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ORIGINAL SCIENTIFIC REPORT WITH VIDEO

First Rib Resection for Thoracic Outlet Syndrome: The Robotic Approach

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Abstract

Objective First rib resection is a well-recognized treatment option for thoracic outlet syndrome (TOS). In case of a vascular insufficiency that can be provoked and/or progressive neurologic symptoms without response to conservative treatment, surgical decompression of the space between the clavicle and the first rib is indicated. The aim of this paper is to present our experience with a new minimally invasive robotic approach using the da Vinci Surgical System®.

Methods Between January 2015 and October 2017, eight consecutive first rib resections in seven patients were performed at our institution. Four patients presented with neurologic (one bilateral), and three patients with vascular (venous) impairment. In all cases, a transthoracic robotic-assisted approach was used. The first rib was removed using a 3-port robotic approach with an additional 2-cm axillary incision in the first six patients. The latest resection was performed through only three thoracic ports.

Results Median operative time was 108 min, and the median hospital stay was 2 days. Postoperative courses were uneventful in all patients. Clinical follow-up examinations showed relief of symptoms in all nonspecific TOS patients, and duplex ultrasonography confirmed complete vein patency in the remaining patients 3 months after surgery.

Conclusions While there are limitations in conventional transaxillary, subclavicular and supraclavicular approaches in the first rib resection, the robotic method is not only less invasive but also allows better exposure and visualization of the first rib. Furthermore, the technique takes advantage of the benefits of the da Vinci Surgical System® in terms of 3D visualization and improved instrument maneuverability. Our early experience clearly demonstrates these advantages, which are also supported by the very good outcomes.

Objectives

Thoracic outlet syndrome (TOS) encompasses three separate disorders depending on whether the subclavian artery, subclavian vein or the brachial plexus is compressed in the triangular space between the first rib, the clavicle and the scalene muscles. The mainstay of management is nonsurgical in most patients; however, surgery is indicated for patients with persisting symptoms despite conservative management and when vascular structures are involved [1, 2].

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Different types of invasive approaches have been described: The vast majority of surgeons prefer a transaxillary, a supraclavicular or a subclavicular approach. These techniques all share the challenge of good exposure of the entire first rib. While access to the posterior part of the first rib is limited when using a subclavicular approach, the medial end of the rib is hardly accessible through a transaxillary or supraclavicular incision. Therefore, each of the abovementioned approaches carries either the risk of an injury of the neurovascular bundle due to insufficient exposure of the whole rib or incomplete rib resection with the risk of recurrence or even persistence of the patients' symptoms. We herein describe our preferred robotic-assisted approach which not only is less invasive compared to the abovementioned open approaches, but also provides excellent exposure of the entire first rib and therefore allows its safe, simple and complete resection.

Methods

Between January 2015 and October 2017, eight consecutive total first rib resections were performed at our institution in seven patients and informed consent was obtained from all of them. While four patients suffered from nonspecific TOS, one of them on both sides, the other three patients were referred for venous TOS (Paget-von Schroetter, refers to axillary-subclavian vein thrombosis) after unsuccessful lytic therapy. All patients mainly suffered from dysesthesia and pain. Patients with nonspecific TOS described dysesthesia either in the form of formication ($n = 4$), reduced sensitivity ($n = 2$) or numbness ($n = 2$). Sometimes pain symptoms also occurred during the night or while working hard or playing an instrument. One patient suffered from intermittent palsy of the ulnar part of the hand. Patients with venous TOS additionally reported swelling and temperature discrepancy in both upper extremities. Diagnosis was achieved by thorough physical examination with Adson and Wright tests, magnetic resonance imaging (MRI) with provocative positioning of the upper extremities ($n = 3$), neurophysiological evaluation with senso-motoric neurography and needle myography for nonspecific TOS ($n = 2$), as well as duplex ultrasonography ($n = 3$) and angiography ($n = 2$) in case of venous TOS.

Neurophysiological evaluations in patients with nonspecific TOS did not show a clear right–left difference, but together with clinical symptoms we could assume, according to our neurologists, that a relevant involvement of neural structures must be present at the same time ruling out carpal tunnel syndrome. Each patient has undergone conservative treatment in the form of physiotherapy for at least 6 months without improvement in symptoms before surgery was offered.

Patients with venous TOS were referred to our department by vascular surgeons or angiologists with a history of recurrent thrombosis of the subclavian vein ($n = 2$) or proven stenosis in duplex ultrasonography and CT scan ($n = 1$). Both patients, 27 and 40 years old, with recurrent thrombosis received interventional local thrombolysis and anticoagulation, initially. One of them suffered from a germ cell malignancy in the testes with pulmonary metastasis that were laser resected in an open procedure 9 years before. In both cases, the initial therapy failed, which is why they were offered surgery within 2 weeks after attempted thrombolysis. Also in the other patient suffering from vascular stenosis, physiotherapy did not improve symptoms.

Surgical technique

Under general anesthesia, a double-lumen tube was placed and patients were put in a lateral decubitus position. Under single-lung ventilation, a camera trocar (12 mm) was placed in the fifth intercostal space in the mid-axillary line, and after insertion of the 30° angled camera, CO2 insufflation was started at 8 mmHg. Two 8-mm working trocars were then placed in the fourth intercostal space in midclavicular line and behind the tip of the scapula, respectively (Fig. 1). The correspondent intercostal spaces were

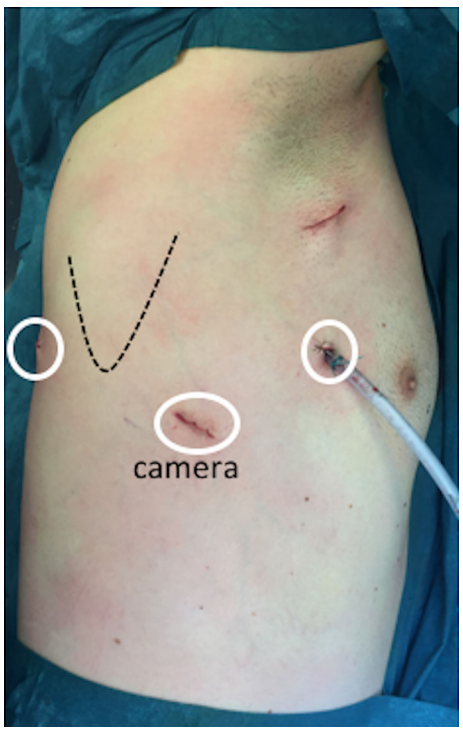

Fig. 1 Port mapping (white circles mark the robotic ports), with indwelling chest tube

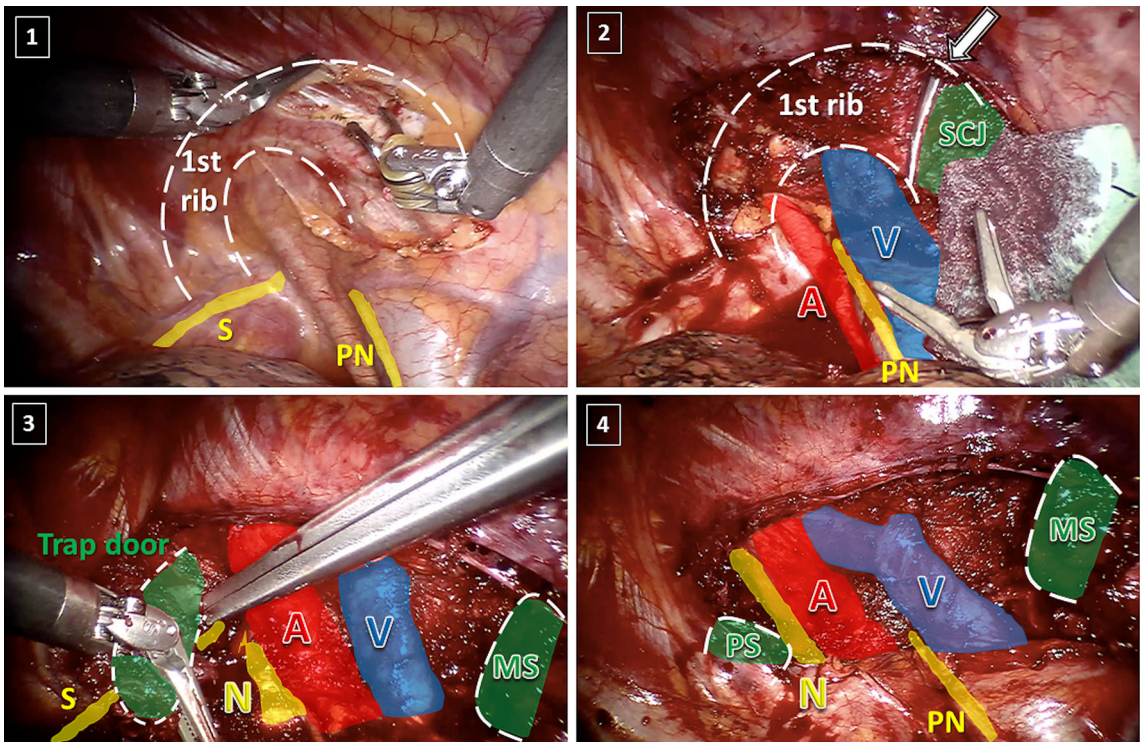

Fig. 2 *1*: Overview with first rib and sternum before resection; *S* sympathetic chain, *PN* phrenic nerve. *2*: Medial border with sternocostal joint (SCJ), cut with mayo scissors (arrow); *A* subclavian artery, *V* subclavian vein. *3*: First rib is almost completely mobilized via trap door mechanism and retracted with da Vinci grasper. The rib is being cut with a Kerrison rongeur at the level of the costovertebral joint; *N* brachial plexus, *MS* medial stump of the first rib. *4*: Situation after the removal of the first rib, *PS* posterior first rib stump

infiltrated posteriorly under visual control with a local anesthetic (ropivacaine).

The patient cart was positioned over the head of the patient, and the dissection of the first rib was started using a Cadière grasper on the left and a bipolar Maryland forceps on the right arm. During dissection, a small additional skin incision of 1–2 cm length was made at the inferior border of the axillary hairline by the assistant at the table. Through this incision, one finger was used for digital blunt dissection, and after complete endoscopic dissection of the medial end of the first rib with the robot, the medial end of the rib was cut through this axillary incision by means of a mayo scissors (Video 1).

By applying gentle digital pressure on the first rib from outside, the created trap door mechanism allows perfect visualization and dissection of the ligaments and scalene muscles, which insert on the first rib. Once the scalene muscles are divided, the neurovascular bundle is completely freed and slightly drops into the thoracic cavity as a sign of complete decompression (Fig. 2). In the posterior part, the rib is then cut by means of a Kerrison rongeur, introduced through the medial robotic trocar, few millimeters lateral to the sympathetic chain. The entire specimen is then retrieved, the lung is re-inflated, and a chest tube is placed.

Results

All procedures have been performed by the same two highly experienced surgeons (GJK and RAS) who developed the technique combining various steps from different minimally invasive approaches and new ideas. We found that for surgeons who are already experienced with the da Vinci Surgical System as well as with conventional video-assisted chest wall resection techniques, the described technique was introduced from 1 day to the next, without any major problems. In all patients, a complete resection of the first rib could be achieved.

The main results are summarized in Table 1. Median operative time was 108 min (range 80–150 min) followed by a median hospital stay until the second postoperative day (range 2–4 days). Postoperative courses were uneventful in all patients. Perioperative highest pain scores ranged from 2 to 4 (median 3) under a standard per oral pain therapy with paracetamol and nonsteroidal anti-inflammatory drugs (NSAIDs). All three patients with venous TOS received their last dose of subcutaneous low molecular weight heparin the night before surgery and 4 h after the procedure heparin was continued with a continuous intravenous administration of 10,000 I.U. heparin/24 h, which was increased to therapeutic levels the day after

Table 1 Main results

Sex	Age	Symptoms	Side	Operative time (min)	Hospital stay (days)	Outcome at 3-month follow-up
F	29	Nonspecific TOS	Right	102	2	Complete relief of symptoms
F	29	Nonspecific TOS	Left	120	4	Complete relief of symptoms
F	41	Nonspecific TOS	Left	88	3	Complete relief of symptoms
M	73	Nonspecific TOS	Right	114	2	Complete relief of symptoms
M	33	Venous TOS	Right	89	2	Complete relief of symptoms (stenting)
M	27	Venous TOS	Right	150	2	Complete relief of symptoms (stenting)
M	40	Venous TOS	Right	117	2	Complete relief of symptoms
F[a]	30[a]	Nonspecific TOS[a]	Right	80[a]	2[a]	Complete relief of symptoms[a]

[a]Patient was operated with a completely portal technique (no axillary incision)

surgery. No significant blood loss was recorded during all the procedures, and no postoperative bleeding complications were observed, and in all patients, the chest tube was removed on the first postoperative day. Follow-up examinations were scheduled 2 weeks and 3 months after the procedure. All patients showed complete relief of their symptoms on routine follow-up 3 months after surgery. In two patients with initial diagnosis of recurrent thrombosis of the subclavian vein, postoperative angiography showed persistent narrowing due to scarring of the vessel in the former thrombotic area, which is why both patients underwent balloon dilation and stenting of the subclavian vein 2 weeks, respectively, 2.5 months postoperatively in order to expand the diameter of the vein. In all three patients with venous TOS final duplex ultrasonography showed complete patency of the subclavian vein 3 months after surgery. Clinical examination alone has been performed in the rest of patients. Total median follow-up was 9 months (range 3–34).

Discussion

The incidence of TOS ranges worldwide from 1 to 10 per 100,000 [3, 4].

Diagnostic tests include clinical observations such as swelling and lividness of upper extremities in case of venous TOS or pulselessness during overhead work in case of arterial TOS. Intermittent symptoms are described as McCleery syndrome.

Nonspecific TOS is much more difficult to diagnose since electromyography (EMG) results and nerve conduction velocity (NCV) times often do not show any pathological values compared to typical neurogenic TOS [5]. Clinical tests such as Adson test, Wright test or Roos stress test can be used, which all can give at least a hint for any relevant form of TOS [6, 7]. Still the main diagnostic tools remain an X-ray of the chest and the cervical spine (exclusion of cervical rib or fractures) and contrasted MRI with and without provocative positioning of the upper extremities to evaluate vascular structures [8].

Until now many different invasive approaches have been described for the surgical therapy of TOS [1, 9, 10]. Each approach has its own limitations, mostly in the form of a lack of exposure during crucial steps of the procedure. The conventional transaxillary approach, which was used at our institution before the year 2015 for nonspecific TOS in 2–3 cases per year, mainly lacks good exposure of the medial as well as the very posterior end of the first rib. Furthermore, due to the limited exposure of the rib only the operating surgeon has a good view and feeling of the extent of resection, which renders the procedure quite difficult to teach. The subclavicular approach on the other hand, which we have used in the past in case of venous TOS in around 1–2 cases per year, only allows limited access to the posterior part of the first rib. The supraclavicular approach may be a good approach for neurogenic TOS, but it only allows limited access to the anterior part of the rib. Thus, these techniques often lead to an incomplete resection of the first rib with unsatisfactory clinical results in the first place or recurrence [1]. The fact that the extent of the resection influences the risk of recurrence has already been reported by Mingoli and colleagues who presented their long-term results after transaxillary first rib resection [11]. The introduction of an endoscopic camera finally allows perfect visualization of the first rib and the neurovascular bundle, which does not only ease the whole procedure, but can also serve as a useful tool for training and teaching purposes [1, 12]. Already in 1998 Martinez et al. [13] started using robotic-assisted instrumentation during endoscopic transaxillary first rib resection for thoracic outlet syndrome. The authors stated that in addition to a better endoscopic view, the use of robotic instruments could provide a more precise handling of the most delicate structures in this area. Invention of Endowrist® instruments and a three-dimensional dual-optic system enables the surgeon to maneuver along structures with an additional degree of freedom which is especially important

when working in such a confined space as the thoracic outlet. To overcome the limitations of a transaxillary approach, in 1999 Ohtsuka et al. and in 2011 Loscertales et al. as well as George et al. in 2017 described the transthoracic approach for the first rib resection with conventional thoracoscopic instruments [14–16]. Although all three authors highlight the excellent visualization during surgery and the shorter hospital stay as the main advantages of a transthoracic minimally invasive approach, the operation was still perceived as challenging due to the lack of angulation dealing with conventional endoscopic instruments. Finally, Gharagozloo et al. presented a robotic transthoracic approach in five patients with venous TOS using a 4-port approach [17].

In order to overcome the abovementioned limitations of limited exposure and maneuverability and based on our many years' experience with the da Vinci Surgical System for anatomic lung resections as well as resection of mediastinal pathologies, we developed the presented robotic-assisted transthoracic 3-port approach using the da Vinci Surgical Si System (Intuitive Surgical, Inc., Sunnyvale, CA, USA) with an additional small axillary utility incision. The transthoracic approach allows perfect visualization of the whole first rib, and in combination with the 3D vision and the improved maneuverability of the robotic platform, this technique allows never seen exposure and handling of all the vital structures in the thoracic outlet. Furthermore, the use of bipolar cautery reduces the risk of irritation of the brachial plexus and/or sympathetic chain/stellate ganglion by inadvertent transmission of electric current. Thanks to the excellent exposure of the complete first rib, it can be easily and safely resected in its whole length from the costovertebral joint to the sternum. The additional small axillary incision adds additional safety to the whole procedure, since the neurovascular bundle can be easily protected during division of the medial rib end. However, as demonstrated in the last patient that we operated on, in case of a clear anatomy and in the absence of dense scar tissue around the neurovascular structures, the whole procedure can also easily be performed without an additional axillary incision through only three robotic ports (Fig. 3).

Fig. 3 Completely portal technique (no axillary incision)

Concerning the need for balloon dilation and stenting in two out of three patients with venous TOS in our series, already Desai et al. described that 13 out of 16 patients (81%) of their patients with venous TOS needed angioplasty after open first rib resection through a combined supra- and infraclavicular approach in order to restore a normal diameter of the scarred and thus narrowed subclavian vein [18]. In our series, we did not only choose a much less invasive approach for the resection of the first rib, but also avoid the need for open angioplasty by taking advantage of interventional techniques of balloon dilation combined with the stenting of the vessel.

The main limitation of our study is the relatively small number of patients and the descriptive nature of the study without a control group. Nevertheless, the procedure was completed in all patients without any intra- or postoperative complications with very good results so far. One possible drawback of this technique that has not been discussed so far is the cost factor. Since we have a robotic unit in our university hospital that is shared between the different disciplines, at least in our institution the use of the robotic console only comes with minor additional costs. Therefore, we must recognize that the proposed approach might only be cost-effective for a surgical team who already has access to a robotic device.

We conclude that the presented minimally invasive robot-assisted approach is safe and effective thanks to excellent exposure and improved instrument maneuverability, resulting in only minimal postoperative pain and excellent outcomes. Since venous scarring is not uncommon in case of venous TOS with recurrent thrombosis, we advocate for a timely postoperative angiographic control (within 2 weeks after surgery) and balloon dilation combined with the stenting of the subclavian vein in these patients, if deemed necessary.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Peek J, Vos CG, Ünlü C, Van De Pavoordt HDWM, Van Den Akker PJ, De Vries J-PPM (2017) Outcome of surgical treatment for thoracic outlet syndrome: systematic review and meta-analysis. Ann Vasc Surg 40:303–326

2. Goss SG, Alcantara SD, Todd GJ, Lantis JC (2015) Non-operative management of paget-schroetter syndrome: a single-center experience. J Invasive Cardiol 27(9):423–428
3. Edwards DP, Mulkern E, Raja AN, Barker P (1999) Trans-axillary first rib excision for thoracic outlet syndrome. J R Coll Surg Edinb 44:362–365
4. Eckstein HH (2013) Compression syndrome of the superior thoracic aperture. Gefässchirurgie 18:175–176
5. Huang JH, Zager EL (2004) Thoracic outlet syndrome. Neurosurgery 55:897–902
6. Sadeghi-Azandaryani M, Bürklein D, Ozimek A, Geiger C, Mendl N, Steckmeier B et al (2009) Thoracic outlet syndrome: do we have clinical tests as predictors for the outcome after surgery? Eur J Med Res 14:443–446
7. Degeorges R, Reynaud C, Becquemin JP (2004) Thoracic outlet syndrome surgery: long-term functional results. Ann Vasc Surg 18:558–565
8. Cornelis F, Zuazo I, Bonnefoy O, Abric B, Borocco A, Strainchamps A et al (2008) Diagnosis of thoracic outlet syndrome. Value of angiography in the sitting position. J Radiol 89:47–52
9. Luoma A, Nelems B (1991) Thoracic outlet syndrome. Thoracic surgery perspective. Neurosurg Clin N Am 2:187–226
10. Glynn RW, Tawfick W, Elsafty Z, Hynes N, Sultan S (2012) Supraclavicular scalenectomy for thoracic outlet syndrome-functional outcomes using the DASH scoring system. Vasc Endovascular Surg 46:157–162
11. Mingoli A, Feldhaus RJ, Farina C, Cavallari N, Sapienza P, di Marzo L et al (1995) Long-term outcome after transaxillary approach for thoracic outlet syndrome. Surgery 118:840–844
12. Chan YC, Gelabert HA (2013) High-definition video-assisted transaxillary first rib resection for thoracic outlet syndrome. J Vasc Surg 57(4):1155–1158
13. Martinez BD, Wiegand CS, Evans P, Gerhardinger A, Mendez J (2005) Computer-assisted instrumentation during endoscopic transaxillary first rib resection for thoracic outlet syndrome: a safe alternate approach. Vascular 13(6):327–335
14. Ohtsuka T, Wolf RK, Dunsker SB (1999) Port access first rib resection. Surg Endosc 13:940–942
15. Loscertales J, Congregado M, Jiménez Merchán R (2011) First rib resection using videothorascopy for the treatment of thoracic outlet syndrome. Arch Bronconeumol 47(4):204–207
16. George RS, Milton R, Chaudhuri N, Kefaloyannis E, Papagiannopoulos K (2017) Totally endoscopic (VATS) first rib resection for thoracic outlet syndrome. Ann Thorac Surg 103(1):241–245
17. Gharagozloo F, Meyer M, Tempesta BJ, Margolis M, Strother ET, Tummala S (2012) Robotic en bloc first-rib resection for Paget–Schroetter disease, a form of thoracic outlet syndrome: technique and initial results. Innovations (Philadelphia, Pa.) 7(1):39–44
18. Desai SS, Toliyat M, Dua A, Charlton-Ouw KM, Hossain M, Estrera AL et al (2014) Outcomes of surgical paraclavicular thoracic outlet decompression. Ann Vasc Surg 28(2):457–464