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ORIGINAL RESEARCH

First Rib Resection Using Videothoracoscopy in Patients With Vascular Thoracic Outlet Syndrome

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Objective: Thoracic outlet syndrome (TOS) comprises a series of signs and symptoms produced by compression of neurovascular structures in any of the anatomical spaces of the thoracic outlet. First rib resection is a therapeutic alternative to decompress the structures of the thoracic outlet at the costoclavicular space. Traditional surgical approaches include transaxillary, supraclavicular, and infraclavicular access. The objective was to describe the surgical experience and follow up results of first rib resection using video assisted thoracoscopic surgery (VATS) in patients with vascular TOS.

Methods: Observational descriptive study based on a retrospective single centre analysis of a prospective database. Patients diagnosed with vascular TOS who underwent VATS first rib resection from January 2017 to December 2023 were included. The diagnosis for each subtype was based on the criteria defined in the standards of the American Society for Vascular Surgery in TOS. Among other things, the response to initial anticoagulation, peri-operative data, complications, symptom improvement, duration of post-operative anticoagulation, and symptom recurrence were investigated.

Results: Twenty nine patients diagnosed with vascular TOS who underwent VATS first rib resection, three of whom had bilateral procedures, were included. The total number of costal rib resections performed was 32 (31 venous TOS and one arterial TOS). The mean age was 29.1 $\pm$ 10.4 years and mean hospital stay was 2.7 $\pm$ 1.2 days. There were neither conversions to open surgery nor intra-operative complications, but there were two major post-operative complications (6.25%). No recurrences were detected during midterm follow up (median of 17.9 months, interquartile range 7.3, 45).

Conclusion: VATS first rib resection is a safe and feasible procedure. Unlike traditional approaches, this procedure allows physicians to make the resection under complete vision of the anatomical structures of the thoracic outlet reducing intra-operative complications and, if necessary, entire rib resection can be performed.

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INTRODUCTION

Thoracic outlet syndrome (TOS) includes a series of signs and symptoms that result from the compression of neurovascular structures at any of the three anatomical spaces of the thoracic outlet (the interscalene triangle, the costoclavicular space, and the pectoralis minor space). The syndrome was first described as a medical diagnosis in 1961 in a patient with thoracic outlet symptoms due to a cervical rib.[1] Depending on the affected anatomical structure, TOS can be classified as neurogenic (compression of the primary inferior trunk of the brachial plexus), venous (compression of the subclavian vein), or arterial (compression of the subclavian artery). Neurogenic TOS (NTOS) is the most frequent (95% of the cases) while arterial TOS accounts for less than 1%.[2,3] NTOS is usually caused by an abnormality of the scalene muscles, not the costoclavicular space. In these patients, rib resection is rarely performed initially, as most patients can manage their symptoms with non-surgical treatments.

Traditional approaches for first rib resection include transaxillary, supraclavicular, and infraclavicular access.[4—8] Thoracoscopic access was first described and published in 1999 by Ohtsuka et al.[9] The main advantage described compared with other approaches, was the possibility to perform the resection under complete vision of the anatomical structures of the thoracic outlet. Since then, six series of cases have been published, including our first experience published in 2021 with 10 resections, which

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showed similar results to those obtained with extrathoracic approaches (Table 1).[3,10–14]

The aim of this study was to describe a single centre expierience with video assisted thoracoscopic surgery (VATS) for first rib resection in patients with venous and arterial TOS and present midterm results.

MATERIALS AND METHODS

This observational descriptive study was based on retrospective single centre analysis of a prospective database from January 2017 to December 2023. The Institutional Review Committee of the Buenos Aires British Hospital reviewed and approved this study (CRIHB number: #9764). Patients diagnosed with venous and arterial TOS who underwent VATS first rib resection were included. The diagnosis for each subtype was based on the criteria defined in the standards of the American Society for Vascular Surgery in TOS.[15]

Demographic characteristics of the patients, their symptoms, the type of TOS, pre-operative anticoagulation, response to the initial anticoagulation, operating times, the amount of rib resected, the duration of chest tubes, complications, hospitalisation periods after surgery, symptom improvement rates, duration of post-operative anticoagulation, and symptom recurrence rates were investigated.

Imaging tests performed to confirm the diagnosis were a Doppler ultrasound followed by chest radiography and computed tomography with intravenous contrast, changing the position of the upper limb. Venography was used when the diagnosis could not be confirmed through the above mentioned methods or when catheter directed thrombolysis (fibrinolytic) was planned. After diagnosis, medical treatment was based on oral anticoagulants (OACs) or local administration of fibrinolytics through a catheter. Fibrinolytics were indicated for patients diagnosed with venous TOS within 14 days of the onset of symptoms. The use of these drugs was subject to the coverage offered by each patient's health insurance plan. The type of OAC was indicated by a haematology expert. Four types were used: vitamin K antagonists (acenocumarol), heparin, selective thrombin inhibitors (dabigatran), and selective factor Xa inhibitors (apixaban or rivaroxaban). Patients with venous TOS were evaluated for underlying coagulation disorders. In all cases, medical treatment was followed by thoracic outlet decompression with VATS first rib resection.

Rib resections were classified using the terminology described by the Society for Vascular Surgery in TOS (total, from the sternum to the transverse process of the spine; posterior resection, from the subclavian artery to the transverse process of the spine; anterior, from the sternum to the subclavian artery; and partial resection, a resection other than the ones described before).[15]

Post-operative complications were classified using the Clavien—Dindo classification (minor complications Grade I — II; major complications Grade III — IV; death Grade V).[16]

The post-operative follow up involved physical examinations in conjunction with a haematologist specialist and an echo Doppler performed within three months of the surgery. In patients without signs of thrombosis, the need to continue with OACs was assessed with the haematology department.

Surgical procedure

The surgery was performed under general anaesthesia with single lung ventilation. The patient is placed in the lateral decubitus position with the arm resting on an arm support. A 10 mm 30° thoracoscope is inserted at the seventh or eighth intercostal space in the midaxillary line and a 25 mm incision is made over the second intercostal space, in the midaxillary line at the bottom of the hair line (instrument port) (Fig. 1A). After identifying the first rib and the different anatomical structures of the thoracic outlet, the parietal pleura on the inferior edge of the rib is opened and dissected up to its upper edge, removing the pleura from the structures of the thoracic outlet. The next step is dissection of the intercostal muscle, the costoclavicular ligament, and the costal insertion of the subclavius muscle (Fig. 1B and C). A high speed drill is used to cut the sternal end of the first rib. The external aspect of the first rib is exposed by pulling the inferior edge of the rib towards the mediastinum (from anterior to posterior), so that the subclavian vein, the anterior scalene muscle, the subclavian artery, the primary inferior trunk of the brachial plexus, and the middle scalene muscle are displayed. Ultrasonic energy or monopolar cautery are used to cut the rib scalene muscle (anterior and middle) insertions (Fig. 1D). Finally, a double articulated shear or a high speed drill is used to cut the posterior end of the rib behind the rib middle scalene muscle insertion (Fig. 1E and F). A chest drain tube is inserted through the optical port (Supplementary Video).

Data were analysed using SPSS 13.0 (statistical software) and presented as median (interquartile range [IQR]), mean ± standard deviation, or counts with percentages.

Table 1. Comparison of peri-operative data of video assisted thoracoscopic surgery first rib resection publications.

First author (year)	Resections	Ports	Operating time — min	Pleural drainage — d	Hospital stay — d	Post-operative complications
Ohtsuka (1999)[9]	3	3	95 ± 14	N/A	2	0
Loscertales (2011)[10]	3	3	N/A	1	1.3	0
Soukiasian (2015)[11]	66	2	N/A	N/A	2.47	8 (12)
George (2017)[3]	10	3	85	1	3	1 (10)
Hwang (2017)[12]	8	3	193 ± 45	6 ± 2.5	9 ± 5.2	2 (25)
Nuutinen (2018)[13]	30	3	83 ± 27	1.27 ± 0.52	1.93 ± 0.64	1 (3,3)
Buero (2021)[14]	10	2	123 ± 17	1.5 ± 0.7	3.1 ± 0.5	1 (10)

Data are presented as number, *number* (%) or as mean ± SD.

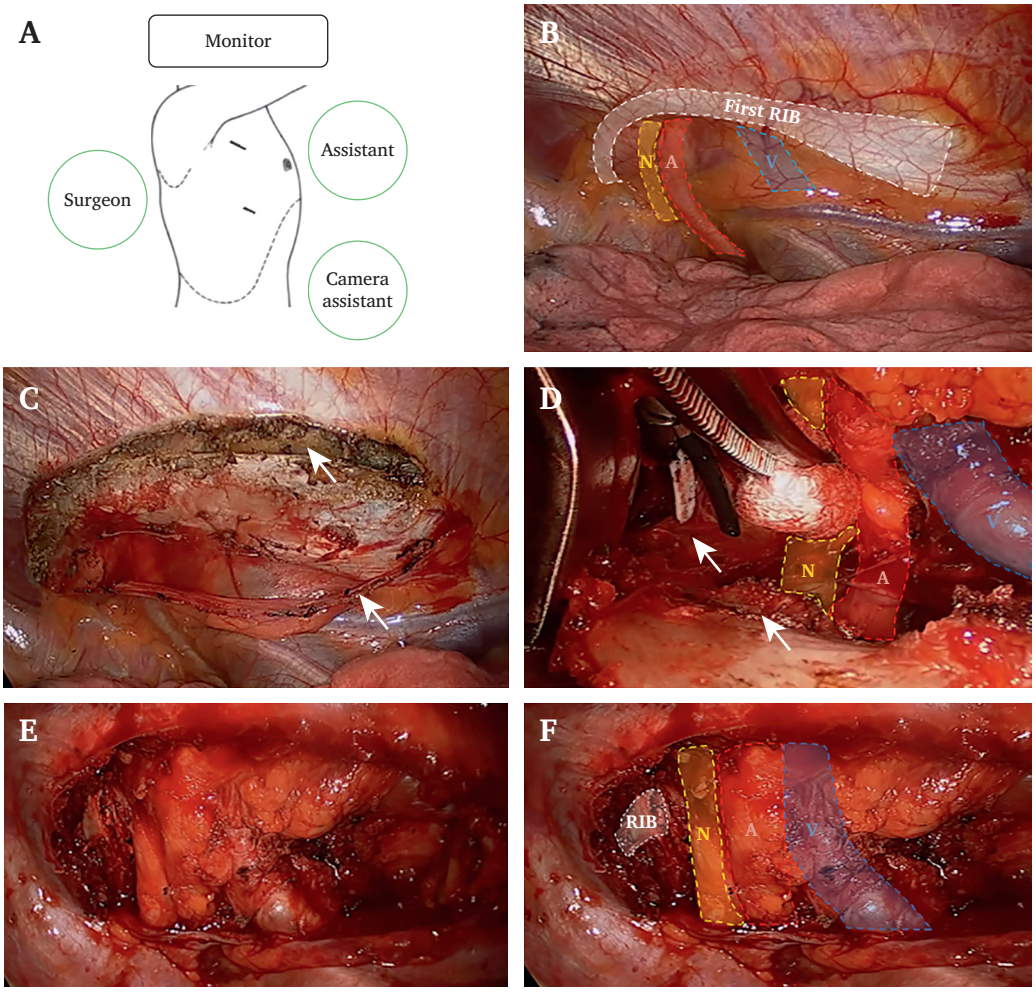

Figure 1. (A) Operating room set up and port location (second intercostal space in the midaxillary line at the bottom of the hair line for instrument port, and seventh or eighth intercostal space for optical port). (B) Right sided thoracoscopic visualisation of thoracic outlet anatomical structures. From right to left: subclavian vein (V), anterior scalene muscle, subclavian artery (A), primary inferior trunk of the brachial plexus (N), and middle scalene muscle. (C) The parietal pleura is opened at the lower margin of the first rib and intercostal muscle is dissected (arrows). (D) Exposure of the external aspect of the first rib and separation of first rib from neurovascular structures by cutting the rib insertion of scalene muscles (arrows) using monopolar cautery and or ultrasonic energy. (E,F) Removal of first rib.

RESULTS

Out of the 29 patients included in the study, 16 (51.7%) were women. The mean age was 29.1 ± 10.4 years. A total of 32 VATS first rib resections were performed: 26 unilateral and three bilateral. Based on diagnostic criteria, TOS cases were classified as venous in 28 patients (three bilateral) and arterial in one patient. The most common symptoms in venous TOS were oedema and pigmentation change in the affected upper limb. In some cases, pain was also reported. The arterial TOS case presented with typical symptoms of acute arterial ischaemia. Twenty seven received OAC therapy from the time of diagnosis to the time of surgery and one patient also underwent a local catheter directed thrombolysis. OACs used were acenocumarol (six), enoxaparin (two), selective inhibitors of thrombin (one), and selective factor Xa inhibitors (17). Local thrombolysis was performed with 1 mg/hour of alteplase (total dose 15 mg) using a multi-perforated catheter that combined infusion pulses with ultrasonic waves (Ekosonic Endovascular System, BTG Interventional Medicine). Three patients presented intermittent compression of the subclavian vein without thrombosis (McCleery syndrome) and, therefore, were not treated with anticoagulants. All patients who received anticoagulants achieved patency of the affected vessel. However, one patient was found to have subclavian vein stenosis following the restoration of vein patency with OACs. The mean time between medical diagnosis or surgery and the examination by the thoracic surgeon/surgery was 471 ± 507 days and 71 ± 56 days, respectively. For bilateral resection patients, the mean time between operations was 2.4 ± 1.2 months.

All patients underwent partial resection of the first rib: from the sternum to the posterior end of the rib insertion of the middle scalene muscle (Fig. 2). The mean operating time was 114 ± 28 minutes. The mean pleural drainage time was 1.1 ± 0.5 days. The mean length of hospital stay was 2.7 ± 1.2 days. There were neither conversions to open surgery nor intra-operative complications. Two major complications

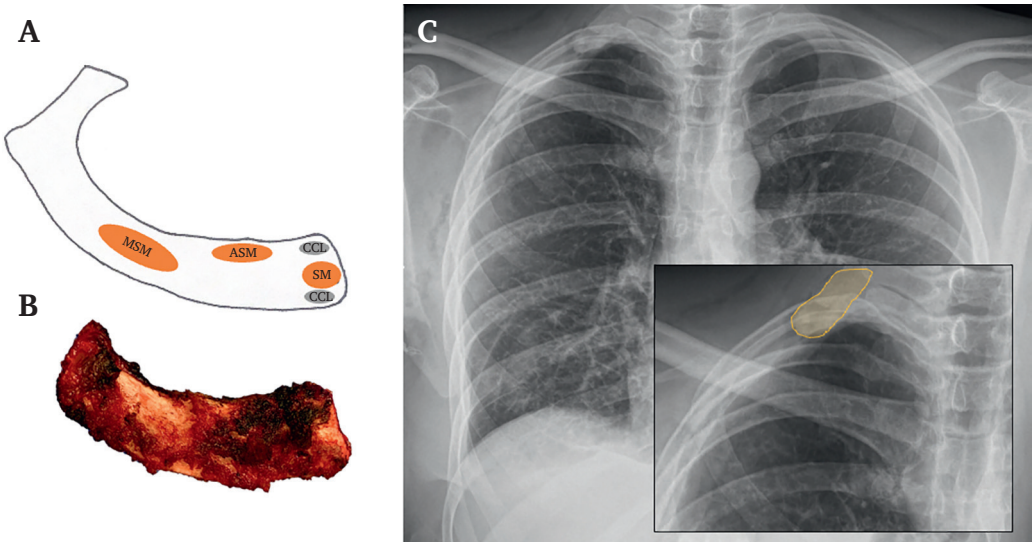

Figure 2. (A) Sketch. First rib with insertions of the anterior and middle scalene muscles (ASM, MSM), costoclavicular ligament (CCL), and subclavius muscle (SM). (B) Partial resection of first right rib: from the sternum to the posterior end of the rib insertion of the middle scalene muscle. (C) Post-operative radiographic view of partial resection of right first rib.

(6.25%) were identified and classified using the Clavien–Dindo classification.[16]

The mean post-operative anticoagulation time was 2.3 ± 2.5 months. The median and mean follow up was 17.9 months (IQR 7.3, 45) and 25 ± 22 months, respectively. All patients reported complete resolution of their symptoms.

Discussion

This study describes the findings of a thoracoscopic approach in the resection of the first rib in patients with vascular TOS. In it, similar surgical outcomes to traditional approaches are described, suggesting certain technical advantages of the former over the latter. While all patients included in the study had vascular origin TOS, it is important to emphasise that the neurogenic type is the most prevalent, accounting for 95% of cases. As TOS is not a common syndrome, diagnosis is often delayed and referral to a specialist usually takes time. Diagnosis tends to be subjective, controversial, and variable, especially in cases of NTOS; consequently, the American Society for Vascular Surgery published the standards for thoracic outlet syndrome in 2016, with the diagnostic criteria for each TOS subtype and standardised terminology, names, and definitions.[15]

NTOS is usually caused by an abnormality at the scalene muscle space, not at the costoclavicular area. Rib resection is not usually performed initially, since most patients can manage their symptoms with a non-surgical treatment based on a multidisciplinary approach including physiatrists, kinesiologists, and global postural re-education experts.[17] Patients who cannot control their symptoms with medical treatment may benefit from surgery. There is controversy regarding the best type of procedure (middle and or anterior scalenectomy and or first rib resection).[18] Considering that scalene muscles are usually involved in the development of TOS, resecting these muscles should be enough. However, advocates of first rib resection argue that removing the rib (base of scalene triangles) would relieve pressure on the inferior trunk and removing the costal insertion of the scalene muscles (anterior and middle) would further decompress structures that pass through both triangles.

At present, there is no standard treatment for venous TOS. The use of anticoagulants alone has a high rate of re-thrombosis as the pathophysiology of thrombosis is due to mechanical endothelial trauma from narrowing of the costoclavicular space (bone compression). If left untreated, these patients would require lifelong anticoagulation, limiting their quality of life. Once surgical decompression is performed, the patient can discontinue anticoagulation and resume normal physical activity. Therefore, the recommendation is to take a combined approach (medical treatment followed by surgical decompression).[19,20] The most successful combination described in the literature is (∼95%) pre-operatory anticoagulants plus catheter directed thrombolytics within 14 days of the onset of symptoms followed by resection of the first rib within six weeks of the onset of symptoms and post-operative coagulation.[19,21–24] In this series, only one patient received thrombolytics plus OACs; the rest of the patients received a combined treatment. The mean interval between medical diagnosis and decompression of the thoracic outlet in this case was significantly longer than the one recommended above (the mean time between medical diagnosis and surgery and examination by thoracic surgeon was 471 ± 507 days and 71 ± 56 days, respectively). However, there were no cases of re-thrombosis. Only one patient was left with a subclavian vein stenosis after achieving vein patency with anticoagulants. This patient, one of the last in the series, underwent surgery at the end of 2023. He is currently asymptomatic, has resumed his normal physical activity that had triggered the thrombosis, and on physical

examination, did not present any asymmetry of the upper limbs. The follow up Doppler ultrasound described venous patency with a larger diameter and good flow. Doppler ultrasound will be repeated to evaluate the need for venous balloon dilation.

As for arterial TOS, it has been shown that the sooner the thoracic outlet is decompressed, the better the results. This is directly related to the damage produced by an anomalous first rib (osteophyte) or a similar anomalous bone structure (cervical first rib or cervical band). After diagnosis of acute ischaemia of the upper limb, management includes thrombectomy (endovascular or open surgery) followed by anticoagulation. Afterwards, imaging (chest magnetic resonance imaging or tomography) is needed to confirm whether vessels are being compressed by an anomalous structure and to assess the extent of arterial damage (aneurysm, ulceration, stenosis, etc.). Finally, decompression is completed by resecting the rib and, if necessary, repairing the artery.[25] The patient with arterial TOS in the series had acute arterial ischaemia and underwent endovascular treatment to restore the patency of the vessel. Later, physicians identified an image compatible with an osteophyte on chest magnetic resonance imaging (Fig. 3).

Surgical decompression of the thoracic outlet consists in removing the first rib. The posterior approach described by Clagett in 1962[26] was not widely accepted because of its technical complexity and, therefore, has not been extensively used. The clavicular (supra and infra) and transaxillary approaches proposed later are the ones currently in use.[4–8] However, these approaches also present limitations related to the visualisation of vessels and nerves during the resection and the amount of rib to be resected.[27] Limited visualisation may result in damage and injury to the structures involved, especially the primary inferior trunk of the brachial plexus. Thoracoscopic access was first described and published in 1999 by Ohtsuka et al.[9] Since 1999, six series of cases treated with this technique have been published showing the feasibility and reproducibility of videothoracoscopic access with similar results to those obtained with open surgery (Table 1).[3,10–14] In the initial series, a total of 10 first rib resections in patients with venous TOS were published.[14]

The complications reported for this procedure, both for open and thoracoscopic surgery, are vascular lesions, nerve injury (brachial plexus, sympathetic chain, phrenic nerve), haemothorax, pneumothorax, and chronic pain, among others. A recently published retrospective study compared thoracoscopic access *vs.* transaxillary access in patients with NTOS; although there were differences in favour of thoracoscopic access, these were not statically significant. These authors analysed and compared post-operative complications (VATS, 3.3%, *vs.* transaxillary 10%) and length of hospital stay (VATS 1.93 $\pm$ 0.64 days *vs.* transaxillary access 2.33 $\pm$ 0.99 days; $p = 0.085$).[13] Even though differences were not statistically significant, the thoracoscopic approach presented fewer complications and a shorter length of hospital stay. Two major complications were found in the initial cases: one patient had to be re-operated on the second post-operative day due to bleeding (haemothorax) and another patient had a chest drain tube re-inserted due to pneumothorax following removal of a drain tube (Grade IIIB and IIIA, respectively). The complication rate was 6.25%. The mean length of hospital stay, pleural drainage, and operating time were similar in the above mentioned series (Table 1). Although intra-operative vascular complications are rare, it would be very difficult to perform vascular reconstruction using a thoracoscopic approach. The literature discusses the use of small bulldog clamps in laparoscopic operations, as well as the use of a percutaneous intravascular balloon through the ipsilateral arm to stop bleeding while accessing the damaged vessel through an alternative approach to facilitate repair.[28]

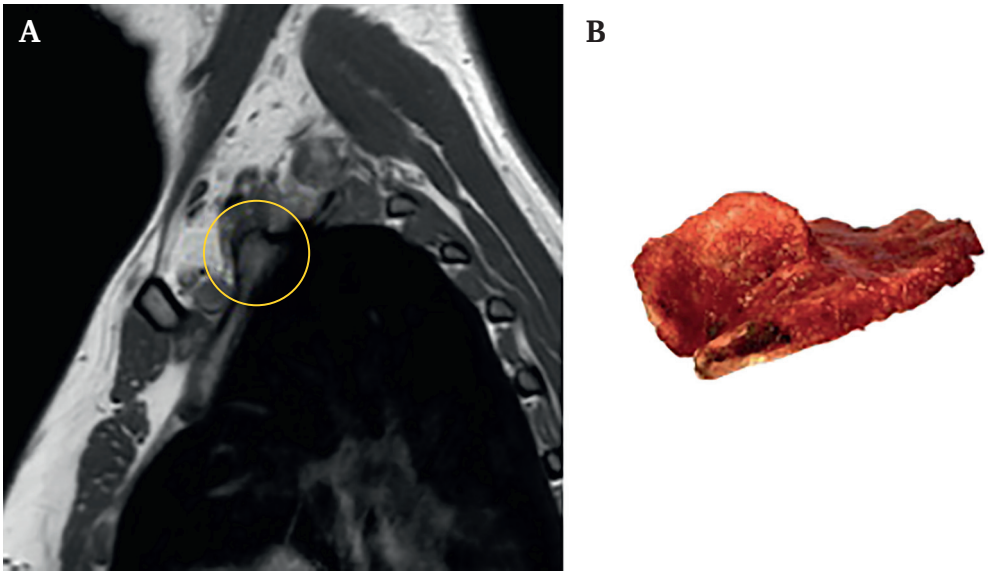

Figure 3. (A) Sagittal view of chest magnetic resonance imaging. Anomalous first rib (osteophyte). (B) Sagittal view of resected first rib. It is possible to see an osteophyte.

In conclusion, VATS first rib resection is a safe and feasible procedure. Based on this experience, it is believed that the main advantages, compared with traditional approaches, reside in the ability to perform resection under complete vision of all thoracic outlet anatomical structures, thus reducing the risk of vascular or nerve injury during surgery. Another significant advantage is the absence of limitations on the amount of rib to be resected, as observed in open techniques such as supraclavicular (posterior rib removal), infraclavicular (anterior rib removal), and transaxillary (anterior rib removal). Since there are no statistically significant differences in recurrence outcomes and complications between the open surgery and VATS approaches, surgeons should choose the approach that suits their expertise until significant superiority of one technique is demonstrated over the other. Further prospective randomised studies are necessary to compare the various approaches and formulate specific recommendations.

CONFLICT OF INTEREST

None.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ejvsvf.2024.06.004.

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