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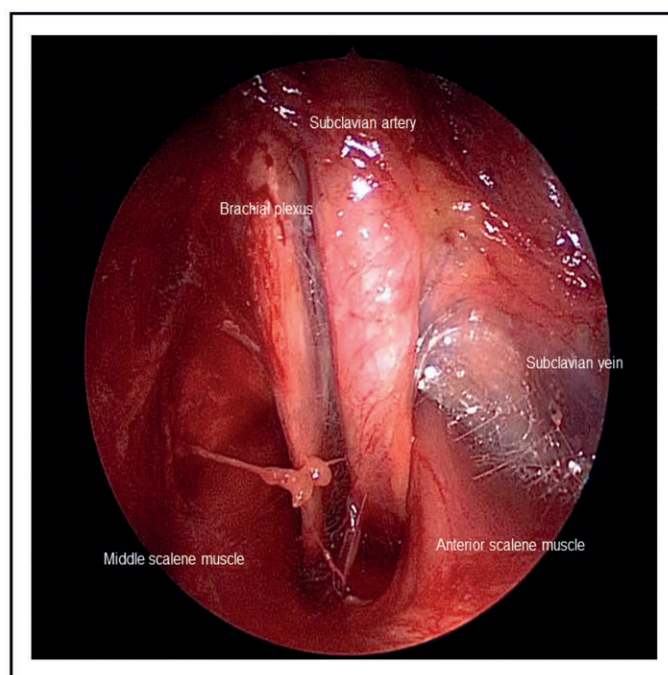
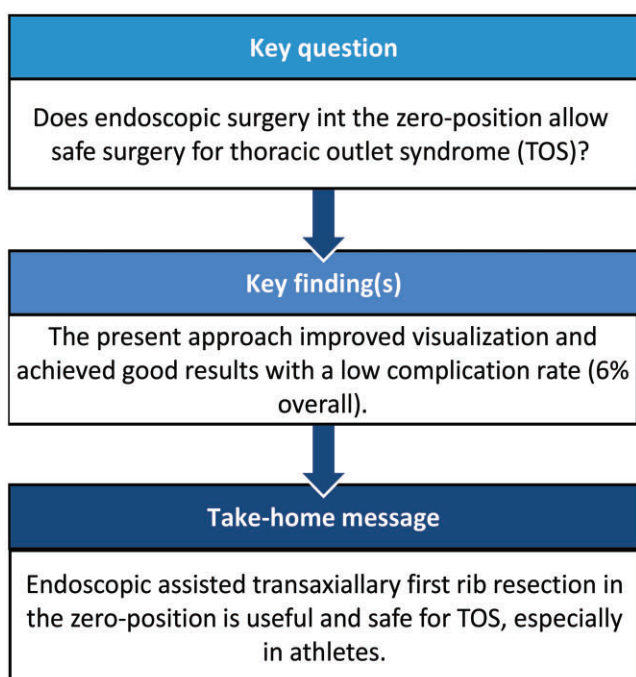
Midterm results of endoscopically assisted first rib resection in the zero position for thoracic outlet syndrome

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).

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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).

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

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 |

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).

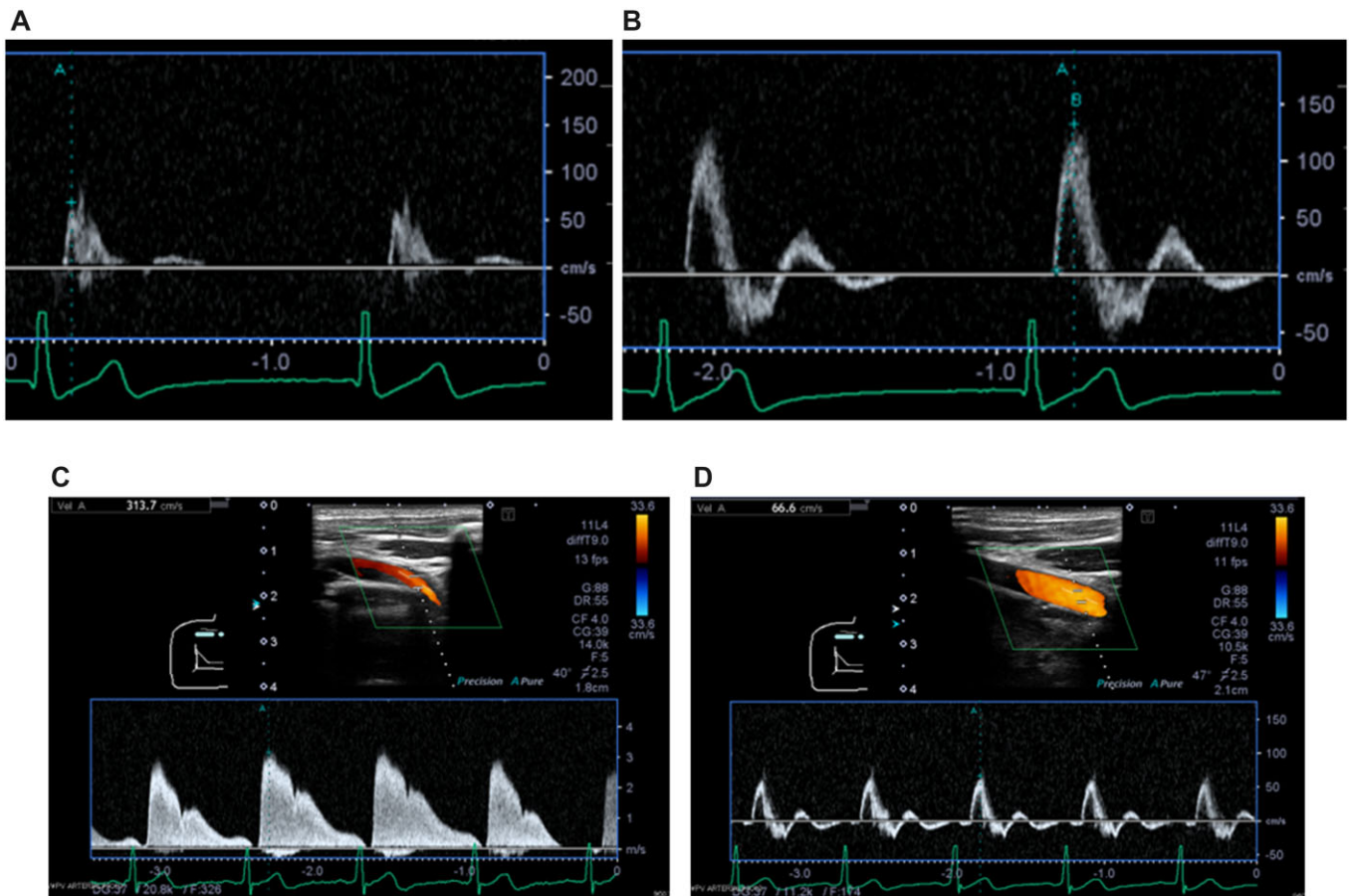


Figure 1: Blood flow in the subclavian artery demonstrated by Doppler sonography. Low blood flow is observed in the affected limb (**A**, 69 cm/s) relative to the contralateral side (**B**, 126 cm/s). Accelerated blood flow is observed at the shoulder in abduction and external rotation (**C**, 314 cm/s) relative to that in the resting position (**D**, 67 cm/s).

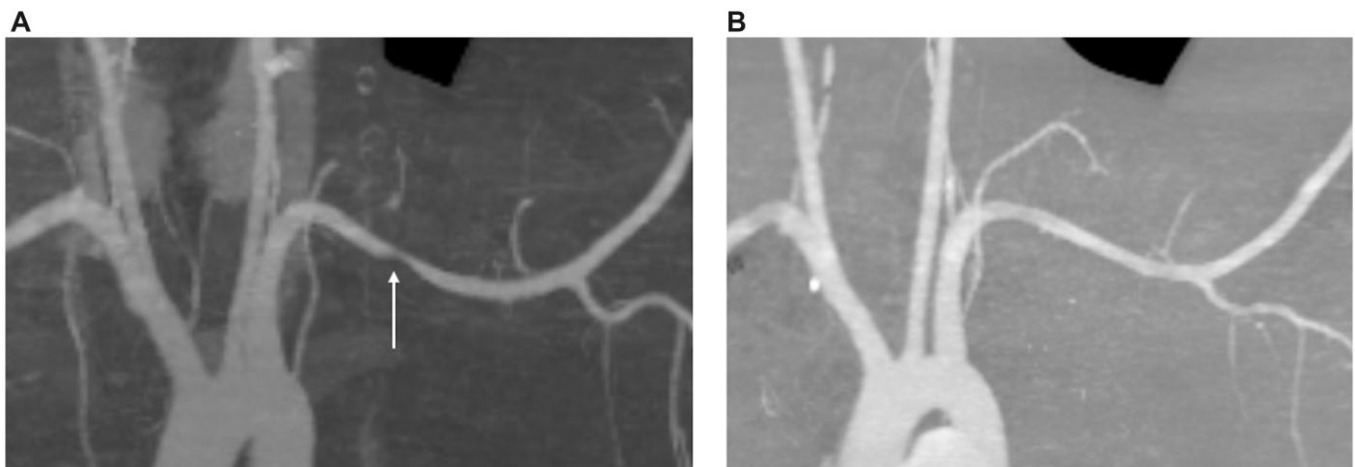


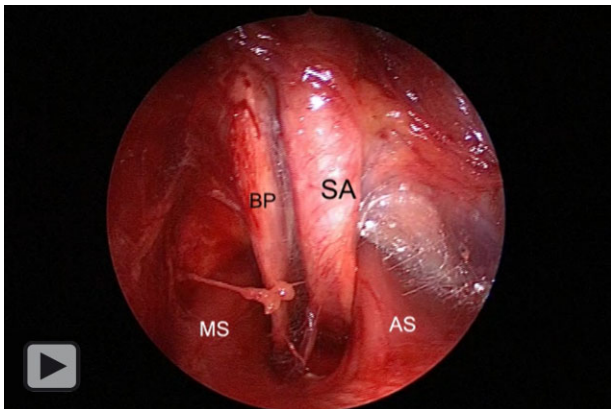
Figure 2: Narrowing of the subclavian artery demonstrated by computed tomography angiography. Preoperative computed tomography (**A**) angiography demonstrating subclavian artery stenosis (arrow). No remarkable stenosis is evident 6 days after surgery (**B**).

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 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.

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.

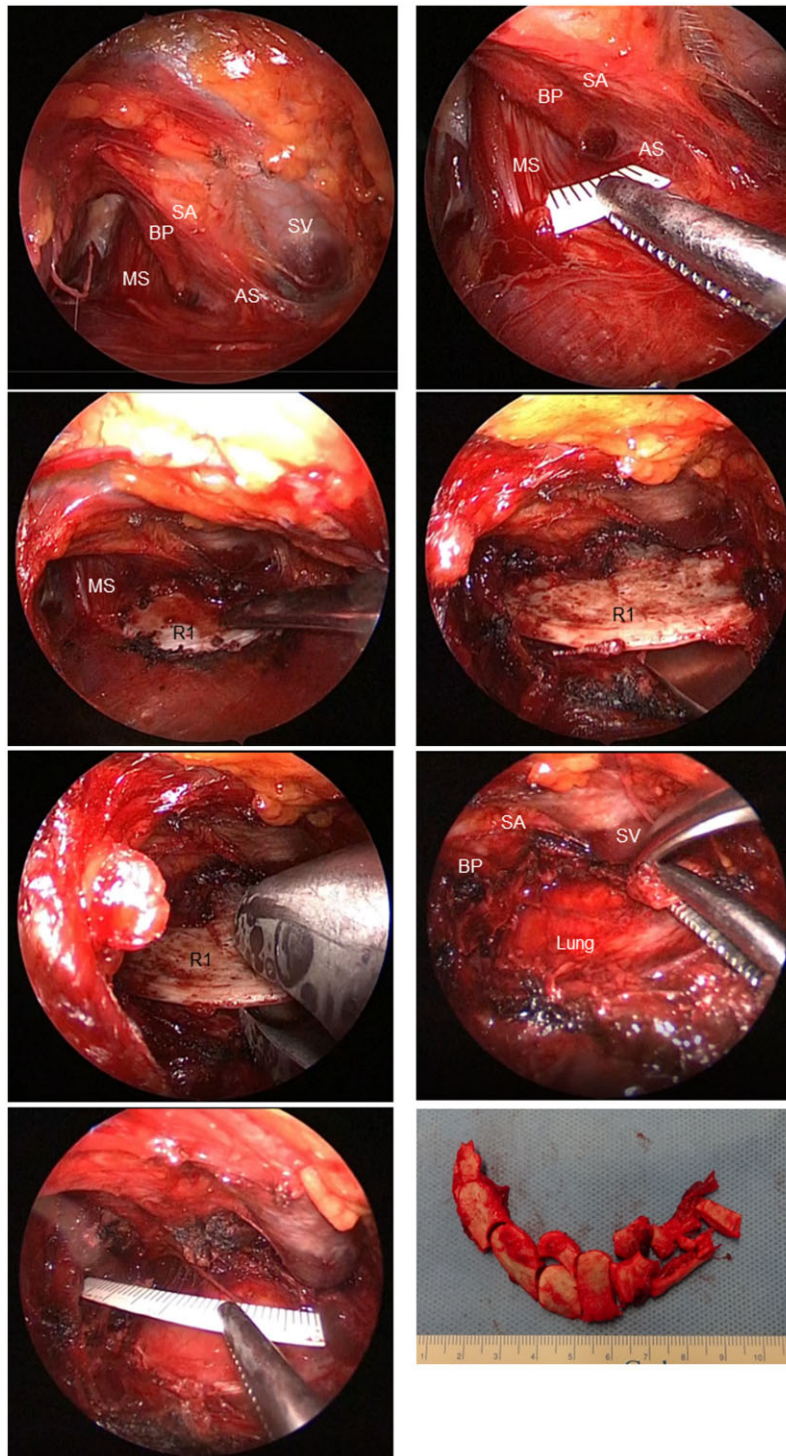
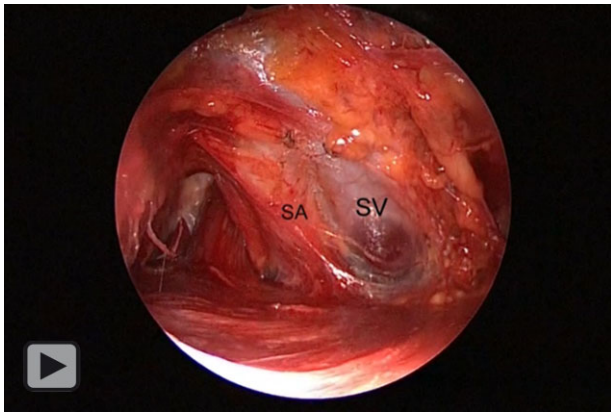


Figure 4: Endoscopically assisted surgery. Right endoscopic transaxillary approach demonstrating the SV, AS, SA, BP, MS, R1 and lung. The width of the interscalene base is 6 mm. Both the AS and MS are detached from R1. R1 is excised piecemeal using a bone cutting rongeur. The amount of R1 resected is 5 cm. AS: anterior scalene muscle; BP: brachial plexus; MS: middle scalene muscle; R1: first rib; SA: subclavian artery; SV: subclavian vein.

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



Video 2: Surgical technique. Right endoscopic transaxillary approach demonstrating the SV, AS, SA, BP, MS, R1 and lung. Both the anterior and middle inter-scalene muscles are detached from the first rib. The first rib is excised piecemeal using a bone cutting rongeur, and neurolysis of the brachial plexus is performed. 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

Table 1: Patient satisfaction and comparison of perioperative QuickDASH scores ($n = 50$)

| Patient satisfaction, n (%) | | | |
|-------------------------------|---------|---------------|-----------|
| Excellent | Good | Fair | Poor |
| 20 (40) | 24 (48) | 6 (12) | 0 |
| QuickDASH, median (IQR) | | P-Value | |
| Preoperative | | Postoperative | |
| Total | | 37 (11–95) | 14 (0–50) |
| | | <0.001 | |

IQR: interquartile range; QuickDASH: Quick Disability of the Arm, Shoulder and Hand.

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,

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

| Patients | Gender | Age | Phase | Blood loss (ml) | Operative time (min) | Intraoperative SIW (mm) | Ultrasonography (mm) | | | | Blood flow by Doppler sonography (cm/s) | | | | CT (mm) |
|----------|--------|------|-------|-----------------|----------------------|-------------------------|----------------------|----------|--------|----------|---|---------|---------|---------|---------|
| | | | | | | | SIW RP | SIW ABER | CCS RP | CCS ABER | AS Rest | CS Rest | AS ABER | CS ABER | CCS |
| 1 | Male | 17 | 1 | 126 | 307 | NA | NA | NA | NA | NA | 69 | 126 | 220 | 131 | 8.6 |
| 2 | Female | 34 | 1 | 9 | 166 | NA | NA | NA | NA | NA | 60 | 237 | 59 | 267 | 9.1 |
| 3 | Male | 17 | 1 | 7 | 260 | NA | NA | NA | NA | NA | 120 | 124 | 139 | 139 | 21.0 |
| 4 | Male | 15 | 2 | 89 | 165 | NA | NA | NA | NA | NA | 107 | 103 | 107 | 109 | 13.6 |
| 5 | Male | 29 | 2 | 101 | 272 | 2 | 12 | 11 | 21 | 18 | 83 | 73 | 263 | 321 | 11.7 |
| 6 | Female | 50 | 2 | 17 | 183 | 5 | 6.9 | 7.8 | 9.1 | 8.6 | 72 | 100 | 62 | 279 | 8.6 |
| 7 | Female | 45 | 2 | 51 | 174 | 8 | 8.4 | 7.8 | 10.6 | 7.8 | 72 | 40 | 73 | 41 | 14.0 |
| 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 | 6.9 | 113 | 89 | 164 | 231 | 13.0 |
| 11 | Female | 29 | 2 | 10 | 86 | 8 | 5.1 | 5.2 | 11.4 | 11 | 120 | 103 | 127 | 115 | 6.5 |
| 12 | Female | 44 | 2 | 10 | 120 | 6 | 14.9 | 14.7 | 5.9 | 5.1 | 71.8 | 53.3 | 120.4 | 67.2 | 6.9 |
| 13 | Female | 29 | 2 | 6 | 120 | 6 | 16.3 | 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 | 8.4 | 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 | 9.9 | 66 | 53 | 42 | 67 | 7.1 |
| 17 | Female | 37 | 2 | 18 | 160 | 8 | 8.4 | 7.4 | 12.5 | 13.1 | 69.5 | 73.1 | 86.7 | 75.6 | 6.4 |
| 18 | Male | 22 | 2 | 26 | 140 | 10 | 6.7 | 5.4 | 6.7 | 4.7 | 88 | 105 | 32 | 126 | 7.0 |
| 19 | Male | 22 | 3 | 20 | 114 | 4 | 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 | 14.3 | 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 | 6.5 | 95 | 92 | 99 | 114 | 8.0 |
| 23 | Female | 17 | 3 | 5 | 70 | 2 | 7.4 | 6.2 | 5.9 | 3.5 | 92 | 81 | 227 | 148 | 6.1 |
| 24 | Female | 44 | 3 | 18 | 88 | 12 | 7.3 | 7.8 | 13.4 | 11.9 | 68 | 66 | 66 | 61 | 12.1 |
| 25 | Male | 17 | 3 | 4 | 71 | 3 | 8.5 | 7.9 | 9.9 | 7.8 | 103 | 123 | 128 | 164 | 10.4 |
| 26 | Male | 17 | 3 | 16 | 132 | 4 | 9.7 | 8.6 | 13.7 | 12.4 | 82 | 103 | 180 | 224 | 12.1 |
| 27 | Male | 17 | 3 | 3 | 78 | 7 | 8.3 | 8.7 | 12.8 | 11.4 | 101 | 83 | 301 | 154 | 8.6 |
| 28 | Female | 44 | 3 | 8 | 100 | 8 | 8.6 | 8.4 | 17.9 | 12.1 | 55 | 54 | 54 | 56 | 12.9 |
| 29 | Male | 22 | 3 | 5 | 62 | 10 | 8.5 | 9 | 7.8 | 8.9 | 90 | 89 | 169 | 108 | 17.6 |
| 30 | Male | 17 | 3 | 15 | 84 | 8 | 7.3 | 7.2 | 9.3 | 6.8 | 96 | 98 | 270 | 214 | 6.1 |
| Mean | | 28.1 | | 25.0 | 135 | 6.2 | 8.7 | 8.1 | 11.2 | 9.6 | 83.2 | 89.8 | 144.1 | 146.1 | 9.9 |

ABER, shoulder in abduction and external rotation position; AS, affected side; CCS, costoclavicular space; CS, contralateral side; CT, computed tomography; NA, not available; Rest, resting position; RP, resting position; SIW, scalene interval width between anterior and middle interscalene muscles.

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 triangular 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 search 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 3: Mid-term outcomes ($n = 30$)

| 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 | | 19 | | Excellent |
| 3 | Baseball | 30 | 75 | 0 | 0 | 30 | 75 | Excellent |
| 4 | Baseball | 68 | 75 | 0 | 0 | 68 | 75 | Excellent |
| 5 | | 27 | | 18 | | 9 | | Good |
| 6 | | 45 | | 34 | | 11 | | Good |
| 7 | | 89 | | 20 | | 68 | | Fair |
| 8 | | 52 | | 5 | | 47 | | Good |
| 9 | | 95 | | 50 | | 45 | | Fair |
| 10 | Baseball | 32 | 75 | 2 | 0 | 30 | 75 | Good |
| 11 | | 84 | | 11 | | 73 | | Good |
| 12 | | 66 | | 25 | | 41 | | Good |
| 13 | | 75 | | 14 | | 61 | | Good |
| 14 | Baseball | 27 | 100 | 0 | 13 | 27 | 87 | Good |
| 15 | | 11 | | 0 | | 11 | | Excellent |
| 16 | | 64 | | 28 | | 36 | | Good |
| 17 | | 23 | | 5 | | 18 | | Good |
| 18 | Baseball | 30 | 50 | 0 | 0 | 30 | 50 | Excellent |
| 19 | | 11 | | 0 | | 11 | | Excellent |
| 20 | | 89 | | 28 | | 61 | | Good |
| 21 | | 50 | | 14 | | 36 | | Good |
| 22 | | 52 | | 23 | | 29 | | Good |
| 23 | FH | 18 | 100 | 0 | 0 | 18 | 100 | Excellent |
| 24 | | 27 | | 5 | | 23 | | 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 | | Excellent |
| 29 | | 20 | | 18 | | 2 | | Fair |
| 30 | Baseball | 32 | 75 | 0 | 0 | 32 | 75 | Excellent |
| Mean | | 42 | 81 | 12 | 1 | 32 | 80 | |

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.

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.

Because the sample size was limited, a controlled trial would have taken much more time, delaying the publication of the preliminary 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.

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Data availability

Data are available on request.

Author contributions

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

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