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Robotic Surgery of the Mediastinum: A Review

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Abstract

Background: The mediastinum is a complex anatomical region which contains many vital structures. Many aspects of mediastinal surgery, like that for other anatomic regions, have evolved from a maximally invasive approach involving a median sternotomy, anterior mediastinotomy, mediastinoscopy or thoracotomy, to a minimally invasive video-assisted approach. Robotic surgery is presently the most advanced form of minimally invasive surgery. **Methods:** We reviewed our experience with a robotic approach to mediastinal pathology. In addition, an extensive search was conducted using PubMed, in order to extract references for the application of robotics to surgical conditions of the mediastinum. **Results:** The first robotic procedure by our group was a mediastinal procedure in 2003. In the past eighteen years, 203 patients have undergone robotic surgery for mediastinal pathology. There were 119 procedures for the Anterior Mediastinum, 33 procedures for the Middle Mediastinum, and 51 procedures for the Posterior Mediastinum. 78 patients underwent robotic thymectomy using a left-sided approach. 43/78 (55%) patients underwent radical thymectomy for Myasthenia Gravis. Thymoma was histologically identified in 32% of patients with Myasthenia Gravis. In patients with thymoma, there was no tumor recurrence. In patients with Myasthenia Gravis, the overall improvement rate after robotic radical complete thymectomy was 91% (39/43). Following robotic surgery for the mediastinal disease, the median hospitalization was 3 days, major complications occurred in 0.9% of patients and there was no mortality. **Conclusion:** With the advent of robotic surgery, many of the current surgical approaches to diseases of the mediastinum will likely be replaced over time by robotic surgery. When applied to the mediastinum, robotics has a number of benefits when compared to conventional Video-Assisted Thoracic Surgery (VATS) including three-dimensional visualization, magnification of the operative field, precise instrument movement, and improved dexterity. Much of the mediastinal disease encountered in an adult is benign, making it especially suited to a minimally invasive approach. With the use of the robot, a complete anatomical and oncological procedure can be performed through a number of small incisions or ports, while at the same time providing the patient with minimally invasive benefits including shorter hospitalizations, quicker returns to preoperative activity, less pain, less inflammatory response and better cosmesis. The excellent range of motion of the robotic instruments makes them particularly suitable to maneuver around the vital structures and the rigid axial skeleton encountered in various compartments of the mediastinum, and for reaching those "distant" areas of the mediastinum that are difficult to explore and dissect with conventional Video-Assisted Thoracic Surgery (VATS).

Keywords

Mediastinum, Robotic Surgery, Anterior Mediastinal Mass, Posterior Mediastinal Mass

1. Introduction

The mediastinum is the portion of the thorax which lies between the two pleural cavities and is bound laterally by the mediastinal pleura. It extends from the thoracic inlet superiorly to the diaphragm inferiorly and from the vertebral bodies posteriorly to the sternum anteriorly. Historically, the mediastinum is divided in an arbitrary fashion into compartments for the purpose of localizing various lesions. These classifications have been based on the position of the lesion on a lateral chest X-ray, because the mediastinal structures are mainly in the anterior to the posterior axis. However, the demarcation of these compartments has been based on imaginary lines superimposed on chest radiographs.

Historically, two main classifications have been used. The first divides the mediastinum into an anterior, superior, middle, and posterior compartment.

The traditional 4 compartment model (Figure 1) is based on the lateral radiograph. These compartments are demarcated by dividing the mediastinum into a superior and inferior division, with the latter being divided into anterior, middle, and posterior compartments. The superior mediastinum is the area above an imaginary plane extending from the manubrio-sternal junction posteriorly to the inferior border of the T4 vertebral body. This plane corresponds roughly to the aortic arch and the tracheal bifurcation. It contains all the structures passing through the superior inlet. The rest of the mediastinum is divided into 3 more compartments, anterior, middle, and posterior. The anterior mediastinum is located between the back of the sternal body and the anterior surface of the pericardium. It contains the main body of the thymus and the pre-aortic lymph nodes in stations 5 and 6. The middle mediastinum, located between the anterior and posterior, is occupied by the pericardium, the carina, the proximal main bronchi and the tracheobronchial lymph nodes of stations 2R and 2L, 4R and 4L, and 7. The posterior mediastinum, located between the back of the pericardium and the anterior spinal ligament contains the esophagus the aorta at the nerves the ganglia and the thoracic duct.

The traditional 3 compartment model (Figure 2) combines the anterior and superior into an antero-superior compartment, and similarly includes a middle and posterior compartment. The latter classification is easier to understand and

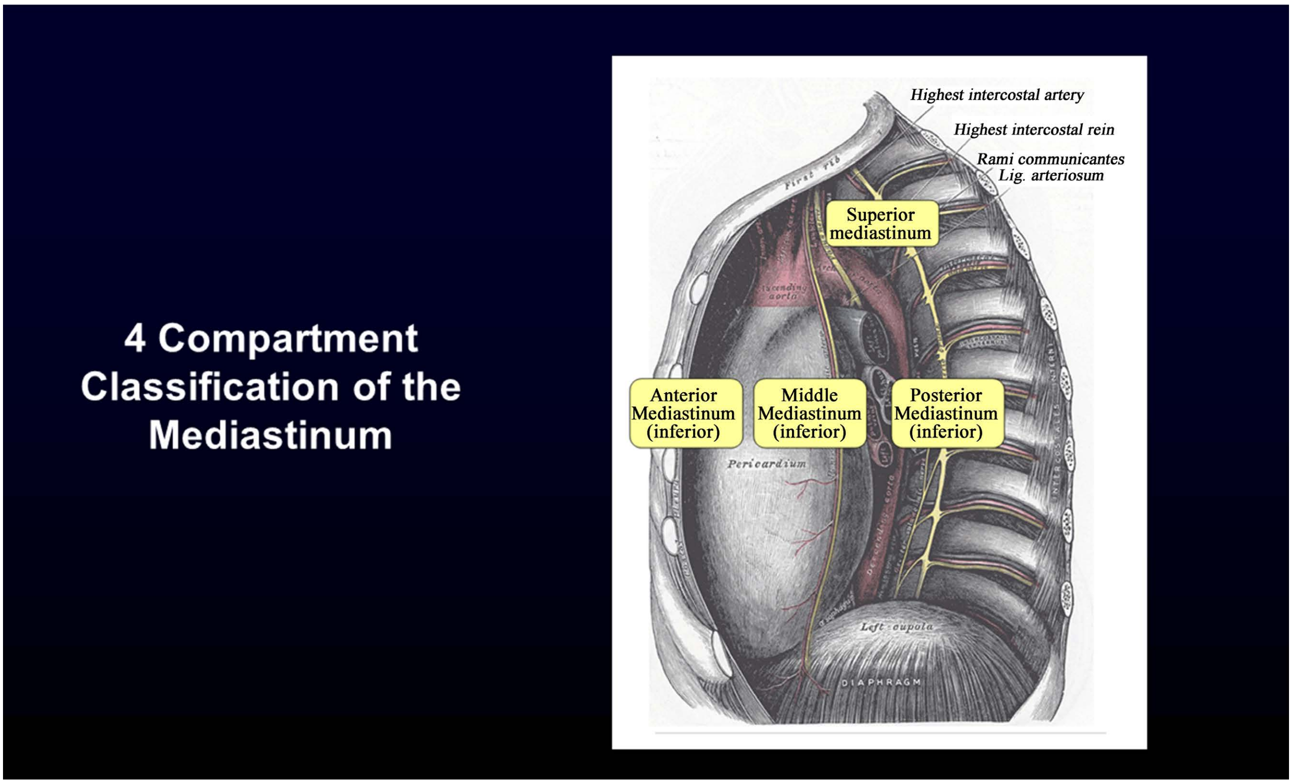

Figure 1. Four compartment classification of the mediastinum.

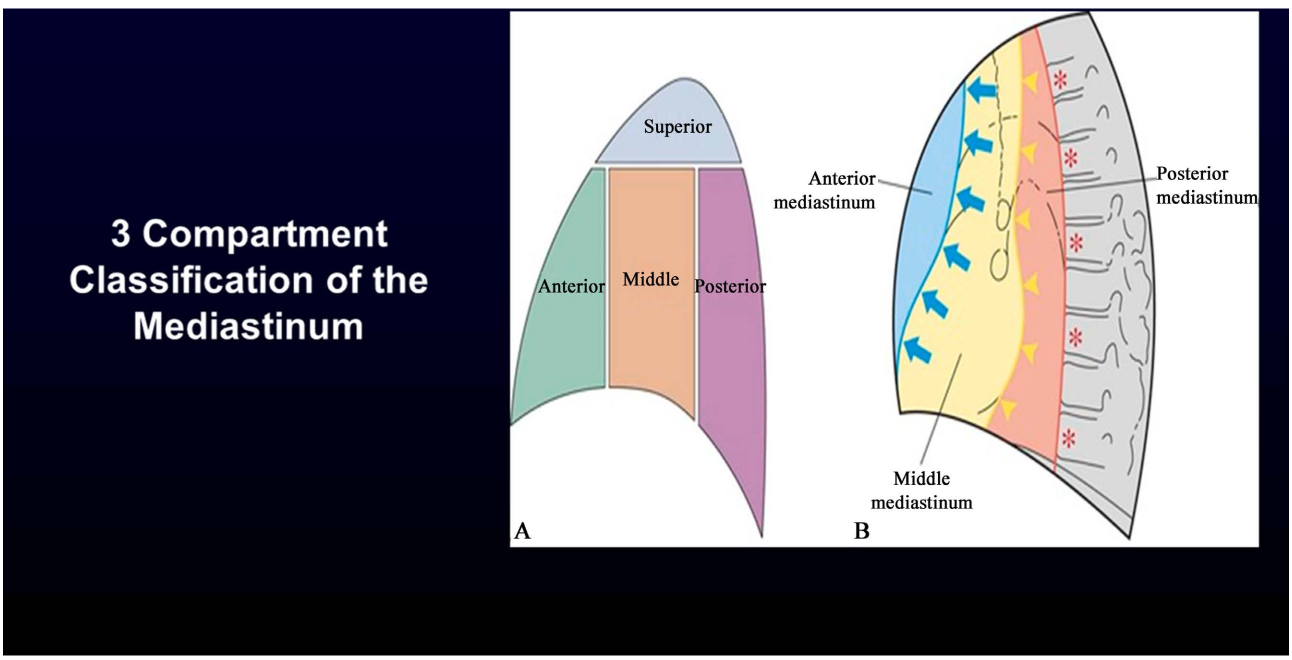

Figure 2. Comparison of the 4 compartment and 3 compartment classifications of the mediastinum.

to conceptualize from both a pathological and a surgical standpoint.

The antero-superior compartment is bordered by the sternum anteriorly and extends posteriorly to the pericardial reflection and innominate vein. The middle mediastinum is bordered anteriorly and posteriorly by the pericardium, extending only as high as the pericardial reflection. The posterior mediastinum extends from the ventral aspect of the vertebral bodies to the ribs and includes the costovertebral angles.

A variant of the 3-compartment model was described by Shields in 1991 [1]. This classification which is more relevant to surgical approaches to the mediastinum, consists of an anterior compartment, the visceral compartment, and the paravertebral sulci bilaterally (**Figure 3**). Each compartment extends from the thoracic inlet to the diaphragm. At their cervical aspect, these 3 compartments correspond to the 3 anatomic dissection zones. The *Anterior Compartment*, located between the undersurface of the sternum and the anterior surface of the great vessels, can be called the Prevascular Zone. The *Visceral Compartment* is located behind the pericardial reflection and contains the heart, great vessels, and the trachea, which can be called the Visceral or Pretrachael Zone. Posterior to these two zones is the *Paravertebral Sulcus* which is also referred to as the Retrovisceral Zone or Periesophageal Zone, and is the only paired component of the mediastinum.

The pathology found in each compartment is related to the structures contained within each compartment. The anterosuperior compartment contains the thymus, lymphoid tissue, aortic arch with its branches and the great veins. The

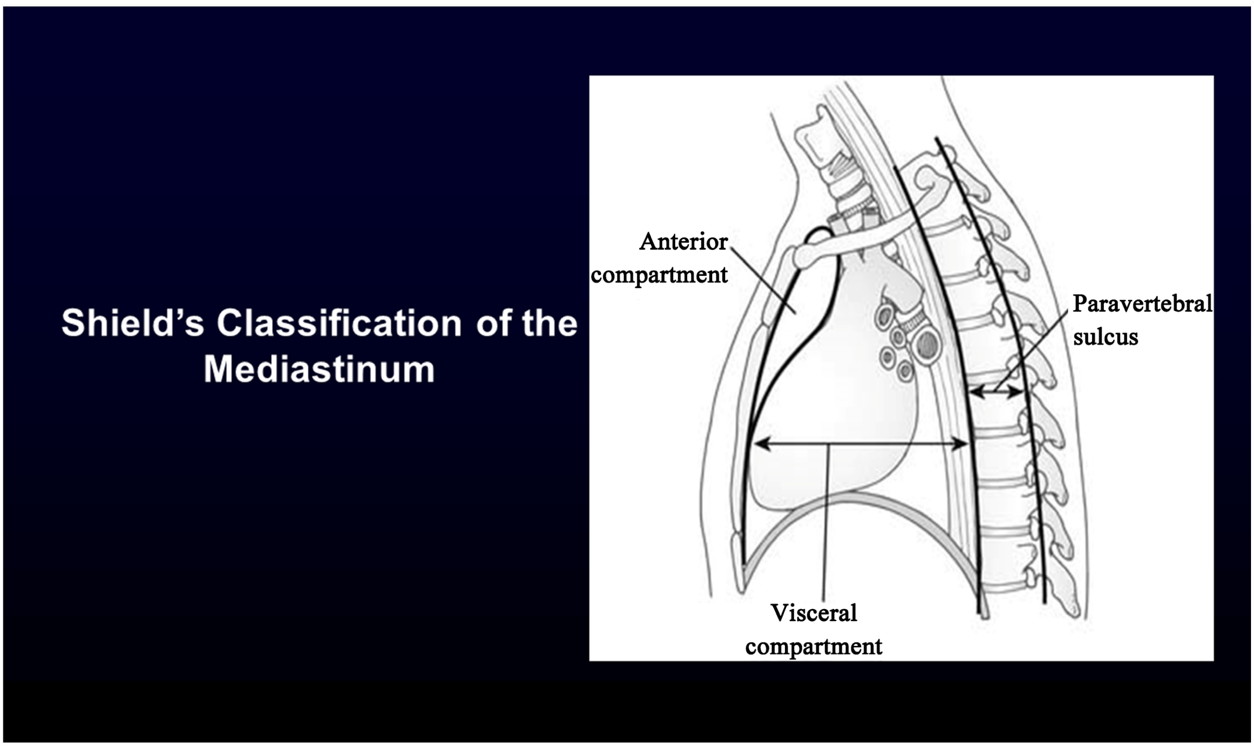

Figure 3. Shield's surgical classification of the mediastinum.

middle compartment contains the phrenic nerves, pericardium, heart, tracheal bifurcation, pulmonary hila and lymphatic tissue. The posterior compartment contains the esophagus, vagus nerves, descending aorta, azygous and hemiazygos venous systems, sympathetic chain, thoracic duct and lymphatics.

2. Pathology

The different compartments of the mediastinum are typically affected by unique processes. The diseases most commonly detected in the anterosuperior compartment in an adult include thymic tumors, lymphoma and germ cell tumors. Less common diseases include substernal extension of a goiter or a true rare ectopic thoracic thyroid, parathyroid adenomas, thymic cysts, thymo-lipomas, and diseases of the aorta. The middle compartment is affected by cysts of the pericardium and bronchus as well as pathologic processes of the hilar and mediastinal nodes. The posterior compartment is affected predominantly by neurogenic tumors. Less commonly enteric or neuroenteric cysts occur in the posterior compartment. The most common mediastinal masses are neurogenic tumors (20%), thymomas (20%), cysts (20%), lymphomas (13%) and germ cell tumors (10%). Antero-superior masses are more likely to be malignant.

3. Clinical Presentation

It is estimated that about two thirds of patients with a mediastinal tumor will be symptomatic at the time of presentation. The most common symptoms include chest pain, cough, dyspnea and fever. Patients presenting with symptoms related to compression of surrounding structures are more likely to have a malignant tumor. Other patients may present with symptoms secondary to hormone production by mediastinal lesions. Patients with a benign tumor are more likely to be asymptomatic.

4. Traditional Surgical Access to the Mediastinum

Pre vascular zone:

Cervical approach with extended mediastinoscopy: A transverse incision in the suprasternal notch traverses the superficial layer of the deep cervical fascia down were dissection allows the transcervical thymectomy and exposure to other tumors in this plane along with lymph nodes in stations 5 and 6 [2].

Anterior mediastinoscopy, Chamberlain procedure: This procedure which was described by Chamberlain in 1966 consist of entering the prevascular substernal space on either side with the parasternal incision carried through the interchondral interspace or through the space of an excised 2nd costal cartilage [3]. This is particularly useful for biopsies of the preaortic lymph nodes in stations 5 and 6.

4.1. Retrovascular, Pretracheal Zone

Classic cervical mediastinoscopy: This procedure was first described by Carlens in 1959 [4]. A transverse incision in the suprasternal notch traverses the superficial layer of the deep cervical fascia including the slap muscles. By deepening the suprasternal notch incision beyond the great vessels and traversing the next layer of deep cervical fascia in the pretracheal space, it is possible to enter the Retrovascular or Pretracheal plane. By blunt digital dissection while remaining anterior to the trachea, access is obtained to the pretracheal and paratracheal areas, the subcarinal area and the two main bronchi. Lymph nodes of stations 2R and 2L, 4R and 4L, and 7 are located in these areas [5].

4.2. Posterior, Prevertebral Zone

Historically conventional approaches to this region of the mediastinum have been limited to drainage of abscesses and mediastinal infections.

Cervical neck approach: A cervical incision is made along the anterior border of the sternocleidomastoid muscle. The middle thyroid vein is divided, and the buccopharyngeal fascia is traversed, the trachea is retracted medially and the carotid sheath is retracted laterally in order to enter the prevertebral, periesophageal space. This approach to the posterior mediastinum is usually necessitated for the drainage of abscesses located in the superior posterior mediastinum.

In addition, more invasive procedures such as an extended thoracotomy approach to the posterior mediastinum, thoracotomy approach to the mediastinum, and sternotomy for access to the anterior mediastinum have been used.

Clearly the conventional surgical approaches to the mediastinum are hampered by difficulty in visualization, limited instrument maneuverability in a confined space, lack of full access to the anatomic structures, potential life-threatening complications due to the presence of a large vessels and possibility of catastrophic bleeding as well as damage to vital structures such as the trachea the heart and the esophagus.

Robotic surgery of the mediastinum is a new and evolving technology. Reports of use of the da Vinci® robot for mediastinal surgery are few. Since we began performing robotic surgery in 2003, we have attempted to perform almost all of our mediastinal surgery using this minimally invasive technique. Advantages include those of the minimally invasive nature of the procedure, with no evident disadvantages provided all basic surgical principles and tenets are respected. The most important rule is to ensure a complete and safe resection equivalent to a conventional "open" approach. At no time should oncological principles be violated. The advantages of minimally invasive thoracic surgery have been documented by several authors and include decreased pain [6] [7] [8] [9], decreased inflammatory response [7], less blood loss [8] and shortened hospital stays with quicker returns to pre-operative function [9].

5. Robotic Surgical Approach

The surgical approach with the three or four arm port-based DaVinci Si and Xi is illustrated for each of the areas of the mediastinum.

5.1. Anterior Compartment or Anterior Mediastinum

Thymic disease:

Our preferred approach is a left-sided robotic approach to thymectomy. The patient is placed in a supine position with downward rotation to the right side 30˚ [10] [11] (**Figure 4**). A beanbag can be used for exact positioning. The left arm is positioned posterior to the chest wall in order to facilitate the movement of the right robotic arm. Single lung ventilation is obtained using a double-lumen endotracheal tube. The operative field is prepped and draped for possible conversion to a median sternotomy or access to the right chest. A 12 mm trocar is placed in the 4th intercostal space at the anterior axillary line (Camera Port). In smaller patients this trocar can be placed between the anterior and mid axillary lines. A Zero (O) degree Endoeye endoscope (Olympus Corporation) is introduced through this trocar and used to determine the position of the other trocars. We prefer the use of this endoscope for trocar placement. After the trocars are in place the DaVinci camera is introduced through the camera port. It is imperative that the camera view the left phrenic nerve directly as the position of the phrenic nerve in the anterior mediastinum determines the point of reference for the dissection. After the trocars are placed, a 30 degree robotic camera is introduced through this port. An 8 mm trocar is placed in the 3rd intercostal space anterior to the mid axillary line in the sub mammary fold. This trocar is used for the right arm of the robot which can carry a curved Maryland Bipolar Dissector or a Permanent Hook Cautery instrument. These instruments in the right hand provide for accurate dissection. We do not use a harmonic dissector in this procedure. Another 8 mm trocar is placed in the 5th intercostal space at the midclavicular line along the mammary fold. This trocar is used for the left arm of the robot and can carry a curved Maryland Bipolar Dissector or Long Tip or Cadiere Forceps. At times we will use a 5 mm port below the camera port in the mid axillary line in the 6th intercostal space as an Accessory Port. In certain cases, due to technical considerations, the assistant can use the Accessory port for retraction.

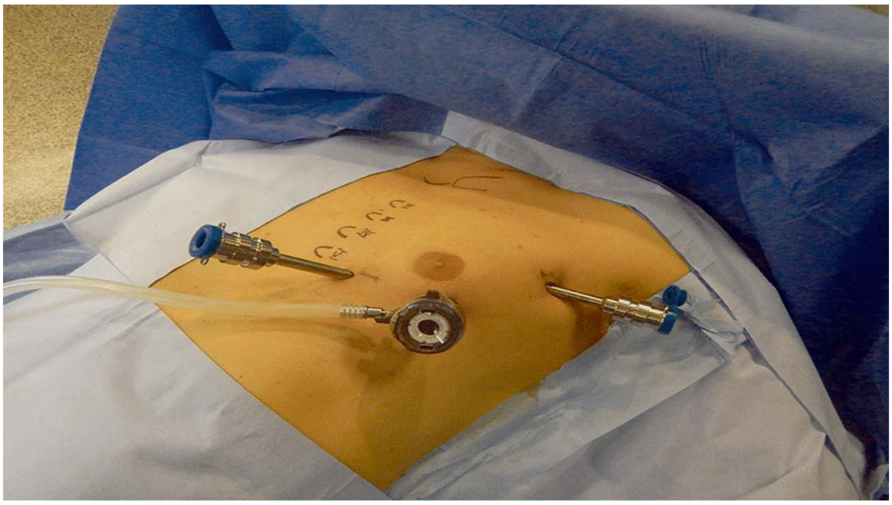

Figure 4. Robot positioned for a left sided thymectomy.

CO_2 is insufflated through the camera port at a flow of 6 to 8 ml/min at a set pressure ranging from 6 - 10 mm Hg. The dissection begins anterior to the phrenic nerve and is extended inferiorly to the left pericardio-phrenic angle. All mediastinal tissue including all fatty tissue is isolated from the phrenic nerve and swept anteriorly. The enblock resection extends to the right xipho-pleural fold. Next, the retrosternal pleura is opened, and dissection is continued to the jugular fold. All fatty tissue is then mobilized from the pericardium. The dissection is carried over the pericardium under the sternum into the right side. The aortocaval groove is dissected free and the right lung is exposed. The anterior wall of the brachiocephalic vein is uncovered and the venous branches extending from the top of the thymus to the brachiocephalic vein are divided between clips. Next the mobilization of the upper poles of the thymus is continued by following the brachiocephalic vein. During the dissection of the upper pole of the left thymic lobe care is taken to separate it gently from the phrenic nerve and avoid injury to the nerve which is usually very close to the thymic pole. By grasping the thymic poles, the thyro-thymic ligament is visualized and divided. Next the right phrenic nerve is identified, and the right thymic pole is separated from the nerve and the nerve is skeletonized by dissection along its path in a caudal direction. The right pleural space is widely opened in order to communicate with the left pleural space. A 28 French chest tube is inserted through the thoracostomy port site in the 5^{th} intercostal space and the lungs are inflated. The patient is extubated in the operating room.

The right sided port placement and robot positioning is shown in Figure 5.

Non-thymic anterior mediastinal mass:

In patients with non-thymic anterior mediastinal disease our robotic approach is slightly different. We use this approach to all other anterior and middle mediastinal disease. Single lung ventilation is utilized with placement of a double lumen endotracheal tube. For a right sided approach, the patient is placed in the

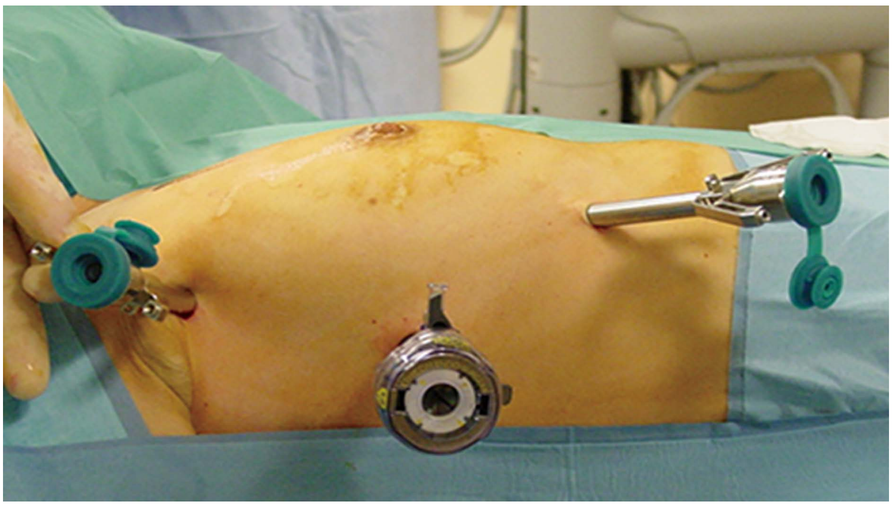

Figure 5. Robot positioned for a right sided thymectomy.

left lateral decubitus position. The standard approach is utilized with ports placed in a lazy V type configuration. The camera port (12 mm) is placed in the 8th ICS in the mid axillary line, with the two additional ports (8 mm) in the 6th ICS in the anterior axillary line and 5th intercostal space in the posterior axillary line. The ports are separated from the adjacent port by one hand's breadth. An accessory port 8mm is placed in the 7th intercostal space in the anterior axillary line. CO_2 insufflation is used. The positioning of trocars is similar for a left sided approach however the instruments and arms are reversed (**Figure 6**, **Figure 7**). The robot is brought in over the head of the patient. A 30˚ camera is used. Instruments similar to the robotic thymectomy procedure are used [12]-[31].

5.2. Visceral Compartment or Middle Mediastinum

Lymphadenectomy:

In certain clinical circumstances, mediastinal lymphadenectomy or biopsy would be indicated. This includes lymphadenopathy of unknown etiology: possible sarcoid, lymphoma or metastatic disease from lung cancer or other malignancies are examples. The robotic is ideally suited to dissection and biopsy of both mediastinal and hilar nodes, the latter may be particularly difficult to biopsy through a VATS technique. We would approach this using a standard technique for other non-thymic mediastinal masses.

After positioning the robot, the mediastinal pleura is incised and reflected off

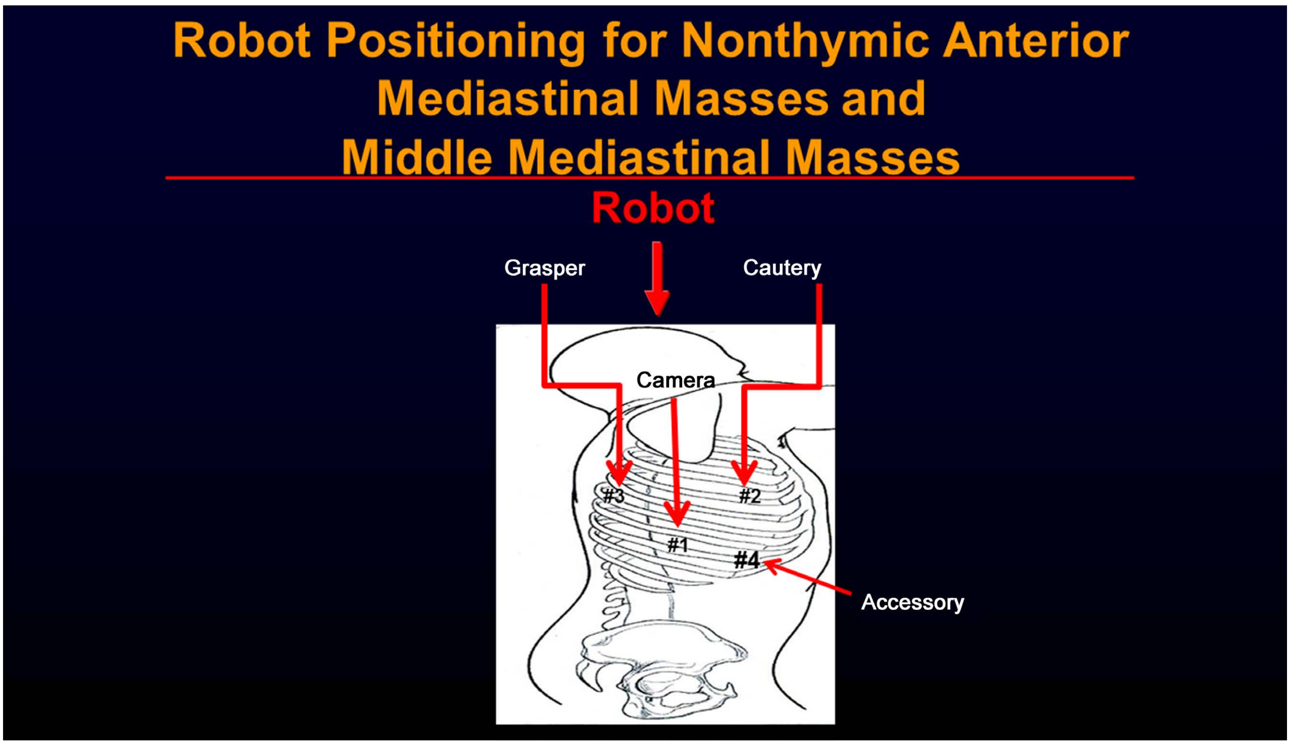

Figure 6. Port placement and robot positioning for right sided approach to non-thymic anterior mediastinal pathology and middle mediastinal pathology.

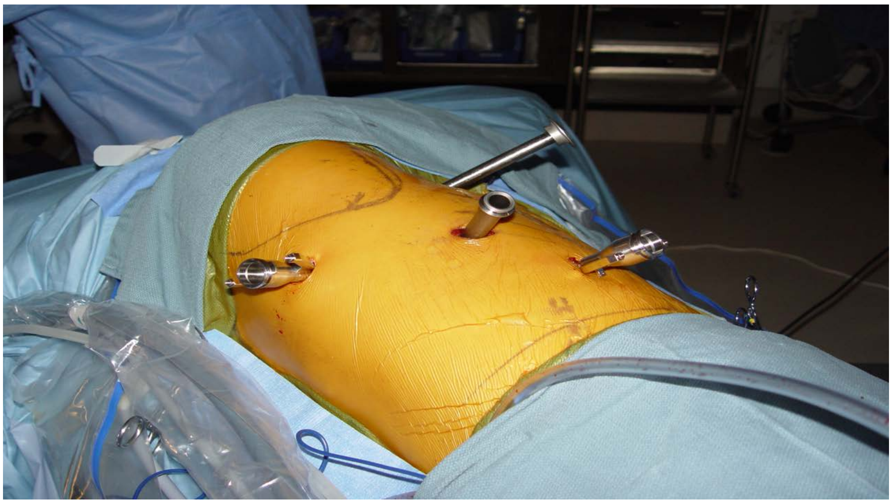

Figure 7. Ports in place for right sided approach to non-thymic anterior mediastinal pathology and middle mediastinal pathology.

the nodal basin. Care is taken to avoid vital structures including the phrenic nerve, particularly on the left where it is more difficult to visualize. In the subcarinal space which we routinely approach from the right side, care must be taken to avoid the esophagus and vagus nerves. While dissecting in the A-P window, the dexterity and range of motion of the robotic is particularly useful in avoiding damage to the recurrent laryngeal nerve. The nodes are gently elevated and dissected free using the electrocautery. Retraction of structures and maintenance of a dry field is performed by the use of rolled gauze by the surgeon or the assistant using a suction catheter. All vasculature is coagulated or clipped with the latter being placed robotically. Once the node is freed it is placed in a specimen bag and removed. Hemostasis is ensured and the chest is closed in the standard fashion.

Other examples of the application of the robotic approach to pathology with difficult access in the visceral compartment or middle mediastinum are:

1) Patients with retained thyroid or other malignancies that have extended not into the anterior compartment but into the visceral compartment or the posterior superior mediastinum.

2) Although the majority of thyroid goiters extend into the anterior compartment, on occasion patients with a large thyroid goiter can have extension into the posterior superior portion of the visceral mediastinum.

3) Bronchogenic cysts: These cysts are the most common cysts of the mediastinum. They arise from the embryonic ventral foregut and are usually located in the right paratracheal or subcarinal position. They may also be located within the pulmonary parenchyma. While they are likely to be asymptomatic, the possibility of infection within the cysts or compression of the esophagus, trachea or bronchi exists. Rarely does the cyst communicate with the tracheobronchial tree. At times, it is difficult to distinguish the cyst from subcarinal nodes. Surgical resection is indicated in all cases to confirm the diagnosis, to alleviate any symp-

toms and to prevent complications. Malignant transformation has rarely been described. These cysts may be densely adherent to surrounding tissue and a complete excision is not always possible. No vital structure should be compromised, and incomplete resection is adequate with deepithelialization of the remaining wall. The cysts are approached from the right side. Surgical technique involves placement of a double lumen endotracheal tube. Single lung ventilation is utilized. The patient is placed in a left lateral decubitus position. The trocar and robot positioning technique for the non-thymic anterior and middle media-stinal masses is used. The cyst is grasped and an attempt is made to excise it completely. These lesions are often densely adherent to surrounding tissue including the trachea, bronchi and esophagus. Care must be taken to avoid damage to these structures during the dissection. In the case of dense attachment to surrounding structures, we excise as much as possible of the cyst wall after aspirating its contents, and gently coagulate the remaining portions of the wall. The lesion is placed in a plastic specimen bag and removed. Frozen section is obtained to ensure its benign nature. Hemostastis is confirmed. Subpleural catheters are placed for post-operative pain management. A single chest tube is placed posteriorly in the apex of the chest through the auxiliary port. All instrumentation is removed and two lung ventilations are initiated. The wounds are closed in the standard fashion.

4) Pericardial cysts: These cysts are the second most common mediastinal cysts and are classically located in the cardiophrenic angles with 70% right-sided, 22% left sided and the remainder being attached to other portions of the pericardium. Communication with the pericardium is possible (5%). They were classically described as "spring water cysts" due to their clear fluid content. The cysts are usually asymptomatic. If diagnosed incidentally, observation or simple aspiration is the initial treatment of choice. Should these cysts recur following aspiration or should the diagnosis be questionable, then excision is indicated. The patient is placed in a left lateral decubitus position. The trocar and robot positioning technique for the non-thymic anterior and middle mediastinal masses is used. The robot is positioned at the head of the patient. Any adhesions between the cyst and the lung are divided with the electrocautery. The cyst is grasped and dissected off the pericardium using the electrocautery. Should the cyst be adherent to surrounding structures, the cyst may be unroofed after aspirating the fluid and the cyst wall should be excised as possible. A single chest tube is placed through the retractor site at completion of the procedure. Subpleural catheters are placed and the wounds are closed in the standard fashion.

5.3. Posterior Compartment: Posterior Mediastinum and Paravertebral Sulcus

In both adults and children, the majority of posterior mediastinal masses are of neurogenic origin. Most of these masses in adults (95%) are benign and are usually asymptomatic. On the other hand, most neurogenic tumors in children are malignant. Neurogenic tumors may arise from intercostals nerves (neurofibroma, neurilemoma and neurosarcoma), sympathetic ganglia (ganglioma, ganglioneuroblastoma and neuroblastoma) or paraganglia cells (paraganglioma). A CT scan is usually sufficient from a diagnostic point of view, although any possibility of intraspinal extension (10%) should be evaluated with a MRI. Preoperative biopsy in an adult is usually not indicated unless the tumor displays unusual characteristics and a malignant tumor is likely.

These lesions are approached in our standard fashion as described above. Single lung ventilation utilizing a double lumen endotracheal tube is initiated. The patient is placed in a lateral decubitus position. For posterior mediastinal masses we use a "V" type placement with the camera at the base of the V. Should the tumor be very low in the thorax, an inverted V type configuration would be used with the camera being placed at a higher interspace.

The robot is then brought in and positioned over the head of the patient for mid or superiorly placed lesions. For lower lesions, the robot is brought in alongside the patient's back (Figure 8).

The pleura adjacent to the mass is incised and the mass is slowly mobilized off the ribs and vertebral bodies. The ability of the robotic endowrist™ to work in 7 degrees of freedom and at 90˚ angles is particularly useful when working between the mass and the ribs. When dealing with an apical mass, the apical portion should be the last area mobilized. Having mobilized all but the apex will allow more traction to be applied while freeing the apical portion and thus

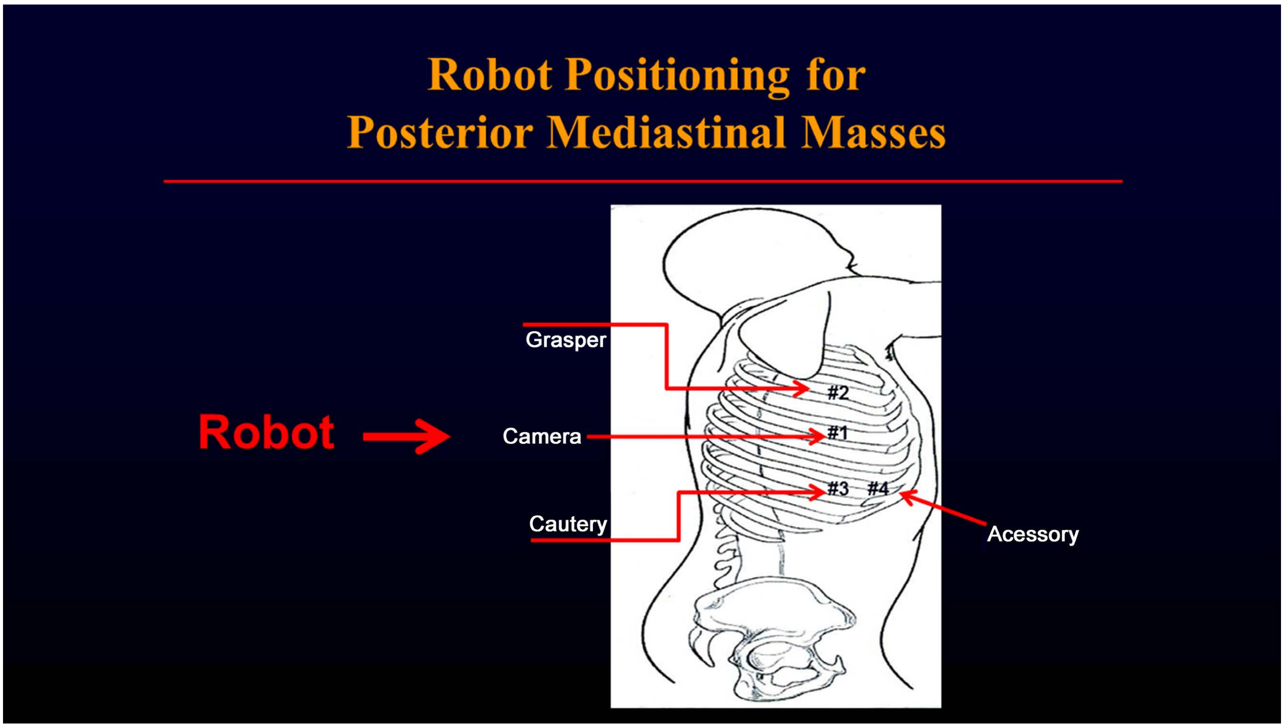

Figure 8. Port placement and robot positioning for right sided approach to the paravertebral sulci and the posterior mediastinum.

avoiding potential damage to the stellate ganglion and subclavian vessels. The neural origin and any vascular supply are clipped with large clips introduced through one of the port sites. The mass is thus freed and placed in a plastic specimen bag. If this is a large mass, this is in turn placed in a second specimen bag and after lubricating the interface between the bags, the mass (within the first bag) is removed through a port site. The site is enlarged as needed in order to extract the lesion. We use one or two subpleurally placed catheters for the constant infusion of bupivicaine 0.5% in the perioperative period. A single chest tube is placed posteriorly in the apex of the hemithorax through the lowest anteriorly port. The lungs are re-inflated under direct vision. Wounds are closed with interrupted polydiaxonone at the muscle layer. The subcutaneous tissues are approximated with absorbable sutures and the skin is closed with a subcuticular absorbable suture.

A Similar approach is used to access the upper portion of the esophagus from the right side.

Another example of esophageal pathology which is amenable to robotic resection is an esophageal duplication cyst.

Fibrous tumors of the paravertebral gutter can be approached in a similar manner.

6. Conclusion

Robot mediastinal surgery is an evolving field incorporating the well-established principles of conventional open surgery yet utilizing the most advanced minimally invasive techniques and instruments available. While limitations of our current VATS techniques have made certain procedures hazardous and inadvisable and thus limited the overall acceptance of minimally invasive surgical options to the mediastinum, robotic instrumentation and technology have made the minimally invasive approach to mediastinal pathology, safe, and ontologically and immune-biologically efficacious. As experience is gained, it is likely that procedures once considered to be strictly feasible only by open techniques will become routine minimally invasive robotic procedures.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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