Minimally Invasive Thymectomy

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Introduction

Myasthenia Gravis (MG) and Thymoma share a common treatment in terms of surgery wherein a repertoire of approaches have been described [1]. Vast experiences have been garnered over the years on video-assisted thoracic surgery (VATS) approaches for thymus which has also modernised over years. VATS is superior in terms of less postoperative pain, better preserved pulmonary function, and improved cosmesis [2, 3] Results of VATS thymectomy are comparable as regards achievement of complete stable remission from MG and symptomatic improvement, as well as safety wherein VATS has proven to be at par and above other conventional surgical techniques [4]. A wider acceptance of VATS by MG patients and their neurologists for early stage thymectomies is being witnessed consequent to the improved attributes and outcomes.

The earliest report on thymectomy, published by Sauerbruch dates way back to 1913 [5]. Blalock performed this procedure in 1936 and popularized it [6–8]. Sugarbaker from Boston [9] first described thoracosopic thymectomy which was furthered by the Belgium group in 1993 [10].

Variants in approach that has evolved in VATS thymectomy include: video-assisted thoracic surgery (VATS) unilateral—right sided/left sided [11] and video assisted thoracoscopic extended thymectomy (VETET) which is a bilateral thoracoscopic approach combined with a cervical incision [12]. Endoscopic robot-assisted thymectomy appears to have promising outcomes; however, long-term data is pending [13]. Minimally invasive techniques have proved advantageous over

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D. Sharma, P. Hazrah (eds.), *Recent Concepts in Minimal Access Surgery*,
https://doi.org/10.1007/978-981-16-5473-2_19

conventional techniques due to their better outcome in terms of less postoperative pain morbidity and mortality, better cosmesis. Optimum surgical approach is still awaiting a universal consensus peeping into the available data. Various factors including a number of classifications, patient demographics, disease spectrum etc. along with various practice guidelines are responsible for variable outcomes in thymectomy patients. The various considerations as to use of VATS thymectomy, salient points on patient selection, specific perioperative management strategies, operative technique and recent outcomes is discussed in this chapter.

Indications

These may be considered as absolute or relative depending upon the degree of severity of the disease, age of patients, medical treatment response. Thymectomy has a clear role in achieving good control in many patients of MG but in those with purely ocular symptoms though its role is doubtful still data and experience suggest that thymectomy might be beneficial in disabled patients particularly those who are in early stages of disease or in patients with disease refractory to conservative therapy [14]. Also those with late severe generalised disease have poor response, as well as a high morbidity and mortality rate, and therefore are poor surgical candidates. Ambiguity exists regarding the role of thymectomy for those in the middle of the disease spectrum. Papatesat as et al. advocated early surgical intervention in all MG patients as thymectomy reduces the risk of development of extra thymic neoplasms in MG [15]. Practically, the need for thymectomy in MG patients are the views of the different specialities: physicians to last extent favour medical management, waiting for surgery till their final push, while surgeons advocate early surgery.

Indications of Thymectomy

1. Thymoma
   (a) Small (<2 cm) intra thymic thymoma
   (b) Large well encapsulated thymoma (preferably <5 cm)
   (c) Minimally invasive thymoma
2. Generalized MG unresponsive to medical treatment
3. MG with ocular disease refractory to treatment

Classification of Thymectomy

1. T1 Transcervical thymectomy
   (a) Basic
   (b) Extended
2. T2 Videoscopic thymectomy
   (a) Classic VATS

        (i) unilateral
        (ii) bilateral
        (iii) subxiphoid
    (b) VATET
        (i) Extended-bilateral thoracoscopy + open cervical exploration
3. T3 Transsternal thymectomy
    (a) Standard
    (b) Extended
4. T4 Transcervical and transsternal thymectomy

Preoperative Evaluation

Computed tomography (CT) with contrast enhancement is necessary to rule out vascular invasion, its relation with innominate veins and superior vena cava and it allows for better delineation of the mediastinal masses. Alternatively, MRI may be used. Patient with anterior mediastinal mass which are suspicious for thymoma are candidates for resection subject to ruling out of vascular lesions or abnormalities. Transthoracic needle aspiration might help in diagnosis of thymoma but not popularised due to various controversies. Preoperative evaluation should also include investigations for detection of associated MG.

Preoperative Preparation

Involvement of anaesthesia, neurology and the surgical team is mandatory from preoperative planning, through intra-operative management and ultimately up to the postoperative period. Evaluation for symptoms like diplopia, ptosis, dysarthria, difficulty chewing, slurred speech, dysphagia, dyspnoea and fatigability should be made. Cardiac stress evaluation and optimization of pulmonary function is of paramount importance.

Preoperative plasmapheresis may be helpful in patients who are poor responder for medical management. Surgery has no role during myasthenia crisis and medical management should be continued till it is resolved and MG patients can undergo surgery only if their medical condition is optimized. The risk of myasthenic crisis after thymectomy can be considerably reduced by appropriate patient selection and taking up for surgery only after the myasthenic symptoms are well controlled. Many thymoma patients have only subtle myasthenic symptoms hence steroids and immunosuppressants may be initiated after surgery in these patients, particularly to reduce the risk of post-operative infection.

Plasma exchange (PLEX) or Intravenous Immunoglobulin (IVIG) therapy may be given prior to thymectomy. This helps to reduce the pre-operative steroid dose, reduces the chances of post-operative worsening and reduces hospital stay. Seggia and colleagues demonstrated that hospital stay and lower cost can be achieved by plasmapheresis which led to significantly improved respiratory function and muscle strength in MG patients undergoing thymectomy [16]. Preoperative anaesthetic medication is minimal, usually consisting only of atropine and a mild sedative. Preoperative anticholinergic medications are avoided. Myasthenic patients pose no particular anaesthetic problems, although long-acting muscle relaxants should be avoided. Deep anaesthesia is maintained by an inhalational agent and short-acting narcotic. A single-lumen endotracheal tube suffices for airway control and ventilation.

Operative Technique

Basic Laparoscopic Instruments required:

- 5 mm 30 Degree Telescope
- Two 5 mm Maryland dissectors/Micro dissectors
- 5 mm Endoscopic suction cannula
- 5 mm Endoscopic energy source (Ultrasonic shears)
- 5 mm Electrocautery hook
- 5 mm Clip applicators and endoclips
- 10 mm Endoscopic retrieval bag

Patient and Port Position: The patient is placed in a 30-degree semi recumbent supine position, with ipsilateral arm abducted and a bag placed under the shoulder. Right-side approach is more commonly preferred for non thymomatous myasthenia gravis, as it provides greater manipulation workspace with the heart out of the way (Fig. 1). A left sided approach is usually reserved for a left sided thymoma.

Pneumothorax is created by inserting 10 mm trocar by open technique into the thoracic cavity at fourth/fifth ICS in mid-axillary line (Fig. 1) similar way like insertion of chest drainage tube and connecting it to gas insufflation setting pressures to

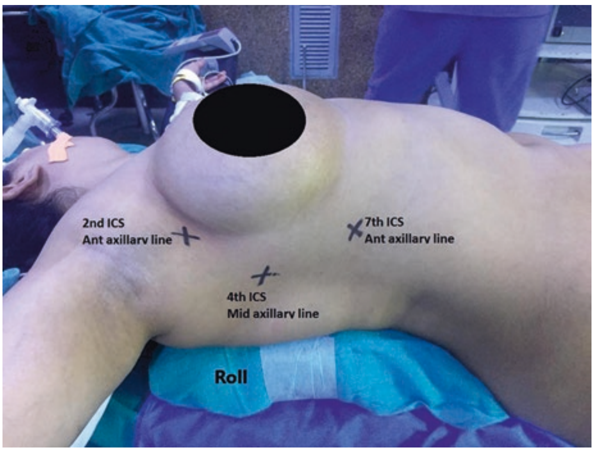

Fig. 1 Patient positioning and initial port placement. Supine with right up 30°, arm outstretched or rested on L-arm rest

6–8 mmHg. This results in compression of lung thus providing space for surgical manoeuvrings. Lung exclusion can also be done with a double lumen endotracheal tube supplemented with insufflation of carbon dioxide (5–8 mmHg pressure at 4 L/min flow rate). Once the lung is adequately deflated the carbon dioxide insufflation is discontinued. Carbon dioxide insufflation alone can be used for lung collapse keeping the pressures to 6–8 mmHg throughout the surgery which alleviates the need of a double lumen tube. A 5 mm 30-degree camera makes it easy to change camera position among all the ports. The surgeon and camera man stand on the same side while the scrub nurse and second assistant positioned on the contalateral side (Fig. 2).

The 3-port technique is commonly used. The initial 10 mm port incision should always be directed in front of the tip of the scapula along the mid/posterior axillary line. The second and third 5-mm instrument ports should be inserted guided under direct thoracoscopic vision at the 2nd/3rd intercostal space and sixth/seventh intercostal space respectively in midaxillary line/anterior axillary line (Fig. 1). A sub mammary fold approach for port placement can be adopted in females for cosmetic reasons. The initial/first 10 mm port is used for specimen removal and after the end of procedure a chest drain with water seal is placed through it.

Dissection of the gland: Dissection begins just anterior to the phrenic nerve, by incising the mediastinal pleura with hook electrocautery/ultrasonic shears. The thymus and pericardial fat are carefully mobilized from the right phrenic nerve. Care should be exercised to prevent thermal or stretch injury to the nerve (Figs. 3 and 4).

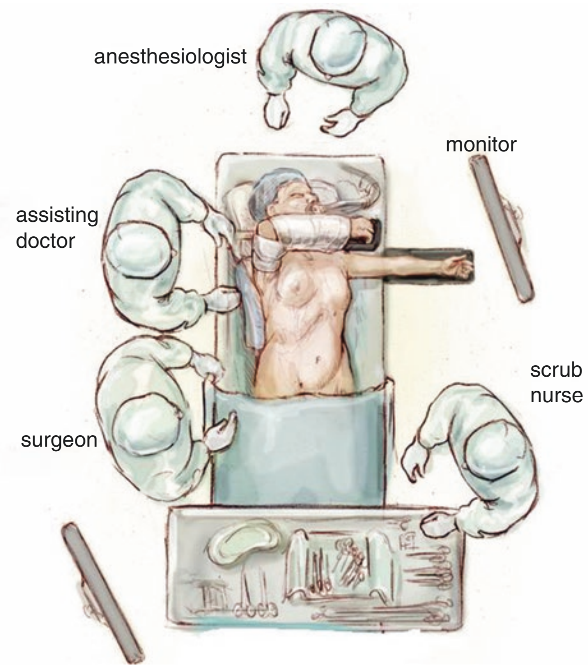

Fig. 2 Operative room set up

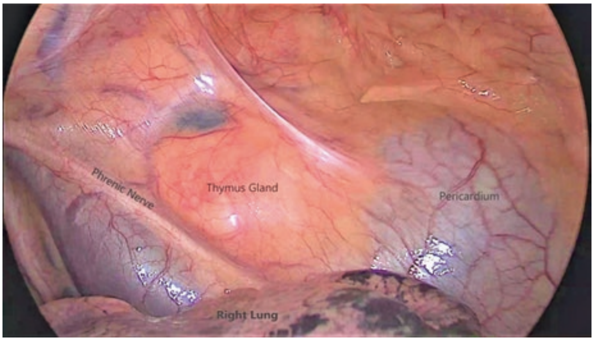

Fig. 3 Thymus gland bounded on either side by phrenic nerve, inferiorly by pericardium and superiorly by innominate vein

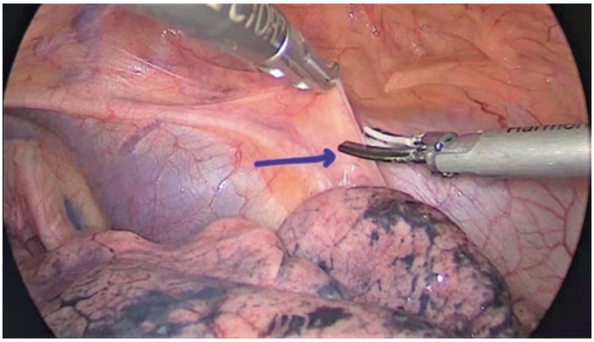

Fig. 4 Dissection begins just anterior to the phrenic nerve (Blue arrow), incising the mediastinal pleura with ultrasonic shears

The pleural incision is extended along the length of the nerve toward the diaphragm, and all thymic tissue and pericardial fat are swept from the pericardium, starting near the diaphragm (Fig. 5). Dissection is achieved via combination of blunt and sharp dissection. Additionally, the thymus is mobilized superiorly by incising the mediastinal pleura along the medial border of the internal mammary vessels.

This dissection is carried superiorly, freeing all soft tissue from the retro sternum and eventually the thymus from the innominate vein. Gentle traction of the thymus is initiated, which facilitates the identification of all vein branches draining into the innominate vein. All thymic veins and attachments are controlled with endoclips along the innominate vein (Figs. 6 and 7).

Complete gland removal: Once all thymic veins and attachments are dissected, the superior poles can be identified with gentle downward traction of the gland. Care should be taken as number and position of thymic veins are not definite and at times may be incongruous. Using careful countertraction, the cephalad attachments of the superior poles can be freed under direct visualization. All arterial connections with the internal mammary arteries in this region are clipped and ligated. Also, care is to be taken to identify the inferior thyroid vein while dissecting the superior horns of the thymus in the thyro-thymic tract as it can be a source of torrential bleed. Following mobilization of the superior poles, medial dissection can continue toward the left chest, taking all thymic tissue and fat from the pericardium (Fig. 8).

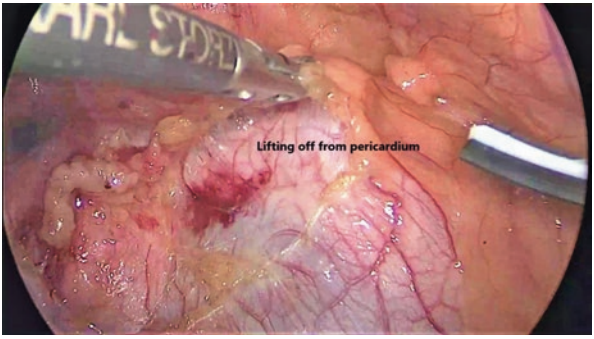

Fig. 5 Thymic tissue and pericardial fat are swept from the pericardium

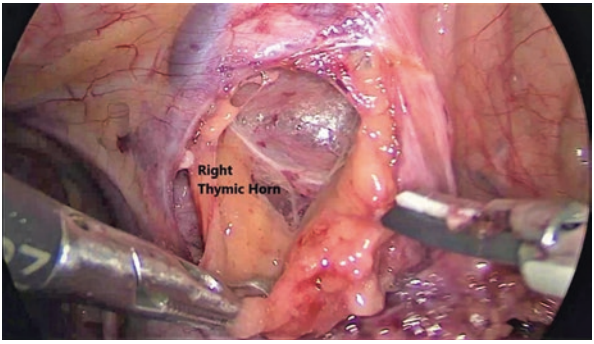

Fig. 6 Superior horn division. The superior horns are gently retracted caudally and exposed using countertraction. Once retracted and visualized, the superior horns are divided with the ultrasonic shears

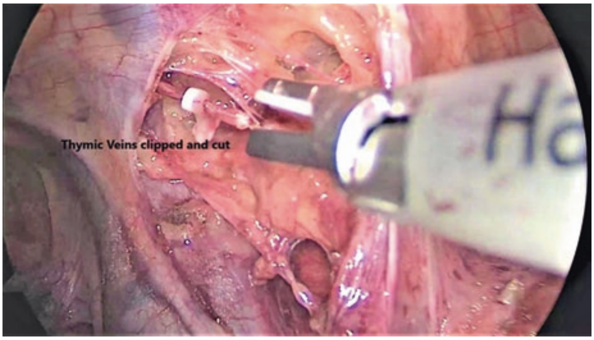

Fig. 7 Clipping and division of a thymic vein. The innominate vein is skeletonized, and all thymic veins and attachments are clipped and divided

Dissection from left side: Left side can be part of thoracoscopic unilateral or in general thoracoscopic bilateral approach. A 5-mm port is inserted into the left chest for dissection of left thymus. Before this, right lung ventilation is started again and maintained till the end of surgery. A 30-degree thoracoscope is inserted into the left chest and is controlled by the surgical assistant. Output from this scope is displayed separate from the primary surgeon's scope/monitor, allowing simultaneous bilateral mediastinal visualization. For more dissection from left side two additional ports can be inserted under direct visualisation on the left side as done in right sided approach.

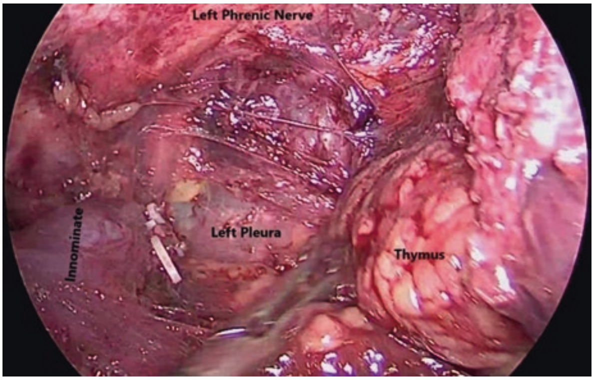

Fig. 8 Medial dissection continued toward the left chest, taking all thymic tissue and fat from the pericardium

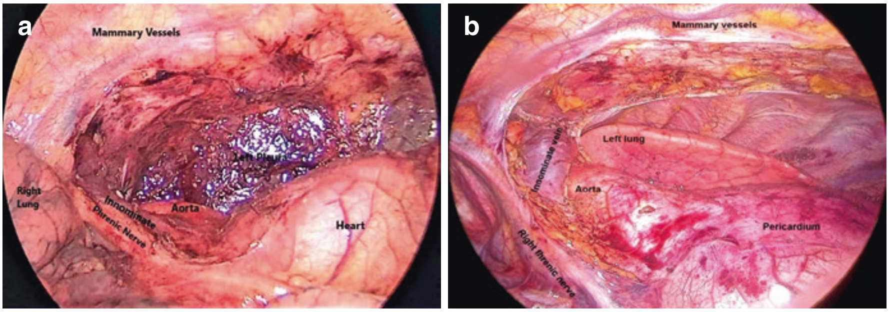

Fig. 9 (**a**) Bare area after complete en bloc dissection, phrenic-to-phrenic resection of all thymic tissue and anterior mediastinal fat. (**b**) Final view from the right side in c/o bilateral approach

The advantages and disadvantages of the various approaches of VATS thymectomy with respect to working space, approach to nerve and vessel identification, tumor resection and anatomical problem encountered is enumerated.

The left cardio-phrenic angle is identified which serves as starting point of dissection, by grasping the thymus and the fat pad anterior to the left phrenic nerve. The thymus gland is lifted by dissecting off the pericardial layer. Opening up the retrosternal plane, the dissection is continued upwards along the left phrenic nerve, to join the thoracic inlet superiorly. The surgical assistant maintains view of the left phrenic nerve and mammary vessels throughout the left thymic dissection. The dissection is carried to the level of the left phrenic, ensuring complete en bloc, phrenic-to-phrenic resection of all thymic tissue and anterior mediastinal fat (Fig. 9a, b). The completely mobilized specimen can then be removed through one of the 10-mm port sites using an endoscopic bag (Fig. 10).

Following specimen removal (Fig. 11), the anterior mediastinum is inspected, ensuring complete removal of all thymus, fat, and soft tissue. It is important to look for extrathymic tissue elsewhere in thoracic cavity as they remain the cause of residual disease (Fig. 12).

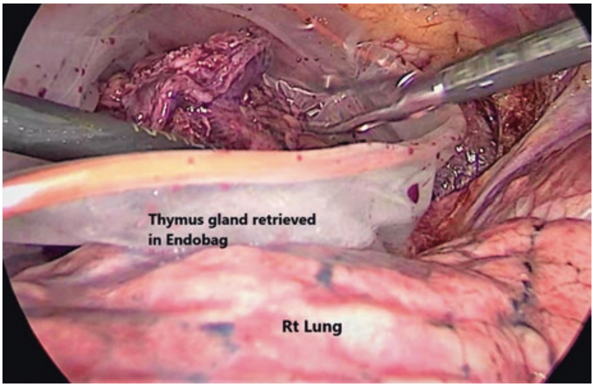

Fig. 10 The completely mobilized specimen can then be removed through one of the 10-mm port sites using an endoscopic bag

Fig. 11 Complete thymus gland showing right and left thymic horns with adenoma in body along with peri thymic fat extending along the phrenic nerve course till diaphragm

Chest drainage: If only right sided approach was adopted a single chest drain suffices. However, in cases where the left pleura is also opened or when left thoracoscopic dissection is added (Bilateral VATS), a chest drain can be passed trans-mediastinal under direct visualization as it is a single cavity. Adequate lung expansion is directly visualized before closing all port sites sequentially in layers with absorbable sutures and skin with glue/sutures (Fig. 13).

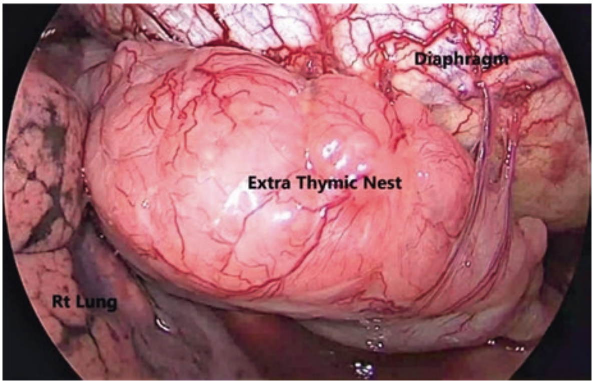

Fig. 12 Extrathymic nest in a patient with thymic carcinoma

Fig. 13 Final outcome of minimally invasive technique (VATS). Two small scars and third port converted to Chest tube drain

Robot Assisted VATS Thymectomy

Some of the drawbacks of conventional minimal access surgery include: having to instruct an assistant to drive the endoscope, amplification of physiologic tremor with long instruments, limited mobility in angles due to rigid instruments and an fulcrum effect. Most of the endoscopes have two dimensional images with loss of depth perception and limited magnification possibilities. Many of these concerns with laparoscopic surgery are alleviated with the advent of the robotic surgical system as any patient who can virtually undergo thymectomy by open technique can undergo thymectomy using the robotic technique. The only relative contraindications of robotic thymectomy is large vessel invasion and very large >12 cm tumour.

Operative Setup

The patient is placed in supine position and induced under general anaesthesia with a dual lumen endotracheal tube. In most thymic lesions a semi right lateral decubitus position is helpful particularly for non-thymomatous myasthenia

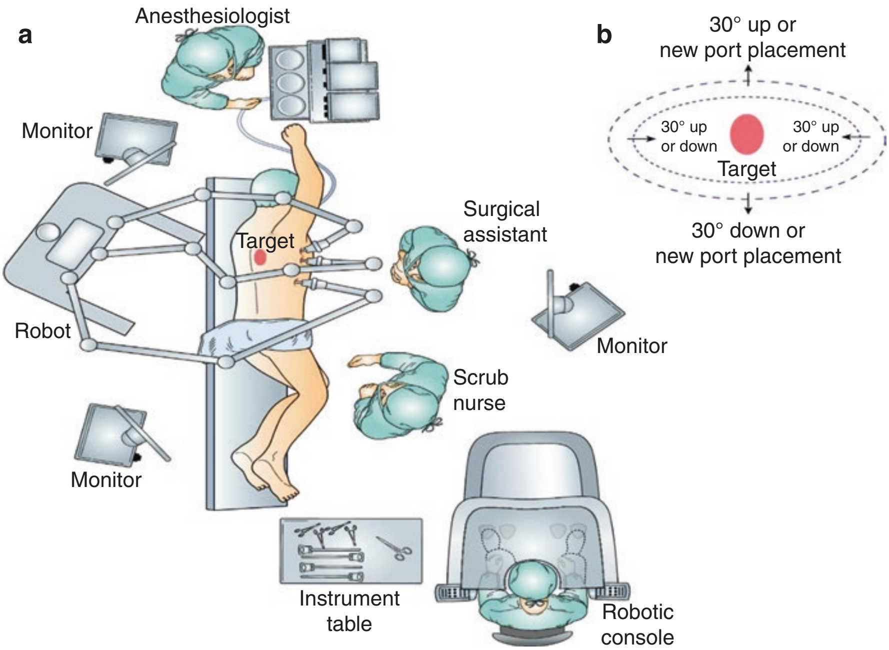

Fig. 14 The robotic platform can be docked from either side of the patient depending on surgical approach and/or operating room layout

gravis, however one may choose a right/left sided approach depending on location of the disease. The patient's chest and hip are elevated, and the position is secured with a de-sufflated bean bag with proper padding of pressure points. The upper arm (side of approach) is outstretched, and the lower arm is secured at the patient's side. The robotic platform can be docked from either side of the patient depending on surgical approach and/or operating room layout (Fig. 14). It is regarded that the left sided approach is possible easily with robotic surgery in spite of less space, leads to more complete removal of all thymic tissue thus preventing myasthenia gravis from developing post-operatively even in patients only presenting with thymoma.

Operative Technique (Left Side Approach)

Once the patient has been positioned, prepped, and draped, the left lung is collapsed and single right lung ventilation is initiated. A Veress needle is inserted into the chest and intrathoracic placement is confirmed with a saline column drop test. The left chest is then insufflated with CO2 to expedite and augment lung collapse and depression of the diaphragm and ventricle from the chest wall and sternum. This is typically well tolerated at a pressure of 8 mmHg on high flow. Alternately 8 mm port can be introduced into thoracic cavity under direct vision by open technique when patient is on single lumen tube and gas insufflation at 8 mmHg works very well in collapsing the lung.

Port position: An 8-mm camera port is inserted into the fifth intercostal space within the inframammary fold at the anterior to mid-axillary line. Rest three trocars are placed under direct vision.

An 8-mm port is placed in the third intercostal space on the anterior axillary line. The next 8-mm port is placed in the fifth intercostal space, just lateral to the sternum (left robotic working arm). Lastly, a 12-mm assistant port is placed caudally in the midaxillary line, typically in the seventh intercostal space for suctioning.

The robotic console is then brought in proximity to the bedside with the central column positioned over the patient's contralateral shoulder. Appropriate instrumentation is then inserted though the trocars under direct visualization and docked to the robot; In general, an ultrasonic shears is preferred energy source in the right working robotic arm port and a bipolar grasper in the left robotic arm port.

Dissection of the gland: Once all instrumentation is docked to the robotic console, direct visualization of the left phrenic nerve is achieved. En bloc resection is initiated through incision of the mediastinal pleura, just medial to the left phrenic nerve.

Careful mobilization of the phrenic nerve is performed, preserving the nerve if adequate oncologic margins are feasible. Pleural incision is carried along the length of the nerve, taking care to prevent stretch injury to the nerve or damage to the adjacent perineural vessels. Dissection is continued medially, using a combination of sharp and blunt dissection. All thymic tissue and pericardial fat are taken off from the pericardium in all directions medially, caudally and cephalad towards the innominate vein.

Upwards, the pleural incision goes anteriorly adjacent to the internal mammary artery and phrenic nerve junction. This dissection is extended downwards to the diaphragm, running medial to the internal mammary vessels. All tissue is then excised from the retro sternum with blunt and sharp dissection to the level of the innominate vein superiorly, and medial to the contralateral internal mammary vessels (better visualized after contralateral pleural incision). The left and right thymic horns are identified at the top which are fully mobilized, and resected en bloc with the specimen.

Following division of the thymic horns, dissection is carried toward the right pleura. At this point in the operation, risk of injury to the contralateral phrenic nerves and/or mammary vessels can be high if adequate visualization is not obtained. It is found that identification of the contralateral nerve and/or internal mammary vessels can be difficult in certain cases and therefore two strategies have been identified to facilitate this. One method is through utilization of simultaneous bilateral visualization of the mediastinum. In this method, we insert a 5-mm thoracoscopic port into the contralateral chest at the level of the infra mammary crease. Thoracoscopic video output from this port, is controlled by the bed side assistant surgeon, can be directly linked to existing robotic platforms, allowing bilateral and simultaneous mediastinal visualization while sitting at the robotic console. The bedside assistant maintains visualization of vital contralateral structures as the primary surgeon operates from the left side.

Additionally, a technique of phrenic nerve visualization described by Wagneret al. through use of near infrared fluorescence imaging can be used [17]. This technology, commercially available in robotic and nonrobotic platforms, utilizes the laser-induced fluorescence of indocyanine green (ICG) imaging contrast to highlight the phrenic nerves and other key vascular structures. ICG solution, 5–10 mg, is given intraoperatively and intravenously, and can be visualized within seconds. The laser-induced fluorescence of ICG is then superimposed onto the surgeon's video display, allowing easy differentiation of phrenic nerves and adjacent pericardiophrenic vessels from surrounding tissues.

Once adequate visualization of the contralateral phrenic nerve and mammary vessels is obtained, the right pleura is incised from the left side. The bedside assistant follows the primary surgeon with the contralateral thoracoscope, ensuring full dissection of thymic tissue is accomplished between both nerves, while preventing injury. Thymic veins are identified and ligated with care to avoid undue traction from the tumour during dissection. Smaller vessels can typically be ligated with the ultrasonic shears, but it is advised to clip larger vessels with a standard handheld or robotic clip applier. The full en-bloc specimen is removed via a 15-mm endoscopic specimen bag. Areas of minor bleeding are controlled with electrocautery, bipolar, or clips. A multilevel intercostal nerve block with 0.25% Bupivacaine solution for postoperative analgesia helps in reducing postoperative pain. A 28-French chest tube or 24-French Blake drain is inserted into the left chest under direct visualization and passed across the mediastinum. The chest tube is secured with sutures and all port sites are closed.

Pearls and Technical Aspects of VATS

- The completeness of dissection is confirmed by anatomical inspection of the resected gland and also the thymic bed for any left-over peri thymic fat or ectopic thymic tissue. Also, care is to be taken to look for accessory horns especially below the innominate vein, where they can be missed easily.
- Safe thymectomy is possible after identification of both phrenic nerves. A safe energy source should be used to minimise any thermal injury to the nerves. Energy sources like harmonic decreases dissection time and allows safe control of the thymic vessels [18].
- It is preferable to dissect first the superior horns from the innominate vein before mobilizing the, body, or the inferior horns to prevent the gland from obscuring the surgical field of visionduring the crucial step of innominate vein dissection. Further the dissected horns can be used as traction for manipulation and dissection thus avoiding injury to the tumour capsule.
- Although thymectomy doesn't require more than three ports, nevertheless routine retraction through the additional medial fourth 5 mm port increases exposure thus making surgery feasible for large hyperplastic glands with abundant perithymic fat [19].

- A semi supine position is preferred as it allows, for an emergency quick sternotomy if the need arises.
- A single chest tube suffices when both pleural cavities are connected
- Final inspection and anatomical completeness should be ensured at the end [19].
- The junction forming the superior vena cava should be clearly visualized after brachiocephalic vein has been skeletonised.

Post-Operative Care

With advent of modern anaestheisa and minimally invasive surgeries early extubation add further to the advocated better outcomes of minimally invasive thymectomy. Normal diet is given, unless there is bulbar weakness due to MG. Chest physiotherapy as well as incentive spirometry is mandated for speedy recovery along with chest x-ray monitoring. It is imperative to monitor Spo2 and bedside spirometry serves well in the early postoperative period to detect early respiratory muscle weakness. A volume of <15 mL/kg, or continuous fall in forced vital capacity should raise an alarm towards respiratory failure. Preoperative medications should be resumed in early postop for the control of MG In the absence of air leak or bleeding intercostal chest drainage tube can be removed after postoperative day 1. Steroids and immune suppressants should also be resumed after surgery and should be gradually tapered over several months. In non-thymomatous MG, there is improvement in 85% of patients of whom 35% of achieve drug-free remission [20]. However, the effect of thymectomy may be observed only after 1–2 years. Remission rate increases with time and reaches 40–60% after 7–10 years.

Advantages of VATS

The relative advantages of VATS are:

1. The VATS and Robotics approaches minimize chest wall trauma which results in lower morbidity, enabling early discharges, and improved patient acceptability for surgery.
2. Conversion from VATS to sternotomy is low ranging from 2.6 to 5.5% [21].
3. The VATS approach is preferred for many reasons.
   (a) Excellent vision: A panoramic vision of thorax and wide angle manipulation is major advantage of VATS
   (b) Handling bleeding: As the thymus, is more an anterior mediastinal structure, chest offers direct approach than the neck and it is easy to handle any bleeding.
   (c) Completion thymectomy: Residual thymic tissue can be taken with ease, in cases where transcervical approach had failed.

(d) Cosmesis: VATS offers better cosmesis which although not arguable to justify a particular approach yet serves better to larger young female population with the disease.
(e) Pulmonary function: A randomized prospective study has clearly attributed an advantage of VATS over open approach in terms of better pulmonary function and a faster recovery for MG [22]. This adds to earlier extubation and thus significant reduction in postoperative pulmonary infections.

Limitations/Contraindications of VATS Thymectomy

Some of the cited limitations of VATS are [21]:

1. Severe coagulopathy
2. Pleural symphysis.
3. Patients with poor lung function, COPD, ILD or other severe underlying lung disease in whom single lung ventilation may be difficult to manage.
4. Young children may not be suitable candidates due to smaller airways which are not amenable to the smallest double-lumen tube andone-lung ventilation with other methods can be more hazardous.
5. Previous surgery in the ipsilateral chest is a relative contraindication

VATS Variants and Future

Single Incision Minimally Invasive Thoracic Surgery

A single port approach is a currently investigational technique in minimally invasive thoracic surgery. This approach requires instruments that articulate and is more challenging than traditional VATS approaches. The operative approach is similar to that in traditional VATS surgery, with the patient placed in the lateral decubitus position. A 2–3 cm incision is created over the desired rib space (typically the fifth), over the anterior axillary line, and a single port accommodating camera in middle and working instruments on its sides. The potential benefit of single incision may include decreased pain and more rapid recovery, but this technique requires further study to prove its superiority.

Future

The uniportal technique could be described as a way of performing surgery with the least number of devices possible, reducing this way a possible compression over the intercostal space when multiple instruments are introduced through a single incision. The use of two specific instruments: a long curved stainless-steel Dennis suction device on the left hand and an energy device on the right hand is the key. The coordination enables a fast and effective dissection and coagulation and exposure in addition, the use of an external articulated camera support allows for a firm and stable handling without an assistant. Future experience gained with the uniportal approach will favour this type of surgery, therefore enabling the optimization of hospital resources [23].

Non-intubated Uniportal VATS Thymectomy

Non-intubated thoracic surgery (NITS) has been the hot topic in past decade. It offers potential advantages over general anaesthesia of avoiding side effects of endotracheal intubation, mechanical ventilation, and general anaesthetic drugs. Thoracic centres are enthusiastic about NITS, although the criteria for patient selection and the standard anaesthetic care for NITS are yet to be established.

The rationale here is to avoid muscle relaxants, which would lower the risk of postoperative muscle weakness and respiratory insufficiency, thus improving patient recovery. Awake endoscopic thymectomy has been reported which allows the patient to eat, drink, and walk in immediate postoperative period. With iatrogenic opening of the pleurae, continuous suction through a nasogastric tube to the pleural hole would help to expand the lung passively [24].

Outcomes of VATS Versus Open Thymectomy

A systematic review of the literature was done comparing open to minimally invasive thymectomy, both nonrobotic and robotic VATS included a total of 20 comparative studies encompassing 2068 patients receiving either open [1230 (59.5%)] or minimally invasive [838 (40.5%)] thymectomy [25]. There was considerable variation regarding patient age, sex, and indication for thymectomy across studies, but all studies were individually well matched between comparison groups. Across studies, there was a consistent trend of significantly lower mean blood loss (VATS: 20–200 mL; Open 86–466 mL), pleural drainage duration (VATS: 1.3–4.1 days; open 2.4–5.3 days), and hospital length of stay (VATS: 1.0–10.6 days; Open 4.0–14.6 days) in patients treated with minimally invasive thymectomy. No consistent differences could be found in terms of operative time, rate of R0 resection of malignancy, or perioperative complications. Long-term outcomes such as remission of myasthenia gravis and thymoma recurrence were similar in open and minimally invasive groups, although follow-up time was limited across studies. Friedant et al. performed a systematic review and meta-analysis of minimally invasive versus open thymectomy for malignancy [26]. They too reported a lower estimated blood loss during minimally invasive thymectomy with a standardized mean difference of −0.78 (95% CI: −1.05, −0.51). Length of hospital stay was also shorter for minimally invasive groups (standardized mean difference −0.88; 95% CI: −1.52, −0.24). There were no significant differences in operative time, rates of R0 resection, complications, or locoregional cancer recurrence.

Outcomes of Robotic Versus Nonrobotic VATS Thymectomy

Few studies have directly compared outcomes for robotic and nonrobotic VATS thymectomy. Ye et al. reported a series of 25 unilateral VATS procedures compared to 21 unilateral robotic VATS procedures for Masaoka stage I thymoma. No significant differences was noted in operating time or estimated blood loss, but a shorter pleural drainage time (1.1 days vs. 3.6 days; $P < 0.01$) and length of hospital stay (3.7 vs. 6.7; $P < 0.01$) was seen in the robotic VATS group. There were similar conversions to open surgery (VATS-1; robotic VATS-0) and incidence of postoperative complications (VATS-1; robotic VATS-1). Robotic VATS as anticipated incurred a significantly higher mean hospitalization cost ($8662 vs. $6097; $P < 0.01$) [27]. Ruckert et al. conducted a cohort study of 79 VATS versus 74 robotic VATS thymectomies for myasthenia gravis. Both groups were well matched with respect to age, sex, and disease severity, and there were similar operating times (198 ± 48 vs. 187 ± 48 min), rates of open conversion [1(1.3%) vs. 1(1.4%)], and postoperative morbidity [2(2.5%) vs. 2(2.7%)] in the VATS and robotic VATS groups, respectively [28].

Marulli and colleagues reported a series of 100 patients undergoing robotic thymectomy for myasthenia gravis. Postoperative complications occurred in 6 (6%) of patients, and median hospital stay was 3 days (range 2 to 14 days) [29]. Ruckert et al. reported a series of 106 consecutive robotic thymectomies for myasthenia gravis, with a 1% rate of open conversion and 2% rate of postoperative morbidity [30].

The purported benefits of a robotic approach are related to its narrow nature and the rigid chest wall. With the use of CO2 this space is widened, resulting in improved visualization and operability. In comparison to VATS, the complications are similar. With regard to clinical outcomes, there appears to be no significant difference, although some suggest that there is a quicker improvement in quality of life and shorter hospital stay.

Conclusion

Various modes of thymectomy have been established in the treatment of thymic pathologies. VATS and robotic-assisted VATS thymectomy have proven to be safe alternatives to open techniques and clearly improve outcome, based on blood loss, hospital length of stay, healing time, and cosmetic appearance. Long-term outcomes such as remission of myasthenia gravis and thymoma recurrence also appear to be comparable. Although the current studies do not provide sufficient evidence establishing superiority in terms of resection but definitely give an edge over decreasing morbidity postoperatively and also improving quality of life. Additionally, numerous techniques have been developed and described using these robotic and nonrobotic VATS technologies, each with their own inherent advantages and challenges. As experience with these minimally invasive techniques continues to grow, clear guidelines can be formulated.

Key Clinical Points

1. Myasthenia Gravis (MG) and Thymoma share a common surgical treatment where in numerous approaches have been described.
2. VATS results in better pain tolerance, preserved pulmonary function and increased cosmetic acceptance.
3. VATS clearly takes an edge over and above open surgery in complete stable remission from MG and symptomatic improvement, without compromising safety.
4. VATS thymectomy may be performed with a unilateral thoracoscopic, bilateral thoracoscopic or infrasternal/subxiphoid approach using the conventional three port or the more recent uniport method.
5. The risk of myasthenic crisis after thymectomy can be considerably reduced by appropriate patient selection and planning surgery only after the myasthenic symptoms are well controlled.
6. Myasthenic patients pose no particular anaesthetic problems, although long-acting muscle relaxants should be avoided. Deep anaesthesia is maintained by an inhalational agent and short-acting narcotic.
7. A preoperative MDCT with 3D reconstruction of thymic veins has been cited to be additionally useful step in ensuring operative safety during thymectomy.
8. In thoracoscopy, the right-side approach is common for any non-thymomatous myasthenia gravis, as it serves with ample manipulation space with the heart safely kept away.
9. Left sided thymoma is better taken from left side.
10. Lung exclusion is usually obtained by using double lumen endotracheal tube in conjunction with carbon dioxide insufflation (5–8 mmHg pressure at 4 L/min flow rate). Carbon dioxide insufflation alone can be used for lung collapse keeping the pressures to 6–8 mmHg throughout the surgery which alleviates the need of a double lumen tube.
11. All concerns with laparoscopic surgery are also alleviated by robotic surgery as any patient who can virtually undergo thymectomy by open technique can undergo thymectomy using the robotic technique.
12. Left sided approach is possible easily with robotic surgery in spite of less space, which leads to more complete removal of all thymic tissue preventing myasthenia gravis developing post-operatively even in patients only presenting with thymoma.
13. A single chest tube suffices when both pleural cavities are open and connected.
14. Completeness of the thymus specimen along with the thymic bed should always be inspected for complete removal.

Editor's Note[1]

VATS thymectomy approach: Thymectomy was traditionally performed using a median sternotomy or cervical incision using the open approach. With the advent of minimally invasive procedures like video assisted thymectomy (VATS) and robotic thymectomy (RVATS) the need to perform more morbid open operations have decreased especially in early disease. The limited space in the anterior mediastinum and need for bilateral approach were the initial problems envisaged in use of VATS approach for thymectomy. The use of laprolift to lift the sternum, CO2 insufflation and bilateral approach when needed has to a large extent circumvented these problems. VATS thymectomy may be performed with a unilateral thoracoscopic, bilateral thoracoscopic or infrasternal/subxiphoid approach using the conventional three port or the more recent uniport method.

Subxiphoid approach: The proponents of the subxiphoid approach for thymectomy propose a lower postoperative pain with the approach as the risk of intercostal nerve injury is minimized as compared to the lateral VATS approach. Additionally, the mediastinal anatomy using this approach is similar to open sternotomy approach. A better aesthetic outcome has also been suggested. Nevertheless, the risk for bleeding from major veins like the innominate vein, maybe difficult to control [1]. A preoperative MDCT with 3D reconstruction of thymic veins has been cited to be additionally useful step in ensuring operative safety during thymectomy.

Outcome -open/ VATS/robotic: A lower intraoperative blood loss, shorter hospital stay, lower complication rates, lesser pulmonary complications, similar mean specimen weight and remission rates have been noted in the VATS approach in meta-analyses comparing open and VATS thymectomy for myasthenia gravis [2, 3]. The results of VATS approach have been encouraging for selected early stage thymomas. When compared with open sternotomy approach lower blood loss, chest drainage, hospital stay has been cited with no difference in R0 resection rates or postoperative recurrence [4–6]. In two systemic review and meta-analysis comparing the VATS with RVATS approach, the two procedures were found to have similar outcomes other than a longer operative time with RVATS (Table EN1) [7, 8].

[1] References: Main chapter references are included after the "References Editor's Note" section.

Table EN1 Comparison of various approaches for VATS thymectomy - advantages and disadvantages [31]

Approach	Working space	Vessel			Nerves		Lung	Pericardium	Tumor resection	Anatomical problem
		Brachiocephalic vein	Intrathoracic vein and artery	Thymic vein and artery	Phrenic nerve	Recurrent nerve (left)				
Trans-cervical	Limited	Possible	Possible	Possible and partially difficult	Difficult	Good	Impossible	Difficult	Limited to small tumor	Impossible to resect large tumor; Impossible to approach lower portion of thymus
One-sided Trans-intrathoracic	Limited but same side: Good Other side: Limited	Possible and partially difficult	Same side: Good Other side: Difficult	Possible and partially difficult	Same side: Good Other side: Difficult	Impossible	Good	Good	Needed intercostal thoracotomy; postoperative pain	Impossible to resect cervical portion; difficult to approach another part of thymus
Bilateral trans-intrathoracic	Good	Possible	Good	Good	Good	Impossible	Good	Good	Needed intercostal thoracotomy; postoperative pain	Difficult to resect cervical portion

(continued)

Table 1 (continued)

Approach	Working space	Vessel			Nerves		Lung	Pericardium	Tumor resection	Anatomical problem
		Brachiocephalic vein	Intrathoracic vein and artery	Thymic vein and artery	Phrenic nerve	Recurrent nerve (left)				
Trans-subxiphoid	Limited	Possible and partially difficult	Possible and partially difficult	Possible and partially difficult	Possible and partially difficult	Impossible	Possible	Possible	No need for thoracotomy	Difficult to resect cervical fat portion completely; difficult to approach the upper portion of left innominate vein

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