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ROBOTIC SURGERY (E BERBER, SECTION EDITOR)

Robotic Thymectomy: An Update

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Abstract
Purpose of Review In the last two decades, minimally invasive approaches for thoracic surgery have become widely adopted. Open thymectomy was previously considered the gold standard; however, minimally invasive techniques including robotic approaches are becoming routine for a variety of pathologies. We review the robotic techniques and approaches to thymectomy currently being performed as well as novel approaches in development.
Recent Findings Robot-assisted thoracoscopic surgery (RATS) has been developed to increase the accessibility of minimally invasive surgery. Better flexibility and transmission and the surgeon's convenient maneuverability in the thoracic cavity are some of the advantages, effectively combining the benefits of minimally invasive techniques with the effectiveness of an open procedure.
Summary Robotic approaches to thymectomy are feasible and safe operations for a variety of benign and malignant pathologies. There is reduced blood loss, chest tube duration, and hospital length of stay without significant differences in perioperative complications, thymoma recurrence, and 5-year survival. Advances continue to be made in the field with the development of newer platforms including single-site and single-port systems, which continue to be increasingly adopted by thoracic surgeons.

Keywords Robotic surgery · Thymectomy · Minimally invasive surgery · Mediastinal surgery · Robotic thoracic surgery · Thymic disease

Introduction

Thymus resections are indicated for both benign and malignant disorders. Historically, the only way to access the anterior mediastinum including the thymus was via an open approach with either a median sternotomy or thoracotomy. These methods allowed for excellent exposure of the entire thymus from the phrenic nerve laterally on one side to the phrenic nerve on the contralateral side, to ensure complete resection. Over time and with advances in technology and surgical technique, surgeons began using video-assisted thoracoscopic surgery (VATS) to access the thymus [1, 2]. This new approach allowed for shorter intensive care stays, decreased overall pain, and similar disease-specific outcomes [3, 4]. VATS allowed for a minimally invasive approach to thymectomies; however, this approach had its own limitations, including poor ergonomics and maneuverability in the tight mediastinum [5]. Once Loulmet and Reichenspurner first described using a surgical robotic platform in the chest to perform a coronary bypass (CABG), the beginning of robotic chest surgery had arrived [6, 7].

Compared with VATS, robotic surgery provides 3-dimensional (3D) visualization and free articulation of the tips of the robotic arms. This offers significant advantages when operating in narrow spaces such as the mediastinum. In 2001, the first robotic thymectomy was performed for a small thymoma. Shortly after that in 2003, the first robotic thymectomy series was described for myasthenia gravis (MG). Originally, the procedure was performed via a

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unilateral approach; however, this series described a bilateral robotic approach to thymectomy [8]. Once the safety and efficacy of this procedure were established, the technique continued to evolve. The existing approach was refined and new approaches were tested, including use of single-site and single-port platforms. Our article reviews the advances in robotic thymectomy over the last decade, focusing on outcomes and reviewing the techniques employed.

Surgical Anatomy of the Thymus

The thymus is a bilobed organ located in the anterosuperior mediastinum and is encased in a fibrous capsule. The thymus has close relations to several important structures in the chest. Superiorly the thymus is often connected via the thyrothymic ligament to the thyroid gland, while inferiorly, the lobes of the thymus directly overlay the pericardium. Anteriorly, the thymus is bordered by the sternum and is deep and inferior to the sternothyroid and sternohyoid muscles moving superiorly, while posteriorly lie the brachiocephalic vein, aorta, and its branches and the pericardium. Laterally, the thymus is bordered by the pleura on each side as well as each phrenic nerve [9].

The thymus receives its arterial supply from numerous structures surrounding it and can be highly variable. This may include direct branches off of the aorta, branches from the inferior thyroid artery, internal mammary artery, and/or phrenic arteries. Unlike other organs, the venous drainage of the thymus does not follow the arterial supply. The thymus drains into a venous plexus that drains blood from the posterior thymic veins, ultimately draining into the brachiocephalic vein or it may drain from the superior thymic veins, ultimately draining into the inferior thyroid vein, although this too is highly variable [9]. Similarly, the anterior and posterior lymphatic ducts follow the perilobular veins and drain into lymph node basins which ultimately drain into the ipsilateral internal jugular and subclavian veins. The superior lymphatic ducts drain into lymph node basins around the internal jugular and innominate veins.

The thymus is functionally an important organ, with a key role in immunogenicity, tolerance, development of T-lymphocytes, and has been implicated in several autoimmune conditions [10].

Indications and Patient Selection

Robotic thymectomy can be employed for a variety of thymic pathologies, including benign and malignant pathologies. It can be used effectively in conditions requiring a total thymectomy including MG and thymic epithelial tumors [11]. Previously, contraindications to minimally invasive thymectomy included great vessel and/or pericardial invasion, severe pleural or pericardial adhesions, and tumors larger than 5 cm [12]. However, several surgeons and institutions have performed robotic interventions on larger tumors up to 8 cm [13], and others have shown that even larger tumors can be safely resected without compromising oncologic outcomes [14•]. Complex vascular and pericardial reconstructions can also now be performed robotically during these thymectomies [15] but should only be attempted by the most experienced surgeons. The pursuit of minimally invasive surgery should not compromise oncologist principles or place the patient at undue risk. Patient selection must be based on a case-by-case basis, with robotic surgery being offered to more patients as technology advances and surgeons become more comfortable and facile with the robotic system.

Techniques

Several techniques have been described for minimally invasive thymectomy, with lateral transthoracic approaches currently being the most commonly employed approach. Other approaches that have been described are transcervical and subxiphoid approaches, with various modifications to each of these techniques. The choice of technique employed is largely dependent on clinician preference and patient/tumor characteristics. The size of the lesion, pathology of the thymus, and the need for extended versus partial thymectomy influence the surgical approach as each of these techniques offers different visualization and thus ease of the procedure. No studies have formally compared the outcomes among these established robotic approaches to thymectomy.

Thymectomies require general anesthesia, typically with a double lumen endotracheal tube (ETT). Double lumen ETT facilitates access to both pleural spaces and allows for excellent visualization of the anterior mediastinum by way of optimal lung isolation. An alternate is to use a bronchial blocker; however, this typically has inferior lung isolation (especially on the right side due to the earlier take off of the upper lobe bronchus). The patient is positioned supine on the operating room table, usually with a slight lateral bump. The thymectomy itself involves dissection of the gland from the phrenic nerve on one side to the contralateral side, taking care to identify and preserve each phrenic nerve and its vascular supply. The thymus is dissected off the pericardial sac posteriorly and away from the diaphragm inferiorly, while the superior aspect of the thymus requires meticulous dissection off the innominate vein, mobilizing the right and left cervical horns of the thymus, while

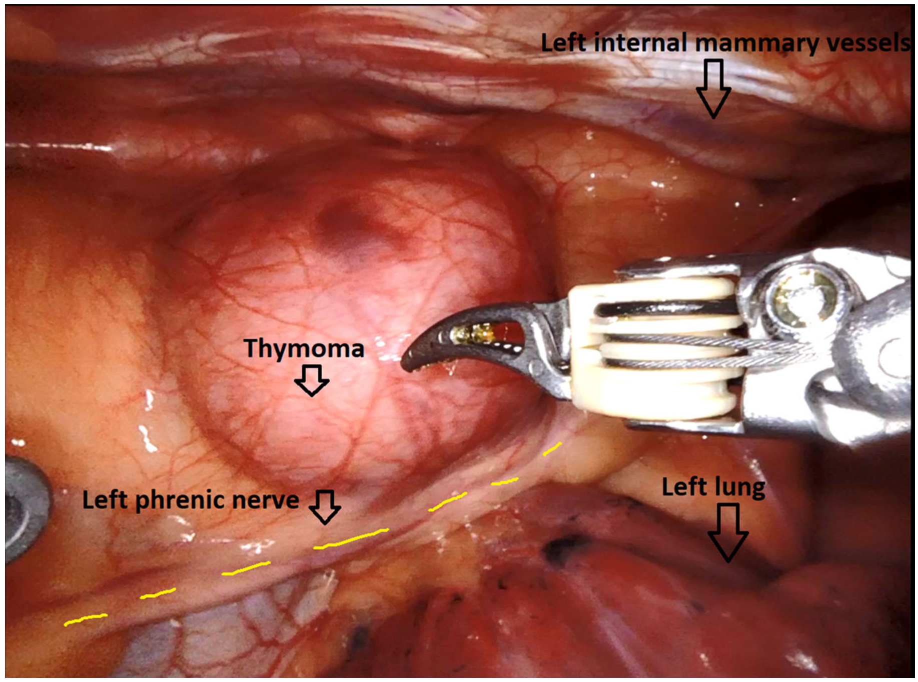

Fig. 1 View from the left chest showing the anterior mediastinum. A left-sided thymic mass is seen, along with the left phrenic nerve running inferiorly (yellow dashed lines). A Maryland bipolar forceps is used to start the dissection along the phrenic nerve in a cephalad dissection. *Original figure*

ligating the tributaries feeding this gland [16]. While the principles of thymectomy itself are similar, each robotic approach has its own benefits and technical limitations.

Lateral Transthoracic

Transthoracic thymectomy is currently the most widely employed technique when robotic thymectomies are performed. This may be performed via a right-sided, left-sided, or bilateral approach, typically with the side of the patient that is accessed slightly elevated with a bump. Single lung ventilation strategies are employed via a double lumen ETT. This technique is typically performed with the use of three robotic arms. Incisions are usually placed in the fourth or fifth intercostal space in the anterior/midaxillary line for the camera and the other two working robotic ports placed superiorly high in the second intercostal space and inferio-anteriorly in the fifth to seventh intercostal space. All ports are placed at least 8 cm apart and care is taken to avoid the breast tissue. An additional access port can be placed inferiorly if needed [17]. Placing the superior port more anterior and using a longer trocar improve mobility of the robotic arm by increasing clearance from the patient shoulder [18]. Others have described the routine use of four robotic arms in complex cases involving thymic malignancies for additional flexibility in dissection [13], especially when complex robotic reconstruction of the diaphragm or pericardial defects is considered. The choice of approach is clinician driven, with some routinely performing left-sided approaches, while others prefer right-sided approaches [18]. The bilateral approach is usually preferred for patients with MG to allow complete removal of all thymic tissue [11].

Carbon dioxide (CO_2) insufflation is standard during these approaches allowing for improved retrosternal visualization. Our preference for a bilateral approach is to start on the left side and the complete the resection from the right side. If there is a question of a possible conversion to open due to pathological considerations, then it may be prudent to start at the side of concern. Dissection of the thymus is typically started anteriorly near the diaphragm and carried superiorly toward the cervical horns of the thymus. Dissection is usually performed using Maryland bipolar forceps, monopolar scissors, monopolar spatula, and/or the vessel sealer. During a single-sided thoracic approach, the contralateral phrenic nerve can usually be visualized; however, if this is not possible, an additional port can be placed in the contralateral chest to facilitate adequate visualization to ensure the phrenic is not injured. Injury to the innominate vein is a feared complication, but can be repaired robotically if encountered; however, if visualization is poor, the robot may be undocked followed by a sternotomy for better and safer access. Additionally, we prefer to perform a small pericardial window creation if the pericardium was not resected during this procedure, as we have, on occasion, seen delayed pericardial effusion from pericarditis (Figs. 1, 2, 3, 4, 5, 6, 7).

Subxiphoid

Trans-subxiphoid robotic thymectomy (TSRT) is another established technique that has been performed both for

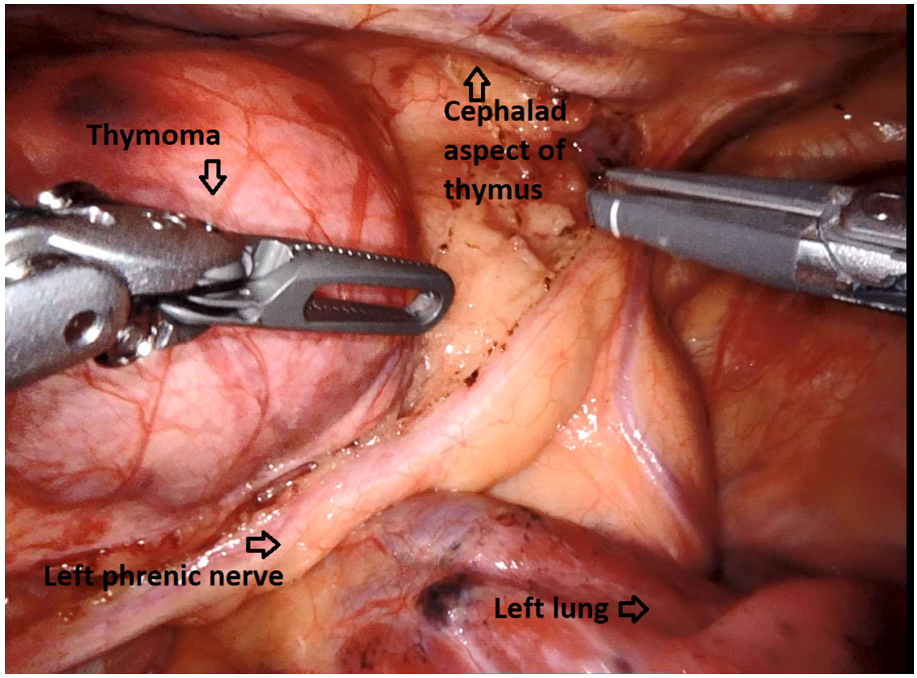

Fig. 2 Dissection is carried along the left phrenic nerve in a cephalad direction, dissecting the thymic and mediastinal tissue off the nerve and separating the superior aspect of the thymus from its surrounding attachments including retrosternal attachments. *Original figure*

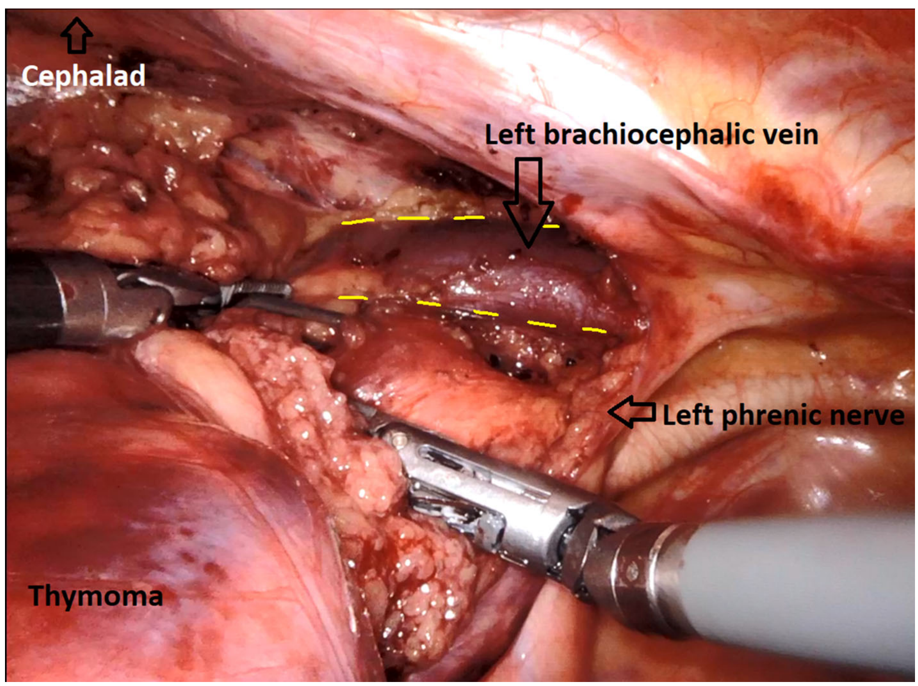

Fig. 3 Left brachiocephalic vein is seen at the superior aspect of the thymus. Great care is taken during this dissection to avoid injury to this structure, using meticulous dissection with a vessel sealer. *Original figure*

thymic tumors as well as for MG. This approach offers the advantage of better visualization of the contralateral thymus, including the cervical area, as well as the contralateral phrenic nerve in a view that is similar to a median sternotomy [19]. Additionally, if a thymic mass encroaches on the superior aspect of the thymus, a lateral transthoracic approach may not adequately visualize structures such as the brachiocephalic vein beyond the mass [20•]. The robotic camera is introduced in the subxiphoid location, while the other robotic arms are introduced into each bilateral pleural space via the fifth or sixth intercostal space in the anterior axillary line. Introduction of the port may be performed by initially entering the left pleural space and dissecting the retrosternal fat to facilitate subxiphoid port placement [21] or starting subxiphoid and then placing the subsequent pleural ports under direct visualization [20•].

A variation of this approach is the single-site subxiphoid thymectomy [22, 23], a technique that utilizes only a

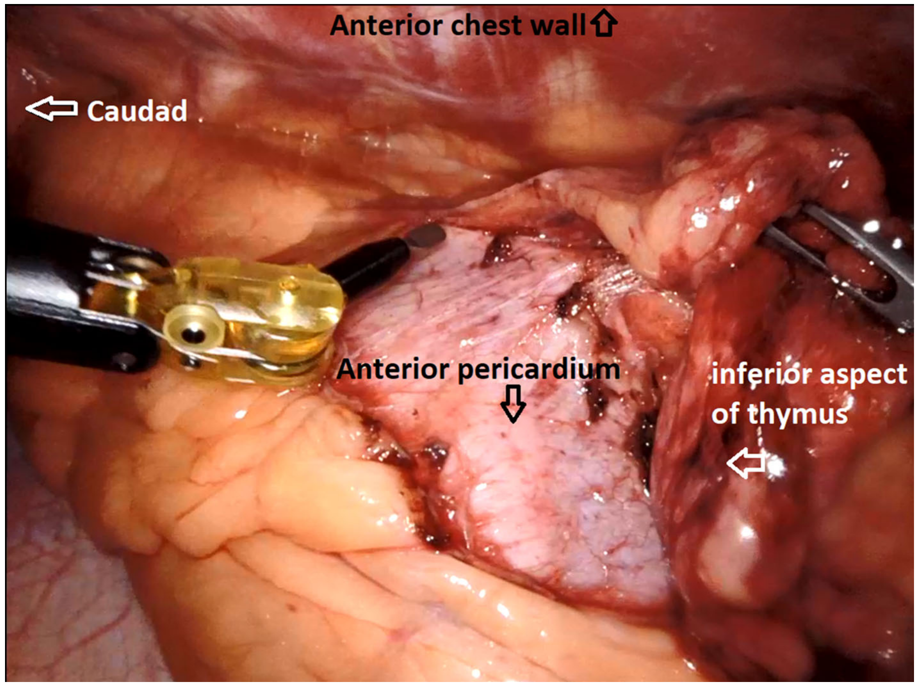

Fig. 4 Dissection of the left inferior horn of the thymus is performed by separating the thymus from the anterior aspect of the pericardium in the relatively avascular plane. The pericardium may be removed en bloc if concern exists for pericardial involvement. *Original figure*

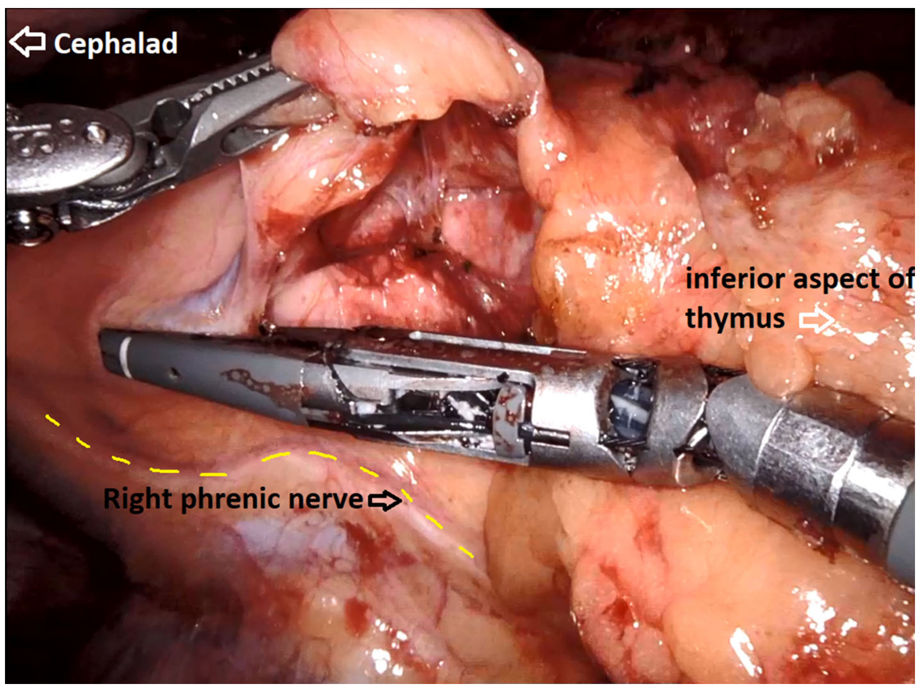

Fig. 5 View from the right chest, depicting dissection of the thymus with phrenic nerve seen coursing below. *Original figure*

3–4 cm vertical incision in the subxiphoid region, without any thoracic ports. Xiphoid resection is performed (if needed) and a special port is placed (usually smaller than the 8-mm robotic port, given the small incision and narrow operative space). Park et al. utilized 2–5-mm instrument ports and an 8-mm camera. They reported that due to the space constraints and inherent limitations of the robot, lesions within 8 cm of the inferior port, as well as the lower aspect of the thymus and pericardial tissue have to be resected via a VATS technique before deploying the robot to complete the dissection. Moreover, given the smaller port used, there are limitations of the energy devices available. Currently, the robotic Harmonic scalpel and vessel sealer are not small enough to fit in a 5-mm port, which would be required for the single-site platform. A further limitation of this system is the inadequacy for vascular or pericardial reconstruction, as this single-port system is still in its infancy [22]. If suturing is anticipated,

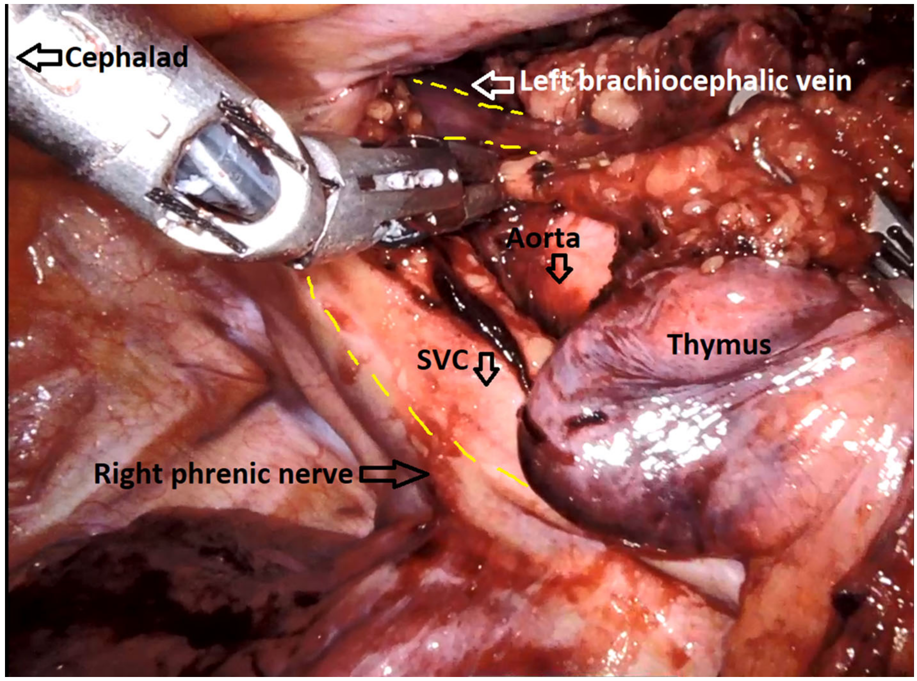

Fig. 6 Dissection of the left thymus (from the right side) taking care to avoid injury to the brachiocephalic and superior vena cava (SVC). Dissection of the left superior horn of the thymus is carried toward the neck. *Original figure*

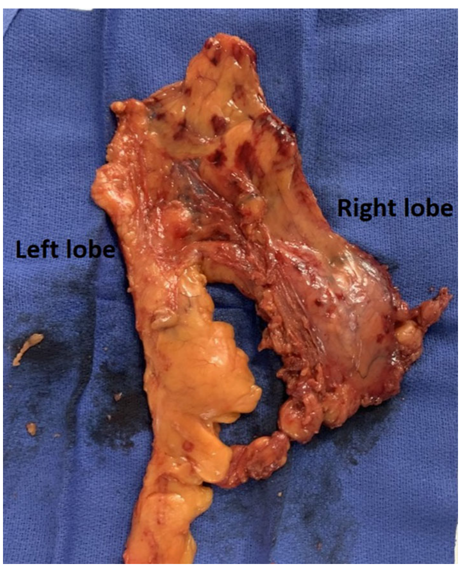

Fig. 7 Extracted specimen showing the intact thymus, with both lobes visible, as well as superior and inferior horns. *Original figure*

an additional port can be placed in the right 5th intercostal space to overcome this limitation [20•].

Learning Curve

The learning curve for robotic thoracic surgery has been shown to be rapid and feasible even in surgeons without prior minimally invasive surgical experience [24]. Robotic thymectomy does appear to have a less steep learning curve compared to anatomic lung resections. Kamel et al. suggested a steep initial learning curve of 15–20 cases for lateral transthoracic thymectomy [25•]. For the subxiphoid approach, 50 cases were required for proficiency and reducing the operative time based on Kang et al.'s experience [26].

Special Considerations

Pectus Excavatum

Patients with pectus excavatum deformities have limited anterior mediastinal space, hence robotic approaches may be quite challenging. Kapriniotis et al. described a technique for robotic thymectomy in a patient with MG and pectus excavatum, performed via lateral transthoracic approach [27]. This was performed successfully using a vacuum bell device during the procedure to increase space in the anterior mediastinum and optimize working space for the robot.

Pericardial Reconstruction

Institutions vary on their approaches to pericardial reconstruction when pericardium is resected as part of a robotic thymectomy. Some centers routinely reconstruct all pericardial defects [13], while others recommend reconstructing based on the size of the defect. Cardiac herniation has been described after robotic thymectomy with pericardial resection [28]. Special consideration should be given to patient positioning and the use of CO_2 insufflation, which may prevent cardiac herniation intraoperatively. If the decision to reconstruct the pericardial defect is made, this can be performed robotically via several techniques, including use of mesh with running or interrupted sutures [15].

Outcomes

As robotic-assisted thoracoscopic surgery gains popularity throughout the world, concern began among clinicians about the safety and long-term outcomes following this approach.

Studies have generally found that when compared with a traditional open approach, a MIS approach was associated with reduced blood loss, chest tube duration, and hospital length of stay (LOS) with no significant differences in perioperative complications, thymoma recurrence, and 5-year survival [5]. Concerns for the use of minimally invasive techniques for thymectomy and thymoma resection have been raised. Many fear the risk of thymoma capsule violation during minimally invasive manipulation, which may lead to pleural seeding, potentially compromising the oncologic efficacy of the procedure with ultimate thymoma recurrence [16].

Over the last few years, several authors described their results with robotic thymectomy both for thymic tumors and in cases of both thymomatous and nonthymomatous MG [3, 5, 25•, 26]. Analysis of this data shows that a robotic approach to thymectomy is a feasible and safe operation considering both early postoperative outcomes and long-term oncological outcomes.

Conclusion

A robotic approach to thymectomy is a feasible and safe operation for a variety of benign and malignant pathologies. There is reduced blood loss, chest tube duration, and hospital LOS without significant differences in perioperative complications, thymoma recurrence, and 5-year survival. Advances continue to be made in the field with the development of newer platforms including single-site and single-port systems, which continue to be increasingly adopted by thoracic surgeons.

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Compliance with Ethical Guideline

Conflict of interest The authors declare that they do not have existing conflicts of interest.

References

Papers of particular interest, published recently, have been highlighted as: "Bullet" Of importance"

1. Marulli G, Comacchio GM, Rea F. Robotic thymectomy. J Vis Surg. 2017;3(5) (cited 1 May 2022). https://jovs.amegroups.com/article/view/14800. Accessed 1 May 2022.
2. Wolfe GI, Kaminski HJ, Aban IB, Minisman G, Kuo HC, Marx A, et al. Randomized trial of thymectomy in myasthenia gravis. N Engl J Med. 2016;375(6):511–22.
3. Raza B, Dhamija A, Abbas G, Toker A. Robotic thymectomy for myasthenia gravis surgical techniques and outcomes. J Thorac Dis. 2021;13(10) (cited 1 May 2022). https://jtd.amegroups.com/article/view/45296. Accessed 1 May 2022.
4. Toker A, Sonett J, Zielinski M, Rea F, Tomulescu V, Detterbeck FC. Standard terms, definitions, and policies for minimally invasive resection of thymoma. J Thorac Oncol. 2011;6(7, Supplement 3):S1739–42.
5. Soder SA, Pollock C, Ferraro P, Lafontaine E, Martin J, Nasir B, et al. Post-operative outcomes associated with open versus robotic thymectomy: a propensity matched analysis. Semin Thorac Cardiovasc Surg. 2021 (cited 1 May 2022). https://www.sciencedirect.com/science/article/pii/S1043067921004846. Accessed 1 May 2022.
6. Loulmet D, Carpentier A, d'Attellis N, Berrebi A, Cardon C, Ponzio O, et al. Endoscopic coronary artery bypass grafting with the aid of robotic assisted instruments. J Thorac Cardiovasc Surg. 1999;118(1):4–10.
7. Reichenspurner H, Damiano RJ, Mack M, Boehm DH, Gulbins H, Detter C, et al. Use of the voice-controlled and computer-assisted surgical system ZEUS for endoscopic coronary artery bypass grafting. J Thorac Cardiovasc Surg. 1999;118(1):11–6.
8. Yoshino I, Hashizume M, Shimada M, Tomikawa M, Tomiyasu M, Suemitsu R, et al. Thoracoscopic thymomectomy with the da Vinci computer-enhanced surgical system. J Thorac Cardiovasc Surg. 2001;122(4):783–5.
9. Safieddine N, Keshavjee S. Anatomy of the thymus gland. Thorac Surg Clin. 2011;21(2):191–5, viii.
10. Zdrojewicz Z, Pachura E, Pachura P. The thymus: a forgotten, but very important organ. Adv Clin Exp Med Off Organ Wroc Med Univ. 2016;25(2):369–75.
11. Park S. Robot-assisted thoracic surgery thymectomy. J Chest Surg. 2021;54(4):319–24.
12. Toker A. Red flags in minimally invasive thymoma resections. Mediastinum (Hong Kong China). 2019;3:20.
13. Na KJ, Kang CH. Robotic thymectomy for advanced thymic epithelial tumor: indications and technical aspects. J Thorac Dis. 2020;12(2):63–9.
14. • Kneuertz PJ, Kamel MK, Stiles BM, Lee BE, Rahouma M, Nasar A, et al. Robotic thymectomy is feasible for large thymomas: a propensity-matched comparison. Ann Thorac Surg. 2017;104(5):1673–8. *An important paper describing that robotic thymectomy is feasible for large thymic tumors too, further paving the way to advance the field of robotic thoracic surgery.*
15. Kodia K, Nguyen DM, Villamizar NR. A 9 cm robotic thymectomy and pericardial repair case report. Mediastinum (Hong Kong China). 2020;4:38.
16. Jurado J, Javidfar J, Newmark A, Lavelle M, Bacchetta M, Gorenstein L, et al. Minimally invasive thymectomy and open thymectomy: outcome analysis of 263 patients. Ann Thorac Surg. 2012;94(3):974–81; discussion 981–2.
17. Kaba E, Cosgun T, Ayalp K, Alomari MR, Toker A. Robotic thymectomy—a new approach for thymus. J Vis Surg. 2017;3:67.

18. Wei B, Cerfolio R. Robotic thymectomy. J Vis Surg. 2016;2:136.
19. Suda T, Tochii D, Tochii S, Takagi Y. Trans-subxiphoid robotic thymectomy. Interact Cardiovasc Thorac Surg. 2015;20(5):669–71.
20. • Suda T. Robotic subxiphoid thymectomy. J Vis Surg. 2016;2:118. *An important technical paper showing a different approach to robotic thymectomy—namely the subxiphoid approach and exploring this approach further comparing it to the already established lateral trans-thoracic approach.*
21. Asaf BB, Puri HV, Bishnoi S, Nanda NS, Pulle MV, Kumar A. Subxiphoid robotic extended thymectomy—the first Indian report. J Minimal Access Surg. 2020;16(4):360–3.
22. Park SY, Han KN, Hong JI, Kim HK, Kim DJ, Choi YH. Subxiphoid approach for robotic single-site-assisted thymectomy. Eur J Cardiothorac Surg Off J Eur Assoc Cardiothorac Surg. 2020;58(Suppl_1):i34–8.
23. Suda T, Sugimura H, Tochii D, Kihara M, Hattori Y. Single-port thymectomy through an infrasternal approach. Ann Thorac Surg. 2012;93(1):334–6.
24. Power AD, D'Souza DM, Moffatt-Bruce SD, Merritt RE, Kneuertz PJ. Defining the learning curve of robotic thoracic surgery: what does it take? Surg Endosc. 2019;33(12):3880–8.
25. • Kamel MK, Rahouma M, Stiles BM, Nasar A, Altorki NK, Port JL. Robotic thymectomy: learning curve and associated perioperative outcomes. J Laparoendosc Adv Surg Tech A. 2017;27(7):685–90. *An important paper investigating the learning curve of 15–20 cases for lateral transthoracic thymectomy, helping pave way for the advancement of robotic surgery for the novice.*
26. Kang CH, Na KJ, Song JW, Bae SY, Park S, Park IK, et al. The robotic thymectomy via the subxiphoid approach: technique and early outcomes. Eur J Cardiothorac Surg Off J Eur Assoc Cardiothorac Surg. 2020;58(Suppl_1):i39-43.
27. Kapriniotis K, Geropoulos G, Vianna T, Mitsos S, Panagiotopoulos N. Facilitating robotic thymectomy in patients with pectus excavatum deformity. Gen Thorac Cardiovasc Surg. 2021;69(3):618–20.
28. Espey J, Acosta S, Kolarczyk L, Long J. Case report: cardiac herniation following robotic-assisted thymectomy. J Cardiothorac Surg. 2020;15:54.