Robotic-assisted first and supernumerary rib resection: case series

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Background: A constriction between bony and muscular structures in the costoclavicular space may lead to compression of the neurovascular bundle to the upper extremity, resulting in thoracic outlet syndrome (TOS). In very few patients suffering from TOS, an additional cervical or supernumerary rib is present. To overcome constraints associated with conventional techniques we implemented now our previously described robotic approach for resection.

Case Description: Between March 2019 and November 2022, in our series of 67 patients undergoing first rib resection, 6 consecutive patients presented with a cervical rib and a resulting TOS. They have been treated using our 3-port robotic approach, where we used two 8-mm working ports and one 8-mm camera port. According to our experience in first rib resection, we extended the procedure to the additional cervical structures. The total surgery time including vascular replacement in two cases was between 75 and 365 min [median 170.5 min; interquartile range (IQR), 90–232 min] without any major complications. Chest tube was removed on postoperative day 1 in all patients and hospital stay after surgery was a median of 3 days (IQR, 3–8 days). In one case an additional arterial graft and neurolysis were performed according to the patients findings. Beside one incisional hematoma in that particular case, no relevant intra- or postoperative complications were observed and complete or subtotal resolution of symptoms was achieved in all patients.

Conclusions: The robotic technique has proven to be a safe approach even in these demanding cases. The good exposure of the entire field of resection in the thoracic outlet region and the possibility of meticulous dissection prevented both intra- and postoperative complications. Therefore, the robotic technique is also suitable for concomitant resection of the first rib as well as supernumerary cervical rib if needed. It is safe and one of the most minimally invasive approaches to date.

Keywords: Robotic; thoracic outlet syndrome (TOS); first rib resection; cervical rib; case series

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Introduction

When dealing with thoracic outlet syndrome (TOS), very few patients present with a cervical or supernumerary (extra) rib. It is a congenital abnormality occurring in about 0.2–1% of the population (1,2). Despite the fact that most cervical ribs are asymptomatic, patients may suffer from the same symptoms that we usually see in TOS—like venous, arterial or neurogenic features. In some rare cases even life-threatening conditions were described (1).

Cervical ribs usually originate from the seventh cervical vertebrae and can vary in length between <1 cm to those

Table 1 Cervical rib classification according to Gruber W (3)

Cervical rib type	Rib configuration
Type 1	Extension to the transverse process of C7
Type 2	Extension beyond the transverse process but no connection to the first thoracic rib
Type 3	Cervical rib with partial fusion to the first rib by fibrous bands or cartilage
Type 4	Fusion by a bony pseudoarticulation with first rib

that fuse to the first rib (2). Originally, cervical ribs were first described by Gruber in 1869 (3). He described four subtypes with especially the longer two types possibly leading to vascular compromise, including arterial compression and aneurysm formation as well as venous thrombosis (*Table 1*). In our series, all patients showed either type 3 or 4 with or without vascular involvement.

Other authors found 17.4% of supernumerary ribs to cause vascular symptoms and 3.8% to show aneurysms distal to the point of compression by the cervical rib and its attachments or subclavian artery thrombosis and embolization that occurs due to the repetitive pulsatile trauma caused by a cervical rib (4,5).

When it comes to the technique of first rib resections, there are a multitude of different approaches, namely supra-/infra-clavicular, transaxillary, and transthoracic. Every technique has its pros and cons. However, there is no high-quality evidence indicating any difference in success rate among the various surgical approaches. The crucial step when treating patients with TOS is optimal visualization of the neurovascular and musculoskeletal structures at the level of the thoracic outlet as well as the ability to perform complete venolysis, arteriolysis as well as neurolysis, if needed. Thus, improved visualization naturally promotes patient safety and complete surgical decompression (6,7).

Since we prefer a completely thoracoscopic 3-port robotic approach for first rib resection in TOS, the implementation and extension to the cervical rib seemed consistent. Hereby we report a case series of 6 consecutive first and cervical rib resections. We present this case series in accordance with the PROCESS reporting checklist (available at https://jovs.amegroups.org/article/view/10.21037/jovs-23-17/rc).

Highlight box

Key findings

- The robotic technique for cervical rib resection shows good safety and efficacy concerning both neurologic and vascular disorders.

What is known and what is new?

- Transthoracic robotic-assisted resection of the first rib for thoracic outlet syndrome has been adopted by many surgeons in thoracic surgery with good results.
- The approach has now been extended also to supernumerary rib resections.

What is the implication, and what should change now?

- Since robotic surgery is spreading fast throughout the world these days in thoracic surgery, the indication for rib resections at the thoracic outlet has to be taken in account for every well-trained robotic surgeon.

Case presentation

Patients

Between January 2015 and September 2022, we performed 67 robotic first rib resections. Therefrom six patients presented with a cervical rib including all different entities of TOS (neurologic, venous and arterial) and equal symptoms to the usual TOS. Four of them were male and two were female.

All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the Helsinki Declaration (as revised in 2013). Informed consent was obtained from all patients prior to inclusion in the study and the study was approved by our institutional review board (No. TS2022.09). A copy of the written consent is available for review by the editorial office of this journal.

In four patients, TOS could be treated by first and cervical rib resection alone, whereas two patients required a venous or Dacron graft replacement for a subclavian/axillary aneurysm in the same procedure. The female arterial TOS patient had been referred by her family physician with recurrent episodes of pain in the forearm. Contrast enhanced computed tomography scan showed presence of a large aneurysm of the subclavian artery (*Figure 1*). The long cervical rib presented with a complete extension to

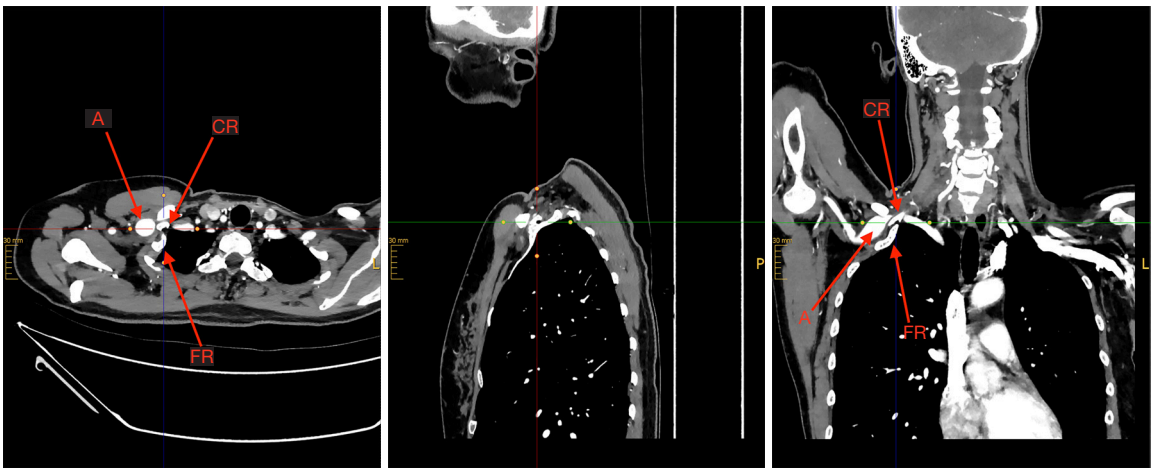

Figure 1 Computed tomography scan with subclavian aneurysm. From left to right: axial, sagittal, coronary views. A, aneurysm; FR, first rib; CR, cervical rib; P, posterior; L, left.

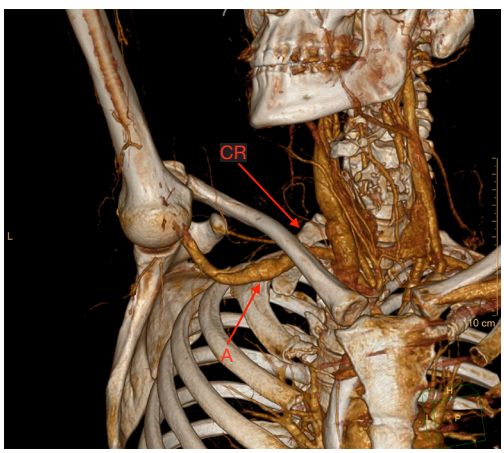

Figure 2 3D-reconstruction with aneurysm and cervical rib. A, aneurysm; CR, cervical rib; 3D, three-dimensional.

the first rib and bony pseudoarticulation (Gruber type 4). Neurologic evaluation showed no signs of peripheral pathology in the upper limb but an acute compression of the brachial plexus by the aneurysm. The duplex sonography showed different thrombotic material in the lumen, partly floating. It was supposed that also a long-lasting Raynaud-like syndrome in the fingers reported by the patient was due to repeated embolic events. Ulnar and radial artery were partly or completely closed, so that an urgent surgical embolectomy has been immediately performed. The male arterial TOS patient was already well known at our vascular surgery department for recurrent thromboembolic events in his forearm, but he refused operative treatment for more than one year. At his last admission to our Vascular Surgery Department, he was first operated twice at the brachial artery for a surgical catheter thrombectomy and venous patch reconstruction, as he presented with acute and critical ischemia of his forearm. For this case we performed a three-dimensional (3D)-reconstruction out of the contrast enhanced computed tomography scan (*Figure 2*). It showed a long cervical rib with partial fusion to the first rib by fibrous bands or cartilage (Gruber type 3).

In venous TOS (vTOS) with acute thrombosis we usually treated patients first with Angio-Jet® thrombectomy before the surgical treatment. If possible, the operative procedure is scheduled 2–4 weeks after the intervention and the patient is put on oral anticoagulants or low-molecular-weight heparins.

Surgical technique

Our robotic trans-thoracic approach using the DaVinci Xi platform (Intuitive Surgical, Sunnyvale, CA) has been previously described (8,9). For the camera we use an 8-mm trocar in the fifth intercostal space midaxillary line and two 8-mm ports in the third intercostal space anterior axillary line and behind the tip of the scapula. Insufflation of carbon dioxide gas facilitates exposure. The first rib is dissected with a bipolar Maryland forceps on the right and a Cadière grasping forceps on the left. After dissection of intercostal muscles, the first rib is cut medially with a long Kerrison rongeur through the posterior 8-mm trocar. In absence of a cervical rib, this creates a trap-door mechanism so that

the rib can be retracted and mobilized downward into the thoracic cavity for optimal visualization and access to all muscles and ligaments inserting there. If the supernumerary rib shows a strong partial or complete fusion with the first rib according to the Gruber subtypes 3 and 4 the bony structures cannot be moved in the same way as we found in all cases. In very slim patients it is possible to dissect the cervical rib directly up close to the transverse process of the seventh vertebra where it is cut also by the Kerrison rongeur. In larger patients the junction between the two ribs has to be cut in advance and both ribs will be dissected separately. The excellent overview allows additional venolysis and neurolysis where applicable.

We cut the posterior part of the rib also with the Kerrison rongeur (inserted through either the medial or posterior robotic trocar, whichever provides better access) lateral to the T1 nerve root only by a few millimeters. At the end, a 20-F chest tube is placed and the lung is reinflated.

For vascular replacement, an open infraclavicular approach was chosen, but thanks to prior rib resection it could be held in a minimalistic fashion through which a resection of the ribs could not have been performed. Accordingly, in one case of neurogenic affection we used an additional small supraclavicular incision for thorough neurolysis of brachial plexus.

Results

In all six patients, a complete resection of the first and cervical rib together was achieved without any intraoperative complications. Surgical time ranged between 75–365 min with a median of 170.5 min (IQR, 90–232 min). This includes also the part of vascular graft replacement in appropriate cases. One minor postoperative complication (subcutaneous hematoma in paraclavicular region) occurred in the female patient with resection of the subclavian aneurysm and neurolysis. We found no brachial plexus palsies (n=0), no phrenic nerve injury (n=0) and no chyle leak (n=0) as reported in other studies (10,11). Median hospital stay was 3 days (IQR, 3–6 days)

In pain management, visual analogue scale showed a median of 3.5 (IQR, 1–4.5) at the first postoperative day while treatment consisted of the following drugs: paracetamol, metamizole and non-steroidal anti-inflammatory drugs.

In vTOS with recent thrombosis, we start treating with oral or subcutaneous anticoagulants on the first postoperative day and continue routinely for 3 months postoperatively, depending on whether impaired venous return or residual thrombus is detected on postoperative venous duplex scan (12,13).

For arterial TOS and graft replacement acetylsalicylic acid was prescribed for at least 6 months postoperatively and for the patient with Dacron graft replacement additional oral anticoagulants have been administered for 3 months due to small vessel embolic occlusions in the preoperative phase.

We usually schedule routine follow-up visitations 3 months, 6 months, and 1 and 2 years postoperatively. All patients presented with a complete (n=4) or partial relief (n=1) where some symptoms reported by the patient already suffering from carpal tunnel syndrome on both hands and a long medical history including surgery. In everyday life, all patients attested a nevertheless substantial improvement of their medical condition. For vascular TOS patients, angiologists regularly controlled the vessels using duplex sonography for vascular patency after 3, 12 and 24 months.

Discussion

We report on our first 6 consecutive combined first and cervical rib resections as case series in two tertiary centers of thoracic surgery. Since we have developed and standardized the 3-port robotic approach for first rib resection in our country, it was a chain of reasoning that also operative treatment for cervical rib resection could be implemented as also described by Wybaillie *et al.* [2018] and Palivela *et al.* [2021] (6,11). The presence of a supernumerary rib that results in TOS is a very rare condition and subsequently only limited evidence can be found in the international literature on this topic (2,14-18). This bony anomaly accounts for about 20% of these patients which is an estimated 40 times higher prevalence than that in the general population with a 76% female rate (19). In some of them, the cervical rib is fused to the second rib lacking a real first rib. It is important to identify these really rare cases are because the anatomy is such that the second rib cannot be accessed easily, or resected via a standard approach (20,21). Such situation is ideal for a transthoracic robotic approach where you benefit most from a great overview with untroubled accessibility to all areas of dissection.

TOS will be encountered most commonly because of extrinsic neurovascular compression from a first rib or other bony abnormality or bands. It will be combined with surrounding hypertrophic muscles, which are the scalene and subclavius. Depending on which structures are compressed, patients present with symptoms of the upper

extremity that can range from pain and paresthesia edema to a pale and pulseless arm (20).

Usually, the rate of neurogenic/mixed, venous and arterial TOS are 90–95%, 3–5%, 1% respectively. In the presence of bony anomalies, the compression of arterial structures rises up to 33% as we could observe in our series. Compression of arterial structures mostly results in forming of an aneurysm. Due to the compromised flow in the vessel, we found embolic complications in two patients preoperatively that required multiple interventions in peripheral arteries in one patient with transcatheter procedures as well as open surgeries. Though, vascular compromise of the very distal upper extremity should always lead to a thorough investigation of the thoracic outlet since the correct treatment can prevent patients from further episodes and chronic functional alterations (5). This might have a higher impact since most of these patients work manually and suffer from inability to work (14).

Where a supernumerary rib is associated with TOS, it should be surgically resected. There are no reports about successful conservative treatment for symptomatic supernumerary ribs. Cervical rib resection was first described by Coote in 1861 (22). For surgical decompression for TOS several reports exist about short- and long-term results. Hereby first rib resection combined with cervical rib resection when present is the recommended treatment of TOS. Even if the combination is controversial, most studies report results of combined first and supernumerary rib resection. Cervical rib resection without the first rib for TOS is rarely studied in the literature.

Nevertheless, the presence of a cervical rib is responsible for specific vascular complications like subclavian aneurysms that require appropriate treatment (23-26). As the main issue with aneurysms in this area is embolic disease with subsequent ischemic complication to the distal part of the limb treatment consists of surgical replacement of the aneurysmatic part of the vessel. Our two arterial TOS cases show good proof of these considerations. Both show good patency of the reconstructions at their 6- and 36-month follow-up. And even the case of an 8-year-old boy with a cervical rib is described in the literature suffering from a subclavian aneurysm (18).

True neurogenic TOS is rare, having a prevalence of around 1 in 1 million patients, but the presence of a supernumerary rib causes a neurogenic TOS in more than 50% of cases with a usually very delayed diagnosis (16). The delay is mainly due to the fact that the largest challenge remains the diagnosis of neurogenic TOS, because standardized diagnostic criteria are lacking. Of course, we find physical tests, electroneurography and radiological imaging as well as the aforementioned criteria for surgery but hardly any consensus on the applicability or threshold value of these examinations can be found in literature. Therefore, future studies should also focus on the diagnostic work-up of TOS (15,23,27).

For vTOS it is widely accepted that these patients will be treated in a quite standardized manner where interventional thrombolysis is thought to be the first step in a multidisciplinary treatment, followed by surgery including first and cervical rib resection when present. If still some narrowing or stenosis of the subclavian vein persists a venous stent placement is recommended. This approach has already been extensively discussed before in our work (12,13,28). After a short course of oral anticoagulants for 3–6 months the patients will remain free of medications or workout restrictions (28).

Surgical approach

Most of the discussion concerning surgical procedures is held about the best technical approach. Since several studies in the last 10 years showed a widespread adoption of robotic surgery for first rib resection, we implemented our large experience in this field for the extension to cervical rib resection (6,8,9,29-33). As a standard we use the completely thoracoscopic 3-port robotic approach with anterior and posterior transection of the rib by means of a Kerrison rongeur.

Advantages of the robotic approach are especially the good visibility of delicate structures and improved surgical morbidity that has been proven in a study by Burt *et al.* [2021] with less postoperative brachial plexus palsies (1% *vs.* 18%), phrenic nerve injury (1% *vs.* 6%), and chyle leak (0% *vs.* 4%). The latter complication occurs very rarely after cervical rib resection with a cervical approach and is reported even bilaterally by Ferris *et al.* [2022] (32,34). Interestingly, it resolved spontaneously by chest drains alone with no sequelae in that case. Some other authors report also Horner's syndrome or subclavian dissection in the list of postoperative complications (9% and 3%, respectively) (14).

Even if the work through the posterior part of the ribs with the Kerrison rongeur in a piece-meal technique is somewhat laborious due to the narrow space, we prefer it to a drilling device since surrounding structures are protected by the smooth surface at the back of the instrument

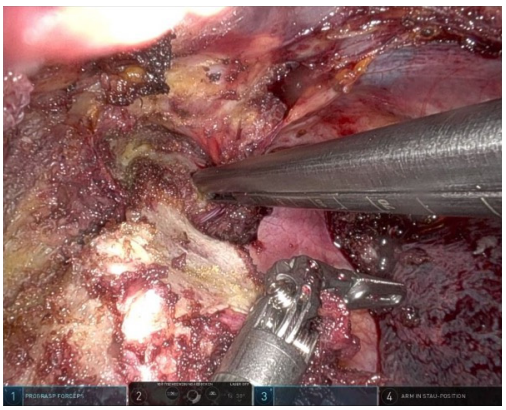

Figure 3 Cervical rib; transection close the costovertebral junction with Kerrison rongeur.

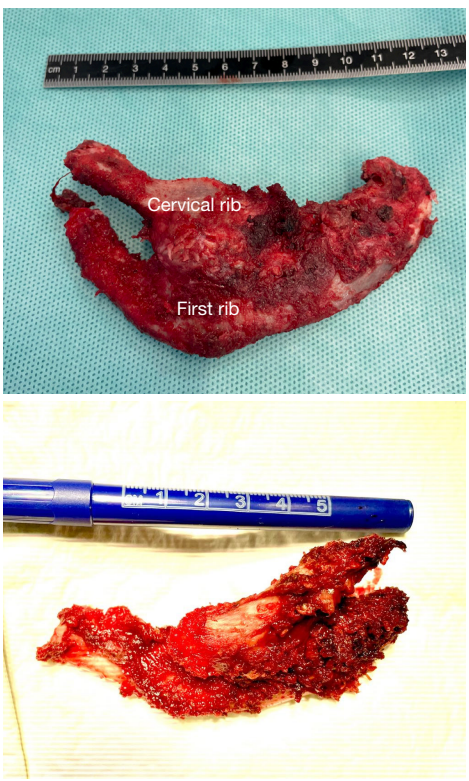

Figure 4 Two different resected specimens including large fusion of first and cervical rib (Gruber type 4). Above: specimen of the right side. Below: specimen of the left side.

(*Figure 3*). Even with a very large area of fusion with the cervical rib it is feasible to remove the specimen in toto thanks to the additional degrees of freedom of the robotic instruments (*Figure 4*).

Though, robotic surgery has the potential to become a standard treatment for all kinds of TOS including supernumerary ribs if an appropriate system is available. The patients benefit from a minimally invasive approach with very precise dissection, resulting in extremely low morbidity.

Conclusions

In times of increasing application of robotic surgery, in all types of surgeries also procedures at the thoracic outlet show very promising results of this most minimally invasive approach so far. In cervical rib resection, the main concern is on the brachial plexus beside other well-known neurovascular structures and the presented technique offers good safety and efficacy.

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Footnote

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