



Minimal Access Surgery for Thymoma

Arvind Kumar¹ · Belal Bin Asaf² · Mohan Venkatesh Pulle² · Harsh Vardhan Puri² · Sukhram Bishnoi² · Srinivas Kodaganur Gopinath³

Received: 30 March 2020 / Accepted: 24 August 2020 / Published online: 5 September 2020
© Indian Association of Surgical Oncology 2020

Abstract

Thymoma is a rare epithelial tumor of the thymus gland. Despite rarity, it is the most common tumor of the anterior mediastinum. Surgical resection in the form of extended thymectomy is the gold standard operation. Conventionally and even in the current era of significant advances in the minimally invasive surgery, open transsternal extended thymectomy is considered the gold standard, particularly for advanced-stage tumors. There is however significant evidence now available for the use of minimally invasive approaches for early-stage thymomas. This article aims to discuss the various minimally invasive approaches currently being employed for thymomas.

Keywords Thymoma · Thoracoscopic Thymectomy · VATS Thymectomy · Thymectomy · Myasthenia Gravis

Introduction

Thymoma is a malignant tumor that arises from thymic epithelial cells. Although it is the commonest tumor of the anterior mediastinum [1], evidence-based management guidelines are lacking due to its rarity. Surgery is the mainstay of treatment, with extended thymectomy being the gold standard [2]. When complete surgical resection is in doubt, induction chemotherapy followed by surgery, with or without post-operative radiotherapy, is recommended [3, 4]. Conventionally, thymectomy has been performed by transsternal approach which gives excellent exposure from the neck to the diaphragm along with access to bilateral pleural cavities. It is still considered the gold standard approach

[5], particularly for advanced-stage tumors. However, sternotomy does inflict lot of “trauma of access” on the body, with its attendant complications [6]. In the last 30 years, evidence has accumulated in the literature about minimal access surgery (MAS) for resection of thymomas and their pros and cons. This article presents an overview of the current status of MAS for thymoma.

Before we discuss the MAS techniques for thymoma resection, it is important to highlight three key issues which have bearing on the surgical and survival outcome of thymoma and need to be strictly adhered to while performing MAS for thymoma. These are (1) extent of resection, (2) tumor handling, and (3) pre-operative optimization of myasthenia gravis (if patient is myasthenic). We have witnessed, with pain and anguish, an attempt by surgeons sometimes to neglect these key issues due to the limitations of MAS techniques and their overenthusiasm to embrace them at any cost. This must be avoided.

✉ Arvind Kumar
arvindreena@gmail.com

Belal Bin Asaf
asafbelal@gmail.com

¹ Department of Thoracic Surgery and Institute of Robotic Surgery, Sir Ganga Ram Hospital, New Delhi, India

² Department of Thoracic Surgery & Institute of Robotic Surgery, Sir Ganga Ram Hospital, New Delhi, India

³ DNB Thoracic Surgery, Department of Thoracic Surgery and Director, Institute of Robotic Surgery, Sir Ganga Ram Hospital, New Delhi, India

1. Extent of resection—completeness of resection is the most important prognostic factor for thymoma [7–9]. For patients of thymoma without myasthenia gravis (MG), the surgery should be total thymectomy (removal of all of thymus gland). For thymoma with MG, an extended thymectomy (removal of all of thymus gland along with the contiguous right and left mediastinal pleura, mediastinal and pericardiophrenic fatty tissues, and dissection of tissue from aortopulmonary window and

aortocaval groove) should be done [10]. In both the cases, any contiguous structure which is involved by the tumor must be resected completely, en-bloc with the main tumor.

2. Tumor handling—another key issue is mobilization of the tumor by “No Touch technique” wherein, at no step in the surgery, the tumor is held by any instrument. Handling of the tumor by the instruments at any stage in surgery can rupture the tumor capsule, leading to tumor seedling in the pleural cavities and subsequent pleural recurrences [11].
3. Pre-operative optimization of myasthenia gravis—a recent evaluation of International Thymic Malignancy Interest Group (ITMIG) database revealed that 38% patients with thymoma had myasthenia gravis also [12]. Therefore, all thymoma patients should be evaluated for evidence of myasthenia gravis. If a patient is found myasthenic, proper pre-operative optimization of MG before surgery is mandatory as inadequately prepared patients have high chances of aggravation of MG and myasthenic crisis in the post-operative period. A close coordination with the neurology team is required for such patients. With adequate pre-operative myasthenic optimization, the operative mortality can be reduced to < 1% [13]. It is also important to realize that patients with thymomatous MG cannot be made to wait indefinitely for MG control and may require more aggressive approach for a quicker control like pre-operative administration of intravenous immunoglobulins or plasmapheresis.

Minimal Access Surgery for Thymoma: a Word of Caution!

Any compromise on “pre-operative optimization of myasthenia gravis” can lead to immediate post-operative myasthenic crisis, whereas violation of the other two principles, i.e., “completeness of resection” and mobilization by the “no touch technique” due to the limitations of MAS can cause local or pleural recurrence and will be disastrous for the patient. If it is so, an open surgery with these principles adhered to is a better option for the long-term outcome for the patient.

Minimal Access Surgery for Thymoma

In recent years, a lot of interest has developed in the MAS for thymoma particularly for stage I and II disease. Included under this term are all procedures done with the intent to perform a radical resection as in open surgery but do not involve thoracotomy, sternotomy, or rib spreading. The surgery is performed using an endo-vision system and dedicated instruments. The minimal access approaches currently practiced include video-

assisted thoracoscopic surgery (VATS), robotic surgery, and transcervical and subxiphoid approaches. All these offer less post-operative pain, early recovery, shorter hospital stay, lower morbidity, and faster return to gainful employment [14]. Although their oncological outcomes were looked at with suspicion in the beginning, there is enough data now to prove their oncological equivalence, if not superiority. However, these techniques have their limitations too, especially in inexperienced hands, and judicious application of these techniques is of paramount importance to offer the benefits of these techniques without compromising patient safety or survival.

VATS Thymectomy

Video-assisted-thoracoscopic surgery (VATS) is the most commonly employed minimal access approach to thymectomy. It was first described by Sugarbaker in 1993, who recommended it as a possible alternative for early stage thymomas [15]. Since then, a large body of data has accumulated testifying to its feasibility and safety [16, 17]. Although oncological equivalence of this approach was an area of concern for some, the currently available data lays this concern to rest [18].

Unilateral Vs Bilateral Approach

VATS thymectomy can be performed from either side of the chest, i.e., unilateral approach—which could be from the right or left side, or it can be done by a bilateral approach.

In the unilateral approach (right or left), the ipsilateral dissection including complete removal of pericardial fat is under vision, hence complete, but the dissection of the opposite pericardial fat and dissection close to the opposite phrenic nerve may become blind at times, with possibility of nerve injury. This is specially the case in right-side dissection, wherein the inferior part of the left phrenic nerve, which dips posterolateral to the heart, is often not properly visible [19]. In such situations, if one is very cautious, the extent of dissection may be compromised. On the other hand, if you are bold, there is a possibility of nerve injury. There is also the issue of complete dissection of tissue in the aortopulmonary window on the left side [20], which is visible from the left but blind from the right side and aortocaval groove, on the right side, which is visible from the right but blind from the left side. Although experienced operators can overcome these difficulties and still be able to do as complete a dissection from either side, for beginners, these issues are vital and need to be addressed so that the benefits of VATS are offered not at the cost of radicality of the operation. Proponents of the right sided unilateral approach claim larger space, easier port placement, easier identification and dissection of the brachiocephalic veins, and overall safety [21]. The proponents of the left-sided approach claim easier and more complete dissection of

the left pericardial fat particularly along the inferior course of left phrenic nerve and better clearance in the aortopulmonary window [22]. Also, the proximal course of left phrenic is more anterior and comes closer to the operative field in contrast to the right phrenic nerve which is more posterior in its proximal course and is relatively better protected when approached from the contralateral side [23].

In the bilateral approach, however, both side dissections are done under complete vision, ensuring complete removal of both pericardial fat pads as well as complete removal of all tissue anterior to both phrenic nerves, of course at the cost of invasion of both sides of the chest. There is no data to support the superiority of one approach over the other. The choice of approaching from the right side or the left side or bilaterally is mainly based on the surgeon's training and preference.

Extent of Resection

Thymoma with Myasthenia Gravis All the current recommendations call for an “extended thymectomy” for patients of thymoma with myasthenia gravis. Any contiguous involved structure(s) must be removed en bloc with the tumor. Special effort should be made to clear the tissue in aortopulmonary window and the aortocaval groove as these sites often have ectopic thymic tissue [10].

Thymoma without Myasthenia Gravis Present evidence suggests the extent of surgery should be “total thymectomy” for patients with non-myasthenic thymoma. However, for the past few years, there has been a debate regarding extent of resection for early-stage (stage I and II) thymoma without myasthenia gravis. A significant interest has grown in less conservative resections like thymomectomy instead of total thymectomy in such cases.

There have been several studies to compare the outcomes of partial versus total thymectomy in early-stage thymoma. A large propensity score-matched analysis of JART (Japanese Association for Research on Thymus) database revealed lower post-operative complications with higher recurrence rate (2.2% versus 0.4%; $p = 0.0613$) in the thymomectomy group compared with total thymectomy for stage I (T1N0M0) thymomas [24]. Another large study using the ChART (Chinese Alliance on Research in Thymomas) database also revealed a higher local recurrence rate, especially in Masaoka-Koga stage II disease following thymomectomy in comparison with total thymectomy [25]. However, neither of the two studies found any difference in overall survival between the two groups. Contrary to these, a study by KART (Korean Association for Research on Thymus) database reported no difference in the 5-year survival and freedom from recurrence rates but with better perioperative outcomes in thymomectomy [26].

The points against thymomectomy include possibility of development of post-operative MG and possibility of occurrence of multifocal tumors in the remaining gland which may increase chances of local recurrence after thymomectomy. Also, thymomectomy involves non-anatomical resection through the thymus gland and hence apparently violates the basic oncological principles. In addition, the differentiation between stage I and stage II disease is not possible on the table but can only be found after the pathological examination of the resected specimen. So, performing thymomectomy/limited thymectomy in thymoma thinking it as stage I disease can increase local recurrence rates, which was proved by ChART study [25].

As per the available evidence, we must continue to perform total thymectomy for all patients with thymoma. Thymomectomy is not recommended as per the current evidence.

Size of the Tumor

An important consideration for selecting cases for MAS is the size of the tumor. There is no consensus regarding the size limit of the tumor. However, most reports suggest that tumors up to 5 cm should be well within the size limit for thoracoscopic thymectomy though the reports have ranged from 0.4 to 15.5 cm [27, 28]. In the study from ITMIG global database, size was not found to be an adverse factor for RO resection, and hence, it appears that it may not be an important consideration for the decision to proceed with VATS approach [29]. However, tumors larger than 5 cm should not be attempted by VATS by inexperienced teams.

Oncological Safety

The literature is full of reports suggesting better short-term outcomes of VATS thymectomy when compared with open approach. Lesser blood loss, shorter chest tube duration, and shorter hospital stay are well-known short-term advantages [30]. While these are not contested by anyone, the oncological long-term outcomes were a concern, particularly the risk of capsule rupture and pleural dissemination during VATS. However, the available data has put this controversy to rest. In a recent comparison of minimal invasive approach for stage I and II thymomas with conventional sternotomy, the rate of RO resection was not different from the open method. The recurrence rates reported in studies have ranged from 0 to 6.7%, not inferior to reports by open methods [31, 32]. In addition, the analysis of Chinese Alliance for Research in Thymomas (ChART) and Japanese Association for Research on Thymus (JART) databases also revealed that for early-stage thymomas, VATS thymectomy provides better perioperative outcome and is equal to open approach in terms of oncological outcomes including recurrence rate and disease-free and overall survival [18, 33]. Another propensity score–

matched analysis of retrospective ITMIG database also revealed that the surgical approach did not affect the rates of R0 resection [29].

However, this oncological equivalence is less clear in advanced-stage tumors like Masaoka stage III. Involvement of the lung, pericardium, and phrenic nerve can be dealt by VATS and has been reported [34]. In spite of few anecdotal reports of resection, the involvement of great vessels such as SVC is generally considered a contraindication for VATS thymectomy [35]. Attempts at VATS resection of such advanced tumors are not recommended routinely in light of available evidence but may be possible at select centers with highly experienced teams.

Uniportal VATS Thymectomy

There is an emerging trend towards reduction of number of ports in thoroscopic procedures, and the same holds true for thymectomy as well. While conventional VATS thymectomy utilizes three 5-mm ports, several reports of uniportal thoroscopic thymectomy have been published. The presumed advantages include decreased post-operative pain, chest wall paresthesia, length of hospitalization, and better cosmesis [36]. However, long-term results for these techniques are not known yet, and the additional advantage in reduction in morbidity may be at best minimal. Till more robust data is available, utilization of uniportal thoroscopic approach for thymectomy will remain an individual preference rather than a recommendation. Even reports of non-intubated uniportal subxiphoid thymectomy have been published [37, 38]. However, this technique is in very early stage of its development and more robust long-term data is needed to substantiate the benefits and safety.

Robotic Thymectomy

Although VATS method has been used extensively for thymectomy, it is limited by 2D vision, lack of depth perception, and counter-intuitive movements. These limitations were addressed by the new technology, i.e., da Vinci robotic surgical system with three-dimensional (3D) vision and the endo-wrist technology leading to intuitive instrument movements. The excellent 3D vision augments the depth perception which helps in precise dissection with better ergonomics. The first application of the da Vinci surgical robotic system for thymectomy was reported by Yoshino et al. from Japan in 2001 [39]. Since then, the utilization of the surgical robot has increased significantly for patients undergoing minimally invasive thymectomy [40, 41]. Most employed approach is the transthoracic robot-assisted surgery either from the right or the left

side. Subxiphoid robotic-assisted approach has also been described [42, 43].

Transthoracic Approach

Right-Side/Left-Side Approach

Transthoracic robotic thymectomy can be performed from either the right or left side or bilaterally. The choice of the side is a debatable issue (similar to VATS approach). The guiding points regarding choosing the side of surgery include location and extension of the tumor, safety of trocar placement, and surgeon's preference [44, 45]. If the mass is predominantly located to the left of the midline, the left-sided approach is preferred and vice-versa. If the tumor is in the midline, it can be approached from either side but depends on the personal choice of the surgeon. Followers of the left-sided approach mention the following reasons: (1) the left thymic portion is larger and extends more up to the cardiophrenic area—requiring more attention and dissection on the left side; (2) the thymic gland may extend more lateral or beneath the left phrenic nerve [46]; (3) in few cases, thymic horns may extend completely or partially posterior to the innominate vein rather than anterior; (4) better access to the aortopulmonary window—a frequent site of ectopic thymic tissue [47]. The points in favor of a right-sided approach include better visualization and delineation of the confluence of bilateral brachiocephalic veins from the right side, better visualization and dissection of the aortocaval groove, and better ergonomic position especially for a right-handed surgeon. In summary, the approach should be tailor-made for individual patient, keeping the anatomy and surgeon's own preference in mind. The final aim is to achieve an extended thymectomy, i.e., complete removal of tumor along with the whole of thymic tissue, anterior mediastinal and pericardial fat from one phrenic nerve to the other, and from thyrothymic ligaments to bilateral pericardiophrenic recess.

Size of the Tumor

Consideration of size of the tumor has been a subject of debate for minimally invasive thymectomy, and the same holds true for the robotic approach as well. While there are no clear cut-off limits, most authors restrict themselves to tumor less than or equal to 5 cm [27, 48]. Though a larger tumor size is not an absolute contraindication, surgeons have reported difficulty in manipulation, prolonged operative time or capsule injury, and increased chances of conversion when operating on larger tumors [49]. Successful removal of tumors larger than 5 cm using robotic approach has been reported by several authors [50, 51].

Oncological Safety

The available literature points towards the safety and feasibility of robotic thymectomy for thymoma along with better

short-term outcomes compared with open surgery with shorter hospital stay, lesser blood loss, reduced rates of post-operative complications, and lesser margin positivity rates [52]. From an oncological point of view, studies have found an oncological equivalence between open and robotic approach; however, a longer follow-up is needed for further assessment [53].

Robotic Thymectomy—Our Experience

We started robotic thymectomy in the country in 2008 and have been performing it ever since. In our experience, large tumor size has not been an absolute contraindication. In the beginning of our experience with robotic thymectomy for thymoma, we chose 4–5 cm as the maximum tumor size for robotic approach. As our experience increased, the technical advantage with the robot allowed us to resect larger and more invasive tumors involving the lung, pericardium, and the phrenic nerve. However, in general, larger tumors should be attempted robotically only by teams very experienced in this approach and should not be routinely employed by teams at the start of their learning curve. Strict adherence to oncological principles can never be overemphasized, and conversion at the slightest doubt of possibility of breach of these principles should be considered prudent and wise rather than a failure.

As a surgical team that moved to robotic thymectomy after having performed VATS thymectomy for over a decade, we find numerous advantages with the robotic system. Robot has much better ease of reach and precise movement of the instruments in the narrow space of anterior mediastinum. It is particularly useful in either extremes of the anterior mediastinum allowing for excellent clearance in the region of thymic horns and pericardiophrenic recess. The movement of the robotic instruments with 7 degrees of freedom of movement supplemented by better magnified stereoscopic view allows for an outstanding clearance with relative ease. It has also allowed us to consider even relatively more advanced lesions with involvement of pericardium, phrenic nerve, and in some cases even the innominate vein. While performing the procedure, all oncological principles are strictly adhered just as one would do at open surgery. If this cannot be achieved, we convert to open surgery immediately. There is debate regarding the superiority of robotic-assisted thymectomy over VATS thymectomy because of the lack of evidence. Having performed large numbers of open VATS as well as robotic thymectomies for over two decades now, we believe that the robot have a lot more to offer than conventional VATS, so much so that we are not inclined to offer VATS thymectomy to our patients today. To us, extra cost is the only disadvantage of robotic procedure currently. The lack of tactile feedback though has been mentioned frequently but has not been severely limiting for us. The exceptional magnified stereoscopic vision more than

compensates for the lack of tactile feedback. Concerns have also been raised about the longer operative time. While it may be true during the learning curve, once the team's experience grows, the time comes down significantly. The same was true initially for VATS also.

Subxiphoid Approach

As already discussed, the transthoracic approach of robotic thymectomy has its inherent limitations of difficulty in locating the contralateral phrenic nerve, difficult dissection of cervical portion of thymic tissue, and post-operative intercostal neuralgia. To address these limitations, the subxiphoid approach was introduced by Kido et al. in 1999, which followed several modifications. These include the single-port subxiphoid thymectomy (involves single subxiphoid incision with use of single-incision laparoscopic surgery—SILS port and CO₂ insufflation) [54] and dual-port subxiphoid approach (an additional port is used on one side) [55]. However, thymectomy through the subxiphoid robotic approach was popularized by Suda et al. from Japan in 2015 [56]. In this approach, camera port is inserted through the subxiphoid location, and both working arms are in the 6th intercostal space bilaterally. Since the camera is inserted through the midline subxiphoid port, the operative field seen is quite similar to mid-sternotomy, and it is quite easy to visualize the neck area and identify the bilateral phrenic nerves. As the working robotic arms are inserted in the 6th intercostal space in the mid clavicular line, the entire thymus lies between the both arms, which enables best robotic performance in dissection as well as suturing pericardial defects [57]. Due to better visualization of the left brachiocephalic vein, it is relatively easy to loop and divide this structure in cases of tumor invasion.

Robotic Subxiphoid Thymectomy—Our Experience

In our own experience of > 25 cases, we found that dissection of the inferior most pericardial fat particularly on the left side was difficult, and we used a modified approach wherein the inferior portion of the pericardial fat in the region of the left pericardiophrenic recess was mobilized thoracoscopically using a subxiphoid and two lateral thoracoscopic port on the left side before robot docking for a standard subxiphoid robotic thymectomy [58].

Transcervical Approach

Historically, transcervical approach was the first described method for performing thymectomy for myasthenia gravis by Sauerbruch in 1911 [59]. This procedure was a partial/

subtotal resection of the gland [60]. However, this procedure was revolutionized by Cooper et al., where the sternum was lifted using a sternal retractor for greater mediastinal visibility and enabled complete resection of the thymus gland with adjoining peri-thymic fatty tissue, i.e., extended transcervical thymectomy [61]. Later on, various modifications were proposed in this approach, such as combining it with a transsternal incision or videothoracoscopy (video-assisted thoracoscopic extended thymectomy) [62] or subxiphoid and video-assisted thoracoscopy (transcervical-subxiphoid-VATS maximal thymectomy) [63]. By these techniques, many authors reported similar rates of complete remission of myasthenia gravis compared with transsternal thymectomy [64, 65].

This procedure is used in only a few institutions, and proponents claim the adequacy of surgical exposure (particularly with video assistance), appropriate extent of resection, less pain, extremely less hospital stay, avoidance of sternotomy, and need for chest drainage as the advantages [66–68]. However, this procedure offers very limited visibility and space which makes dissection difficult. A visible scar in the neck is also a drawback as also the need for opening the bilateral pleural cavities for achieving completeness of surgery which requires intercostal drain placement [69]. Due to all these concerns, it has remained controversial and did not get wide acceptance among surgeons.

Conclusion

Minimally invasive surgery for thymomas is rapidly moving towards becoming the standard of care for early-stage thymomas and offers a significantly lower morbidity, early recovery, and shorter hospital stay. Current evidence also suggests the oncological equivalence, if not superiority of VATS and robotic thymectomy methods for thymoma resection juxtaposed to transsternal thymectomy. Robotic approach should be considered a refinement over VATS approach and will have much more significant role to play in minimally invasive surgery for thymoma in the future. The role of minimally invasive approaches for advanced lesions needs to be studied further in long-term studies.

However, irrespective of the method of surgery, the 3 cardinal principles, i.e., extent of resection, tumor handling, and pre-operative optimization of myasthenia gravis (in myasthenics) must be adhered to during MAS thymectomy. At any stage, if there is a compromise in these principles, immediate elective conversion to open surgery is a mature surgical judgment in the long-term interest of the patient, and not a surgical defeat. Patient safety and radicality of the operation should not be compromised due to the limitations of the minimal access approaches.

References

1. Cohen AJ, Thompson L, Edwards FH, Bellamy RF (1991) Primary cysts and tumors of the mediastinum. *Ann Thorac Surg* 51:378–386
2. Girard N, Ruffini E, Marx A, Faivre-Finn C, Peters S, ESMO Guidelines Committee (2015) ESMO guidelines committee. Thymic epithelial tumours: ESMO clinical practice guidelines for diagnosis, treatment and follow-up. *Ann Oncol* 26:v40–v55
3. Falkson CB, Bezjak A, Darling G, Gregg R, Malthaner R, Maziak DE, Yu E, Smith CA, McNair S, Ung YC, Evans WK, Lung Cancer Disease Site Group of Cancer Care Ontario's Program in Evidence-Based Care (2009) The management of thymoma: a systematic review and practice guideline. *J Thorac Oncol* 4:911–919
4. Hamaji M, Ali SO, Burt BM (2015) A meta-analysis of induction therapy for advanced thymic epithelial tumors. *Ann Thorac Surg* 99:1848–1856
5. Keynes G (1946) The surgery of the thymus gland. *Br J Surg* 33: 201–214
6. Xie A, Richard T, Kevin P et al (2015) Video-assisted thoracoscopic surgery versus open thymectomy for thymoma: systematic review. *Ann Cardiothorac Surg* 4:495–508
7. Venuta F, Rendina EA, Anile M, de Giacomo T, Vitolo D, Coloni GF (2012) Thymoma and thymic carcinoma. *Gen Thorac Cardiovasc Surg* 60:1–12
8. Shapiro M, Korst RJ (2014) Surgical approaches for stage IVA thymic epithelial tumors. *Front Oncol* 3:332
9. Riely GJ, Huang J (2010) Induction therapy for locally advanced thymoma. *J Thorac Oncol* 5:S323–S326
10. Toker A, Sonnett J, Zielinski M et al (2011) Standard terms, definitions and policies for minimally invasive resection of thymoma. *J Thor Oncol* 6:S1739–S1742
11. Pennathur A, Qureshi I, Schuchert MJ, Dhupar R, Ferson PF, Gooding WE, Christie NA, Gilbert S, Shende M, Awais O, Greenberger JS, Landreneau RJ, Luketich JD (2011) Comparison of surgical techniques for early-stage thymoma: feasibility of minimally invasive thymectomy and comparison with open resection. *J Thorac Cardiovasc Surg* 141:694–701
12. Huang J, Ahmad U, Antonicelli A, Catlin AC, Fang W, Gomez D, Loehrer P, Lucchi M, Marom E, Nicholson A, Ruffini E, Travis W, van Schil P, Wakelee H, Yao X, Detterbeck F (2014) Development of the international thymic malignancy interest group international database: an unprecedented resource for the study of a rare group of tumors. *J Thorac Oncol* 9:1573–1578
13. Gronseth GS, Barohn RJ (2000) Practice parameter: thymectomy for autoimmune myasthenia gravis (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. *Neurology* 55:7–15
14. Zahid I, Sharif S, Routledge T, Scarci M (2011) Video-assisted thoracoscopic surgery or transsternal thymectomy in the treatment of myasthenia gravis? *Interact Cardiovasc Thorac Surg* 12:40–46
15. Sugarbaker DJ (1993) Thoracoscopy in the management of anterior mediastinal masses. *Ann Thorac Surg* 56:653–656
16. Coosemans W, Lerut TE, Van Raemdonck DE (1993) Thoracoscopic surgery: the Belgian experience. *Ann Thorac Surg* 56:721–730
17. Kaiser LR (1994) Thymoma. The use of minimally invasive resection techniques. *Chest Surg Clin N Am* 4:185–194
18. Agatsuma H, Yoshida K, Yoshino I, Okumura M, Higashiyama M, Suzuki K, Tsuchida M, Usuda J, Niwa H (2017) Video-assisted thoracic surgery thymectomy versus sternotomy thymectomy in patients with thymoma. *Ann Thorac Surg* 104:1047–1053
19. Tomulescu V, Popescu I (2012) Unilateral extended thoracoscopic thymectomy for nontumoral myasthenia gravis—a new standard. *Semin Thoracic Surg* 24:115–122

20. Rückert JC, Czyzewski D, Pest S, Müller JM (2000) Radicality of thoracoscopic thymectomy—an anatomical study. *Eur J Cardiothorac Surg* 18:735–736
21. Toker A, Tanju S, Sungur Z, Parman Y, Senturk M, Serdaroglu P, Dilege S, Deymeer F (2008) Videothoracoscopic thymectomy for nonthymomatous myasthenia gravis: results of 90 patients. *Surg Endosc* 22:912–916
22. Mineo TC, Pompeo E, Lerut TE, Bernardi G, Coosemans W, Nofroni I (2000) Thoracoscopic thymectomy in autoimmune myasthenia: results of left-sided approach. *Ann Thorac Surg* 69:1537–1541
23. Li Y, Wang J (2014) Left-sided approach video-assisted thymectomy for the treatment of thymic diseases. *World J Surg Oncol* 12:398
24. Nakagawa K, Yokoi K, Nakajima J, Tanaka F, Maniwa Y, Suzuki M, Nagayasu T, Asamura H (2016) Is Thymomectomy alone appropriate for stage I (T1N0M0) thymoma? Results of a propensity-score analysis. *Ann Thorac Surg* 101:520–526
25. Gu Z, Fu J, Shen Y, Wei Y, Tan L, Zhang P, Han Y, Chen C, Zhang R, Li Y, Chen K, Chen H, Liu Y, Cui Y, Wang Y, Pang L, Yu Z, Zhou X, Liu Y, Liu Y, Fang W, Members of the Chinese Alliance for Research in Thymomas (2016) Members of the Chinese Alliance for Research in Thymomas. Thymectomy versus tumor resection for early-stage thymic malignancies: a Chinese Alliance for Research in Thymomas retrospective database analysis. *J Thorac Dis* 8:680–686
26. Narm KS, Lee CY, Do YW, Jung HS, Byun GE, Lee JG, Kim DJ, Hwang Y, Park IK, Kang CH, Kim YT, Cho JH, Choi YS, Kim J, Shim YM, Hwang SK, Kim YH, Kim DK, Park SI, Chung KY, Korea Association for Research on the Thymus (2016) Limited thymectomy as a potential alternative treatment option for early-stage thymoma: a multi-institutional propensity-matched study. *Lung Cancer* 101:22–27
27. Marulli G, Rea F, Melfi F, Schmid TA, Ismail M, Fanucchi O, Augustin F, Swierzy M, di Chiara F, Mussi A, Rueckert JC (2012) Robot-aided thoracoscopic thymectomy for early-stage thymoma: a multicenter European study. *J Thorac Cardiovasc Surg* 144:1125–1130
28. Takeo S, Tsukamoto S, Kawano D, Katsura M (2011) Outcome of an original video assisted thoracoscopic extended thymectomy for thymoma. *Ann Thorac Surg* 92:2000–2005
29. Burt BM, Yao X, Shrager J, Antonicelli A, Padua S, Reiss J, Wakelee H, Su S, Huang J, Scott W (2017) Determinants of complete resection of thymoma by minimally invasive and open thymectomy: analysis of an international registry. *J Thorac Oncol* 12:129–136
30. Hess NR, Sarkaria IS, Pennathur A, Levy RM, Christie NA, Luketich JD (2016) Minimally invasive versus open thymectomy: a systematic review of surgical techniques, patient demographics, and perioperative outcomes. *Ann Cardiothorac Surg* 5:1–9
31. Odaka M, Tsukamoto Y, Shibasaki T et al (2017) Surgical and oncological outcomes of thoracoscopic thymectomy for thymoma. *J Vis Surg* 10:54
32. Kimura T, Inoue M, Kadota Y, Shiono H, Shintani Y, Nakagiri T, Funaki S, Sawabata N, Minami M, Okumura M (2013) The oncological feasibility and limitations of video-assisted thoracoscopic thymectomy for early-stage thymomas. *Eur J Cardiothorac Surg* 44:e214–e218
33. Wang H, Gu Z, Ding J et al (2016) Members of the Chinese Alliance for Research in Thymomas. Perioperative outcomes and long-term survival in clinically early-stage thymic malignancies: video-assisted thoracoscopic thymectomy versus open approaches. *J Thorac Dis* 8:673–679
34. Wang GW, Tao T, Li CK, Li QC, Duan GX, Sang HW, Dong HJ, Wang ZY (2019) Comparison between thoracoscopic and open approaches in thymoma resection. *J Thorac Dis* 11:4159–4168
35. Xu N, Gu Z, Ji C, Zhang X, Chen T, Fang W (2019) Thoracoscopic thymectomy with partial superior vena cava resection for locally advanced thymomas. *J Thorac Dis* 11:438–444
36. Scarci M, Pardolesi A, Solli P (2015) Uniportal video-assisted thoracic surgery thymectomy. *Ann Cardiothorac Surg* 4:567–570
37. Liu Z, Yang R, Sun Y (2019) Non-intubated subxiphoid uniportal video-assisted thoracoscopic thymectomy. *Interact Cardiovasc Thorac Surg* 29:742–745
38. Jiang L, Liu J, Shao W, Li J, He J (2016) Non-intubated subxiphoid uniportal video-assisted thoracoscopic thymectomy using glasses-free 3D vision. *J Thorac Dis* 8:E1602–E1604
39. Yoshino I, Hashizume M, Shimada M, Tomikawa M, Tomiyasu M, Suemitsu R, Sugimachi K (2001) Thoracoscopic thymomectomy with the da Vinci computer-enhanced surgical system. *J Thorac Cardiovasc Surg* 122:783–785
40. Rea F, Bortolotti L, Girardi R et al (2003) Thoracoscopic thymectomy with the ‘da Vinci’ surgical system in patient with myasthenia gravis. *Interact Cardiovasc Thorac Surg* 2:70–72
41. Marulli G, Schiavon M, Perissinotto E, Bugana A, di Chiara F, Rebusso A, Rea F (2013) Surgical and neurologic outcomes after robotic thymectomy in 100 consecutive patients with myasthenia gravis. *J Thorac Cardiovasc Surg* 145:730–736
42. Rueckert J, Swierzy M, Badakhshi H et al (2015) Robotic-assisted thymectomy: surgical procedure and results. *Thorac Cardiovasc Surg* 63:194–200
43. Suda T (2016) Robotic subxiphoid thymectomy. *J Vis Surg* 2:118
44. Cerfolio RJ, Bryant AS, Minnich DJ (2011) Starting a robotic program in general thoracic surgery: why, how, and lessons learned. *Ann Thorac Surg* 91:1729–1736
45. Ismail M, Swierzy M, Ruckert JC (2013) State of the art of robotic thymectomy. *World J Surg* 37:2740–2746
46. Ismail M, Swierzy M, Rückert RI, Rückert JC (2014) Robotic thymectomy for myasthenia gravis. *Thorac Surg Clin* 24:189–195
47. Mineo TC, Pompeo E, Ambrogi V (1997) Video-assisted thoracoscopic thymectomy: from the right or from the left? *J Thorac Cardiovasc Surg* 114:516–517
48. Toker A, Erus S, Ozkan B, Ziyade S, Tanju S (2011) Does a relationship exist between the number of thoracoscopic thymectomies performed and the learning curve for thoracoscopic resection of thymoma in patients with myasthenia gravis? *Interact Cardiovasc Thorac Surg* 12:152–155
49. Marulli G, Maessen J, Melfi F, Schmid TA, Keijzers M, Fanucchi O, Augustin F, Comacchio GM, Mussi A, Hochstenbag M, Rea F (2016) Multi-institutional European experience of robotic thymectomy for thymoma. *Ann Cardiothorac Surg* 5:18–25
50. Keijzers M, Dingemans AC, Blaauwgeers H et al (2014) 8 years’ experience with robotic thymectomy for thymomas. *Surg Endosc* 28:1202–1208
51. Kneuert PJ, Kamel MK, Stiles BM, Lee BE, Rahouma M, Nasar A, Altorki NK, Port JL (2017) Robotic thymectomy is feasible for large Thymomas: a propensity-matched comparison. *Ann Thorac Surg* 104:1673–1678
52. O’Sullivan KE, Kreaden US, Hebert AE et al (2019) A systematic review of robotic versus open and video assisted thoracoscopic surgery (VATS) approaches for thymectomy. *Ann Cardiothorac Surg* 8:174–193
53. Marulli G, Comacchio GM, Schiavon M, Rebusso A, Mammana M, Zampieri D, Perissinotto E, Rea F (2018) Comparing robotic and trans-sternal thymectomy for early-stage thymoma: a propensity score-matching study. *Eur J Cardiothorac Surg* 54:579–584
54. Suda T, Sugimura H, Tochio D, Kihara M, Hattori Y (2012) Single-port thymectomy through an infra-sternal approach. *Ann Thorac Surg* 93:334–336
55. Suda T, Ashikari S, Tochio D, Tochio S, Takagi Y (2014) Dual-port thymectomy using subxiphoid approach. *Gen Thorac Cardiovasc Surg* 62:570–572

56. Suda T, Tochii D, Tochii S, Takagi Y (2015) Trans-subxiphoid robotic thymectomy. *Interact Cardiovasc Thorac Surg* 20:669–671
57. Suda T Subxiphoid robotic extended thymectomy with a pericardial patch closure. CTSNet. Available online: <http://www.ctsnet.org/article/subxiphoid-roboticextended-thymectomy-pericardial-patch-closure>. Accessed 4 April 2022
58. Asaf BB, Puri HV, Bishnoi S, Nanda NS, Pulle MV, Kumar A (2019) Subxiphoid robotic extended thymectomy - the first Indian report. *J Minim Access Surg* 0:0. https://doi.org/10.4103/jmas.JMAS_34_19
59. Keesey JC (2004) A history of treatments for myasthenia gravis. *Semin Neurol* 24:5–16
60. Papatostas AE, Genkins G, Kornfeld P et al (1987) Effects of thymectomy in myasthenia gravis. *Ann Surg* 206:79–88
61. Cooper JD, Al-Jilaihawa AN, Pearson FG et al (1988) An improved technique to facilitate transcervical thymectomy for myasthenia gravis. *Ann Thorac Surg* 45:242–247
62. Novellino L, Longoni M, Spinelli L, Andretta M, Cozzi M, Faillace G, Vitellaro M, de Benedetti D, Pezzuoli G (1994) “Extended” thymectomy, without sternotomy, performed by cervicotomy and thoracoscopic technique in the treatment of myasthenia gravis. *Int Surg* 79:378–381
63. Zieliński M (2000) Technique of transcervical–subxiphoid–vats “maximal” thymectomy in treatment of myasthenia gravis. *Przegl Lek* 57:64–65
64. de Perrot M, Bril V, McRae K, Keshavjee S (2003) Impact of minimally invasive trans-cervical thymectomy on outcome in patients with myasthenia gravis. *Eur J Cardiothorac Surg* 24:677–683
65. DeFilippi VJ, Richman DP, Ferguson MK (1994) Transcervical thymectomy for myasthenia gravis. *Ann Thorac Surg* 57:194–197
66. Calhoun RF, Ritter JH, Guthrie TJ, Pestronk A, Meyers BF, Patterson GA, Pohl MS, Cooper JD (1999) Results of transcervical thymectomy for myasthenia gravis in 100 consecutive patients. *Ann Surg* 230:555–561
67. Shrager JB, Deeb ME, Mick R, Brinster CJ, Childers HE, Marshall MB, Kucharczuk JC, Galetta SL, Bird SJ, Kaiser LR (2002) Transcervical thymectomy for myasthenia gravis achieves results comparable to thymectomy by sternotomy. *Ann Thorac Surg* 74:320–327
68. Donahoe L, Keshavjee S (2015) Video-assisted transcervical thymectomy for myasthenia gravis. *Ann Cardiothorac Surg* 4:561–563
69. Zieliński M, Rybak M, Solarczyk-Bombik K, Wilkojc M, Czajkowski W, Kosinski S, Fryzlewicz E, Nabialek T, Szolkowska M, Pankowski J (2018) Transcervical thymectomy. *Mediastinum* 2:28

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.