Robotic First Rib Resection for Thoracic Outlet Syndrome

Purpose: First rib resection is a key component of the treatment of Thoracic Outlet Syndrome (TOS). We report our experience with, and technique for, robotic first rib resection.

Methods: Patients diagnosed with TOS underwent robotic first rib resection of the offending portion of the first rib with disarticulation of the costo-sternal joint. Definitive diagnosis of TOS was made by Magnetic Resonance Angiography (MRA) with maneuvers.

Results: A total of 67 patients underwent robotic first rib resection. Neurogenic TOS: 39 patients underwent robotic resection for Neurologic Symptoms of the upper extremity (Neurogenic TOS). There were 14 men and 25 women, with a mean age of 34 ± 9.5 years. Paget-Schroetter Syndrome (PSS) or Venous TOS: 28 patients underwent transthoracic robotic first rib resection for PSS. There were 16 men and 12 women, with a mean age of 24 ± 8.5 years. Operative time was 87.6 ± 10.8 minutes. There were no intraoperative complications. Hospital stay ranged from 2 to 4 days with a median hospitalization of 3 days. There were no neurovascular complications. There was no mortality. In patients with Neurogenic TOS, QuickDASH Scores (mean ± SEM) decreased from 60.3 ± 2.1 preoperatively to 5 ± 2.3 in the immediate postoperative period and to 3.5 ± 1.1 at 6 months (p<0001). Immediate relief of symptoms was seen in 35/39 patients (91%). Persistent paresthesia was seen in 4/39 (9%) immediately postop, and in 2/39 (2.5%) at 6 months. Thirty-seven of 39 (97.5%) patients reported complete relief of symptoms. Among patients with PSS or Venous TOS, 9/28 (32%) required endovascular venoplasty to completely open the subclavian vein after the relief of extrinsic compression. At a median follow-up of 24 months, all patients with PSS had an open subclavian vein, for a patency rate of 100%.
Robotic First Rib Resection for Thoracic Outlet Syndrome
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Conclusions: Robotic transthoracic first rib resection allows for minimally invasive resection of the first rib in patients with TOS, with excellent relief of symptoms and no neurovascular complications.

The actual pathophysiology of the disease, the appropriate diagnostic tests, and the appropriate therapeutic interventions, including some confusion about the pathophysiology of the disease, the appropriate diagnostic tests, and the appropriate therapeutic interventions, has been associated with several controversies,1 including some confusion about the actual pathophysiology of the disease, the appropriate diagnostic tests, and the appropriate therapeutic interventions.

Recently, examination of the medial aspect of the resected first ribs in patients with Paget-Schroetter Syndrome (PSS) (Venous TOS) has demonstrated the presence of a congenitally malformed bony tubercle that forms a tighter and wider joint at the junction of the first rib and the sternum.2-4 The same tubercle has been demonstrated in patients who present with Neurogenic TOS. The present understanding of TOS is that it is the manifestation of a congenital malformation of the first rib (Fig 1). The congenital malformation is in the form of a pronounced tubercle that results in an abnormal costo-clavicular-sternal joint and compression of the subclavian vein at its junction with the innominate vein. The congenital disease is bilateral, with variable symptomatic expression. The compression of the subclavian vein in the thoracic outlet results in a spectrum of disease that ranges from neurologic symptoms resulting from venous ischemia of the upper-extremity nerves (Peet’s Neurogenic TOS) to thrombosis of the subclavian vein with prolonged compression (Paget-Schroetter or Peet’s Venous TOS).

The extrinsic compression of the subclavian vein by the tubercle at the medial aspect of the first rib can be demonstrated on dynamic Magnetic Resonance Angiography (MRA) with maneuvers (Fig 2), which is the definitive diagnostic test for the presence of the abnormal tubercle and the presence of TOS.

Resection of the abnormal first rib with relief of extrinsic compression of the subclavian vein is the treatment of choice in patients with TOS. Surgical approaches to resection of the first rib have included transthoracic, trans-axillary, supraclavicular, infraclavicular, and thoracoscopy.5-11 However, these approaches are associated with neurovascular complications, incomplete decompression of the subclavian vein and the median aspect of the thoracic outlet, and incomplete resection of the most medial portion of the rib. These complications are in large part the result of the extrathoracic surgical approach and difficulties with exposure and access. Theoretically, a minimally invasive transthoracic approach aimed at removing the offending compressive portion of the first rib would allow for complete resection of the offending portion of the first rib and obviate neurovascular symptoms.

Robotic surgical systems have the advantages of 3D high-definition visual-
Patients diagnosed with Neurogenic and Venous TOS (PSS) who underwent robotic transthoracic resection of the offending portion of the first rib were reviewed. The data were accrued prospectively and reviewed retrospectively.

The diagnosis of PSS was made in a small cohort of patients from a larger group of patients who presented with swelling of the upper extremity and a clinical diagnosis of upper-extremity venous obstruction. The diagnosis was established by a clinical history of effort thrombosis, physical exam, ultrasound studies, venography with dynamic images obtained after abduction of the arm, and MRA with maneuvers. All patients were evaluated for underlying coagulation disorders.

The diagnosis of Neurogenic TOS was made in a small cohort of patients from a larger group of patients who presented with pain in the upper extremity and who had negative tests to localize the cause of symptoms using physical exam, radiographs, CT of the chest, MRI of the neck, and nerve conduction studies. Neurogenic TOS was established definitively by MRA with maneuvers.

**Surgical technique**

The operation is performed using a video-assisted thoracoscopic surgery (VATS) platform. The robot is used to dissect the first rib, disarticulate the costo-sternal joint and divide the scalene muscles. General anesthesia with single-lung ventilation is used and patients are placed in the lateral decubitus position with the affected side up (Fig. 3). Three 2 cm, nontrocar, incisions are made. In the right chest, incision #1 is made at the 5th intercostal (IC) space at the midaxillary line. Incision #2 is made in the 4th IC space at the anterior axillary line. Incision #3 is made in the 4th IC space at the posterior axillary line. A 1 cm incision (#4) is made in the 6th intercostal space at the anterior axillary line. For the left chest, incisions are placed in a mirror-image configuration. A retractor (Endopaddle Retract; Auto Suture, Covidien Inc., Mansfield, MA) is introduced through this incision (#4) and used to retract the lung inferiorly. At the end of the procedure, a chest drain is inserted through this incision. The surgical robot (da Vinci, Intuitive Surgical, Inc., Sunnyvale, CA) is positioned over the head of the patient. The camera is placed in incision #1. The right robotic arm with a hook cautery is positioned in incision #2. The left robotic arm with a second hook cautery is positioned in incision #3. The pleura overlying the first rib is dissected. Next, the robotic arms are withdrawn and the rib under the subclavian artery is divided using a 6 mm thoracoscopic Kerrison bone cutter (Depuy Inc., Raynham, MA). This area represents the thinnest portion of the first rib and is most suitable for an osteotomy. Division of the rib at its midpoint allows for the rib to be pivoted on the costo-sternal and costovertebral joints in a trapdoor configuration. The robotic arms are replaced in the same ports and the first rib is dissected and removed (Fig. 4). The scalene muscles that insert onto the first rib are divided.

In patients with PSS, two weeks following rib resection and extrinsic decompression of the subclavian vein, patients underwent venous angiography with appropriate intervention based on the patency of the subclavian vein. If the vein was not fully patent, vein patency was obtained by balloon angioplasty alone or in combination with stenting.
Patients who had a patent subclavian vein on postoperative venogram were anticoagulated with Warfarin for 3 months. Patients who underwent balloon angioplasty were also anticoagulated with Warfarin for 3 months. Patients who required stenting received antiplatelet therapy coupled with Warfarin anticoagulation for 3 months.

Data Analysis

Data points analyzed included indication for operation, patient age and sex, operative time, morbidity, death, upper-extremity exam, and vein patency. Follow-up was performed by physical exam and MRA with maneuvers at 3 months, 6 months, and 1 and 2 years in all patients. In addition, patients who required intervention to obtain vein patency underwent venography at 3 months. At the time of follow-up, the success of first rib resection was assessed by a normal upper extremity and a patent subclavian vein.

This study was reviewed by the institutional review board and determined to be exempt under 45 CFR 46.101 (b)(4).

RESULTS

A total of 67 patients underwent robotic first rib resection. Thirty-nine patients underwent robotic resection of the offending portion of the first rib for neurologic symptoms of the upper extremity (Neurogenic TOS). There were 14 men and 25 women, with a mean age of 34 ± 9.5 years. Twenty-eight patients underwent transthoracic robotic first rib resection for Paget-Schroetter Syndrome (Venous TOS). There were 16 men and 12 women, with a mean age of 24 ± 8.5 years.

Extrinsic compression of the subclavian vein by the medial aspect of the first rib was demonstrated on MRA in 37/39 (95%) of patients with neurologic symptoms. In 2/39 (5%) patients with neurologic symptoms, there was extrinsic compression of the subclavian vein and artery. Extrinsic compression of the subclavian vein by the medial aspect of the first rib was demonstrated on MRA with maneuvers in all patients with PSS.

The first rib was removed en bloc. In all patients, a bony protuberance articulated with the underside of the clavicle just lateral to the sternocostal joint. Operative time was 87.6 ± 10.8 minutes. There were no intraoperative complications. Hospital stay ranged from 2 to 4 days with a median hospitalization of 3 days. There were no neurovascular complications. There was no mortality.

In patients with neurologic symptoms, QuickDASH Scores (mean ± SEM) decreased from 60.3 ± 2.1 preoperatively to 5 ± 2.3 in the immediate postoperative period, and to 3.5 ± 1.1 at 6 months (p<0001). Immediate relief of symptoms was seen in 35/39 patients (91%). Persistent paresthesia was seen in 4/39 (9%) immediately postop and in 2/39 (5%) patients at 6 months. While 2/39 (2.5%) patients reported persistent symptoms of pain in the upper extremity at 6 months, 37/39 (97.5%) reported complete relief of symptoms. On postoperative MRA, there was relief of extrinsic compression of the subclavian vein in all patients.

In patients with PSS, 9/28 patients (32%) required endovascular venoplasty to completely open the subclavian vein after the relief of extrinsic compression. At 3, 6, 12 and 24 months, in all patients, MRA with maneuvers showed relief of extrinsic compression and patency of the subclavian vein. At 2 years after robotic resection of the offending portion of the first rib and obtaining patency of the subclavian vein, all patients remained asymptomatic and had full function of the affected upper extremity.

DISCUSSION

In 1956, Peet attempted to unify a group of diverse patients with symptoms in the shoulder and upper extremity who presented with pain, numbness, tingling, and swelling under the umbrella of Thoracic Outlet Syndrome. Peet’s classification of TOS was based on anatomic, rather than symptomatic, presentation of the disease. In the 6 decades since Peet’s publication, the only consistent aspects of TOS have been the confusion among medical practitioners and the poor results with surgical intervention. Furthermore, if the purpose of unifying the group of patients with neurovascular symptoms of the upper extremity was to improve therapeutic outcomes, based on the published experience, this effort has not been successful. 

Paget-Schroetter Syndrome (PSS), or
“Effort” thrombosis of the subclavian vein, results from compression of the subclavian vein at the thoracic inlet. Historically, it has been hypothesized that extrinsic compression of the subclavian vein is secondary to a more pronounced lateral insertion of the costo-clavicular ligament onto the first rib. Recently, it has been demonstrated that a congenitally malformed tubercle at the medial aspect of the first rib at the costo-sternal junction results in compression of the subclavian vein at the thoracic inlet. Furthermore, it has been shown that, with elevation of the upper extremity above the shoulder, the malformed tubercle on the medial aspect of the first rib results in extrinsic compression and occlusion of the subclavian vein. It has been suggested that, without the benefit of sophisticated modern imaging and relying only on intraoperative observations, it is likely that, historically, surgeons have erroneously referred to this tubercle as the hypertrophied costo-clavicular ligament and the hypertrophied scaleneus anticus tubercule. In patients with PSS, Gharagozloo et al. have demonstrated that disarticulation of the costo-sternal joint and resection of the offending portion of the first rib (portion of the rib medial to the subclavian artery) results in decompression of the subclavian vein. Furthermore, preoperative dynamic MRA has been demonstrated to have a positive predictive value of 100% for surgical success in patients with PSS.

A study of patients with Neurogenic TOSS who had persistent upper-extremity pain following first rib resection by the transaxillary and supraclavicular approaches revealed persistent extrinsic compression of the subclavian innominate joint on dynamic MRA. These patients underwent video-assisted exploration of the chest, which showed a persistent costo-sternal joint despite evidence for prior removal of the first rib. Disarticulation of the costo-sternal joint and removal of the remaining portion of the first rib which bore a tubercle similar to that which was seen in patients with PSS alleviated extrinsic compression of the subclavian-innominate vein junction on postoperative dynamic MRA and resulted in the relief of neurogenic symptoms in all patients. Based on this observation, it was hypothesized that Neurogenic TOSS may be the manifestation of nerve pain which results from venous compression and the resultant venous ischemia of the nerves in the upper extremity. This hypothesis is based on the fact that the upper extremity is fed by a single artery and vein as an “end organ”. In such a setting, studies have demonstrated that the blood-nerve barrier in the nerve root was more easily broken by venous congestion than by arterial ischemia. Venous congestion may be an essential factor precipitating circulatory disturbance in nerve roots and inducing neurogenic intermittent claudication.

Therefore, compression of the subclavian vein at its junction with the innominate vein may result in the elevation of venous pressure, a decrease in arterial flow, and relative ischemia of the nerves of the upper extremity. Venous ischemia of the upper-extremity nerves may manifest as pain, tingling, paresthesia and numbness, and varying degrees of neurogenic intermittent claudication depending on the degree and duration of venous compression. Elevation of the extremity above the shoulder may result in greater compression of the subclavian vein, further venous congestion, further decrease in arterial flow, greater degree of ischemia of the upper extremity nerves, and exacerbation of symptoms. This phenomenon is demonstrated on dynamic magnetic resonance imaging and venography. The pathophysiology of nerve pain in this setting has been likened to symptoms that result from “crossing one leg over the knee”, which is well known and experienced by all humans as paresthesia, numbness, and pain. Despite the commonly held belief that “Crossing Leg” syndrome results from compression of the peroneal nerve, it has been shown that, in fact, it is the result of compression of the popliteal vein by the contralateral knee.

Only 5% of patients with a diagnosis of Neurogenic TOSS are found to have a cervical rib and are best classified as Cervical Rib Syndrome. The remaining 95% of patients with a diagnosis of Neurogenic TOSS are believed to have neurologic manifestations of upper-extremity ischemia and compression of the subclavian vein by an abnormal first rib at the thoracic outlet. Therefore, it was hypothesized that robotic transthoracic resection of the medial aspect of the first rib at the costo-sternal junction in patients with Neurogenic TOSS diagnosed by MRA will result in relief of symptoms.

The present understanding of TOSS is that it is the manifestation of a congenital malformation of the first rib. This congenital malformation is in the form of a pronounced tubercle that results in an abnormal costo-clavicular-sternal joint and compression of the subclavian vein at its junction with the innominate vein. The congenital disease is bilateral with variable symptom expression. The compression of the subclavian vein in the thoracic outlet results in a spectrum of disease, which ranges from neurologic symptoms resulting from venous ischemia of the upper-extremity nerves (Peet’s Neurogenic TOSS) to thrombosis of the subclavian vein with prolonged compression (Paget-Schroetter or Peet’s Venous TOSS).

Resection of the first rib has been performed by a high posterior thoracotomy, the transaxillary approach, the supraclavicular approach, the combined supracavicular and infracavicular approach, and thoracostomy. High posterior thoracotomy was abandoned due to associated morbidity and adoption of the transaxillary approach, which was described in the 1960’s. The transaxillary approach, which was originally described for decompression of the brachial plexus and the subclavian artery, was first reported by Roos in 1966. Proponents of the transaxillary approach have asserted that it is less complicated than the supracavicular or infracavicular approaches, as retraction of the brachial plexus and the vessels is not required. The supracavicular approach is advocated by vascular surgeons. In patients with PSS, some surgeons have advocated the anterior infracavicular approach combined with venoplasty and stent placement. However, the supracavicular approach is hampered by the complexity of dissection around the brachial plexus and the vessels, and incomplete resection of the medial portion of the first rib. In general, extrathoracic approaches to the first rib have been hampered by the potential of neurovascular complications and incomplete resection of the medial portion of the first rib.

Transthoracic thoracoscopic first rib resection was reported by Wolfe and colleagues. This procedure represented a minimally invasive approach to the first rib that could potentially obviate the need for retraction of the neurovascular structures necessitated by extrathoracic approaches. However, although this procedure was based on sound reasoning, it was limited by the shortcomings of conventional endoscopic instruments and two-dimensional visualization.
Robotic surgical systems allow for high-definition magnified three-dimensional visualization of the operative field, are associated with accurate instrument maneuverability in a confined space, and may overcome the potential shortcomings of the conventional thoracoscopic approach.

In the present study, removal of the compressive portion of the first rib (the offending portion) and disarticulation of the costo-sternal joint resulted in the relief of extrinsic compression of the subclavian vein at its junction with the innominate vein. In patients with Neurogenic TOS, subjective symptoms were assessed by the Quick Disabilities of the Arm, Shoulder and Hand Questionnaire Score (QuickDASH). The QuickDASH is an abbreviated version of the original DASH outcome measure. In comparison to the original 30-item DASH outcome measure, the QuickDASH only contains 11 items. It measures an individual’s ability to complete tasks and absorb forces, and the severity of symptoms. The QuickDASH tool uses a 5-point Likert scale from which the patient can select an appropriate number corresponding to his/her severity level/function level. Patients with Neurogenic TOS had a statistically significant decrease in the QuickDASH score following robotic first rib resection. This corresponded to a relief of neurogenic symptoms in 97.5% of patients; the remaining 2.5% of patients did not achieve complete vein patency. These patients were treated with antplatelet therapy in addition to Warfarin for 3 months. Repeat venography at the conclusion of Warfarin therapy revealed a patent subclavian vein in all patients. These patients were followed with MRA and maneuvers for the remainder of the follow-up period and exhibited a patent vein at rest and with arm elevation at 24 months.

Two patients who exhibited venous compromise on the postoperative venogram required balloon angioplasty and stent placement to achieve complete vein patency. These patients were treated with antplatelet therapy in addition to Warfarin for 3 months. Repeat venography at the conclusion of Warfarin therapy revealed a patent subclavian vein in all patients. These patients were followed with MRA and maneuvers for the remainder of the follow-up period and exhibited a patent vein at rest and with arm elevation at a median of 24 months.

The following limitations of this study should be considered before drawing definitive conclusions. The study was limited to a small number of patients. In addition, the study was retrospective and represented a highly selected group of patients.

However, these shortcomings are outweighed by the greater accuracy of robotic dissection, the lower incidence of neurovascular complications, and the excellent long-term patency of the subclavian vein. The results of this study require validation by a randomized prospective study.

The authors declare that they have no competing interests.

REFERENCES