Midterm results of endoscopically assisted first rib resection in the zero position for thoracic outlet syndrome

Hiroshi Satake*, Ryusuke Honma, Toshiya Nito, Yasushi Naganuma, Junichiro Shibuya, Masahiro Maruyama, Tomohiro Uno and Michiaki Takagi

Department of Orthopaedic Surgery, Yamagata University Faculty of Medicine, Yamagata, Japan

* Corresponding author. Department of Orthopaedic Surgery, Yamagata University Faculty of Medicine, 2-2-2, Iida-Nishi, Yamagata 9909585, Japan. Tel: +81-23-628-5355; fax: +81-23-628-5357; e-mail: hsatake@med.id.yamagata-u.ac.jp (H. Satake).

Received 17 June 2022; received in revised form 5 August 2022; accepted 9 September 2022.

Abstract

OBJECTIVES: We have hypothesized that an endoscopically assisted transaxillary approach in the zero position would be able to improve visualization and allow safe surgery for thoracic outlet syndrome.

METHODS: We performed surgery only for patients with certain objective findings, including blood flow disruption, low blood flow and accelerated blood flow in the subclavian artery demonstrated using Doppler sonography, narrowing of the scalene interval width between the anterior and middle interscalene muscles (interscalene base) or costoclavicular space demonstrated using Duplex ultrasonography or computed tomography angiography. The present study included 45 consecutive patients (50 limbs) who underwent endoscopic transaxillary first rib resection with scalenotomy and brachial plexus neurolysis. We assessed the intraoperative parameters, including the interscalene base, blood loss, operation time, patient satisfaction, preoperative and postoperative Quick Disability of the Arm, Shoulder and Hand and complications.

RESULTS: The mean intraoperatively measured interscalene base width was 6.4 mm. All patients showed improvement after surgery. The outcome was excellent in 40% of cases, good in 48%, fair in 12% and poor in none. Pneumothorax was present in 6%. There were no other complications and no recurrences. Among patients who had been followed up for at least 2 years, the Quick Disability of the Arm, Shoulder and Hand score was significantly improved (42 before surgery vs 12 at final follow-up), especially in athletes relative to non-athletes (0.2 vs 16). The present approach achieved complete relief in 43% of cases overall (91% in athletes and 16% in non-athletes).

THORACIC VC The Author(s) 2022. Published by Oxford University Press on behalf of the European Association for Cardio-Thoracic Surgery. This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (https://creativecommons.org/licenses/by-nc/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com
CONCLUSIONS: Endoscopically assisted transaxillary first rib resection and brachial plexus neurolysis in the zero position are useful and safe for thoracic outlet syndrome, especially in athletes.

Keywords: Thoracic outlet syndrome • Endoscopic surgery • First rib resection • Brachial plexus neurolysis • Ultrasonography

INTRODUCTION

The diagnosis of thoracic outlet syndrome (TOS) is controversial, and no specific set of diagnostic criteria has yet been established [1]. Morley [2] described that brachial pressure neuritis occurred in the absence of a cervical rib and that resection of a normal rib yielded very satisfactory results. Several surgical treatments for TOS have been reported, including supraclavicular scalenotomy leaving the first rib intact [3], supraclavicular first rib resection with scalenotomy [4] and transaxillary first rib resection [5]. 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 [6–8]. Endoscopically assisted transaxillary first rib resection (EATFRR) and robotically assisted thoracoscopic first rib resection have been attempted to reduce the incidence of these complications [9–12]. However, use of an extrapleural approach with thoracoscopic video assistance still remains experimental and it is still unclear whether it has any obvious advantages over standard surgical approaches [13].

We have hypothesized that an endoscopically assisted transaxillary approach would 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 endoscope. We were the first to attempt EATFRR surgery for TOS in the subordinate pivotal position/zero position where the deltoid, supraspinatus and infraspinatus were relaxed [14]. No previous reports have detailed the midterm results (at least 2 years after surgery) of EATFRR. The purpose of the present study was to evaluate the midterm results of EATFRR with scalenotomy and brachial plexus neurolysis for TOS that had been diagnosed by ultrasonography.

MATERIALS AND METHODS

Ethical statement

This study was approved by the Institutional Review Board of Yamagata University (identification number 2020-358, 9 February 2020).

Patients

Since 2016, we have performed surgery for 52 limbs with TOS in our department. We excluded 1 patient (2 limbs) associated with bilateral cervical ribs, which were excised by the supraclavicular approach. The present study included 45 consecutive patients (50 limbs) who underwent EATFRR with scalenotomy and brachial plexus neurolysis performed by a single-hand surgeon between April 2016 and November 2021. There were 26 males and 19 females, and the mean age at surgery was 29.2 years (range, 15–50 years).

Diagnosis

We diagnosed patients as having TOS on the basis of symptomatic presentation, physical examination manoeuvres including the Roos test [15], Wright test [16] and Moley test [2] and lack of any evidence of a more likely cause. Patients with traumatic TOS were excluded. Colour Doppler and Duplex ultrasonography are useful diagnostic modalities in this context (Fig. 1) [17, 18]. The measures assessed included blood flow disruption, low blood flow and accelerated blood flow in the subclavian artery demonstrated by Doppler sonography (Fig. 1), the scalene interval width between the anterior and middle interscalene muscles (interscalene base) [19], and the costoclavicular space demonstrated by Duplex ultrasonography [20, 21] in a resting position with the shoulder in abduction and in the external rotation (ABER) position sitting on a chair by a medical technologist. Furthermore, enhanced computed tomography (CT) was performed with the shoulder in full abduction to confirm the presence of stenosis of the subclavian artery (Fig. 2) [22] and the costoclavicular space [23].

We performed surgery only for patients with certain objective findings, including blood flow disruption, low blood flow (Fig. 1A, affected limb, and B, contralateral side), and accelerated blood flow (Fig. 1C, affected limb, and D, 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. 2).

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 anaesthesia. We used single-lumen intubation and did not perform differential lung ventilation. The upper limb position was set at full abduction in the early phase (n = 3), 90° of abduction with the arm pulled upwards according to Roos [24] in the middle phase (n = 15), and in the subordinate pivotal position/zero position [14] in the late phase (n = 32, Fig. 3). At the beginning, it was difficult to obtain appropriate visualization. Therefore, we changed the position in 3 stages to improve the visualization (Video 1).

ABBREVIATIONS

| ABER       | Abduction and in the external rotation |
| CT         | Computed tomography                  |
| EATFRR     | Endoscopically assisted transaxillary first rib resection |
| QuickDASH  | Quick Disability of the Arm, Shoulder and Hand |
| TOS        | Thoracic outlet syndrome              |

Patients

Since 2016, we have performed surgery for 52 limbs with TOS in our department. We excluded 1 patient (2 limbs) associated with bilateral cervical ribs, which were excised by the supraclavicular approach. The present study included 45 consecutive patients (50 limbs) who underwent EATFRR with scalenotomy and brachial plexus neurolysis performed by a single-hand surgeon between April 2016 and November 2021. There were 26 males and 19 females, and the mean age at surgery was 29.2 years (range, 15–50 years).

Diagnosis

We diagnosed patients as having TOS on the basis of symptomatic presentation, physical examination manoeuvres including the Roos test [15], Wright test [16] and Moley test [2] and lack of any evidence of a more likely cause. Patients with traumatic TOS were excluded. Colour Doppler and Duplex ultrasonography are useful diagnostic modalities in this context (Fig. 1) [17, 18]. The measures assessed included blood flow disruption, low blood flow and accelerated blood flow in the subclavian artery demonstrated by Doppler sonography (Fig. 1), the scalene interval width between the anterior and middle interscalene muscles (interscalene base) [19], and the costoclavicular space demonstrated by Duplex ultrasonography [20, 21] in a resting position with the shoulder in abduction and in the external rotation (ABER) position sitting on a chair by a medical technologist. Furthermore, enhanced computed tomography (CT) was performed with the shoulder in full abduction to confirm the presence of stenosis of the subclavian artery (Fig. 2) [22] and the costoclavicular space [23].

We performed surgery only for patients with certain objective findings, including blood flow disruption, low blood flow (Fig. 1A, affected limb, and B, contralateral side), and accelerated blood flow (Fig. 1C, affected limb, and D, 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. 2).

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 anaesthesia. We used single-lumen intubation and did not perform differential lung ventilation. The upper limb position was set at full abduction in the early phase (n = 3), 90° of abduction with the arm pulled upwards according to Roos [24] in the middle phase (n = 15), and in the subordinate pivotal position/zero position [14] in the late phase (n = 32, Fig. 3). At the beginning, it was difficult to obtain appropriate visualization. Therefore, we changed the position in 3 stages to improve the visualization (Video 1).
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. 3B). Careful dissection was performed to allow the confirmation of subclavian artery pulsation with a finger. An endoscopic incision was made more superior and posterior at the third rib level (Fig. 3B). We used a 4–0-mm 30° arthroscope, detached both the anterior and middle inter-scalene muscles from the first rib and excised the first rib piecemeal using bone cutting rongeurs (LUER-STILLE BONE RONGEUR, STILLE, Sweden), and neurolysis of the brachial plexus was performed with endoscopic assistance in all cases (Fig. 4 and Video 2). Neurolysis involved only dissection around the brachial plexus.

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 (C, 314 cm/s) relative to that in the resting position (D, 67 cm/s).

Figure 2: Narrowing of the subclavian artery demonstrated by computed tomography angiography. Preoperative computed tomography (A) angiography demonstrating subclavian artery stenosis (arrow). No remarkable stenosis is evident 6 days after surgery (B).
Appropriate visualization could not be obtained simply by inserting the endoscope with full limb abduction or at 90° of limb abduction with the arm pulled upwards. Therefore, we needed to improve the visualization using some large retractors. However, better visualization was obtained simply by inserting the endoscope without any retractors at a subordinate pivotal position [14] where the deltoid, supraspinatus and infraspinatus were relaxed (Fig. 3 and Videos 1 and 2). Appropriate visualization was also obtained by applying antifog to the arthroscope and attaching suction to the side of the arthroscope, thus significantly decreasing the amount of intraoperative blood pooling. We placed only a Penrose drain in the early phase. However, there was little bleeding after surgery and pneumothorax was observed in only limited cases. Therefore, we did not systematically add pleural drainage after surgery.

Range of motion exercise for shoulder abduction up to 90° was allowed immediately after surgery, and unlimited shoulder motion was allowed after 4 weeks. The patients returned to full activities, such as sports, between 2 and 3 months after surgery.

**Figure 3:** Intraoperative limb position. The upper limb is set at full abduction in the early phase (A), 90° 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 PM and the LD muscles. An endoscopic incision (arrowhead) is made more superior and posterior at the third rib level (D). LD: latissimus dorsi; PM: pectoralis major.

**Video 1:** Endoscopy. Right endoscopic transaxillary approach demonstrating the SV, AS, SA, BP and MS. Appropriate visualization can be obtained simply by inserting the endoscope at the subordinate pivotal position/zero position. AS: anterior scalene muscle; BP: brachial plexus; MS: middle scalene muscle; SA: subclavian artery; SV: subclavian vein.
Evaluation of clinical data

A comprehensive review of medical records was conducted. 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; patient satisfaction; preoperative and postoperative Quick Disability of the Arm, Shoulder and Hand (QuickDASH) [25]; and complications at a mean of 28 months (range, 6–67 months) after surgery. Patient satisfaction was divided into 4 categories according to Derkash et al. [26]: excellent, complete relief; good, almost complete relief; fair, partial relief; poor, no improvement. Furthermore, midterm results were assessed by Derkash assessment and QuickDASH among patients who had been follow-up.

Figure 4: Endoscopically assisted surgery. Right endoscopic transaxillary approach demonstrating the SV, AS, SA, BP, MS, 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. AS: anterior scalene muscle; BP: brachial plexus; MS: middle scalene muscle; R1: first rib; SA: subclavian artery; SV: subclavian vein.
for at least 24 months (mean, 37.7 months, range, 24–67 months). We compared the clinical results among these patients according to whether or not they were athletes.

**Statistical analysis**

The QuickDASH was compared using Wilcoxon test, Mann–Whitney U-test and Fisher’s exact test. We compared patient age between athletes and non-athletes using Wilcoxon 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).

**RESULTS**

**Perioperative measurements**

The preoperative Roos test was positive in all cases. The mean blood flow was 93.1 cm/s (range, 48–220 cm/s) at rest and 135.4 cm/s (range, 0–314 cm/s) in the ABER position sitting in a chair demonstrated by Doppler sonography. The mean interscalene base width was 8.7 mm (range, 5.1–16.3 mm) at rest and 8.3 mm (range, 0–15.1 mm) in the ABER position sitting in a chair demonstrated by Duplex ultrasonography. The mean costoclavicular space demonstrated by Duplex ultrasonography was 9.6 mm (range, 4.7–18.0 mm) in the ABER position sitting on a chair and the mean costoclavicular space demonstrated by CT was 9.6 mm (range, 4.6–21.0 mm) with the shoulder at full abduction.

The mean intraoperative measured width of the interscalene base, intraoperative blood loss and operation time were 6.4 mm (range, 2–12 mm), 21 ml (range, 2–126 ml) and 114 min (range, 56–307 min), respectively. We did not have to control bleeding by thoracotomy.

**Outcomes ($n = 50$)**

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 20 patients (40%), good in 24 (48%), fair in 6 (12%) and poor in none. The mean QuickDASH score was 37 (range, 11–95) before surgery and 14 (range, 0–50) at final follow-up, demonstrating a significant improvement ($P < 0.001$). The postoperative Roos test was negative in 48 limbs (96%). We performed Doppler sonography for 11 cases at a mean of 177 days (range, 5–480 days) after surgery. The mean blood flow was 81.6 cm/s (range, 29–153) at rest and 103.7 cm/s (range, 44–192 cm/s) in the ABER position. The numbers of patient having accelerated blood flow were decreased from 7 to 1. There was no difference in blood flow at rest, but accelerated blood flow was clearly reduced after surgery. Pleura damage was detected in 3 cases (6%) during surgery and pneumothorax was detected by postoperative X-ray. Among them, the degree of pneumothorax was slight in 2 cases and the patients had no complaint, achieving healing without any additional treatment. Only 1 patient (2%) had chest wall pain after surgery, for which we placed a pleural drain for 1 day. There were no other complications and no cases of recurrence (Table 1).

**Midterm outcomes ($n = 30$)**

The midterm results are shown in Tables 2 and 3. We could not achieve good vision of the interscalene base and the costoclavicular space by Duplex ultrasonography in the first 4 cases. The athletes were significantly younger than the non-athletes ($P < 0.001$). The mean QuickDASH score at final follow-up was 0.2 (range, 0–2) in athletes and 16 (range, 0–50) in non-athletes ($P < 0.001$, Table 4). The QuickDASH score was significantly better in athletes ($P < 0.001$, Table 4). Among 30 limbs followed up over mid-term, complete relief with the present methods was achieved in 13 limbs (43%) of the patients (91% of athletes and 16% of non-athletes).

**DISCUSSION**

Vascular TOS cases can be diagnosed by colour Doppler and Duplex ultrasonography [17, 18] or CT angiography [22]. 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 the ABER position. Neurogenic TOS is considered a ‘diagnosis of exclusion’ in that imaging and/or electrophysiology studies are usually negative [27]. Neurogenic TOS is caused by compression and subsequent irritation of the brachial plexus nerves as they pass through the scalene triangle at the base of the neck.
between the clavicle and first rib [27]. Therefore, we checked the interscalene base and the costoclavicular space using Duplex ultrasonography and enhanced CT. Neurogenic TOS cases can also be diagnosed by Duplex ultrasonography [20, 21]. In cadaver studies, the mean interscalene base width and the mean costoclavicular space have been reported to be 10.7 and 13.5 mm, respectively [19]. The mean costoclavicular space measured by CT was 12.5 mm [23]. Preoperative and intraoperative measures of the interscalene base can predict disorders due to scalene triangle and costoclavicular space. If narrowing of the interscalene base and/or costoclavicular stenosis. However, both the brachial plexus and subclavian artery pass through the scalene triangle and costoclavicular space. If narrowing of the interscalene base and/or costoclavicular space is detected, it is difficult to diagnose the patient having a neurogenic TOS and/or a vascular TOS. In the presence of clinical TOS, the scalene muscles compress the structures of the brachial plexus and subclavian artery in the thoracic outlet between the anterior and middle scalene muscles. Therefore, both scalenotomy and first rib resection provide significant functional improvements in patients with TOS.

Endoscopic surgery requires appropriate visualization, especially when inserting an arthroscope in a place other than a joint. Therefore, we changed the upper arm position in 3 phases. Better visualization was obtained at the subordinate pivotal position/zero position [14]. This limb position is usually used to reduce shoulder dislocation. The relationship between the neurovascular bundle and the scalene muscles could be observed clearly using an endoscope in the zero position. Endoscopic neurolysis was possible when the brachial plexus and subclavian artery were adherent. Endoscopically assisted surgery allowed decompression for both vascular and neurogenic TOS. Usually, this pathology is treated surgically by vascular surgeons, thoracic surgeons or general surgeons. We consulted only vascular surgeons before the first surgery. However, there were no cases that required collaboration with vascular surgeons. This procedure was performed by a single-hand surgeon. Hand surgeons are already well accustomed to handling blood vessels, nerves, and arthroscopy (endoscopy).

There are 3 major procedures for TOS in the absence of a cervical rib: transaxillary first rib resection [6, 24], supraclavicular first rib resection [2, 4, 7], and supraclavicular release of the anterior and middle scalene muscles leaving the first rib intact [28]. Statistically, there is no significant difference in outcome between the 3 procedures, with fair results being reported in 4–8% of each group [7]. A systematic literature review revealed that both supraclavicular scalenotomy and transaxillary first rib resection had a high probability of success [8]. In the present study, endoscopically assisted surgery achieved some degree of improvement in all patients. The mean improvement in the QuickDASH score was 28, and complete relief was obtained 40% of the patients. TOS sometimes occurs in throwing athletes. Athletes show better improvement than non-athletes after first rib resection and

![Table 2: Patient demographics and perioperative measurements (mid-term follow-up patients)](image)

| Patients | Gender | Age | Phase | Blood loss (ml) | Operative time (min) | Intraoperative SIW (mm) | Ultrasonography (mm) | Blood flow by Doppler sonography (cm/s) | CT (mm) |
|----------|--------|-----|-------|----------------|----------------------|-----------------------|---------------------|------------------------------------------|--------|
| 1        | Male   | 17  | 1     | 126           | 307                  | NA                    | NA                  | NA                        | NA        |
| 2        | Female | 34  | 1     | 9             | 166                  | NA                    | NA                  | NA                        | NA        |
| 3        | Male   | 17  | 1     | 17            | 260                  | NA                    | NA                  | NA                        | NA        |
| 4        | Male   | 15  | 2     | 89            | 165                  | NA                    | NA                  | NA                        | NA        |
| 5        | Male   | 29  | 2     | 101           | 272                  | 2                     | 12                  | 11 21                     | 18        |
| 6        | Female | 50  | 2     | 17            | 183                  | 5                     | 6.9                 | 7.8 9.1                    | 8.6        |
| 7        | Female | 45  | 2     | 51            | 174                  | 8                     | 8.4                 | 7.8 10.6                    | 7.8        |
| 8        | Female | 45  | 2     | 25            | 170                  | 8                     | 10.7                | 9 10.1 9.9                 | 48 64 45 42 | 5.6        |
| 9        | Female | 29  | 2     | 11            | 148                  | 3                     | 5.3                 | 8.3 14 11                  | 79 71 125 104 | 5.4        |
| 10       | Male   | 16  | 2     | 71            | 130                  | 6                     | 6.8                 | 8.2 6.9                    | 113 89 164 231 | 13.0       |
| 11       | Female | 29  | 2     | 10            | 86                   | 8                     | 5.1                 | 5.2 11.4                    | 120 103 127 115 | 6.5        |
| 12       | Female | 44  | 2     | 10            | 120                  | 6                     | 14.9                | 14.7 5.9                    | 71.8 53.3 120.4 67.2 | 6.9        |
| 13       | Female | 29  | 2     | 6             | 120                  | 6.3                   | 14.6                | 14.1 13.1                  | 70 89 79 158 | 15.1       |
| 14       | Male   | 16  | 2     | 25            | 135                  | 6                     | 9.8                 | 8.7 12.7                    | 127 130 295 183 | 10.0       |
| 15       | Male   | 22  | 2     | 20            | 156                  | 3                     | 8.3                 | 6 10.8 8.9                 | 68 70 314 251 | 4.6        |
| 16       | Male   | 35  | 2     | 10            | 122                  | 6                     | 6.5                 | 7.1 11.8                    | 66 53 42 67 | 7.1        |
| 17       | Female | 37  | 2     | 18            | 160                  | 8                     | 8.4                 | 7.4 12.5                    | 69.5 73.1 86.7 75.6 | 6.4        |
| 18       | Male   | 22  | 2     | 26            | 140                  | 10                    | 6.7                 | 5.4 6.7                    | 88 105 32 | 126 70     |
| 19       | Male   | 22  | 2     | 3             | 210                   | 114                   | 7.4                 | 0 7.3 6.4                   | 70 67 251 314 | 8.0        |
| 20       | Male   | 35  | 3     | 12            | 90                   | 6                     | 7.2                 | 6.9 15.1                    | 53 66 67 42 | 7.2        |
| 21       | Female | 30  | 3     | 8             | 96                   | 6                     | 13.6                | 14 12.3 11.9               | 89 70 158 79 | 13.3       |
| 22       | Female | 30  | 3     | 3             | 60                   | 5                     | 5.1                 | 5.3 7.3                    | 95 92 99 114 | 8.0        |
| 23       | Female | 17  | 3     | 5             | 70                   | 24                    | 7.4                 | 6.2 5.9                    | 92 81 227 148 | 6.1        |
| 24       | Female | 44  | 3     | 18            | 88                   | 12                    | 7.3                 | 7.8 13.4                    | 68 66 66 61 | 12.1       |
| 25       | Male   | 17  | 3     | 4             | 71                   | 3                     | 8.5                 | 7.9 9.9                    | 103 123 128 164 | 10.4       |
| 26       | Male   | 17  | 3     | 16            | 132                  | 4                     | 9.7                 | 8.6 13.7                    | 82 103 180 224 | 12.1       |
| 27       | Male   | 17  | 3     | 3             | 78                   | 7                     | 8.3                 | 8.7 12.8                    | 101 83 301 154 | 8.6        |
| 28       | Female | 44  | 3     | 8             | 100                  | 8                     | 8.6                 | 8.4 17.9                    | 55 54 54 56 | 12.9       |
| 29       | Male   | 22  | 3     | 5             | 62                   | 10                    | 8.5                 | 9 8.9 8.9                   | 90 89 169 108 | 17.6       |
| 30       | Male   | 17  | 3     | 15            | 84                   | 8                     | 7.3                 | 7.2 9.3                    | 96 98 270 214 | 6.1        |
| Mean     |        | 28.1| 25.0  | 135           | 6.2                  | 8.7                 | 8.1 11.2                   | 96 83.2 89.8 144.1 146.1 | 9.9        |
scalenotomy [29]. Here, complete relief was observed significantly more often in athletes than in non-athletes (91% vs 16%). However, the athletes were significantly younger than non-athletes. These age differences might have affected the QuickDASH scores.

Transaxillary first rib resection has a higher incidence of complications than supraclavicular scalenotomy, being 22.5% and 12.6%, respectively [12]. Among 538 cases of TOS treated by transaxillary first rib resection, there were 138 (23%) cases of intraoperative pneumothorax [6]. EATFRR is associated with a high risk of pneumothorax. Abdellaoui et al. [9] reported 28 cases treated by EATFRR surgery, and pneumothorax occurred in 78% of them. In the present study, intraoperative pneumothorax occurred in 6% (additional treatment being needed in only 1 case, 2%) and no other complications or recurrences were observed after endoscopic surgery. Ohtsuka et al. [30] have reported thoracoscopic first rib resection. However, as this procedure poses a significant potential risk to the neurovascular bundle, modified techniques with appropriate instrumentation have been developed [11]. A pleural drain is needed after thoracoscopic surgery for TOS, but not after endoscopic surgery for TOS. Furthermore, EATFRR using a 10-mm endoscope has resulted in a lower incidence of complications [9]. In the present study, EATFRR and brachial plexus neurolysis using a 4.0-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. We think this approach associated with a faster healing and a shortened recovery. However, as we have no experiences of other types of surgery, we were unable to compare our results with other procedures. 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.

Table 3: Mid-term outcomes (n = 30)

| Patients | Sports | Preoperative QuickDASH D/S | Preoperative QuickDASH Sports | Postoperative QuickDASH D/S | Postoperative QuickDASH Sports | Differences of QuickDASH D/S | Differences of QuickDASH Sports | Patient satisfaction |
|----------|--------|----------------------------|-------------------------------|----------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------|
| 1        | Baseball | 27 | 100 | 0 | 0 | 27 | 100 | Excellent |
| 2        |         | 19 | 0   | 0 | 0 | 19 | Excellent |
| 3        | Baseball | 30 | 75 | 0 | 0 | 30 | 75 | Excellent |
| 4        | Baseball | 68 | 75 | 0 | 0 | 68 | 75 | Excellent |
| 5        |         | 27 | 18  | 9 | 9 | 27 | 18  | Good |
| 6        |         | 45 | 34  | 11 | 11 | 45 | 34  | Good |
| 7        |         | 89 | 20  | 68 | 68 | 89 | 20  | Fair |
| 8        |         | 52 | 5   | 47 | 47 | 52 | 5   | Good |
| 9        |         | 95 | 50  | 45 | 45 | 95 | 50  | Fair |
| 10       | Baseball | 32 | 75 | 2 | 0 | 30 | 75 | Good |
| 11       |         | 84 | 11  | 73 | 73 | 84 | 11  | Good |
| 12       |         | 66 | 25  | 41 | 41 | 66 | 25  | Good |
| 13       |         | 75 | 14  | 61 | 61 | 75 | 14  | Good |
| 14       | Baseball | 27 | 100 | 0 | 13 | 27 | 87  | Good |
| 15       |         | 11 | 0   | 11 | 11 | 11 | 0   | Excellent |
| 16       |         | 64 | 28  | 36 | 36 | 64 | 28  | Good |
| 17       |         | 23 | 5   | 18 | 18 | 23 | 5   | Good |
| 18       | Baseball | 30 | 50 | 0 | 0 | 30 | 50 | Excellent |
| 19       |         | 11 | 0   | 11 | 11 | 11 | 0   | Excellent |
| 20       |         | 89 | 28  | 61 | 61 | 89 | 28  | Good |
| 21       |         | 50 | 14  | 36 | 36 | 50 | 14  | Good |
| 22       |         | 52 | 23  | 29 | 29 | 52 | 23  | Good |
| 23       | FH      | 18 | 100 | 0 | 0 | 18 | 100 | Excellent |
| 24       |         | 27 | 5   | 23 | 23 | 27 | 5   | 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 | 11 | 11 | 0   | Excellent |
| 29       |         | 20 | 18  | 2 | 2 | 20 | 18  | Fair |
| 30       | Baseball | 32 | 75 | 0 | 0 | 32 | 75 | Excellent |
| Mean     |         | 42 | 81  | 12 | 12 | 42 | 81  | Excellent |

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

Table 4: Comparison of perioperative QuickDASH scores between athlete and nonathlete

| QuickDASH, median (IQR) | P-Value |
|-------------------------|---------|
| Preoperative            | Postoperative |
| Athlete                 | 31 (16–68) | 0.2 (0–2) | <0.001 |
| Nonathlete              | 48 (11–95) | 16 (0–50) |
| Total                   | 42 (11–95) | 12 (0–50) | <0.001 |

IQR: interquartile range; QuickDASH: Quick Disability of the Arm, Shoulder and Hand.
Because the sample size was limited, a controlled trial would have taken much more time, delaying the publication of the pre-
liminary outcomes. EATFRR in the zero position 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. In the present study, we excluded 1 patient associated with a cervical rib. We diagnosed TOs using Doppler sonography adopting an ABER method or CT angiography.

CONCLUSION

Our findings suggest that endoscopically assisted transaxillary first rib resection and brachial plexus neurolysis in the zero position are useful and safe for both vascular and neurogenic TOs.

ACKNOWLEDGEMENTS

The authors thank M.T. Tomoyuki Kazama at Yamagata University Hospital for the assessment of ultrasonography.

Conflict of interest: none declared.

Data availability

Data are available on request.

Author contributions

Hiroshi Satake: Conceptualization; Data curation; Formal analysis; Investigation; Writing—original draft. Ryusuke Nonma: Writing—review & editing. Toshiya Nitto: Conceptualization; Data curation. Yasushi Maganuma: Methodology; Validation. Junichiro Shibuya: Data curation; Validation. Masahiro Maruyama: Data curation; Validation. Tomohiro Uno: Data curation. Michiaki Takagi: Supervision; Validation; Writing—review & editing.

Reviewer information

Interactive CardioVascular and Thoracic Surgery thanks Pete Vlah-Horea Botianu, Kaushal K Tiwari and the other, anonymous reviewer(s) for their contribution to the peer review process of this article.

REFERENCES

[1] Povlsen B, Hansson T, Povlsen SD. Treatment for thoracic outlet syndrome. Cochrane Database Syst Rev 2014;26:CD007218.
[2] Morley J. Brachial pressure neuritis due to a normal first thoracic rib: its diagnosis and treatment by excision of rib. Clin J 1913;42:461-4.
[3] Adson AW, Coffey JR. Cervical rib: a method of anterior approach for relief of symptoms by division of the scalenus anticus. Ann Surg 1927;85: 839-57.
[4] Falconer MA, Li FW. Resection of the first rib in costoclavicular compression of the brachial plexus. Lancet 1962;1:59-63.
[5] Roos DB, Owens JC. Thoracic outlet syndrome. Arch Surg 1966;93:71-4.
[6] Orlando MS, Likes KC, Mirza S, Cao Y, Cohen A, Lum YW 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.
[7] Sanders RJ, Pearce WH. The treatment of thoracic outlet syndrome: a comparison of different operations. J Vasc Surg 1989;10:626-34.
[8] 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.
[9] Abdellaoue A, Atwan M, Reid F, Wilson P. Endoscopic assisted transaxillary first rib resection. Interact CardioVasc Thorac Surg 2007;6:644-6.
[10] Furushima K, Funakoshi T, Kusano H, Miyamoto A, Takahashi T, Horiiuchi Y et al. Endoscopic-assisted transaxillary approach for first rib resection in thoracic outlet syndrome. Arthrosports Med Rehabil 2021;3:e153-e162.
[11] George RS, Milton R, Chaudhuri N, Kefaloyannisis E, Papagiannopoulos K. Totally endoscopic (VATS) first rib resection for thoracic outlet syndrome. Ann Thorac Surg 2017;103:241-5.
[12] Kocher GJ, Zehnder A, Lutz JA, Schmidli J, Schmid RA. First rib resection for thoracic outlet syndrome: the robotic approach. World J Surg 2018; 42:3250-5.
[13] 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.
[14] Ozaki J, Kawamura I. “Zero-position” functional shoulder orthosis. Prosthet Orthot Int 1984;8:139-42.
[15] Roos DB. Congenital anomalies associated with thoracic outlet syndrome. Anatomy, symptoms, diagnosis, and treatment. Am J Surg 1976;132:771-8.
[16] Wright IS. 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. Am Heart J 1945;29:1-19.
[17] Longley DG, Yedlicka JW, Molina EJ, Schwabacher S, Hunter DW, Letourneau LG. Thoracic outlet syndrome: evaluation of the subclavian vessels by color duplex sonography. AJR Am J Roentgenol 1992;158:623-30.
[18] Wadhwani R, Chaubal N, Sukthankan R, Shroff M, Agarwala S. Color Doppler and duplex sonography in 5 patients with thoracic outlet syndrome. J Ultrasound Med 2001;20:795-801.
[19] Dahlstrom KA, Olinger AB. Descriptive anatomy of the interscalene triangle and the costoclavicular space and their relationship to thoracic outlet syndrome: a study of 60 cadavers. J Manipulative Physiol Ther 2012;35:396-401.
[20] Fried SM, Nazarian LN. Dynamic neuromusculoskeletal ultrasound documentation of brachial plexus/thoracic outlet compression during elevated arm stress testing. Hand (N Y) 2013;8:358-65.
[21] Mattox R, Battaglia PJ, Weik AB, Maeda Y, Haun DW, Kettner NW. Reference values for the scalene interval width during varying degrees of glenohumeral abduction using ultrasonography. J Manipulative Physiol Ther 2016;39:662-7.
[22] Rémy-Jardin M, Remy J, Masson P, Bonnel F, Debatselier P, Vinckier L et al Helical CT angiography of thoracic outlet syndrome: functional anatomy. AJR Am J Roentgenol 2000;174:1667-74.
[23] Duarte FH, Zerati AE, Gornati VC, Nomura C, Puech-Lebrun I, Puech-Lebrun P. Normal costoclavicular distance as a standard in the radiological evaluation of thoracic outlet syndrome in the costoclavicular space. Ann Vasc Surg 2021;72:138-46.
[24] Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354-8.
[25] 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;87:1038-46.
[26] Derkash RS, Goldberg VM, Mendelson H, Mevicker R. The results of cervical rib resection in thoracic outlet syndrome. Orthopedics 1981;4:1025-9.
[27] 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;87:1038-46.
[28] Cheng SWK, Reilly LM, Nelken NA, Ellis WV, Stoney RJ. Neurogenic thoracic outlet syndrome: rationale for sparing the first rib. Cardiovasc Ther 2016;39:662–7.
[29] Duarte FH, Zerati AE, Gornati VC, Nomura C, Puech-Lebrun L, Puech-Lebrun P. Normal costoclavicular distance as a standard in the radiological evaluation of thoracic outlet syndrome in the costoclavicular space. Ann Vasc Surg 2021;72:138-46.
[30] Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354-8.
[31] 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;87:1038-46.
[32] Derkash RS, Goldberg VM, Mendelson H, Mevicker R. The results of cervical rib resection in thoracic outlet syndrome. Orthopedics 1981;4:1025-9.
[33] Ohman JW, Thompson RW. Thoracic outlet syndrome in the overhead athlete: diagnosis and treatment recommendations. Curr Rev Musculoskelet Med 2020;13:457-71.
[34] Cheng SWK, Reilly LM, Nelken NA, Ellis WV, Stoney RJ. Neurogenic thoracic outlet syndrome: rationale for sparing the first rib. Cardiovasc Ther 2016;39:662-7.
[35] Duarte FH, Zerati AE, Gornati VC, Nomura C, Puech-Lebrun L, Puech-Lebrun P. Normal costoclavicular distance as a standard in the radiological evaluation of thoracic outlet syndrome in the costoclavicular space. Ann Vasc Surg 2021;72:138-46.
[36] Roos DB. Transaxillary approach for first rib resection to relieve thoracic outlet syndrome. Ann Surg 1966;163:354-8.
[37] 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;87:1038-46.