection. **Innovations (Phila)** **10**, 21-26 (2015).

20. Codman, E.A. The Shoulder. Rupture of the supraspinatus tendon and other lesions in or about the subacromial bursa. (Thomas Todd Co., Boston, 1934).

21. Longley, D.G. et al. Thoracic outlet syndrome: evaluation of the subclavian vessels by color duplex sonography. Am. J. Roentgenol. **158**, 623-630 (1992).

22. Wadhwani, R., Chaubal, N., Sukthankar, R., Shrroff, M. & Agarwala, S. Color Doppler and duplex sonography in 5 patients with thoracic outlet syndrome. Ultrasound Med. **20**, 795-801 (2001).

23. Buller, L.T., Jose, J., Baraga, M. & Lesniak, B. Thoracic outlet syndrome: current concepts, imaging features, and therapeutic strategies. J. Orthop. (Belle Mead NJ) **44**, 376-382 (2015).

24. Gillet, R. et al. **Dynamic CT angiography for the diagnosis of patients with thoracic outlet syndrome: correlation with patient symptoms.** Cardiovasc. Comput. Tomogr. **12**, 158-165 (2018).

25. Remy-Jardin, M. et al. **Helical CT angiography of thoracic outlet syndrome: functional anatomy.** Am. J. Roentgenol. **174**, 1667-1674 (2000).

26. Fried, S.M. & Nazarian, L.N. Dynamic neuromusculoskeletal ultrasound documentation of brachial plexus/thoracic outlet compression during elevated arm stress testing. Hand (N Y) **8**, 358-365 (2013).

27. Mattox, R. et al. Reference values for the scalene interval width during varying degrees of glenohumeral abduction using ultrasonography. Manipulative Physiol. Ther. **39**, 662-667 (2016).

28. Dahlstrom, K.A. & Olinger, A.B. Descriptive anatomy of the interscalene triangle and the costoclavicular space and their relationship to thoracic outlet syndrome: a study of 60 cadavers. Manipulative Physiol. Ther. **35**, 396-401 (2012).

29. Duarte, F.H., Zerati, A.E., Gornati, V.C., Nomura, C. & Puech-Leão, P. Normal costoclavicular distance as a standard in the radiological evaluation of thoracic outlet syndrome in the costoclavicular space. Vasc. Surg. **50**(6), 609-615 (2016).

30. Saha, A.K. Theory of shoulder mechanism: descriptive and applied. Charles C Thomas, (Springfield, 1961).

31. Dale, W.A. & Lewis, M.R. Management of thoracic outlet syndrome. Surg.181, 575-585 (1975).

32. Leffert, R.D. & Perlmutter, G.S. Thoracic outlet syndrome. Orthop. Relat. Res. **368**, 66-79 (1999).

33. Roos, D.B. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Surg. **163**, 354-358 (1966).

34. Chandra, V., Olcott, C. 4th. & Lee, J.T. Early results of a highly selective algorithm for surgery on patients with neurogenic thoracic outlet syndrome. Vasc. Surg. **45**, 1698-1705 (2011).

35. Hempel, G.K., Shutte, W.P., Anderson, J.F. & Bukhari, H.I. 770 consecutive supraclavicular first rib resections for thoracic outlet syndrome. Vasc. Surg. **10**, 456-463 (1996).

36. Sanders, R.J. & Annest, S.J. Technique of supraclavicular decompression for neurogenic thoracic outlet syndrome. Vasc. Surg. **61**, 821-825 (2015).

37. Alexandre, A., Coro, L., Azuelos, A. & Pellone, M. Thoracic outlet syndrome due to hyperextension-hyperflexion cervical injury. Neurochir. Suppl. **92**, 21-24 (2005).

38. Cheng, S.W.K., Reilly, L.M., Nelken, N.A., Ellis, W.V. & Stoney, R.J. Neurogenic thoracic outlet decompression: rationale for sparing the first rib. Surg. **3**, 617-623; discussion: 624 (1995).

39. Ciampi, P. et al. Surgical treatment of thoracic outlet syndrome in young adults: single centre experience with minimum three-year follow-up. Orthop. Surg. **5**, 1179-1186 (2011).

40. Thompson, R.W. et al. Performance metrics in professional baseball pitchers before and after surgical treatment for neurogenic thoracic outlet syndrome. Vasc. Surg. **39**, 216-227 (2017).

41. Twaij, H., Rolls, A., Sinisi, M. & Weiler, R. Thoracic outlet syndromes in sport: a practical review in the face of limited evidence–unusual pain presentation in an athlete. J. Sports Med. **47**, 1080-1084 (2013).

42. Betteck, B. et al. Comparison of athletes and nonathletes undergoing thoracic outlet decompression for neurogenic thoracic outlet syndrome. Vasc. Surg. **54**, 269-275 (2019).

43. Ohtsuka, T., Wolf, R.K. & Dunsker, S.B. Port-access first-rib resection. Endosc. **13**, 940-942 (1999).

44. Roos, D.B. Thoracic outlet syndrome is underdiagnosed. Muscle Nerve **22**, 126-129; discussion 137-138 (1999).

45. Wilbourn, A.J. Thoracic outlet syndrome is overdiagnosed. Muscle Nerve **22**, 130-136; discussion 136-137 (1999).
4. Gilliatt, R.W., Le Quesne, P.M., Logue, V. & Summer, A.J. Wasting of the hand associated with a cervical rib or band. *Neurol. Neurosurg. Psychiatry* **33**, 615-624 (1970).

47. Tender, G., Thomas, A.J., Thomas, N. & Kline, D.G. Gilliatt-Sumner hand revisited: a 25-year experience. *Neurosurgery* **55**, 883-890; discussion 890 (2004).

48. Povlsen, B., Hansson, T. & Povlsen, S.D. Treatment for thoracic outlet syndrome. *Cochrane Database Syst. Rev.* 26(11):CD007218 (2014).

49. Roos, D.B. Congenital anomalies associated with thoracic outlet syndrome. Anatomy, symptoms, diagnosis, and treatment. *J. Surg.* **132**, 771-778 (1976).

50. Wright, I.S. The neurovascular syndrome produced by hyperabduction of the arms: the immediate changes produced in 150 normal controls, and the effects on some persons of prolonged hyperabduction of the arms, as in sleeping, and in certain occupations. *Heart J.* **29**, 1-19 (1945).

51. Derkash, R.S., Goldberg, V.M., Mendelson, H. & Mevicker, R. The results of first rib resection in thoracic outlet syndrome. *Orthopedics* **4**, 1025-1029 (1981).

52. Kanda, Y. Investigation of the freely available easy-to-use software ‘EZR’ for medical statistics. *Bone Marrow Transplant.* **48**, 452-458 (2013).

**Figures**

**Figure 1**

Blood flow in the subclavian artery demonstrated by Doppler sonography. Low blood flow is observed in the affected limb (a, 69 cm/s) relative to the contralateral side (b, 126 cm/s). Accelerated blood flow is observed at the shoulder in abduction and external rotation (ABER) (c, 314 cm/s) relative to that in the resting position (d, 67 cm/s).
Figure 2

Narrowing of the subclavian artery demonstrated by CT angiography. Preoperative CT (a) angiography demonstrating subclavian artery stenosis (arrow). No remarkable stenosis is evident six days after surgery (b).

Figure 3

Intraoperative limb position. The upper limb position is set at 150 degrees of abduction in the early phase (a), 90 degrees of abduction with the arm pulled upwards in the middle phase (b), and in the subordinate pivotal position/zero-position in the late phase (c). A transverse 4-cm skin incision (arrow) is made over the third rib between the pectoralis major (PM) and the latissimus dorsi (LD) muscles. An arthroscopic incision (arrowhead) is made more superior and posterior at the third rib level (d).
Figure 4

Attaching suction to the side of the arthroscope.

Figure 5

Doppler sonography and Duplex ultrasonography. Blood flow, interscalene base, and costoclavicular space are measured in a resting position (a) and with the shoulder in abduction and external rotation (ABER) (b) sitting on a chair.
Figure 6

Arthroscopically assisted surgery. Right arthroscopic transaxillary approach demonstrating the subclavian vein (SV), anterior scalene muscle (AS), subclavian artery (SA), brachial plexus (BP), median scalene muscle (MS), first rib (R1), and lung. The width of the interscalene base is 6 mm. Both the AS and MS are detached from R1. R1 is excised piecemeal using a bone cutting rongeur. The amount of R1 resected is 5 cm.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Video1.wmv
- Video2.wmv
- Video3.m2ts
- Video4.wmv