Robotic-assisted mediastinal surgery appears to be superior to the open approach and is comparable with videothoracoscopic mediastinal surgery.

Robotic-Assisted Videothoracoscopic Mediastinal Surgery
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Background: Tumors of the mediastinum as well as normal thymus glands in patients with myasthenia gravis have traditionally been resected using large and morbid incisions. However, robotic-assisted mediastinal resections are gaining popularity because of the many advantages that the robot provides. However, few comprehensive reviews of the literature on robotic-assisted mediastinal resections exist.

Methods: A systemic review of the current medical literature was performed, excluding cases related to esophageal pathology. These studies were evaluated and their findings are reported in this comprehensive review. Approximately 48 papers met the inclusion criteria for review.

Results: Robotic-assisted surgical systems are increasingly being used in mediastinal resections. Based on the available literature, robotic-assisted thoracoscopic surgery in the mediastinum is feasible and safe. Robotic-assisted mediastinal surgery appears to be superior to open approaches of the mediastinum and is comparable with videothoracoscopic surgery when patient outcomes are considered.

Conclusions: Increased robotic experience and more studies, including randomized controlled trials, are needed to validate the findings of the current literature.

Introduction
The mediastinum is the region of the thorax that lies between the 2 pleural cavities. Anatomically, the mediastinum can be divided into 3 compartments — the anterosuperior, middle, and posterior — that represent convenient subdivisions because pathology tends to be specific to a particular area of the mediastinum. Masses in the anterosuperior region are generally thymomas, teratomas, substernal thyroid/parathyroid tissue, or lymphomas. Pericardial and bronchogenic cysts are located in the middle mediastinum, and neurogenic tumors or esophageal cysts are generally found in the posterior mediastinum.

The history of mediastinal resections has evolved like much of surgery. Initially, maximum exposure was necessary and was accomplished with various incisions, including median sternotomy, posterolateral thoracotomy, unilateral anterior thoracotomy with partial sternotomy (hemi-clamshell), and bilateral anterior thoracotomy with transverse sternotomy (clamshell). Secondary to the morbidity associated with these procedures, more minimally invasive approaches were developed, including videothoracoscopic surgery and combined approaches, such as subxiphoid videothoracoscopic surgery and transcervical plus subxiphoid videothoracoscopic surgery.

Although videothoracoscopic surgical access to the mediastinum decreases morbidity and hospital length of stay (LOS) when compared with the traditional open approaches, drawbacks still exist.
The mediastinum is a relatively narrow space in the thorax that contains many vital structures at risk of injury during surgery. Therefore, the 2-dimensional view afforded by a videothoracoscopic surgical approach can be less than optimal. Typically, the instruments used during videothoracoscopic surgery do not articulate, and this represents a limitation that can cause difficulty when the surgeon is trying to navigate around vital structures.

As a result of these shortcomings, new technology was developed that employed the use of robotic assistance. The benefits of the robotic system, including a high-definition, 3-dimensional view and articulating endo-wristed instruments, improve on the shortcomings of videothoracoscopic surgery while allowing for small, less-morbid incisions. Furthermore, the robotic-assisted surgical system filters hand tremors from surgeons and scales down movement, which is vital when working in small areas such as the mediastinum.5-4

Despite these advantages, thoracic surgeons are slow to adopt robotic assistance, typically citing the costs associated with robotic-assisted thoracoscopic surgery. Performing robotic-assisted surgery costs more than videothoracoscopic surgery, and most of the cost burden relates to instrumentation.5,6 Furthermore, a paucity of literature exists on robotic-assisted mediastinal resection because it is relatively new technology compared with more established operative approaches.

Thymectomy
Surgical resection of the thymus is performed to diagnose myasthenia gravis (MG) or thymoma. Independently, Blalock et al6 demonstrated in the early twentieth century that symptom improvement among those with MG could be accomplished with thymectomy, causing an increase in this procedure worldwide. The most common approach remained median sternotomy until the 1960s, which is when a series of 59 transcervical thymectomies was performed without significant complications or mortality.7 However, with the results of some studies showing that thymic tissue could reside within the mediastinum or neck outside of the gland, many surgeons felt that maximum exposure techniques were more appropriate to ensure complete resection.8 The debate between transcervical and trans-sternal thymectomies continued until a less invasive approach involving videothoracoscopic surgery was popularized in thoracic surgery.9 Both unilateral and bilateral videothoracoscopic surgical techniques are gaining in popularity based on the benefits of shorter LOS and relatively fewer surgical complications without compromising therapeutic outcomes when compared with trans-sternal thymectomies.2

In an attempt to improve on these benefits, use of a robotic-assisted surgical system was implemented for the first time in the resection of a mediastinal mass in 2001 by Yoshino et al.10 Since then, use of robotic-assisted surgery has been increasing worldwide for thymectomy. Early studies demonstrated that robotic-assisted thymectomy was a safe operation with limited morbidity and mortality.11-13 These early studies identified the advantages and disadvantages of utilizing robotic assistance. Bodner et al11 found that certain complex surgical procedures, such as dissection of the superior horns of the thymus, were technically easier to perform with robotic assistance than with traditional thoracotomy.

Another benefit noted in a separate series is that these operations could be performed with decreased risk of postoperative wound complications.13 This finding is an important observation because patients with MG typically take corticosteroids, and wound complications can be problematic with this patient population when undergoing median sternotomy. Total operative times varied in these early studies, ranging from 96 to 129 minutes, and some studies stated that the time needed to set up the robot was cumbersome.11,12 However, multiple studies have shown that, with increased surgeon and operating room staff experience, both the times to set up the robot and the length of operation decrease.14-16

Cakar et al17 published the first series comparing robotic-assisted thymectomy to median sternotomy, which is the gold standard of treatment. This group demonstrated a significant decrease in complications among those assigned to the robotic-assisted group compared with the median sternotomy group. A decrease in LOS was also established in the robotic-assisted group.17 Balduyck et al18 compared the same groups using quality-of-life assessment questionnaires. When compared with preoperative assessment, the median sternotomy group had a decline in general function and increased levels of fatigue at 1 month following surgery; a similar finding was not evident in the robotic-assisted group.18 However, the robotic-assisted group had increased shoulder pain 3 months after the surgery compared with the pain level at baseline, and this finding was not seen in the median sternotomy group.18

Weksler et al19 stated that robotic-assisted thymectomy was superior to median sternotomy, demonstrating decreased rates of intraoperative blood loss, complications, and LOS in the robotic group. Another series published by Seong et al20 compared the 2 groups and showed a decrease in the number of drains used and amount of drainage at 24 hours, lower rates of hemoglobin loss, shorter duration of chest tubes, and shorter LOS in the robotic group.

Other studies have compared robotic-assisted thymectomy with videothoracoscopic surgery, and, initially, results for robotic-assisted thymectomy were compared with historical videothoracoscopic
surgery controls.\textsuperscript{5} Augustin et al\textsuperscript{5} demonstrated that robotic-assisted thymectomy had similar LOS (2–5 days) and overall shorter operative times than videothoracoscopic surgery thymectomies reported in the literature. They also found that robotic-assisted thymectomies cost up to 91\% more than videothoracoscopic thymectomies performed in their institution, a number they attributed to instrument price (instruments can be reused in up to 10 cases before they must be replaced).\textsuperscript{5,21}

Rückert et al\textsuperscript{22} performed the first single institution comparison of robotic-assisted and videothoracoscopic thymectomies. Between the 2 groups, no differences were seen in rates of mortality, postoperative morbidity, operating time, or conversion rate.\textsuperscript{22} Another study comparing these groups demonstrated decreased LOS and duration of postoperative pleural drainage in the robotic-assisted group; however, no differences were noted in operative time or intraoperative blood loss between the 2 cohorts.\textsuperscript{25}

Because the most common indications for thymectomies are MG and thymomas, surgeons must be assured that robotic-assisted thymectomies can yield the same clinical improvements as other types of thymectomies. Thus, many series have confirmed that robotic-assisted thymectomy is a plausible treatment option for patients with MG.\textsuperscript{24-30} Hartwich et al\textsuperscript{30} showed that robotic-assisted thymectomy can improve symptoms in children with MG. Collectively, 82\% to 92\% of patients had improved symptoms of MG following robotic-assisted thymectomy, and the complete remission rate was as high as 28.5\%.\textsuperscript{29}

Reports have also shown that thymomas can be completely resected and cured using robotic-assisted thymectomy. R0 resections have been accomplished using robotic-assisted surgery for thymomas less than 4 cm.\textsuperscript{14} Furthermore, multiple studies have shown no recurrence of thymoma in study patients followed for up to 14.5 months.\textsuperscript{28,31} A longer study with 36 months of average follow-up time revealed 1 intrathoracic recurrence but no thymoma-related deaths.\textsuperscript{52}

**Ectopic Parathyroid Tissue in the Mediastinum**

Hyperparathyroidism and its manifestations are due to the excess secretion of parathyroid hormone by the parathyroid glands. Typically, the culprit gland or glands are located in the cervical region, but they can be found in ectopic locations 15\% to 20\% of the time, and some of these ectopic glands are found in the mediastinum.\textsuperscript{33} Traditionally, a cervical incision is utilized to remove such glands, but occasionally they are inferiorly or posteriorly located and require more exposure (eg, sternotomy, thoracotomy).

With improved technology, more minimally invasive approaches such as videothoracoscopic surgery are being used. Surgeons have also begun to use robotic-assisted surgery to resect ectopic parathyroid glands located in the mediastinum. To date, published data on robotic-assisted mediastinal parathyroid extirpation are limited to case reports and small case series.\textsuperscript{34-41} Data from these series demonstrate that resection of these mediastinal parathyroid glands is feasible and safe when using the robotic-assisted system. In addition, when navigating around areas such as the aortopulmonary window, use of the robotic-assisted system has been shown to be superior to videothoracoscopic surgery.\textsuperscript{34} Transient weakness of the left recurrent laryngeal nerve is the only postoperative complication recorded in these series, and this complication completely resolved by 8 months.\textsuperscript{35}

One case series of 5 study patients was reported by Ismail et al.\textsuperscript{37} No postoperative complications and no conversions to open or videothoracoscopic surgery were reported. Mean operative time was 58 minutes, and the average LOS was 3 days.\textsuperscript{37} Case patients were followed for 41 months, at which time all 5 patients were free of symptoms and had calcium levels within the normal range, thus demonstrating that robotic-assisted mediastinal parathyroidectomy is effective.\textsuperscript{37}

A larger series of 6 patients who underwent robotic-assisted mediastinal parathyroidectomy was published by Karagkounis et al.\textsuperscript{42} Median operating time was 168 minutes, and nearly all study patients (all except 1) had an effective operation, as evidenced by a decreased level of intraoperative parathyroid hormone of more than 50\% 10 minutes following excision.\textsuperscript{42} The mean pain score was 7.7 out of 10 on postoperative day 1 and 1.5 out of 10 on postoperative day 10, and the average LOS was 2.2 days.\textsuperscript{42} A complication occurred in 1 study patient (pericardial and bilateral pleural effusions requiring drainage).\textsuperscript{42}

**Posterior Mediastinum**

Regarding robotic-assisted resection of tumors residing in the posterior mediastinum, few data have been published. The largest study to date comes from Cerfolio et al.\textsuperscript{43} The researchers reviewed the data of 75 study patients with disease in the posterior or inferior mediastinum, including neurogenic-based tumors, recurrent thymomas, esophageal and bronchogenic cysts, and metastatic lymph nodes.\textsuperscript{43} Median LOS was 1 day and conversion to open surgery secondary to staple malfunction took place in 1 study patient.\textsuperscript{43} The morbidity rate was 12\%, and 1 major complication was noted (delayed esophageal leak following epiphrenic diverticulectomy); no mortalities were reported.\textsuperscript{35} Thus, the researchers determined that the robotic-assisted approach used to resect these tumors is safe and practical.\textsuperscript{43} A learning curve was evident because the median operative time decreased after both the first and second groups of
25 study patients (n = 50). Specific techniques to approach these difficult-to-reach tumors were also noted to aid the surgeon and included driving the camera in from the posterior aspect of the study patient and placing ports anteriorly for better visualization. Furthermore, for tumors larger than 3 cm, the researchers recommended placing the study patient in the lateral decubitus position or tilted forward to allow the lung to fall away from the posterior mediastinum.

Nakamura et al published their Japanese experience with robotic-assisted resection of posterior mediastinal masses. The series included 14 study patients; the most common pathology in the study cohort was neurogenic tumor (57% of the patients). The overall average operative time was 142.6 minutes; the average console time was 68.7 minutes. No conversions or complications were recorded. On average, study patients were discharged on postoperative day 5.

Other smaller studies have demonstrated that operating on tumors in the posterior mediastinum is feasible when using the robotic-assisted approach. Results from 2 studies showed that pathology uncommon to the posterior mediastinum, such as thyroid goiters, can also be resected using robotic-assisted systems. Chon et al noted that robotic-assisted resection of double primary tumors within different areas of the mediastinum (anterior and posterior) is possible with a single-stage operation.

**Other Mediastinal Pathology**

Tumors occurring less frequently within the mediastinum have been resected with robotic assistance. Meehan and Sandler described their experience with robotic-assisted resections of mediastinal lesions in children. Of their 5 study patients, 1 had a teratoma and another had a germ cell tumor that were both resected using the robotic-assisted system. No surgical complications and no conversions to open surgery were reported. Another series by Melfi et al included 9 cases of pleuropericardial cysts and 3 teratoma cases. The results from both of these series demonstrate that even uncommon pathology within the mediastinal borders can be extirpated with good results.

**Conclusions**

Initial operations within the mediastinum began to appear in the medical literature in the early 20th century. Such operations were initially performed via large incisions and had increased rates of morbidity. Throughout the last century, less invasive surgical approaches have been developed to access the mediastinum so as to reduce morbidity. A common minimally invasive approach to the mediastinum is videothoracoscopic surgery, which has advantages when compared with traditional open approaches, including decreased rates of morbidity and postoperative pain levels as well as shorter length of hospital stays. However, its disadvantages include its 2-dimensional image projection and lack of articulating instruments — both of which are detrimental when operating in narrow spaces with vital structures (eg, mediastinum).

The da Vinci Surgical System (Intuitive Surgical, Sunnyvale, California) can be used in many different surgical specialties, including general surgery, urology, and cardiac surgery. Benefits of the robotic-assisted system include improved visualization with a 3-dimensional viewing screen and articulating instruments — both of which are useful when operating in the mediastinum and other narrow spaces. Because of these advantages, the robotic-assisted platform has been gaining popularity, and case series have demonstrated decreased rates of complications, intraoperative blood loss, chest tube duration, and length of stay when compared with the gold standard of median sternotomy for thymectomy. In addition, when compared with videothoracoscopic thymectomy, robotic-assisted thymectomy has similar rates of morbidity and length of stay. Multiple studies have demonstrated that oncological results for tumor resections from the mediastinum with robotic assistance are comparable with those of other surgical approaches.

In addition, among study patients with myasthenia gravis undergoing thymectomy, those undergoing robotic-assisted thymectomy have similar rates of symptom improvement and cure compared with those undergoing other surgical modalities.

Despite these positive results for robotic-assisted surgery in the mediastinum, thymectomy is still the most published operation of all robotic-assisted mediastinal resections; as of 2012, approximately 3,500 cases have been registered with Intuitive Surgical. In addition, median sternotomy is considered the gold standard approach for thymus gland removal — a fact that could be due to the perceived increased cost associated with robotic surgery. However, some data suggest that robotic-assisted surgery costs less than videothoracoscopic surgery because of reduced length of hospital stays and the overall nursing care required.

Furthermore, some surgeons may not feel comfortable with the relatively new robotic-assisted technology because they may not have been formally trained to use the platform. The paucity of published literature on robotic-assisted mediastinal resections may also deter surgeons from using this approach. Despite the positive results previously published on the subject, in our opinion, a randomized controlled trial comparing robotic-assisted mediastinal resections with other approaches is still warranted to elucidate all of the benefits of robotic-assisted videothoracoscopic mediastinal surgery.