Robotic En Bloc First-Rib Resection for Paget-Schroetter Disease, a Form of Thoracic Outlet Syndrome

Technique and Initial Results

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Objective: First-rib resection is a key component of the treatment of Paget-Schroetter disease. There are many controversies regarding the management of this disease. We report a safe, effective, minimally invasive robotic transthoracic approach for resection of the first rib.
Methods: Over an 8-month period, five patients underwent robotic first-rib resection. Preoperative assessment included physical examination and bilateral venous angiography. On a thoracoscopic platform using three 2-cm incisions and one 1-cm incision, the robot was used to dissect the first rib and divide the scalene muscles. Success of the first-rib resection was assessed by postoperative venous angiography.
Results: There were four men and one woman. Mean age was 34.6 ± 10 years. Mean operative time was 195 ± 24.6 minutes. There were no complications and no mortality. All patients had a patent subclavian vein on the postoperative venogram and were anticoagulated with warfarin for 3 months. At a median follow-up of 12 months, all patients had an open subclavian vein for a patency rate of 100%.
Conclusions: Robotic thoracoscopic first-rib resection represents a feasible minimally invasive approach to en bloc resection of the first rib. This technique minimizes the risk of neurovascular complications that are associated with conventional techniques.

Key Words: Paget-Schroetter disease, Paget-Schroetter syndrome, Robotic thoracoscopic first-rib resection, Thoracic outlet syndrome, Technique.

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Thoracic outlet syndrome encompasses three separate disorders where the subclavian artery, subclavian vein, or the brachial plexus are compressed in the triangular space between the first rib, the clavicle, and the scalene muscles. Paget-Schroetter disease, or "Effort" thrombosis of the subclavian vein, results from compression of the subclavian vein at the thoracic inlet. The extrinsic compression of the subclavian vein is secondary to a congenital anatomic tubercle instead of a groove for the subclavian vein on the first rib.[1]

The diagnosis of Paget-Schroetter disease is made by clinical history, physical examination with dynamic upper extremity maneuvers (Adson and Wright tests), and dynamic venography.

Appropriate management consists of thrombolytic therapy and anticoagulation, followed by resection of the first rib. Surgical approaches to first-rib resection have included transthoracic, transaxillary, supraclavicular, infraclavicular, and thoracoscopic first-rib resection. These approaches are associated with incomplete resection of the most medial portion of the first rib and neurovascular complications. Theoretically, a minimally invasive transthoracic approach would obviate these problems and allow for complete resection of the offending portion of the first rib without neurovascular complications. The robotic surgical systems have the advantages of three-dimensional (3D) high-definition visualization, precise instrument movement in a confined space, and appropriate downscaling to fit the operative field. Through three small 2-cm incisions, the surgical robot can be introduced into the pleural space and be used to resect the first rib while obviating the need to dissect the extrathoracic neurovascular structures. Therefore, robotic minimally invasive first-rib resection can present a new paradigm in the management of patients with Paget-Schroetter disease.

We present our initial experience with robotic transthoracic en bloc first-rib resection for Paget-Schroetter disease. This technique can be applied to other forms of thoracic outlet syndrome.

METHODS

This study is a retrospective review of patients with Paget-Schroetter disease who underwent robotic thoracoscopic first-rib resection at our institution during an 8-month period. The diagnosis of Paget-Schroetter disease was made in a small cohort of patients from a larger group of patients who presented with swelling of the upper extremity and with a clinical diagnosis of venous obstruction. The diagnosis of Paget-Schroetter disease was established by clinical history of effort thrombosis, physical examination with Adson and

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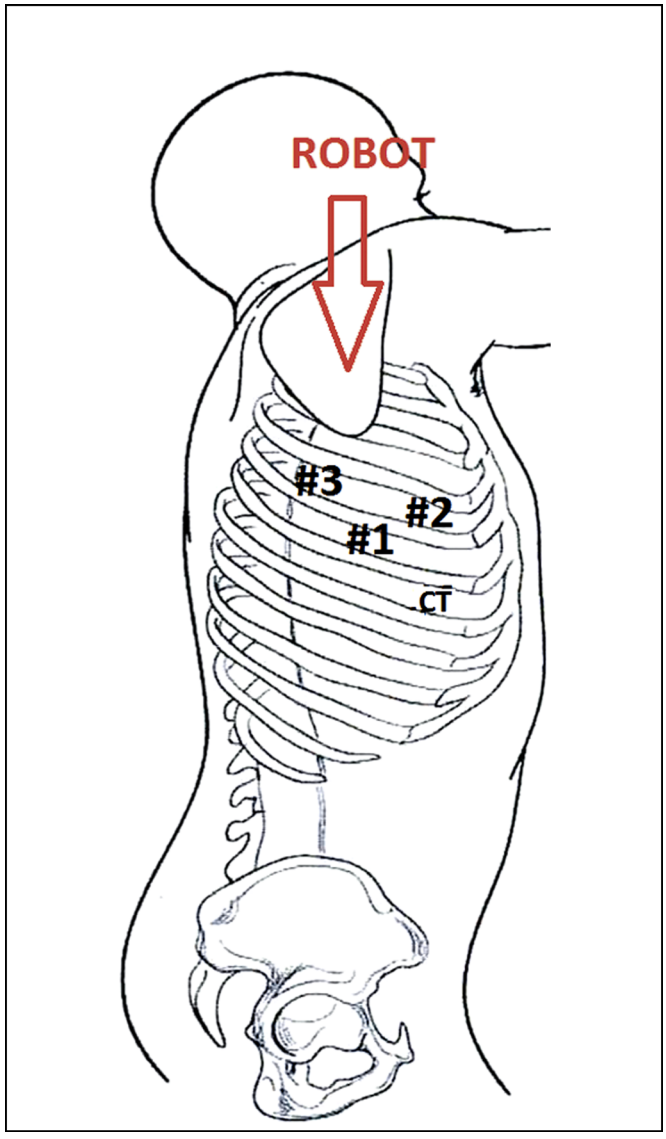

FIGURE 1. Port placement and robot positioning for robotic first-rib resection. Numbers 1, 2, and 3 indicate incisions. CT indicates chest tube placement.

Wright maneuvers, duplex ultrasonography, and venography through a median antecubital vein with dynamic images obtained after abduction of the arm. During the study period, all patients who were diagnosed with Paget-Schroetter disease underwent robotic transthoracic first-rib resection. There were no contraindications to this surgical approach.

Surgical Technique

The operation is performed on a video-assisted thoracoscopic surgery (VATS) platform. The robot is used to dissect the first rib and divide the scalene muscles. The procedure is performed in four phases.

Phase 1: VATS Entry

General anesthesia with single lung ventilation is used, and patients are placed in the lateral decubitus position with the affected side up. Three 2-cm, nontrocar incisions are made. Incision 1 is made in the fifth intercostal (IC) space at the midaxillary line. Incision 2 is made in the fourth IC space at the anterior axillary line. Incision 3 is made in the fourth IC space at the posterior axillary line. In addition, a 1-cm incision (incision 4) is made in the sixth IC space at the anterior axillary line. This incision will be used intraoperatively for placement of a lung retractor (Endopaddle Retract; Auto Suture, Covidien Incorporated, Mansfield, MA USA) and postoperatively for placement of the chest drain (Fig. 1).

Phase 2: Robotic First-Rib Dissection

The surgical robot (da Vinci, Intuitive Surgical, Inc, Sunnyvale, CA USA) 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 an Endograsper is positioned in incision 3. The pleura overlying the first rib is dissected. The superior and inferior borders of the rib are defined. Dissection is carried in a cephalad extrathoracic direction to expose the upper surface of the rib by a few millimeters. The thickness of the rib is assessed and the area between the subclavian vein and artery is isolated. This area represents the thinnest portion of the first rib and is most suitable for an osteotomy (Fig. 2).

Phase 3: Rib Division by VATS

In this phase, the robotic arms are withdrawn and the rib is cut at a point between the subclavian vein and artery using a 6-mm thoracoscopic Kerrison bone cutter (Depuy Inc, Raynham, MA USA). The division of the rib near its midpoint allows for the rib to be pivoted on the costosternal and costovertebral joints in a trap door configuration. Division of the bone results in great mobility of the two pieces of the first rib (Fig. 3).

Phase 4: Robotic Excision of the First Rib

The robotic arms are replaced in the same ports. At this point, a hook cautery is placed in both robotic arms. In an alternating fashion, one hook is used to retract the rib inferiorly, whereas the other hook with cautery attachment is used to dissect the rib and divide the scalene muscles from the upper aspect of the rib (Fig. 4). The portion of the rib that underlies the subclavian artery and vein is removed (the medial two thirds of the rib). The lateral aspect of the rib is left intact (the lateral one third of the rib). This technique takes advantage of the maneuverability of the robotic arms and compensates for the changing 3D geometry of the structures as the rib is being removed. The first rib is dissected with division of the scalene muscles and disarticulation at the joints. The entire specimen is placed in an endobag and removed through incision 2 without the need for enlargement. The lung is inflated, a chest tube and subpleurally tunneled pain catheters are placed, and the incisions are closed.

A video of robotic transthoracic first-rib resection can be found at http://youtu.be/s6Nl63EKUfI.

After recovery from surgery, a dynamic venogram is obtained. A patent subclavian vein on venography is used as the endpoint (Fig. 5).

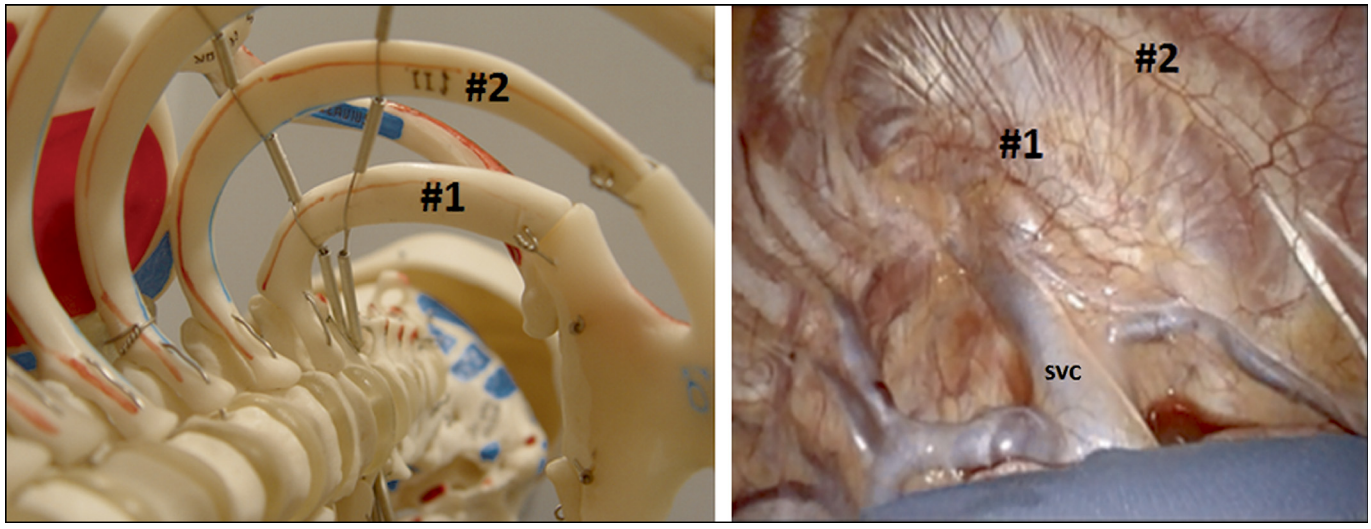

FIGURE 2. Intrathoracic view of the first rib. The left picture depicts an intrathoracic view of the right chest in a replica of an adult human skeleton. The right picture depicts an intrathoracic view of the right chest in a patient. The first rib can be seen at the apex of the chest. 1, first rib; 2, second rib; SVC, superior vena cava.

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

RESULTS

There were five first-rib resections for Paget-Schroetter disease. All patients were on anticoagulation at the time of referral. There were four men and one woman. Mean age was 34.6 ± 10 years. At the time of initial presentation, the subclavian vein was thrombosed on the right side in four patients and the left side in one patient. In five of five (100%) patients, subclavian vein thrombosis occurred with activity involving the upper extremity. All patients originally presented to an emergency department with upper extremity swelling. Initially, the diagnosis of subclavian vein thrombosis was made by ultrasonography, and all patients underwent lytic therapy. In all patients, anticoagulation was instituted based on clinical symptoms and ultrasound findings. A venogram was not obtained before the institution of anticoagulation therapy. All patients were then referred for surgical evaluation. The median time from the institution of anticoagulation to surgical referral was 4 weeks.

On physical examination, all patients had swelling of the affected arm. All extremities demonstrated positive Adson and Wright signs.

All patients were evaluated for underlying coagulation disorders at the time of initial presentation. Coagulation studies were negative in two of five patients (40%). Factor V Leiden deficiency was seen in one of five patients (20%). Mutation in the methylene-tetrahydrofolate reductase gene was diagnosed in two of five patients (40%).

All patients underwent a venogram before surgical intervention. In these patients, the static upper extremity venography showed a partially occluded subclavian vein in five of five (100%) patients. On hyperabduction of the affected extremity, there was occlusion of the vein at the sternocostal junction in five of five (100%) patients. Upper extremity venography of the unaffected side showed a patent subclavian vein in five of five (100%) patients. However, hyperabduction of the unaffected extremity showed partial occlusion of the vein in all patients.

Operative times ranged from 164 to 233 minutes, with a mean of 195 ± 24.6 minutes.

Postoperative hospital stay ranged from 2 to 7 days, with a median hospitalization of 3 days. Prolonged hospitalization occurred in one patient because of prolonged chest tube output.

There were no surgical complications. There were no neurovascular injuries. There was no mortality.

Five of five (100%) patients did not require postoperative venous angioplasty or stenting. In all patients, on postoperative venogram, the subclavian vein was open. These patients received warfarin for 3 months.

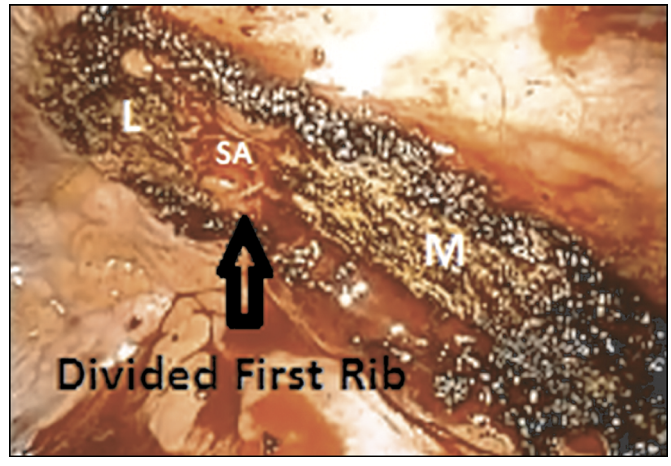

FIGURE 3. Intrathoracic view of a right first rib from the robotic camera. The arrow marks the site of the divided first rib. L, lateral portion of the first rib; M, medial portion of the first rib; SA, subclavian artery.

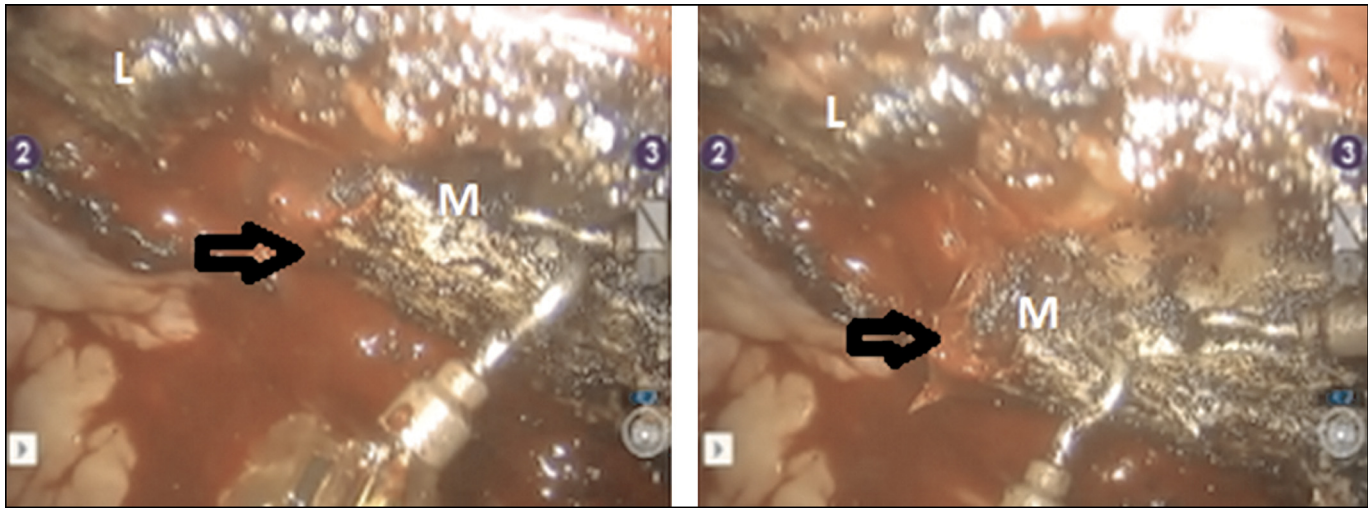

FIGURE 4. Intrathoracic view of a right first rib from the robotic camera. The picture on the left shows the left hook cautery retracting the first rib inferiorly while the right hook cautery dissects the superior/posterior area of the first rib. The picture on the right shows further downward retraction with the hook cautery to aid in dissection of the superior aspect of the first rib. The arrow marks the site of the divided first rib. L, lateral portion of the first rib; M, medial portion of the first rib.

Follow-up was complete in all patients. Follow-up ranged from 7 to 14 months, with a median follow-up of 12 months. At the time of follow-up, the subclavian vein was open in all patients. All patients were asymptomatic and had returned to normal activity.

DISCUSSION

Sir James Paget of London described subclavian vein thrombosis in 1875.[2,3] In 1884, von Schroetter of Vienna theorized that subclavian vein thrombosis was the result of excessive upper extremity activity.[2,4] In 1949, the English surgeon Hughes coined the term *Paget-Schroetter syndrome* for patients with occlusion of the subclavian vein after overuse of the upper extremity.[2,5]

Historically, Paget-Schroetter disease was managed conservatively with anticoagulation and elevation of the affected extremity.[6–8] However, conservative treatment alone results in significant morbidity.[6,7,9,10] The landmark experience reported by Urschel and Patel[6] changed the management of this disease to thrombolytic therapy followed by prompt first-rib resection.

Paget-Schroetter disease is associated with a number of controversies. Controversies include the surgical approach, role of venous stents, bilateral nature of the disease, pathology of the first rib, and the extent of first-rib resection.

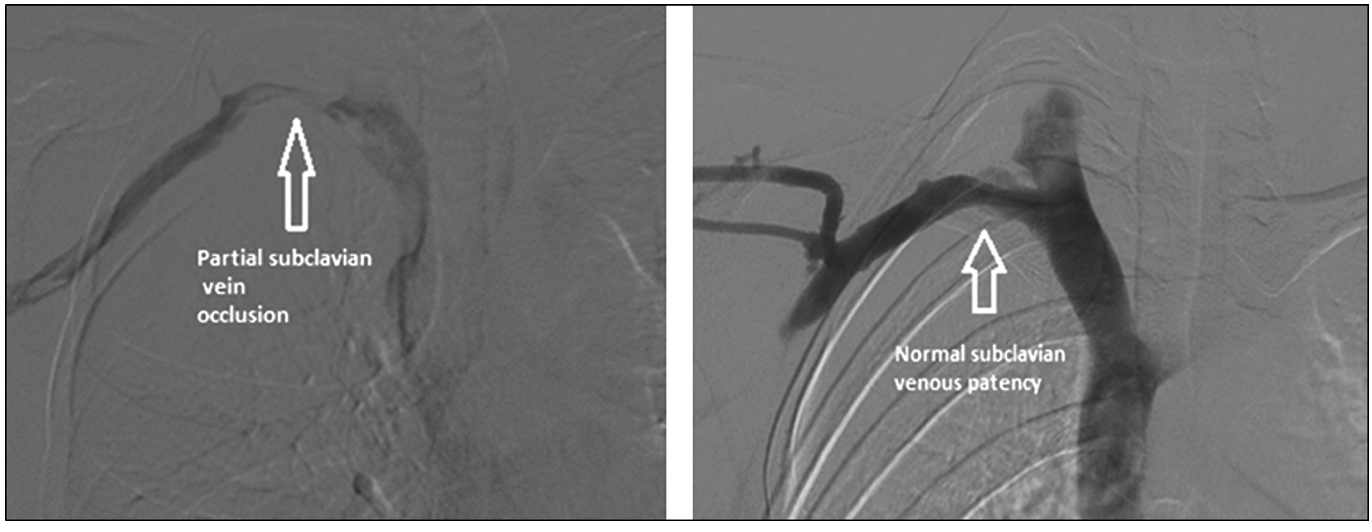

FIGURE 5. Anterior-posterior view of right upper extremity venography with the right upper extremity in the abducted position. The left picture depicts venography before first-rib resection. Partial occlusion of the subclavian vein can be seen. The right picture depicts venography after first-rib resection. There is normal subclavian venous patency with normal flow of contrast into the superior vena cava.

Resection of the first rib has been performed by a high posterior thoracotomy,[11,12] the transaxillary approach, the supraclavicular approach, the combined supraclavicular and infraclavicular approach,[2] and thoracoscopy.[13] High posterior thoracotomy was historically the first approach to the resection of the first rib but was abandoned because of the associated morbidity and the report of the transaxillary approach by Roos[14] in 1966. Originally, the transaxillary approach was advocated for the decompression of the brachial plexus and the subclavian artery. Urschel and Patel[6] has reported the largest experience with the transaxillary approach for patients with Paget-Schroetter disease and asserted that it is less complicated than the supraclavicular or infraclavicular approaches as retraction of the brachial plexus and the vessels is not required. The supraclavicular approach is advocated by other surgeons.[15] However, this approach is hampered by the potentially dangerous dissection around the brachial plexus and the vessels covering the first rib. In addition, the supraclavicular approach has been associated with incomplete resection of the anterior portion of the first rib. Robicsek and Eastman[16] first reported a single-incision combined supraclavicular and infraclavicular approach. Urschel and Patel[17] has reported the combined supraclavicular and infraclavicular approach for arterial reconstruction and advised against the use of this approach for venous decompression. Molina and colleagues[18] have advocated the anterior infraclavicular approach with venoplasty and stent placement, with excellent results. These authors have asserted that the transaxillary approach invariably leaves a significant rib stump anteriorly and fails to adequately resect the costoclavicular ligament and the subclavius tendon. In general, the extrathoracic approaches to the first rib have been hampered by the potential of neurovascular complications and incomplete resection of the medial most portion of the first rib.

Transthoracic thoracoscopic first-rib resection was reported by Ohtsuka and colleagues.[19] This approach represents a novel, minimally invasive approach to the first rib from inside the chest. It had the promise of direct access to the first rib without retraction of the neurovascular structures. However, this approach was hampered by the limited maneuverability of the conventional videoendoscopic instruments and 2D visualization. These shortcomings could result in potentially catastrophic injury to the nerves and vessels on the other side of the rib.

At our institution, first-rib resection has been performed by the transaxillary and supraclavicular approaches. In our experience, these approaches have been hampered by poor exposure of the medial aspect of the first rib and, therefore, incomplete resection of the medial aspect of the rib with risk of nerve injury. We have concluded that the optimal approach to first-rib resection is through the chest. This approach would allow for complete visualization of the first rib from a caudocephalad direction without the need for dissection of the neurovascular structures, which overly the rib. We have felt that the robotic surgical systems would allow such an approach without the need for a thoracotomy. Robotic surgical systems allow for high-definition magnified, 3D visualization of the operative field, are associated with significant instrument maneuverability in a confined space, and may overcome the potential shortcomings of the conventional thoracoscopic approach.

In this series of robotic first-rib resections in patients with Paget-Schroetter disease, we present a minimally invasive transthoracic robotic technique that obviates the risk of brachial plexus injury as well as facilitates en bloc removal of the medial two thirds of the first rib. We believe that only the medial two thirds of the rib should be removed in patients with Paget-Schroetter disease. The lateral one third of the rib does not underlie the subclavian vessels, and removal of this portion is not necessary and can be associated with division of the sympathetic chain. This technique can be applied to first-rib resection in patients with thoracic outlet syndrome resulting from arterial and neurogenic causes.

In this series of patients, the median length of stay was 3 days, and in one patient, there was prolonged chest tube drainage. Our length of stay is slightly longer compared with that of patients who undergo first-rib resection using a transaxillary or supraclavicular approach. This may represent a potential shortcoming of the transthoracic approach. Although the robotic transthoracic approach has the potential advantage of en bloc resection of the offending portion of the first rib and decreased chance for nerve injury, there is a potential for injury to the subclavian artery and vein. In this small series, we have not experienced such a complication. However, with larger experience, we would expect the possibility of a venous or arterial injury. In that setting, the artery and vein can be repaired using robotic suture techniques.

In practice, the approach to the diagnosis and treatment of Paget-Schroetter disease is inconsistent. Paget-Schroetter disease should be entertained in all patients with swelling of the upper extremity and a diagnosis should be confirmed with venography. Preoperative angioplasty and stent placement should be avoided. Stent placement before first-rib resection has been associated with a high failure rate.[2,20]

All patients should undergo a bilateral venogram to confirm the compression of the vein on the affected side as well as the unaffected side. The bilaterality of Paget-Schroetter disease and the presence of similar first-rib pathology in the unaffected contralateral extremity have been hypothesized.[21] In this series, on venography, all of the patients who were diagnosed with Paget-Schroetter disease were found to have subclavian vein compression on abduction of the contralateral extremity. The morbidity associated with Paget-Schroetter disease is significant and includes swelling of the affected extremity, pulmonary emboli, and complications related to thrombolytics and anticoagulation. Therefore, advocating prophylactic first-rib resection of the contralateral side in patients with Paget-Schroetter disease would be a reasonable treatment option. A minimally invasive, low-risk, effective surgical approach such as robotic transthoracic first-rib resection in an otherwise asymptomatic extremity would meet with greater patient acceptance. Since the implementation of robotic transthoracic first-rib resection at our institution for patients with Paget-Schroetter disease, five patients have undergone first-rib resection on the contralateral unaffected side based on the presence of partial or total occlusion on the asymptomatic side during dynamic venography. There are eight other patients with partial or total occlusion of the contralateral subclavian

vein on dynamic venography who are scheduled for robotic first-rib resection. After appropriate follow-up, these patients will be a subject of future study. The criterion for first-rib resection on the contralateral side has been partial or total occlusion of the subclavian vein at the time of dynamic venography.

Although this is a small series, based on the excellent patency rates of the subclavian vein and the low morbidity associated with first-rib resection, we would conclude the following:

1. Paget-Schroetter disease should be entertained in all patients with swelling of the upper extremity, and if suspected, the diagnosis should be confirmed with venography. Preoperative angioplasty with stent placement should be avoided because of a high failure rate.[1,19]
2. Patients should be anticoagulated and referred for first-rib resection as soon as possible.
3. After en bloc first-rib resection, the subclavian vein patency should be assessed by postoperative venography typically 1 to 2 weeks after surgery. Patients with a patent subclavian vein should be anticoagulated with warfarin for 3 months.
4. Contralateral upper extremity venogram should be obtained in all patients, and prophylactic first-rib resection should be entertained if the subclavian vein partially or completely occludes with dynamic maneuvers. Staged, contralateral prophylactic rib resection should be performed 3 months after first-rib resection from the affected side to allow for recovery from the initial operation and minimize chance for recurrence on the contralateral unaffected side.

Greater experience is required to compare this technique with transaxillary and supraclavicular approaches in terms of morbidity, postoperative pain, length of stay, and cost.

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CLINICAL PERSPECTIVE

Of all of the thoracic surgical procedures that we perform, thoracic outlet syndrome procedures leave patients more commonly dissatisfied. Likely, there are numerous reasons: patients or their referring physicians typically wait a particularly long period before seeking definitive therapy, the problem is multifocal and the surgical procedure or procedures chosen may not adequately address the problem, and the surgical approach chosen may be as problematic as the original medical condition. There are 2 basic approaches for the treatment of thoracic outlet: one transaxillary and the other is transcervical. Both approaches are time tested and have their advocates. This article describes an additional approach, one that has been previously described with the video-assisted thoracoscopic surgery technique using robotically assisted technology. In a small group of patients with venous obstruction, the combination of both a robotic and thoracoscopic approach seemed to provide a safe means of relieving vascular obstruction.