Kemp Kernstine
Editor

Atlas of Robotic Thoracic Surgery

Springer

Atlas of Robotic Thoracic Surgery

Kemp Kernstine
Editor

Atlas of Robotic Thoracic Surgery

Springer

Editor
Kemp Kernstine
Division of Thoracic Surgery
UT Southwestern
Dallas, TX
USA

ISBN 978-3-319-64506-3 ISBN 978-3-319-64508-7 (eBook)
https://doi.org/10.1007/978-3-319-64508-7

Library of Congress Control Number: 2018959882

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

I would like to dedicate this book to my dear wife, Cassandra; without her understanding, support, and encouragement, this book would not have been written. I would also like to thank our grown children and my mother for their understanding of the time necessary to complete this book.

Preface

Minimally invasive chest surgery was introduced in the early 1990s and the performance of complex minimally invasive chest procedures soon followed, but there were instrument limitations that hindered full acceptance by the thoracic community. It was not until 2000 that the Food and Drug Administration approved the *da Vinci* system for surgical use. The first descriptions of robotic chest procedures, such as lobectomy, esophagectomy, and thymectomy, appeared in the literature. For each procedure there were different approaches. So for the novice surgeon to learn how to perform the different robotic procedures, there have been few illustrations and photographs in the literature and limited Internet videos, especially there is no available resource repository that provides a description of commonly performed chest procedures and the details to minimize postoperative complications. To satisfy the need we have composed the first surgical atlas of robotic thoracic surgical procedures and it is written for those surgeons who wish to surgically treat their patients using robotic technology.

This book was the vision of Dr. Randolph "Ranny" Chitwood who orchestrated a plan for an atlas of different robotically performed cardiothoracic surgical procedures. The chapter authors were chosen nearly a decade ago for their experience with the procedures and their publication record. Initially, a single volume was planned, but because of the number of procedures and different approaches, it became impractical to put them into a single volume. We divided the book into two volumes, a cardiac and a thoracic surgery volume, each based on similar themes.

For the individual chapter the authors provide the background and indications supporting their robotic procedure, the operative setup, and the anesthetic management. Also included is the illustrated stepwise conduct of the operation outlining the key aspects of each procedure. Given their experience with their robotic surgical approach, they were asked to comment on what they had learned and to provide the tips to perform an efficient, safe, and successful case, and to describe the pitfalls and how have they may be overcome. Finally, the authors were asked to provide us the outcomes of the described robotic procedure(s). This information should be sufficient for a thoracic surgeon and the surgical team to perform the procedure.

Acknowledgements

I would like to thank Ms. Barbara Lopez-Lucio and Mr. Grant Weston from Springer Publishing for their thoughtful guidance and patience in the preparation of this book.

Contents

List of Editor and Contributors

Editor

Kemp Kernstine Sr., M.D., Ph.D. Division of Thoracic Surgery, Robert Tucker Hays Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

Contributors

Pietro Addeo, M.D. Department of Surgery, UIC, Chicago, IL, USA

Rafael S. Andrade, M.D. Section of Thoracic and Foregut Surgery, Department of Surgery, University of Minnesota Medical Center, Minneapolis, MN, USA

Florian Augustin, M.D. Department of Visceral, Transplantation and Thoracic Surgery, Innsbruck University Hospital, Innsbruck, Tirol, Austria

Johannes Bodner, M.D., M.Sc., F.E.B.T.S. Department of Thoracic Surgery, Klinikum Bogenhausen, Munich Community Hospital, Munich, Bayern, Germany

Jennifer A. Cameron, M.D., M.P.H. Department of Plastic Surgery, Aspirus Health System, St. Paul, MN, USA

Robert B. Cameron, M.D. Division of Thoracic Surgery, Department of Surgery, West Los Angeles Veterans Administration Medical Center, David Geffen School of Medicine at UCLA, Los Angeles, CA, USA

Javier H. Campos, M.D. Department of Anesthesia, University of Iowa Health Care, Iowa City, Iowa, USA

Ramzi K. Deeik, M.D. Department of Cardiothoracic Surgery, Santa Rosa Memorial Hospital, Santa Rosa, CA, USA

Nisha Dhanabalsamy, M.D. Department of Surgery, Section of Minimally Invasive and Robotic Surgery, University of Arizona, College of Medicine, Tucson, AZ, USA

Andres Falabella, M.D. City of Hope Helford Medical Clinical Research Hospital, Arcadia, CA, USA

Carlos A. Galvani, M.D. Department of Surgery, Division of General Surgery, Section of Minimally Invasive and Robotic Surgery, University of Arizona, College of Medicine, Tucson, AZ, USA

Farid Gharagozloo, M.D. Center for Advanced Thoracic Surgery, Global Robotics Institute, Florida Hospital Celebration, Celebration, FL, USA

Pier Cristoforo Giulianotti, M.D., F.A.C.S. Department of Surgery, Minimally Invasive and Robotic Surgery, University of Illinois Hospital and Health Sciences System, Chicago, IL, USA

Arielle Hodari Gupta, M.D. Department of Surgery, Henry Ford Hospital, Detroit, MI, USA

Jeroen M.H. Hendriks, M.D., Ph.D. Department of Thoracic and Vascular Surgery, Antwerp University Hospital, Edegem, Belgium

Santiago Horgan, M.D. UC San Diego Health—La Jolla, San Diego, CA, USA

Michael K.Y. Hsin, MBBChir, MA, FRCS, FHKAM Department of Cardiothoracic Surgery, Queen Mary Hospital, Hong Kong, China

Mahmoud Ismail, M.D. Department of Thoracic Surgery, University Medicine Berlin (Charité), Clinic for Surgery, Berlin, Germany

Dae Joon Kim, M.D., Ph.D. Department of Thoracic and Cardiovascular Surgery, Severance Hospital, College of Medicine, Yonsei University, Seoul, Republic of Korea

Christiaan Kroese, M.D. Department of Anesthesiology, Intensive Care and Emergency Surgery, University Medical Center Utrecht, Utrecht, The Netherlands

Patrick Lauwers, M.D. Department of Thoracic and Vascular Surgery, Antwerp University Hospital, Edegem, Belgium

Michael A. Maddaus, M.D. Department of Surgery, University of Minnesota, Minneapolis, MN, USA

Marc Margolis, M.D. MedStar Georgetown University Hospital, Washington, DC, USA

Ozanan R. Meireles, M.D. Department of General and Gastrointestinal Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, MA, USA

Rudy Mercelis, M.D., Ph.D. Department of Neurology, Antwerp University Hospital, Edegem, Belgium

Pieter Mertens, M.D. Department of Anesthesiology, University Hospital Antwerp, Edegem, Belgium

Jeffrey A. Morgan, M.D., F.A.C.S. Division of Cardiothoracic Transplant and Circulatory Support, Advanced Heart Failure Center, Baylor College of Medicine, Texas Heart Institute, CHI Baylor St. Luke's Medical Center, Houston, TX, USA

Raghav Alampalli Murthy, M.B.B.S Department of Cardiovascular Surgery, Rady Children's Hospital, University of California San Diego, San Diego, CA, USA

Bernard J. Park, M.D. Department of Surgery, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

Seong Yong Park, M.D., Ph.D. Department of Thoracic and Cardiovascular Surgery, Severance Hospital, College of Medicine, Yonsei University, Seoul, Republic of Korea

Jens C. Rückert, M.D., Ph.D. Department of Thoracic Surgery, University Medicine Berlin (Charité), Clinic for Surgery, Berlin, Germany

Ralph-Ingo Rückert, M.D., Ph.D. Department of Surgery, Franziskus-Krankenhaus Berlin, Berlin, Germany

Michael A. Savitt, M.D., M.S.E. Department of Cardiothoracic Surgery, Indiana University Health System, Muncie, IN, USA

Thomas Schmid, M.D. Department of Visceral, Transplantation and Thoracic Surgery, Center of Operative Medicine, Innsbruck University Hospital, Innsbruck, Tirol, Austria

Eric Strother, L.S. Washington Institute of Thoracic and Cardiovascular Surgery, The George Washington University Medical Center, Washington, DC, USA

Marc Swierzy, M.D. Department of Thoracic Surgery, University Medicine Berlin (Charité), Clinic for Surgery, Berlin, Germany

Barbara Tempesta, B.S.N., C.R.N.P. Center for Advanced Thoracic Surgery, Florida Hospital Celebration, Celebration, FL, USA

Keinich Ueda, M.D. Department of Anesthesia, University of Iowa Health Care, Roy and Lucille Carver College of Medicine, Iowa City, IA, USA

Senne Van Donink, B.M. Department of Thoracic and Vascular Surgery, University Hospital of Antwerp, Edegem, Belgium

Richard van Hillegersberg, M.D., Ph.D. Department of Surgical Oncology, University Medical Center Utrecht, Utrecht, The Netherlands

Paul E.Y. Van Schil, M.D., Ph.D. Department of Thoracic and Vascular Surgery, Antwerp University Hospital, Edgem, Belgium

Roy J.J. Verhage, M.D., Ph.D. Department of Surgical Oncology, University Medical Center Utrecht, Utrecht, The Netherlands

Innes Y.P. Wan, MBChB, FCSHK, FRCSEd, FHKAM Department of Surgery, The Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong, China

John K. Waters, M.D. Cardiothoracic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

Heinz Wykypiel, M.D. Department of Fisceral, Transplant and Thoracic Surgery, Medical University Innsbruck, Innsbruck, Tirol, Austria

Part I

Overview

Principles of Robotic Thoracic Surgery, Program Development and Equipment

1

Kemp Kernstine Sr.

Abstract

Robotic surgical technology, as it is applied to thoracic surgery procedures, offers surgeons greater dexterity, three-dimensional view, and tremor adjustment that results in the ability to perform complex procedures in small thoracic spaces. There is the potential of less trauma to surrounding structures that may result in less pain and debility. The selection and development of a surgical team with the interest, skills, knowledge, devotion, and focus to achieve quality outcomes is especially important in this new technology.

The overall principles of operating theater organization, body positioning, and port placement are reviewed in principle. For thoracic procedures, the available robotic and non-robotic instruments are reviewed in a general sense. There are great opportunities as robotic surgical technologies is further developed that should offer better outcomes for patients.

Keywords

Robotic surgery • Computer-assisted technology • Computer-assisted surgery • Surgical education

The purpose of this chapter is to provide the general principles of how the computer-assisted surgical system or robot can be set up by a surgical team for a safe and efficient thoracic surgical procedure. The remaining chapters deal with a number of thoracic surgical procedures by internationally recognized surgeons who at the time this book was conceived each had more than 5 years of robotic surgical experience in their specific approaches. If optimally used, the robot can minimize tissue manipulation; thus, should be at the least equivalent; if not superior to its open-large incision or the video-assisted counterpart.

There are numerous factors that determine the quality of a robotic surgical procedure; these include patient selection, the capabilities of the health care facility, the technique used by the surgeon, the surgeon's training, interest and knowledge of the pathology/procedure; the abilities of the surgical support team, and the quality of the hospital including the administration and all components of the medical and paraprofessional support staff. All of these summate to result in the morbidity, mortality and other outcomes for a given procedure. The new computer-assisted technology does not take the place of a coordinated team, but it does offer the capacity to minimize debility from the surgical approach.

Training the surgeons, the surgical team, and the hospital support system is complex; each has different needs. To date, training in surgical robotics has not been adequately incorporated into cardiothoracic residency training programs or postgraduate training opportunities in the technology and new surgical culture. Most robotic programs rely on industry for guidance, rather than on science and academia. There are no agreed-upon standards and no evidence-based guidelines to acquire the skills necessary to perform a safe and efficient robotic procedure. One example of a means to

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Department of Cardiovascular and Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th Floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_1

help introduce cardiothoracic surgeons to this new technology is the "buddy system" developed by the European Society of Thoracic Surgeons and the European Association of Cardio-Thoracic Surgery; surgeons with greater experience, especially for a particular procedure, can help guide those just getting started. In contrast, in the United States, like in Europe and Asia, there are industry-developed recommendations that are often modified by each local medical center. We have no way of knowing how this approach fairs with a more traditional surgical training program-based system. The training of the individual surgeon is of greater concern. Currently, once the surgeon has completed the on-line, equipment/robot, and simulator training with, in some cases, cadaver and/or live animal experience, the thoracic surgeon is proctored by another robotic surgeon, not necessarily a thoracic surgeon, for a few cases; the number determined by the medical center. Once these few cases are performed, the new robotic thoracic surgeon can embark on their own robotic thoracic surgical cases. Since this is a surgical cultural shift for the surgeon and their hospital team, rather than the introduction of a new device, such as a new heart valve or stapler, the odds of achieving ideal outcomes may be compromised. These surgeons and their hospitals often are pressured to be competitive and this may supersede their pursuit of quality. From a safety and economic standpoint, the current situation is not sustainable for patients, the health care system, or for the future of robotic technology. Unfortunately, there does not appear to be a reasonable resolution on the horizon.

As with the robotic surgeons, there are no adequate training programs to educate and prepare the robotic thoracic assistant surgeon. Without general regulation, the robotic first assistant surgeons come from a variety of health care roles; surgeons, physician assistants, nurses, surgical technicians, and physicians-in-training from interns to fellows. At many medical centers, the determination of who should be at the bedside often is up to the robotic surgeon, but hospital regulatory committees and outside consultant groups are becoming increasingly aware and involved with these decisions, potentially making decisions based on the economics, rather than on quality and safety. For thoracic surgery, dependent upon the procedure, the stakes can be quite high. An inadvertent move can injure an airway or major vascular structure and the result could be catastrophic. Needless to say, the bedside surgeon impacts the outcome of a robotic procedure more than the corresponding role in the open or video-assisted approaches. So, the individual chosen, like the robotic surgeon, must have the interest, training, experience, and technical skills capable of performing a safe minimally invasive robotic procedure and capable of remedying an emergent situation should it occur. This is not to say that it has be a thoracic surgeon, but a health care professional that is capable of performing the described function. There should be a formalized training program for these individuals to learn the nuances of the robot machines, robotic surgery, and minimally invasive surgery.

Additional key members of the surgical team are the scrub technician and operating room nurse circulator. These individuals must have thorough familiarity with the robot equipment, the robotic and accessory instruments, and should be capable of maintaining sterility of the bedside cart, and management of the computer system and instrumentation. Through instructional videos, seminars, hands-on sessions, and on-boarding training with an experienced robotic mentor; these selected individuals are trained in the efficient use of the machinery. Hospitals should avoid attempting to train all members of the surgical staff on the robot. Only certain surgical staff members should be trained; those that have the interest and those who are capable of functioning well on the surgical robotics team. Like anything else that is technology-driven, if a select team is not created, then the experience will be diluted across an entire staff, the result being a constantly inexperienced team with long, inefficient, and costly cases, and likely poor outcomes. If done correctly, a core group of robotic team members are carefully chosen to be educated in this new technology/culture paradigm and will have sufficiently familiarized themselves with this new system, have proven that they have mastered it, and have demonstrated that they are capable of achieving the necessary outcomes, a process that usually requires 8–12 months. New team members should not be introduced until team goals have been achieved. Of course, these robotic team members will need to be available to cover the cases being performed. Additionally, to provide the necessary feedback to the robotic team, medical centers should support a means of collecting patient-related use and outcomes data on each of their robotic procedures. It is extremely important to cultivate this core group of individuals to achieve optimal outcomes and cost efficiency.

The anesthesiologist is another key member of the robotic team. Due to the bulky robotic chassis and the robotic arms obstructing patient access and visibility and unusual body positions used for the robotic surgical procedures, anesthesiologists are disrupted from their usual routine. The CO_2 insufflation intrathoracic pressure and body positions necessary for a given procedure, such as the reverse Trendelenburg position may make hemodynamic management challenging. Airway management adds further to the complexity of these robotic chest cases. Combining these with the numerous issues related to the thoracic surgical population, advanced age and numerous co-morbidities make for a very challenging case requiring appropriate training and experience.

Once the robotic team has been assembled and has obtained sufficient training, the first series of procedures chosen for the team should be simple with minimal risk and on low risk patients. The planned robotic case time should be expected to be less than one hour. Furthermore, immediately after each of the initial procedures, the robotic team, including the surgeons, should meet and review the case. Flow of the case, equipment issues, and outcomes should be discussed and plans for improvement developed. A series of early successful procedures will help the institution to rally around the opportunities afforded by a successful thoracic robotic surgical program.

Finally, to develop a successful thoracic robotics program, a host of other individuals and departments must be incorporated into the overall medical center team necessary to create a system capable of achieving collective goals for their medical center, their practices, and their patients. To optimize cost effectiveness, the robotic resources must be shared across multiple surgical specialties. Enlisting the support of interested urologists, gynecologists, otolaryngologists, cardiac and general surgeons will significantly increase the odds of acquiring support from the administration, as the overall robotic program is more likely to be cost-effective and the greater case volume will assist in training the robotic team. All of the team members should receive continued feedback and provided support for ongoing education.

When it comes to robotic team development, often underrecognized and appreciated is the hospital administration. The administration should not be viewed solely as a source of resources, but should be fully engaged and informed about the robotic program. In kind, the administration should not view the robotic program as a marketing gimmick; instead, it should represent a method to improve surgical outcomes. They must be convinced that the introduction of the technology will change the medical center culture, not just the operating room staff. The administration and the team should identify quality indicators that might be important to outside regulatory agencies, such as the Joint Commission on Accreditation of Health Care Organizations (JCAHO). Obviously, the amount of time that the robot is used and the number of procedures performed robotically are important indicators of resource utilization for the administration, but intraoperative surgical complications as well as postoperative outcomes should be measured and compared to similar nonrobotic procedures at the same and other similar institutions. Finally, to provide a range of ideas and participation across a medical center, it would be helpful to include referring physicians and patient advocates in the robotic program. These recommendations should help to perpetuate the program and allow it to achieve consistent success.

1.1 Case Setup

Preoperative imaging is important for determining the appropriateness of a robotic approach, patient body position, placement of the ports, and direction of the robot bedside cart to the patient. Recent computed tomogram scan (CT) images with 1 to 5-mm "cuts" with reconstruction and with multiple views provides some direction in performing most robotic thoracic surgical cases. Even pericardial and subdiaphragmatic procedures may be facilitated by a preoperative CT scan. Abdominal and chest ports are positioned relative to immobile bony structures such as the manubrium, the xiphoid process and the costal arch and the intended "target." It is preferable that these images are available in the operating room for repeated reference, as necessary. For malignant disease, positron emission tomography (PET) scan, especially PET-CT, provides information about local and systemic involvement. This information helps to direct attention to the appropriate areas to be surgically addressed, such as potentially involved lymph nodes. For lesions close to the hilum, chest wall, chest apex, great vessels, diaphragm, pericardium or spine, magnetic resonance image may provide additional information that may guide the approach.

Patient body position can be used to improve exposure and reduce the need for retraction, allows counter tension of tissues for incisions to be made, and creates small spaces in otherwise crowded and cramped areas of the chest and upper abdomen. Furthermore, body position can also be used to keep the operative field free of any bleeding and other bodily fluids by creating a dependent space for these materials to collect. Once the target of the procedure is identified, accounting for the relationship of it to surrounding structures, and the fact that the robotic video port and arms work most efficiently when the target is positioned between the tip of the videoscope and the base of the robotic chassis, the patient's body is positioned to achieve maximal surgical efficiency. Minor adjustments of a few degrees of anterior or posterior rotation when the patient is rotated on a vertical plane or placed in a reverse Trendelenburg will create exposure (Figs. 1.1 and 1.2, Table 1.1).

The operating room chosen for robotic surgery (Fig. 1.3) must be large to accommodate the robotic machines, the robotic chassis (also referred to as the bedside cart), the robotic surgeon console, and the integrative system or the control cart and the operating table and anesthesia equipment. The room must meet the electrical requirements for the machines. Also, given the limitations of the power lines to the control cart, the robotic chassis must be in fairly close proximity to the control cart. The robotic console must also be placed away from the operating room entrance, yet close enough to the control cart and the patient so that the power

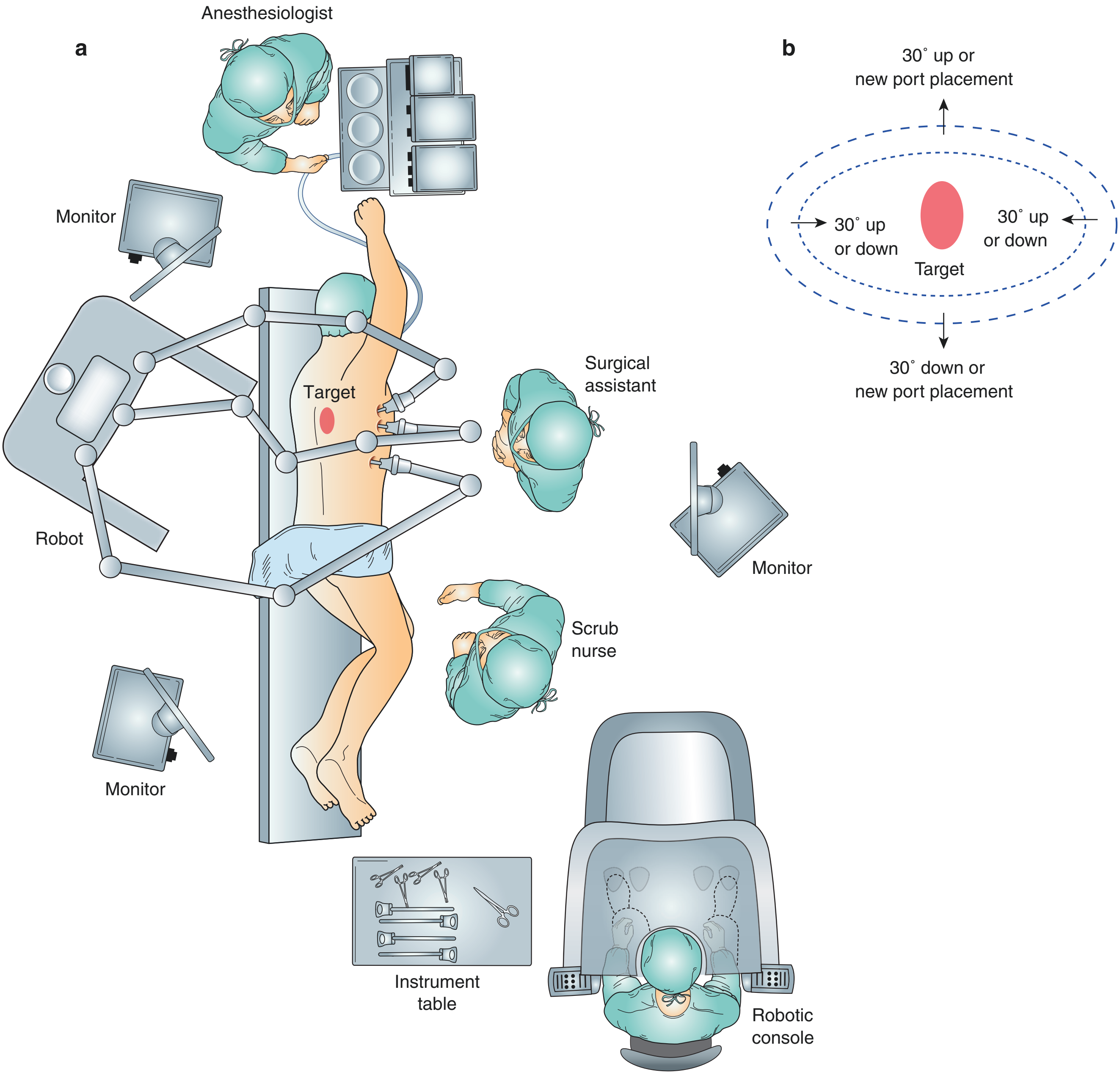


Fig. 1.1 Ideal location of robotic video port and robotic arms. Examples of the operating room organization (**a**) and zones of efficiency (**b**) for a robotic Schwannoma resection. An approximation of target location, the Schwannoma, is marked on the surface (see *oval* marked on the midportion of the patient's back adjacent to the spine) of the patient and the planned placement of the bedside cart and the port for the robotic videoscope. Once the robot or bedside cart is brought into place, the actual target is centrally located in the view of the robot (**b**). The robot instruments work best when all of them are aimed towards the base of the bedside cart. As with a Schwannoma, a very precise area in three-dimensional space, the surgical target for every robotic surgical procedure is chosen as a result of the understanding of the disease/pathology and location on preoperative imaging. The ports are arranged so that the target is situated between the robotic videoscope and the base of the bedside cart. After placement of the ports and docking the robot, as a result of appropriate organization of the bedside cart and the ports/instruments, the robotic instruments and view will be optimized (area within *inner* the *dotted line* (**b**)). When converting to a 30° angle up or down robotic video scope, the lateral margins of ideal maneuverability will be narrowed, the *inner dotted line* is narrower, but greater exposure and function is improved, up or down, as indicated by the diagram. The *second dotted line* is a region of less robotic instrument function, but is still useable. When outside these regions, as necessary, a new port or ports can be placed to achieve needed function and view. When areas cannot be reached, the laparoscopic or thoracoscopic ports can be pushed further into the body cavity to achieve the needed reach

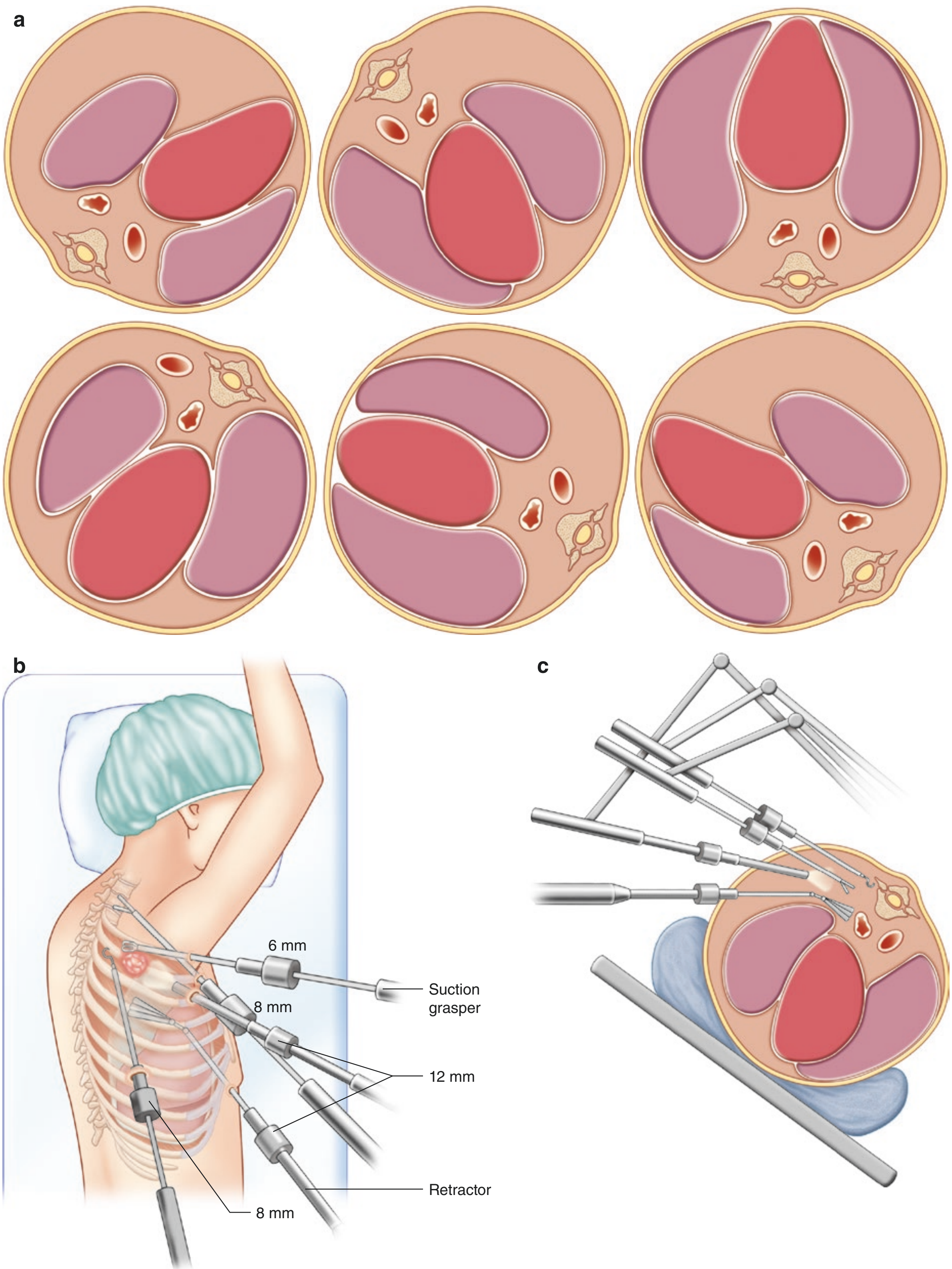


Fig. 1.2 Supine to prone positioning provides operative exposure. The patient's body position can make an efficient case, such as rotation of the patient forward or backward allowing for the weight of the mediastinal structures to provide some of the needed exposure, creating space for visibility and dissection and creates counter tension for dissection (**a**). Reverse Trendelenburg reduces venous pressure in the upper chest, again creating space by the lungs and the tumor falling toward gravity (**b**). In a cross sectional view of the chest, a middle or posterior mediastinal structure can be more easily visualized and resected by rotating the patient and table anteriorly (**c**)

Table 1.1 Body positions found best for surgical targets

Body position	Target locations
Lateral Decubitus	Middle and posterior mediastinum, diaphragm, paratracheal-tracheal, superior sulcus, first rib resection
Supine	Gastroesophageal junction, Anterior mediastinal, anterior chest wall, internal mammary vessels and pericardium
Prone	Esophagus, thoracic duct, spine, mid to lower trans-thoracic paraesophageal, posterior chest wall
Trendelenburg	Rarely necessary for chest procedures, more common in pelvic procedures
Reverse Trendelenburg	Commonly utilized for thoracic and upper abdominal procedures
Anterior rotation or posterior rotation of any position before bedside cart	Provides some extra exposure for any of the above target locations. Always undock the robot when changing bed or patient position

lines for the function of the console, the cautery unit and harmonic scalpel will reach the command center. Figure 1.3 provides an example of a typical room arrangement for a thoracic robotic case.

1.2 Port Placement

For the first several cases, if not, for each case, an indelible skin marker is used to mark out on the chest wall or abdomen the location of the intended target or the focus of the procedure to be performed based upon the findings from the preoperative radiological imaging and the surface anatomy of the patient. As an example, the target for a lobectomy is the hilum or for the thoracic portion of an esophagectomy, it is the entire length of the esophagus. In a parallel plane to the operating room floor, the videoport location is chosen to provide the greatest view of the target, ideally 10 cm directly opposite of the front edge of the target most mid or central

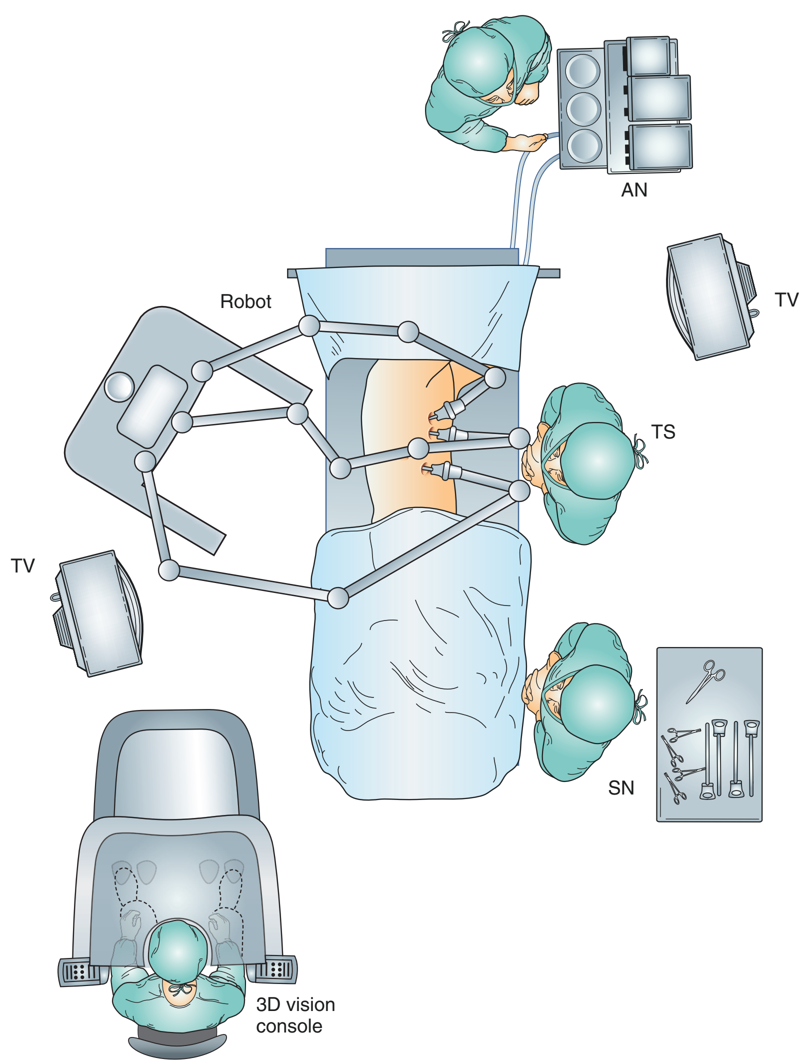


Fig. 1.3 Room organization: example of room organization for a right upper or middle lobectomy. The room should be large enough for all of the robotic equipment and operating room personnel and should have all of the electrical outlets necessary for the robot and associated instrumentation. Operating table position is important to obtain the necessary visibility; some tables are awkward and slow; sliding the table in different directions, Trendelenburg or reverse Trendelenburg, rotation anterior to posterior, should be efficient and safe. Once the robot is docked, the table should not be moved

aspect. The distance may not be achievable in small patients. The direction to obtain the best view is one that has the least obstruction and allows the passage of equipment through the robot arms and accessory ports to perform procedures. For example, when considering the hilum as the target for an upper and middle lobectomy, the best location for the video port is close to the costal arch looking obliquely at the hilum and just cephalad and anterior to the location of the major fissure (Fig. 1.3).

Once the videoscope direction has been determined, then a triangle is drawn on the patient's chest (Figs. 1.4 and 1.5), the base of the triangle being the full extent of the target, if it is the thymus, it is the full extent of the intended resection from the base of the neck and to the diaphragm. In some cases, the base of the triangle can be quite small, such as when removing a posterior mediastinal mass, such as a leiomyoma. The apex of the triangle is the videoscope port. Once determined, then a triangle is drawn with a marker, this being the triangle of visibility for the procedure. No ports, robotic or accessory, should be placed inside this triangle to avoid instrument conflicts in and outside the chest.

For a robotic case, there are three port sizes used; the 12-mm, 8-mm, and 5-mm. The 12-mm port is used for the video scope, a Fan (Covidien-Medtronic) or a Paddle retractor (Covidien-Medtronic), endostapler, the passage of sutures, and any equipment capable of passing through a smaller port, including an 8-mm robotic arm. The 8-mm (and for children the 5-mm) port comes with the Intuitive Surgical Incorporated system, it is metal and has an attached self-sealing ring seat in case the port is used as a thoracoscopic or laparoscopic port to

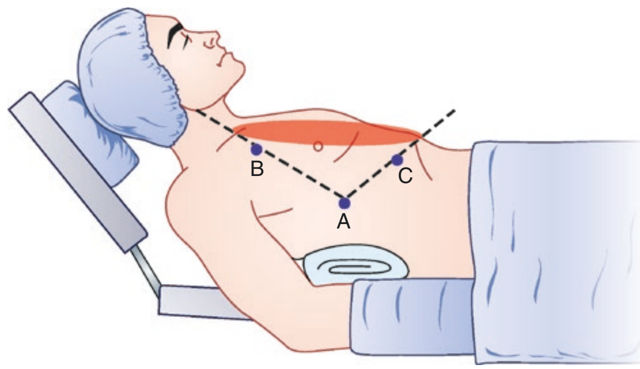


Fig. 1.4 Triangle of visibility. Port placement for a right-sided mediastinal mass removal or thymectomy. Prior to placing the ports, the target (the *oval* mark on the anterior chest) is drawn onto the patient's chest; in this case, it would be the thymus and all of the perithymic tissue. Then, we draw a line from the midportion of the target 10 cm away from the anticipated closest margin of the target for the robotic video port, **Port** *A*. Then, from that port to the most superior and most inferior aspect of the target a line is drawn. This triangle that is created is an area that should not have any ports placed to reduce instrument conflict inside and outside of the chest cavity; the two robotic arms can be placed, **Ports** *B* and *C*

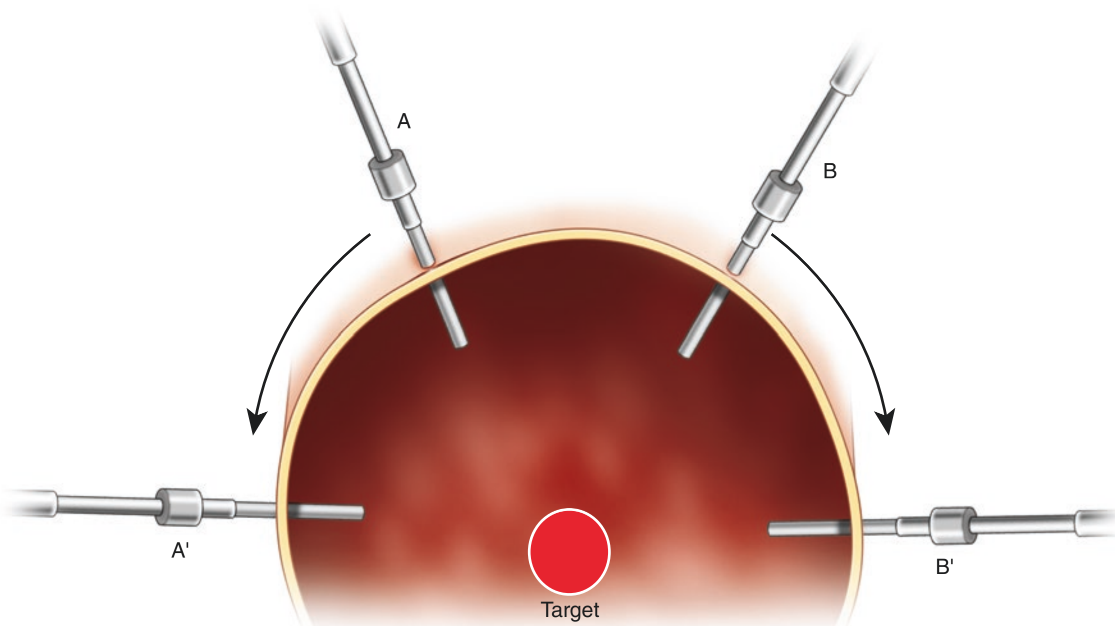


Fig. 1.5 Accessory port placement relative to the target. A cross sectional view of a patient's chest that demonstrates the curvature of the chest wall and the potential target. Accessory port placement is important for an efficient case; the bedside surgeon can be more actively involved with the procedure. When looking at the cross section of the chest and thinking of the chest as a half arc, the accessory ports for a given procedure are placed to achieve optimal function for each port. Unlike the video-assisted techniques where the ports are often placed over the top of the arc of the chest, **Ports** *A* and *B*, the greater maneuverability of the robotic arms allows for the accessory ports to be placed in a more direct route to the target, **Port** *A* moved instead to **Port** *A′* location and **Port** *B* to **Port** *B′*

prevent the escape of insufflated CO_2 after a non-robotic instrument, such as a endograsper, is passed through it. Port positions are drawn out onto the chest or abdomen with a marker and if wrong can be wiped away with an alcohol wipe. On the horizontal plane, ideally, the ports should be about 10–14 cm away from the videoport, wider for the original system and narrower for the Si or Xi systems or when the target is small. On a horizontal plane relative to the target, this distance must be maintained even when the ports are placed anterior or posterior to the video port site. Narrowing this distance will result in instrument conflict. Accessory ports are placed according to their intended function and sized according to the planned instruments to be passed through them. Thus, a distance of about 10–14 cm from a robotic arm port or video port is best. An additional consideration is the three-dimensional relationship of the accessory port to the target and the function of the port. For example, endostaplers have limits to the angles that make to perform their function. If placed high on the chest as noted in Fig. 1.5 for **port sites A and B**, there will be limitations that result from the angles necessary to perform the stapler function. Instead, placing the stapling port closer to the spine on a vertical plane to the floor is better than a port placed at the top of the lateral chest (Fig. 1.5). Potential robotic arm, ancillary port/instrument, and torso conflict outside the chest may be a challenge for some planned procedures and in some patients and may be managed by changing the videoscope angle and the bed position (Fig. 1.6). Another consideration is the addition of a third instrument robotic port or a fourth arm to the procedure. For small patients, this could be a challenge. It may require moving the ports closer to each other and as a result, having less instrument function and more instrument interference; the trade-off being that, it does offer advantage of an additional instrument for the console surgeon to suture, grasp, and retract.

After the planning is completed, the sequence of events is that the 12-mm videoscope port is placed first. Placement of this port into the chest is the most dangerous of any of the ports to be placed. So, if there is particular concern in the placement of this port, perhaps risking potential injury to the diaphragm in an obese patient, one of the other planned port sites may be chosen first before the video port is placed to allow for direct vision from inside the chest for the video port. Prior to the placement of each port, we often inject a long-acting local anesthetic to assist in postoperative analgesia. Epinephrine added to the anesthetic helps to vasoconstrict

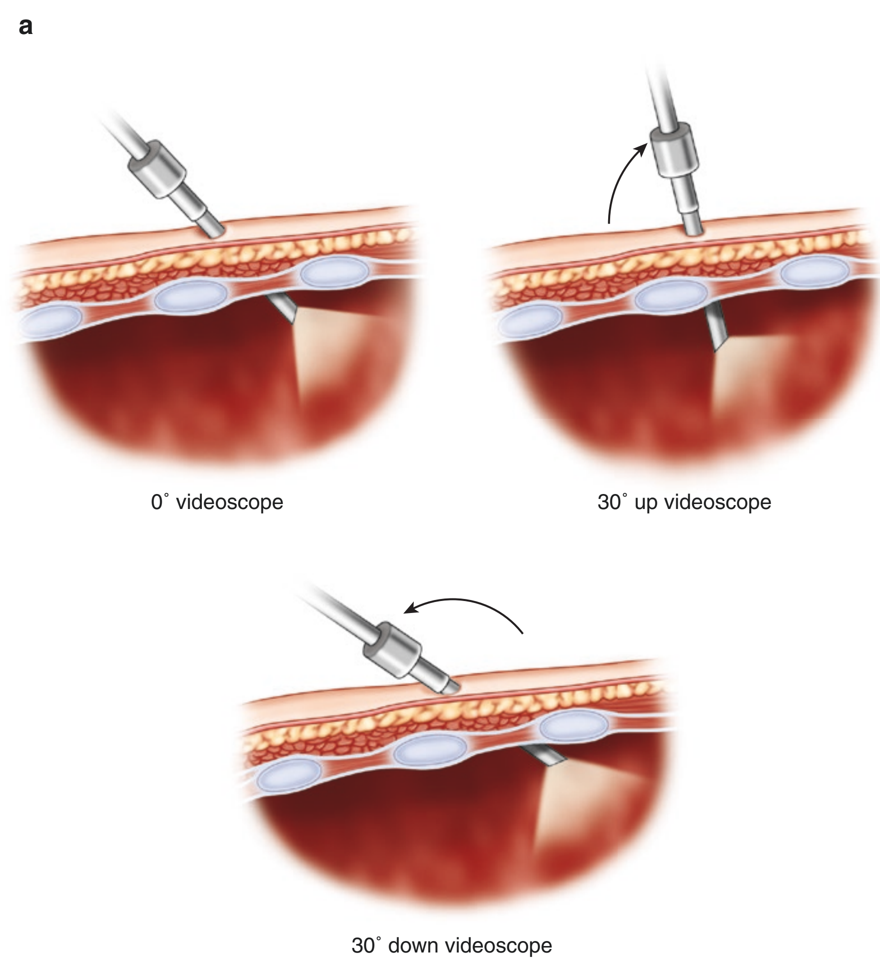
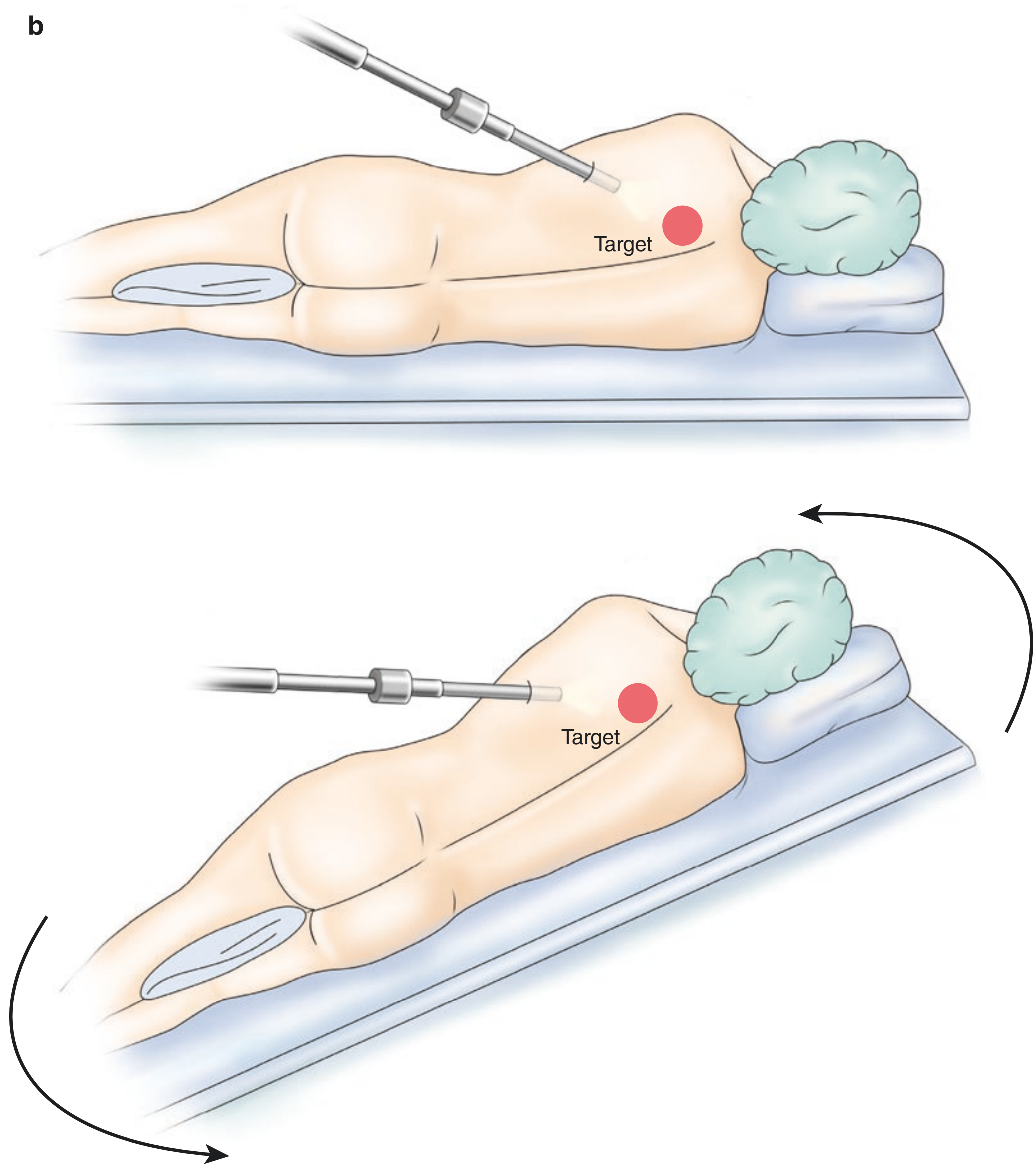


Fig. 1.6 The effect of changing from a 0° to a 30° robotic video scope and changing the bed position. Instrument conflict can occur outside the patient and ways to avoid or manage it can include the use of different angle for the videoscope and change in body position. Conversion from a 0° to a 30° up videoscope will move the videoscope arm outside the chest toward the direction of view as depicted in the *middle panel* of (**a**). Doing this can take the scope off of the hips for a lateral decubitus case and can be of particularly help in patients with large hips. Another way to deal with instrument conflict outside of the patient is to undock and change the body position. The large hip patient can be placed in steeper reverse–Trendelenburg (**b**), this raises the target in three-dimensional space, taking the hips away from the trajectory of the robotic videoscope arm

Fig. 1.6 (continued)



vessels within the tissue around the port site to reduce bleeding and helps to prolong the effect of the injected anesthetic. A 12-mm incision is made within Langer's lines and just over the most cephalad aspect of the adjacent rib that has been marked. Entry into the chest through this incision can be accomplished safely with a moderately blunt tipped surgical instrument such as a Tonsil or Hemostat clamp and performed after all ventilation has been stopped. This maneuver minimizes the inadvertent injury to the ipsilateral lung or to mediastinal structures. Alternatives to this technique are optical trocar entry (OptiView, Endopath XCEL® Trocars, Ethicon, Johnson & Johnson) and placement of a 14-gauge angiocath directly into the chest to create a pneumothorax. Both techniques have the potential of injury to thoracic structures. If CO_2 is to be infused during the case, it should never be introduced through the port until intrathoracic placement is confirmed. Accidental misdirected CO_2 infusion has been reported into the liver and lung parenchyma/vasculature and has resulted in severe complications and even death; so, caution should be exercised when attaching the CO_2 insufflation line to the trocar.

Dependent upon the procedure being performed, there should be a plan to deal with emergencies. The plan must be verbalize and thoroughly rehearse with the assistant/bedside surgeon, the anesthesiologist, and the operating room team. The most disastrous emergency is bleeding. In preparation for severe bleeding, a ring clamp with a Surgicel (Johnson & Johnson) or a half-laparotomy pad clamped into its jaws is readied for direct pressure to be applied to any bleeding structure by the bedside surgeon (Fig. 1.7). Fortunately, in most cases, bleeding can be managed by direct application of adjacent tissue, such as the lung, over the bleeding site, and

Fig. 1.7 Preparation for a vascular emergency. Preparations for emergent bleeding are made at the outset of all robotic surgical cases and rehearsed with the entire surgical team. Surgicel® (Johnson & Johnson), usually 2–3, or a half-laparotomy pad is placed into the jaws of a ring clamp in preparation for a vascular disaster. If a vascular disaster occurs that requires external compression by the bedside surgeon, the surgical ring clamp can be inserted through one of the 12-mm port sites or a new incision made directly over the bleeding site and out of the way of the robotic arms. Direct pressure is placed on the bleeding. All robotic cases should have a thoracotomy or a laparotomy tray available in the room unopened and ready to be opened in case they are necessary

relaxing any retraction. For the pulmonary artery or vein, holding pressure for 5–10 min and in some cases placing Surgicel® (Johnson & Johnson) on the bleeding site will stop the bleeding. Arterial bleeding from a small bronchial artery or a small tear in the aorta can be more challenging to control than small tears in the pulmonary artery or vein. We roll up a Surgicel® into a tight roll that is small enough to fit through a 12-mm port and tied in multiple locations with a Vicryl. The bedside surgeon can use this in a grasper to hold pressure and an endosuctioning device to provide adequate visualization to control bleeding with the cautery or Harmonic system or possibly suture ligation. In cases where the bleeding cannot be sufficiently controlled, the case is converted from a robotic procedure to either a video-assisted technique, creating a small access incision, or conversion to an open incision procedure, such as a thoracotomy. The first step in this process is to apply direct pressure by using the robotic grasper to grasp adjacent tissue and hold adjacent tissue over the bleeding until a thoracoport or laparoscopic port can be removed. The previously prepared ring clamp with the Surgicel® is inserted by the bedside surgeon either through one of the port sites or a newly made incision and direct pressure is applied. The bedside surgeon should use 1–2 suctioning instruments to keep the field free of blood. Then, the bedside pressure is held on the bleeding site while the robotic instruments are removed and the robot detached from the ports and the robot moved away from the patient. At the same time, the scrub nurse should be preparing the open thoracotomy or laparotomy instrument tray for the conversion. Once the large incision is made for access, the case is completely converted to an open procedure for bleeding control.

1.3 General Tips

1. 30° up or down or zero degree robotic videoscope. The 0° scope provides the greatest lateral view and widest range of robotic instrument function. The 30° upward or downward facing scopes provide an oblique view of the target with a limited lateral view and instrument function.
2. The most common instruments used in a robotic chest case are the following: Typical Robotic and Chest Procedure Specific Instruments-ProGrasp (420093), Cadiere (420049), Robotic Harmonic (420174), Hook cautery (420183), Robotic Needle Driver (420006, Mega 420194), Robotic DeBakey Forceps (420036), Robotic Hot Curved Endoshears (420179), Paddle retractor EndoPaddle Retract™ 12 mm Retractor (9 × 9 m polyester paddle, Covidien, Norwalk, CT,

173046), Fan retractor (EndoRetract II, Covidien, Norwalk, CT, 176647), Endo-peanut (Covidien, Norwalk, CT, 173019), Landreneau Ring and Straight clamp, Forrester Ring Clamp robotic clip applier (small clip applier 420003), large Hem-o-lok Clip Applier (420230) and liver retractor (5-mm Snowden-Pencer Diamond Flex triangular liver retractor (89–6216) with the bedside self-retaining mount, or the Mediflex Nathanson Liver Retractor (69701 or 7300)), laparoscopic needle driver, laparoscopic suture scissors, Surgicel® Absorbable Hemostat (1952, Ethicon Inc., A Johnson & Johnson, Co., Cincinnati, Ohio)
3. The SH and CT-1 needle easily fits through a 12-mm accessory port and is best passed with a laparoscopic needle holder, rather than an endograsper, given the greater security needle holder's hold on the suture or the needle. In most situations suture lengths of 8–10 cm will suffice. 3–0 Vicryl and 3–0 or 0-Ethibond is most commonly used. A 4–0 or 5–0 Prolene on an RB-1 needle can be used for repair of a vascular injury.
4. Carbon dioxide gas infusion can be used to inflate the abdomen to a pressure of 15 mmHg, sufficient to create space for the intended surgical procedure. Although not necessary, CO_2 can be used in the chest cavity as well, usually at lower pressures, but if the pressure is gradually increased, most patients can tolerate intrapleural pressures of 10–20 mmHg. Humidifying and heating the CO_2 may reduce the hypothermia, reduce camera lens fogging, potentially reduce the postoperative pain and possibly reduce the moisture splatter that is made occur from the desiccation of the pleural surfaces. (Insuflow® Filter Heater Hydrator, Lexicon Medical, St. Paul, MN) Carbon dioxide, rather than other available gases, is used because it is relatively inexpensive, water soluble, and is not combustible. Using CO_2 insufflation in the chest hastens lung deflation faster than it would with single lung ventilation alone, it creates more operative space by pushing the mediastinum and diaphragm away from the operative area, and continually circulates cautery smoke and aerosolized harmonic dissection vapor away from the operative view.
5. Avoid cutting anything that is not adequately visualized. Instead, perform blunt dissection and attempt to use retraction to gain greater exposure and knowledge of the anatomy before incising structures.
6. Grasping bowel, lung, or vessels with robotic graspers can result in injury such as perforation and bleeding. Instead, the bedside surgeon can use the atraumatic graspers to pull structures away and the robotic graspers can be used as a spatula to lift tissues away for exposure.
7. Introduce instruments into the body cavity with caution. The surgeon and team should avoid introducing the robotic instruments into the chest without direct vision. Blindly inserted instruments can impale critical structures.
8. Keep all robotic instruments in the field of view at all times. Although this may seem cumbersome, moving the instruments in synchrony may improve operative efficiency. For the novice robotic surgeon, it is not uncommon for the surgeon to lose an instrument from the field of view while using one arm for the dissection. Greater experience by the console and bedside surgeon should help to avoid single instrument dissection.
9. X-rays in the room. All pertinent images should be readily available for frequent review. This reduces the likelihood for wrong site surgery and helps the surgical team to understand the goals of the robotic case.
10. Anesthesia and the surgical team should function as a coordinated unit. The operating room team should be educated in the procedure to be performed and the objectives. Drawings and videotapes should be available so that they understand the sequence of events. Too, for the first several cases, it is recommended that a process improvement meeting be conducted, ideally, immediately after the case to discuss the flow of the procedure and issues that had arisen.
11. Once the robot is docked, do not change the patient body, table position, or robot position. This must be rehearsed with the anesthesia team.

1.4 The Future

Surgical robotics shows great promise in all fields of surgery to provide greater precision and allow for smaller access incisions. On the horizon and in some cases already available in a nascent form are narrower robotic arms, thus requiring even smaller access incisions, superior instrument function, less expense, less bulk to the machinery, robotic suctioning, robotic training stimulators, improved high-definition visibility that is no longer fixed to a rigid pole and with peripheral vision and intracorporeal lens cleaning, visualization methods to identify the extent of tumor and areas of potential metastasis, and nonintubated general anesthesia and regional anesthesia managed surgery. Future surgeons should be able to train on procedure-specific simulation programs to prepare them for a procedure and any potential nuances for a particular case. Finally, this technology will allow us to assess surgical technique and correlate it with quality and outcomes and provide surgeons and their teams with the feedback necessary to achieve the best results.

Currently, there does not appear to be any specific indication for a robotic thoracic approach that could not be accomplished by an open thoracotomy, thoracoscopy, laparoscopy, median sternotomy or laparotomy approach. However, as the robotic technologies improve, and our knowledge of them continue to evolve and our understanding of their role in surgically-treated diseases, it is likely that newer indications, potentially specific for robotics, will be identified. Thus, a patient that may not be capable of undergoing an open or a non-robotic minimally invasive approach may be able to undergo the same procedure robotically.

Selected References

A Consensus Document on Robotic Surgery. Prepared by the SAGES-MIRA Robotic Surgery Consensus Group. 2007. http://www.sages.org/publications/guidelines/consensus-document-robotic-surgery/

Carreyrou J. Surgical robot examined injuries. The Wall Street Journal 2010 May 4; 2010.

Cerfolio RJ, Bryant AS, Minnich DJ. Starting a robotic program in general thoracic surgery: why, how, and lessons learned. Ann Thorac Surg. 2011; 91:1729–36; discussion 36–7.

Ferguson MK, Umanskiy K, Warnes C, Celauro AD, Vigneswaran WT, Prachand VN. Training in minimally invasive lobectomy: thoracoscopic versus robotic approaches. Ann Thorac Surg. 2014;97:1885–92.

Griffen FD, Sugar JG. The future of robotics: a dilemma for general surgeons. Am Coll Surg Bull. 2013;98:9–15.

Hashizume M, Tsugawa K. Robotic surgery and cancer: the present state, problems and future vision. Jpn J Clin Oncol. 2004;34:227–37.

Poston R, Gharagozloo F, Khalpey Z, Kim S. Robotic training in cardiothoracic surgery. Ann Thorac Surg. 2014;97:378.

Prasad SM, Maniar HS, Soper NJ, Damiano RJ Jr, Klingensmith ME. The effect of robotic assistance on learning curves for basic laparoscopic skills. Am J Surg. 2002;183:702–7.

Rabin RC. Salesmen in the surgical suite. New York Times 2013 March 25, 2013.

2 Anesthesia for Robotic Thoracic Surgery

Javier H. Campos, Keinich Ueda, and Andres Falabella

Abstract

Minimally invasive surgery involving the thoracic cavity is on the rise. With the introduction of the da Vinci robot system more than 10 years ago, cardiac and thoracic operations have been performed.

The literature on this topic currently includes case reports or series of clinically prospective or retrospective observational reports with the use of robotic systems, involving the thoracic cavity (mediastinal mass resection, lobectomies, esophagectomies, mitral valve surgery, assisted endoscopic coronary artery bypass grafting and atrial septal defect repair).

The basic principles applied to minimally invasive surgery of the chest apply to robotic-assisted thoracic surgery. The combination of patient position management, of one-lung ventilation techniques and surgical manipulations after ventilation and perfusion from dependent and non-dependent or collapsed lung. The preferred method for lung isolation during robotic assisted thoracic surgery is the use of a left-sided double-lumen endotracheal tube because of the greater margin of safety and faster lung collapse. Visualization during robotic thoracic surgery may be enhanced by continuous intrathoracic carbon dioxide insufflation which may increase airway pressures and depress hemodynamic performance.

Patient positioning during robotic thoracic surgery represents a challenge for anesthesiologists each particular case might require specific patient position so the surgeon can gain enough space in the axilla for the robot arms and accessory port/instruments in thoracic surgery. Special attention should be given to avoid unnecessary stretching of the elevated arms because it can damage brachial plexus.

The success of robotic thoracic and cardiac surgery includes skills in lung isolation techniques, fiberoptic bronchoscopy techniques, the use of transesophageal echocardiography (cardiac cases) and clear understanding of the concept of robotic surgery and anesthesia.

Keywords

Anesthesia for robotic cardiac and thoracic surgery • Lung isolation, one lung ventilation with left-sided double-lumen endotracheal tube • Fiberoptic bronchoscopy techniques during robotic thoracic surgery • Carbon dioxide (CO_2) insufflation intrathoracic • Brachial plexus injuries during robotic thoracic surgery • Use of transesophageal echocardiogram in robotic cardiac surgery • Regional anesthesia, paravertebral blocks during robotic cardiac and thoracic surgery

J. H. Campos, M.D. (✉) • K. Ueda, M.D.
Department of Anesthesia, University of Iowa Health Care,
Roy and Lucille Carver College of Medicine, 200 Hawkins Drive,
Iowa City, IA 52242, USA
e-mail: javier-campos@uiowa.edu

A. Falabella, M.D.
City of Hope Helford Medical Clinical Research Hospital,
Arcadia, CA, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_2

2.1 Introduction

Minimally invasive surgery approaches have become increasingly popular in cardiac, thoracic and esophageal surgery. With the introduction of robotic systems more than 10 years ago, particularly the da Vinci® Robot System, cardiac and thoracic operations have been performed with some provocative results and limited defined advantages. This review provides an overview of the anesthetic implications and the use of the robotic system in patients undergoing robotic-assisted surgery through the thoracic cavity, with particular emphasis on the mediastinum, lungs, and esophagus.

2.2 Anesthesia Considerations in Robotic Thoracic Surgery

The basic principles applied to minimally invasive surgery of the chest (i.e. thoracoscopic surgery) apply to robotic-assisted thoracic surgery. The combination of patient position, management of one-lung ventilation (OLV) techniques, and surgical manipulations alter ventilation and perfusion from the dependent and non-dependent or collapsed lung. The preferred method for lung isolation during robotic assisted thoracic surgery is the use of a left-sided double-lumen endotracheal tube (DLT) because of the greater margin of safety and faster lung collapse. Also it provides ready access for bronchoscopic evaluation of the airway during surgical resection. In general, careful attention must be given to airway devices because changes in body position may cause tube migration. OLV anesthetic management is more challenging during robotic thoracic surgery due to the presence of the robot chassis that is stationed over the patient. The patient's airway is also usually located far from the anesthesia field. In some instances access to the airway, if needed, is not the most optimal because of the presence of robotic arms nearby.

Visualization during robotic thoracic surgery may be enhanced by continuous intrathoracic carbon dioxide (CO_2) insufflation, which may increase airway pressures and depress hemodynamic performance. When CO_2 is used, intrathoracic pressures greater than 10–15 mmHg are rarely necessary and may compromise the cardiorespiratory function. Increasing the intrathoracic pressure (i.e. >25 mmHg) can decrease venous return and cardiac compliance; in addition, the dependent lung develops higher airway pressures and ventilation can become difficult. During OLV and the robotic surgical procedure, to maintain oxygen saturation above 95%, the FiO_2 may need to be maintained at 100% and the peak inspiratory pressure should be kept <30 cmH_2O. The rate of ventilation should be adjusted to maintain the $PaCO_2$ at approximately 40 mmHg. Table 2.1 shows the surgical procedures performed in thoracic surgery with the da Vinci® Robotic Surgical System.

Table 2.1 Surgical procedures performed in thoracic surgery with the da Vinci® Robotic Surgical System

• Thymectomy
• Mediastinal mass extirpation
• Fundoplications
• Esophageal dissections
• Esophagectomy
• Pulmonary lobectomy

2.3 Robotic-Assisted Surgery and Anesthesia for Mediastinal Masses

Among the thoracic surgical procedures performed to date with the use of the da Vinci® Robotic Surgical System is the thymectomy [1]. Of the patients scheduled for robotic-assisted thymectomy, some have the diagnosis of myasthenia gravis or the presence of a thymic tumor. For patients with myasthenia gravis, adequate preparation of the patient for surgery includes neurological evaluation to assess the patient's neurological status and optimization of myasthenia; continuation of anticholinesterase therapy, plasmapheresis or immunoglobulin therapy may be indicated [2–4]. Precautions regarding anesthetic management include the proper dosing of muscle relaxants and the potentially dire consequences of a large mediastinal mass on airway obstruction and reduced parenchymal compliance.

Patients undergoing robotic thymectomy require the use of lung isolation devices. The most common device used in the setting is the left-sided DLT. Patient positioning for a thymectomy may require a nearly supine with a 30° angle right or a left lateral decubitus position with the use of a beanbag or role. The padded arm of the elevated side is positioned at the patient's side below the level of the table as far back as possible so the surgeon can gain enough space in the axilla for the robotic arms and accessory ports/instruments. While the robot is in use it is imperative to consider strategies to protect all pressure points and to avoid unnecessary stretching of the elevated arm, because this can cause damage to the brachial plexus. In addition, to avoid lung injury before the instruments are placed into the chest cavity, a complete lung collapse must be achieved throughout the procedure. Once the robot has been docked, the current robotic system does not allow for patient body position changes on the operating room table. An additional concern is that the operating room table is rotated obliquely away from the anesthesiologist's field positioning it relative to the robotic chassis. As a result access to the airway to make adjustments to the DLT during the surgery can be challenging and appropriate planning will allow for a safer procedure. In some cases a bilateral surgical approach may be required. In these cases the operation is performed in two stages, one side then the other, and requires undocking the robot and rotating the table 180° to provide surgical access to the opposite chest wall for the second portion of the operation. The anesthesiologist must be cautious during these changes to avoid dislodging the endotracheal tube and ventilator connection tubing, and to ensure that the lines and continuous pulse oximetry, electrocardiogram monitor wires and blood pressure monitoring lines have enough slack to accommodate changes in position. The anesthesiologist must be aware during these cases that possible injury to the contralateral mediastinal pleura to the first side, especially if CO_2 insufflation is used, as the elevated intrathoracic pressure in the contralateral hemithorax can make ventilation of the contralateral ventilated lung difficult and result in cardiovascular collapse essentially "tension" physiology. Special attention must be given to the elevated arm or head to prevent crushing or abrasive injury from the movement of the robotic arms. A recent case report [5] described a brachial plexus injury in an 18-year-old male after robot-assisted thoracoscopic thymectomy. The authors described that the left upper limb was in slight hyperabduction. It is important to keep in mind that hyperabduction of the elevated arm to provide sufficient surgical space can lead to a neurologic injury. Communication between the surgeon and the anesthesiologist provides a safe robotic procedure, reducing the likelihood for such injuries. The elevated arm should be protected with padding and by using a sling device that allows the arm to rest in a relaxed position. The heat from the robotic videoscope light source can be another cause of potential injury. Direct contact of these devices with surgical drapes and the patient's skin can quickly develop fires and burns, respectively, during the changing of the telescopes and cameras.

The reports of complications occurring during or following a robotic thymectomy are few. Bodner et al. [6] reported their retrospective review of 13 patients who underwent a complete *en bloc* thymectomy with the da Vinci® system showed no intraoperative complications or surgical mortality. Savitt et al. [7] reported on 14 patients robot-assisted complete thymectomies intraoperatively managed with OLT and arterial and central venous pressure catheters. All of the patients were approached from the right side and CO_2 insufflation to a pressure of 10–15 mmHg was used to compress the lung away from the operative area. Again, there were no conversions to thoracotomy or median sternotomy, nor any intraoperative complications or surgical mortality; the median hospital stay was 2 days with a range of 1–4 days. Through a left-sided approach, Rückert et al. [8] reported the largest series of robotic thymectomies, 106, with a zero percent mortality and an overall postoperative morbidity rate of 2%. Thus, in the publications to date, the initial robotic thymectomy experience appears to be safe and offers a minimally invasive opportunity for a complete thymectomy.

2.4 Robotic-Assisted Pulmonary Lobectomy

One of the first thoracic applications of the da Vinci® Robotic system was for lobectomy. Numerous investigators reported a sporadic and inconsistent use of robotics to perform lobectomy. In 2006, Park et al. [9] reported the largest and consistent use of the robot in a series of 30 patients, attempting it in 34. Four of the patients (12%) required conversion to thoracotomy Anderson et al. [10] reported a series of 21 robotic lung resection patients in which the 30-day mortality and conversion rate was 0%. The median operating room time and blood loss was 3.6 h and 100 mL. The complication rate was 27%, and included atrial fibrillation and pneumonia. Gharagozloo [11] reported a series of 100 consecutive robotic-assisted lobectomies for lung cancer and concluded that robotic surgery is feasible for mediastinal, hilar, and pulmonary vascular dissection during video-assisted thoracoscopy lobectomy.

Like the thymectomy, positioning the patient for a robotic lobectomy includes placing the patient over a bean bag or some other position maintaining device and typically flexing the operating table to open the intercostal spaces and swing the hip out of the way. The ipsilateral side arm is slightly extended cephalad and/or anteriorly to gain exposure to the axilla. There must be sufficient space to avoid injury to the arm, chest wall and hip. OLV is utilized. Ideally, the anesthesiologist should have experience in placing a DLT [12]. The left-sided DLT is most commonly used double-lumen system and is positioned with a flexible fiberoptic bronchoscope [13]. The airway, in a few instances, is difficult to place a DLT and, instead, a bronchial blocker [14]. Ideally, the operated lung must be isolated from ventilation to minimize lung motion, optimize visibility and reduce parenchymal bleeding.

The monitoring for lobectomy is the same as described above for the thymectomy. Preparation for a potential thoracotomy is important and may occur at any time. Park [9] in their early experience converted to open thoracotomy in 12% of their patients 75% of them for bleeding. The lateral decubitus position and the 180° rotation away from the anesthesiologist's field present particular challenges in managing the endotracheal tube. The chassis of the robot is often positioned over the patients head leaving a very small area for the anesthesiologist to access the airway. As with the thymectomy, some surgical teams use thoracic cavity 10–15 cmH_2O CO_2 insufflation to gain operative exposure. In some patients, this may present challenges and the anesthesiologist must adjust the pressure as the patient accommodates.

With their greater surgical experience with minimally invasive lobectomy, safety is being demonstrated by Gharagozloo et al. [11] reporting their experience in 100 consecutive robotic lobectomies requiring no emergent thoracotomies. Postoperative analgesia was addressed with the infusion of a local anesthetic (0.5% bupivacaine, 4 mL/h) through catheters placed in an extrapleural tunnel placed from intercostal space 2–8. All patients in this report were extubated in the operating room. Their 30-day mortality was 4.9%, with a median length of stay of 4 days. Postoperative complications included atrial fibrillation in four cases, prolonged air leak in two cases, and pleural effusion requiring drainage in two cases, similar complication and rates to the experience with video thoracoscopic surgery. Although lobectomy can be performed via robot-assisted surgery, the advantages at the present time are not well defined.

2.5 Robotic-Assisted Esophageal Surgery

The esophagus can be removed using a robot in using four basic techniques: chest only, transhiatal, abdomen then chest technique with the anastomosis in the neck and the abdomen then chest technique with the anastomosis in the chest. From a patient management viewpoint, the chest then abdomen or the esophagolymphadenectomy technique presents particular challenges [15, 16]. Basically, there are two phases or stages. Each stage requires a different patient position and the operating room needs to be set up according to the patient's new position. The first part of the operation is the dissection of the esophagus and lymph nodes in the thorax. The patient is positioned on a beanbag on the left lateral decubitus position, and the table is tilted to the right so that the patient is almost in the prone reverse Trendelenburg position. The left upper extremity is hyperextended and placed on a sling device very close to the patient's face to create chest space for the robotic ports/instruments. The operating room table is rotated 100° away from the anesthesia field. This part of the operation requires OLV and CO_2 insufflation to provide visualization of the esophagus. The anesthesiologist should anticipate hemodynamic and respiratory changes during CO_2 insufflation; resection of the contralateral pleura is not infrequently required and the CO_2 leakage into the opposite chest presents hemodynamic and ventilatory challenges.

The second stage of the procedure is the abdominal portion, the dissection of the stomach, and creation of the gastric tube and neck pharyngoesophageal-gastric anastomosis. This part of the procedure is performed with the patient in the supine position and with the operating room table rotated 180° away from the anesthesiologist's field. The patient is supine and the robot is brought in over the patient's head limiting the exposure to the airway and the endotracheal tube. The anesthesiologist should be aware that ventilatory pressures and hemodynamics can change rather acutely once the transhiatally-approached mediastinal pleura is breached. This occurs during the dissection around the gastroesophageal junction, CO_2 can escape into the chest trough the hiatus. In this case, the combination of insufflation, fluid flux and the reverse Trendelenburg body position can have an adverse impact on the hemodynamic status of the patient. Adjustments in fluid management, CO_2 pressure, light pressors and ventilatory pressure adjustments are often simultaneously required.

The initial experience with the da Vinci® system in esophageal surgery involved a patient who had a thoracic esophagectomy with wide celiac axis lymphadenectomy; the case was reported by Kernstine et al. [15] and had promising results. Thereafter, another report using the using the da Vinci® system 6 esophagectomy patients without intraoperative complications [17] was published. The surgical approach in this report was performed from the right side of the chest first. A left-sided DLT was used to selectively collapse the right lung. In a report by Van Hillegersberg et al. [18] 21 consecutive patients with esophageal cancer underwent a robot-assisted thoracoscopic esophagolymphadenectomy, 18 cases were completed thoracoscopically and three required conversion to open procedures (because adhesions or intraoperative hemorrhage). In this case series report, all patients received a left-sided DLT and a thoracic epidural catheter as part of their anesthetic management. Positioning of these patients was in a left lateral decubitus position, and the patient was tilted 45° towards the prone position. Once the robotic thoracoscopic phase was completed, the patient was then placed in supine position and a midline laparotomy was performed. A cervical esophagogastrostomy was performed in the neck for the completion of surgery. Of interest, in this series, pulmonary complications occurred in the first ten cases (60%); the authors surmised were caused primarily by left-sided pneumonia and associated acute respiratory distress syndrome in three patients (33%). These complications were felt related to barotrauma to the left lung (the ventilated, or dependent, lung) attributed to high tidal volumes and high peak inspiratory pressures. In the 11 patients that followed, the same authors modified their ventilatory setting to administer continuous positive airway pressure (CPAP) ventilation, 5 cm H_2O during OLV and pressure-controlled ventilation was used; with this approach the respiratory complication rate was reduced to 32%.

Another study [16] involved 14 patients who underwent esophagectomy using the da Vinci® system in different surgical stages. It showed that for a complete robotic esophagectomy including laparoscopic gastric conduct, the operating room time was an average of 11 h with a console time by the surgeon of 5 h, an estimated average blood loss of 400 ± 300 mL. In this report after the robotic thoracoscopic part of the surgery was accomplished with the patient in the lateral decubitus position, patients were then placed in supine position and reintubated, and the DLT was replaced with a single-lumen endotracheal tube. The technique required that

Table 2.2 Complications of robotic-assisted thoracic surgery

Author	Number of cases	Operation	Intraoperative complications	Postoperative complications
Rea et al. [1]	33	Thymectomy	0	Chylothorax n = 1
				Hemothorax n = 1
Pandey et al. [5]	1	Thymectomy	–	Brachial plexus injury
Bodner et al. [6]	14	Mediastinal mass resection	0	Postoperative hoarseness due to lesion to left laryngeal recurrent nerve
Savitt et al. [7]	15	Mediastinal mass resection	0	Atrial fibrillation n = 1
Rückert et al. [8]	106	Thymectomy	Bleeding n = 1	Phrenic nerve injury n = 1
Park et al. [9]	34	Lobectomy	Conversion to open thoracotomy n = 3	Supraventricular arrhythmia n = 6
			Lack lung isolation n = 1	Bleeding n = 1
				Air leak n = 1
Gharagozloo et al. [11]	100	Lobectomy	0	Atrial fibrillation n = 4
				Air leak n = 2
				Bleeding n = 1
				Pleural effusion n = 2
Van Hillegersberg et al. [18]	21	Esophagectomy	Conversion to open procedure n = 3	Pulmonary complication 60% first 10 cases
				Pulmonary complication 32%, 11 patients
Kernstine et al. [15]	14	Esophagectomy	Conversion to open procedure n = 1	Thoracic duct leak n = 3
				Vocal cord paralysis n = 3
				Atrial fibrillation n = 5

the head be turned upward and to the patient's right, exposing the left neck for the cervical part of the operation. Atrial fibrillation was the more common complication presenting in five out of 14 patients.

Kim et al. [19] studied 21 patients undergoing robotic-assisted esophagectomy. The airway was managed with the use of a Univent® bronchial blocker endotracheal tube to isolate the right lung. Once the trocars were placed CO_2 insufflation was initiated at 8–10 mmHg pressure. Hemodynamic and respiratory parameters showed an increase in central venous pressure and mean pulmonary artery pressure when the patients were in a prone position and they were further elevated during OLV. All variables returned to baseline when the patients were repositioned to the supine position at the end of the thoracic phase. Cardiac index and mean arterial blood pressure were maintained with no significant changes during the procedure. The authors also reported elevation of peak airway pressure and plateau pressure with a decrease in static lung compliance during the pone position with no alterations in PaO_2 or $PaCO_2$. After OLV was initiated, static lung compliance significantly decreased below 50% of baseline. This change also caused a marked increase in peak airway and plateau pressures with a decrease in PaO_2 and an increase in $PaCO_2$.

In the report by Kernstine et al. [15], among the recommendations to improve efficiency in these cases is the "use of an experienced anesthesiologist who can efficiently intubate and manage single-lung ventilation and hemodynamically support of the patient during the procedure." This follows what Nifong and Chitwood [12] have reported in their editorial that a team approach with expertise in these procedures involving nurses, anesthesiologists, and surgeons with an interest in robotic procedures is required. Table 2.2 displays the complications of robotic-assisted thoracic surgery involving the mediastinum, lung, and esophagus.

2.6 Carbon Dioxide Insufflation During Thoracoscopy

Continuous low-flow insufflation of CO_2 has been demonstrated as an aid for surgical exposure during minimally invasive thoracic procedures. It has been used as the only means of providing surgical exposure to the thoracic cavity, or more frequently in conjunction with a DLT or a bronchial blocker. The compression of the lung parenchyma assists in retraction, and it also helps by effacing subpleural lesions [20].

Vassiliades [21] reported the results of a study in 75 patients undergoing minimally invasive coronary artery bypass graft surgery (CABG) and showed that CO_2 insufflation in combination with single-lung ventilation increases central venous pressures and pulmonary artery pressures, while negative effects were seen on systemic blood pressure, cardiac output, and stroke volume at higher pressures. He concluded that single-lung ventilation and CO_2 insufflation enhance the technical ease of thoracoscopic internal mammary harvest, and he suggested that while it is safe in the majority of patients, CO_2 insufflation should be use with caution in hypovolemic patients and patients with poor left ventricular function. Tomescu et al. [22], reported in 24 patients a statistically significant decrease in cardiac index, stroke index, and mean arterial blood pressure however, these changes had minimal clinical relevance. A study by Ohtsuka et al. [23] involving 38 patients undergoing minimally invasive internal mammary harvest found significant increases in mean central venous pressure, pulmonary artery pressure and the pulmonary artery wedge pressure. They also found that on the right side hemithorax, but not on the left side, slight decreases were noted in the mean arterial blood pressure and cardiac index. They concluded that the hemodynamic effect from continuous insufflation of CO_2 at 8–10 mmHg for 30–40 min is mild in both hemithoraces, although the impact is greater on the right. This information was supported by another study [24]. This study involving 20 patients undergoing thoracoscopic sympathectomy and concluded that compared to the left side hemithorax the impact of CO_2 insufflation on the vena cava and the right atrium during right-sided procedures was associated with reduction of venous return and low cardiac index and stroke volume.

The impact of CO_2 insufflation on the respiratory system has also been studied. El-Dawlatly et al. [25] reported a significant pressure-dependent increase in peak airway pressure and a decrease in dynamic lung compliance but no difference in tidal volume or minute ventilation.

Insufflation of CO_2 should only be started after initial thoracoscopic evaluation has ruled out that the port of insufflation has not compromised a vascular structure or the lung parenchyma. Communication between the surgeon, anesthesiologist, and operating room personnel is crucial at this point. Insufflation is ideally started at low pressures of 4–5 mmHg and is gradually increased while monitoring the patient's vital signs. The use of intrathoracic pressure of more than 15 mmHg has not been reported in the literature and should be avoided because it increases the risks of cardiovascular collapse. The anesthesiologist should always be aware of the possibility of gas embolization during these cases. In the case of sudden cardiac collapse, the CO_2 flow should be discontinued immediately. Ventilation during CO_2 insufflation should be titrated to keep adequate oxygenation and a normal PCO_2 and pH. Also, damage to the contralateral pleura may occur resulting in CO_2 flow to the contralateral chest, making ventilation difficult and also causing hemodynamic compromise.

2.7 Anesthesia Considerations in Robotic Cardiac Surgery

Robotic cardiac surgery has been developing over the last 10 years. In the United States as of 2008, approximately 1700 cardiac surgeries are performed robotically, and the number continues to increase [26]. The major advantages of introducing robotic technology in cardiac surgery are to minimize surgical incision by avoiding sternotomy and to minimize postoperative pain and recovery time. Common robotic cardiac cases include mitral valve repair (MVR) [27–29] coronary artery bypass grafting (CABG) [30–32], atrial septal defect (ASD) repair [33–35], and intracardiac tumor resection [36, 37]; robotic arrhythmia surgery and resynchronization have been reported as well [38, 39]. Table 2.3 displays common robotic cardiac surgical cases and outcomes.

Robotic cardiac surgery and anesthesia requires knowledge in thoracic anesthesia and regional anesthesia, also these surgical cases require invasive monitoring including a transesophageal echocardiogram (TEE) and a pulmonary artery catheter. OLV with a lung isolation device is required for robotic cardiac surgery, because the robotic arms enter through either the right or left thorax. Lack of lung collapse will interfere with the procedure or even require conversion of the procedure to sternotomy. The most common devices used for an absolute lung isolation is the left-sided DLT because of its margin of safety. However, specific situations, i.e. difficult airway or mechanical ventilation in the postoperative period (as commonly presented in cardiac surgery), will require the use of a single-lumen endotracheal tube and the use of an independent bronchial blocker [40]. In order to maximize the benefit of robotic, minimally invasive surgery, the anesthesia technique should be modified accordingly.

2.8 Anesthetic Considerations in Robotic Mitral Valve Surgery

Robotic mitral valve surgery requires left OLV, as the right chest is entered through a 4–5 cm right lateral thoracotomy in the fourth intercostal space. On selected patients this robotic surgery is well tolerated and there have been no case reports of conversion [29, 41]. The patient is positioned in a modified lateral decubitus position with the right chest elevated 30–40°. The right arm can be suspended over the patient's forehead. There may be less risk of brachial plexus injury if the arm is positioned at the patient's side, with moderate flexion at the elbow [42]. Because access to the heart is

Table 2.3 Case reports robotic cardiac surgery

	Case reports	N	Surgical time CPB time (min)	ICU stay (h)	LOS (days)	Comments
Robotic mitral valve repair	Tatooles et al. [27]	25	199 ± 43 (140–287)	35.4 ± 18.5	2.68 ± 3.1	n = 21 extubated in the OR
			126 ± 25 (89–186)	(18–72)	(1–16)	n = 8 discharge within 24 h
						n = 2 required MV replacement
	Nifong et al. [28]	112	266 ± 73 (150–463)	36.6 ± 24.7	4.7 ± 3.0	Multicenter phase II FDA study
			168 ± 47 (82–316)	(6–140)	(1–18)	No deaths, strokes, or device-related complications
						No sternotomy conversion
						n = 6 required reoperations replacement and 1repair
	Chitwood et al. [29]	300	Surgical time *NIA* 158 ± 4	32.4 ± 67.3	5.2 ± 4.2	n = 9 were converted to videoscopic assisted minimally invasive approach (da Vinci system malfunction (n = 3), poor surgical exposure (n = 4), external instrument conflicts (n = l), need for MV replacement (n = l))
						n = 16 required reoperation
						1\vo 30-days mortalities and 6 late mortalities
Robotic assisted IMA harvesting	Subramanian et al. [30]	30	444 ± 49	NIA	NIA	Average number of bypass grafts 2.6
			NIA (off-pump CABG)			n = 29 were extubated immediately after surgery
						n = 15 were discharged within 24 h after surgery
						n = 2 required reexploration for bleeding
						n = 2 readmitted to hospital within 30 days (pleural effusion (n = l), wound infection (n = l))
	Srivastava et al. [31]	150	311 ± 11	NIA	3.9 ± 2.9	Bilateral internal mammary artery harvest with da Vinci system
			NIA (off-pump CABG)			Average number of bypass grafts 2.6 ± 0.8
						Bilateral IMA revascularization was completed in 148 (99%) patients
						n = 5 required reexploration for bleeding
AHTECAB	Argenziano et al. [32]	98	353 ± 89 (200–600)	35 ± 37	5.1 ± 3.4	Multicenter trial of IMA harvest and LIMA-LAD with AHTECAB
			117 ± 44 (41–254)			n = l8 were converted to another approach intraoperatively (failed peripheral cannulation for CPB (n = l0), poor visualization of coronary targets (n = 2), dense pleuropericardial adhesions (n = l), damage of the graft (n = 2), inadequate coronary anastomosis (n = 3))

(continued)

Table 2.3 (continued)

	Case reports	N	Surgical time CPB time (min)	ICU stay (h)	LOS (days)	Comments
Robotic ASD repair	Argenziano et al. [33]	17	CPB time 122 (Median)	20 (Median)	4 (Median) (2.5–10)	n = 1 required reoperation for recurrent shunt on POD-5
	Bonaros et al. [34]	17	314 (215–590)	26 (15–150)	8 (5–14)	
			144 (91–239)			
Rumor removal	Murphy et al. [36]	3	CPB time 103 ± 40	NA	4	Totally robotic resection of myxoma.
Arrhythmia and Resynchronization surgery	Jansens et al. [38]	15	150 ± 48	NA	NA	Robotic-enhanced biventricular resynchronization
						Two patients required conversion to a small thoracotomy
	Loulment et al. [39]	1	255	NA	NA	First case report of robotic assisted epicardial pulmonary veins isolation

CPB cardiopulmonary bypass, *ICU* intensive care unit, *LOS* length of stay, *IMA* internal mammary artery, *AHTECAB* arrested heart totally endoscopic robotic coronary artery bypass grafting, *LIMA-LAD* left internal mammary artery to left anterior descending coronary artery, *POD* post operative day

limited during thoracoscopic surgery, external defibrillator patches must be placed on the thoracic cage away from the surgical incision. Of note, when the patient requires external defibrillation, immediate termination of lung isolation might be necessary in order to conduct sufficient electric current through the heart [43]. A TEE is also essential for robotic mitral surgery [44]. Moreover, some rare complications of robotic thoracic surgery, such as aortic dissection and atrial or ventricular perforation, can be identified with TEE. LeVan et al. [45] reported the case of a left atrial appendage perforation during femoral venous cannulation. They immediately converted the procedure to sternotomy after significant pericardial effusion was diagnosed by TEE.

Cardiopulmonary bypass (CPB) is established with femoral arterial inflow and inferior vena cava drainage through femoral venous and superior vena cava through right internal jugular vein cannulation. Aortic cross-clamp and cardiac arrest can be done by either port access or the transthoracic cross-clamp technique. The transthoracic cross-clamp technique has been shown to have fewer complications compared to the port access system [46, 47]. If the patient has had a previous sternotomy, a pacing pulmonary artery catheter should be considered because there may be limited access to the ventricle.

Postoperatively, the patients can be extubated immediately after surgery or at an early postoperative stage during their stay in the surgical intensive care unit. Tatooles et al. [27] reported a successful fast-track postoperative course following a robotic mitral valve surgery. The mean operating time was 199 min, CPB time 126 min, and aortic cross-clamp time 87 min. Twenty-one out of 25 (84%) patients were extubated in the operating room, and the remainder of the patients was extubated within 5 h after surgery. The average length of stay in the hospital was 2.7 days. Despite a high re-admission rate (28%), the author of the study commented that early discharge did not alter postoperative morbidity and that select patients with close follow-up can be safely discharged on their first postoperative day. In a US 11-center trial, the operation time, CPB time, and aortic cross-clamp time ranged from 150 to 463 min, 82 to 316 min, and 60 to 227 min, respectively [28]. Thus, a longer operating time may preclude early postoperative extubation. Some studies have shown that operating time decreases significantly with greater surgeon experience in robotic cardiac surgery [28, 48].

2.9 Robotic-Assisted Endoscopic Coronary Artery Bypass Grafting

Robotic-assisted endoscopic CABG spans a range from robotic-assisted endoscopic internal mammary artery (IMA) harvesting and direct graft anastomosis via thoracotomy to totally endoscopic coronary artery bypass grafting (TECAB), with or without CPB [31, 49]. When TECAB is performed with CPB, the port access system is utilized.

Robotic-assisted endoscopic CABG requires essentially the same anesthetic preparation as robotic MVR except for the side of OLV. Because the robotic arms and endoscope enter from the left thorax, right OLV should be applied to the patient. To facilitate the instruments' entrance, the patients are positioned supine with the left chest elevated 30° and the left arm placed lower than the posterior axillary line [50]. Insufflation of CO_2 is used for effective lung collapse at the pressure of 5–15 mmHg. OLV with insufflation of CO_2 can deteriorate hemodynamics. Immediately after initiation of CO_2 insufflation, the right ventricle is compressed, and venous return is obstructed by artificial tension pneumothorax. To attenuate this acute hemodynamic instability, volume therapy should be necessary before the onset of CO_2 insufflation [51]. Hypercarbia and hypoxia could induce acute pulmonary hypertension and right ventricular failure. In selected groups, patients tolerate OLV with insufflation of CO_2; nevertheless, some cases had to be converted to sternotomy [50, 52].

Subramanian et al. reported successful fast-tracking of 30 patients who underwent off-pump minimally invasive multivessel coronary bypass with robotic-assisted IMA harvesting [30]. Twenty-nine (97%) patients were extubated in the operating room, 15 patients (50%) were discharged within 24 h, and only two patients had a length of stay more than 3 days. There were only two patients who required re-admission within 30 days. There have been some reported failures of completion of these procedures (~13%) [32, 53]. Pleuropericardial adhesions, unstable hemodynamics with OLV, inadequacy of IMA flow, inadvertent injury during IMA harvesting, difficulties with CPB cannulation, poor visualization of target vessel, and inadequacy of the coronary anastomosis might require intraoperative conversion to an open procedure.

2.10 Robotically Assisted Totally Endoscopic Atrial Septal Defect Repair

There are limited reports of ASD repair and intracardiac tumor resection with the use of the robotic da Vinci® Robot System. Torracca et al. [54] reported first six cases of ASD closure using a robotic device. Subsequently, studies [34, 35] reported that the learning curve is steep for the procedure, enhanced postoperative recovery, and improved patient quality-of-life. Intracardiac tumors, including left atrial myxoma and aortic valve papillary fibroelastoma, have been successfully removed with a robotic surgical system [36, 37, 55].

Anesthesia preparation is similar as robotic MVR. Right lung isolation is required because the robotic arms enter through the right hemithorax. Note that continuous vigilance with TEE is needed for potential gas embolism during insufflation with CO_2 because this could cause a stroke due to right-to-left shunt [56].

2.11 Robotic Arrhythmia Surgery and Resynchronization

Cardiac electrophysiological therapy also can be assisted by robotic technology. Robotic assisted surgery for atrial fibrillation with or without CPB has been reported [39, 57]. The choice of DLT for the lung isolation device is recommended when epicardial isolation of the pulmonary veins technique is applied because the robotic arms enter right hemithorax, followed by the left hemithorax.

Robotic-assisted left ventricular epicardial lead implantation for resynchronization therapy merged as rescue technique due to the 10–15% failure rate of left ventricle lead placement via coronary sinus percutaneously [58]. Left lung isolation is required because the robotic arms enter through the left hemithorax. The patient is placed in the right decubitus position, the same position as with a posterolateral thoracotomy position [59]. Notably, those patients who are candidates for this procedure are mostly presented with decompensated heart failure.

2.12 Postoperative Pain Control in Robotic Cardiac Surgery

Postoperative pain management can be accomplished with various regional anesthesia techniques. Although duration of pain control is limited, an intercostal block under direct vision is commonly performed by the surgeon. Also, continuous local anesthetic infusion catheter could be placed at the spaces between the muscle layer and the ribs, as well as the muscle layer and the subcutaneous tissue [31]. A neuraxial block, including thoracic epidural anesthesia (TEA) and spinal anesthesia, has been utilized in cardiac surgery with excellent pain control. An epidural hematoma from systemic heparinization is a potential complication of these techniques [60], though the rate of incidence is extremely low and comparable to non-cardiac surgery. A thoracic paravertebral block is another alternative for post-thoracotomy pain control. Mehta et al. [61] showed that a paravertebral block was comparable to TEA with regard to quality of analgesia after robotic-assisted CABG.

2.13 Complications of Robotic Cardiac Surgery

With selected patients and experienced surgeons, robotic cardiac surgery can be safely performed with comparable or fewer complications than a traditional approach via sternotomy. Chitwood et al. [29] reported the results of robotic MVR of 300 patients with 0.7% 30-day mortality and fewer complications, including strokes (0.7%), transient ischemic attacks (0.7%), myocardial infarctions (1.0%), and reoperations for bleeding (2.3%). Surgeons have identified complications that are more specific or related to robotic cardiac surgery; Table 2.4 displays the complications in robotic cardiac surgery. Aortic dissection caused by femoral arterial or antegrade cardioplegia cannulation is a rare but serious complication [46, 48]. Perforation of the right ventricle by the endopulmonary vent in the port access system [47] is another cannula-related complication. The unique positioning required for robotic system access often presents new

Table 2.4 Robotic cardiac surgery and complications

Complications	Incidence	References
Early postoperative death (<30 days)		
MVR	1–3%	[28, 40, 64]
CABG	0%	[29, 30, 31, 51, 52, 62]
Revision due to lack of completion of procedure		
MVR	0–2.9%	[27, 28, 40, 46, 64]
CABG	1–18%	[30, 31, 51]
Reoperation for bleeding		
MVR	2–6%	[28, 40, 46, 64]
CABG	2–5%	[30, 31, 51]
Complication related to robotic system	Patients	
Aortic/femoral artery dissection	n = 3	[33, 45, 47]
RV perforation	n = 1	[46]
Left atrial appendage perforation	n = 1	[44]
Lower extremity compartment syndrome	n = 1	[32]
Groin lymphocele or infection	n = 4	[26, 31, 61]
Tracheal injury from DLT placement	n = 1	[46]

MVR mitral valve repair, *CABG* coronary artery bypass grafting, *RV* right ventricle, *DLT* double-lumen tube

anesthesia-related complications. There is a report of a tracheal rupture from DLT placement [47] in a patient undergoing robotic surgery. Perioperative blood loss and transfusion rate do not seem to be reduced by robotic approach even though sternotomy is avoided. In a study by Folliguet et al. [62] compared robotic mitral valve repair with conventional sternotomy approach and there were no differences in blood loss and transfusion rate between two groups.

2.14 Summary

Robotic thoracic and cardiac surgeries have evolved, and the technology is still improving at an exponential rate. To achieve success with robotic cardiac and thoracic surgery, including completion of the procedure through minimal access and a fast-track postoperative recovery, anesthesiologists must be skilled in lung isolation techniques, fiberoptic bronchoscopy techniques and transesophageal echocardiography (TEE) and have an understanding of the concept of robotic surgery and anesthesia [63].

References

1. Rea F, Marulli G, Bortolotti L, et al. Experience with the "da Vinci" robotic system for thymectomy in patients with myasthenia gravis. Ann Thorac Surg. 2006;8:455–9.
2. Baraka A. Onset of neuromuscular block in myasthenic patients. Br J Anaesth. 1992;69:227–8.
3. Abel M, Eisenkraft JB. Anesthetic implications of myasthenia gravis. Mt Sinai J Med. 2002;69:31–7.
4. Kernstine KH. Preoperative preparation of the patient with myasthenia gravis. Thorac Surg Clin. 2005;15(2):287–95.
5. Pandey R, Elakkumanan LB, Garg R, et al. Brachial plexus injury after robotic-assisted thoracoscopic thymectomy. J Cardiothorac Vasc Anesth. 2009;23:584–6.
6. Bodner J, Wykypiel H, Greiner A, et al. Early experience with robot-assisted surgery for mediastinal masses. Ann Thorac Surg. 2004;78:259–65.
7. Savitt MA, Gao G, Furnary AP, et al. Application of robotic-assisted techniques to the surgical evaluation and treatment of the anterior mediastinum. Ann Thorac Surg. 2005;79:450–5.
8. Rückert JC, Ismail M, Swierzy M, et al. Thoracoscopic thymectomy with the da Vinci® robotic system for myasthenia gravis. Ann N Y Acad Sci. 2008;1132:329–235.
9. Park BJ, Flores RM, Rusch VW. Robotic assistance for video-assisted thoracic surgical lobectomy: technique and initial results. J Thorac Cardiovasc Surg. 2006;131:54–9.
10. Anderson CA, Hellan M, Falabella A, et al. Robotic-assisted lung resection for malignant disease. Innovations. 2007;2:254–8.
11. Gharagozloo F, Margolis M, Tempesta B, et al. Robot-assisted lobectomy for early-stage lung cancer: report of 100 consecutive cases. Ann Thorac Surg. 2009;88:380–4.
12. Nifong LW, Chitwood WR Jr. Challenges for the anesthesiologist: robotics? Anesth Analg. 2003;96:1–2.
13. Campos JH. Update on tracheobronchial anatomy and flexible fiberoptic bronchoscopy in thoracic anesthesia. Curr Opin Anaesthesiol. 2009;22:4–10.
14. Campos JH. Progress in lung separation. Thorac Surg Clin. 2005;15:71–83.
15. Kernstine KH, DeArmond DT, Karimi M, et al. The robotic, 2-stage, 3-field esophagolymphadenectomy. J Thorac Cardiovasc Surg. 2004;127:1847–9.
16. Kernstine KH, DeArmond DT, Shamoun DM, Campos JH. The first series of completely robotic esophagectomies with three-field lymphadenectomy: initial experience. Surg Endosc. 2007;21:2285–92.
17. Bodner JC, Zitt M, Ott H, et al. Robotic-assisted thoracoscopic surgery (RATS) for benign and malignant esophageal tumors. Ann Thorac Surg. 2005;80:1202–6.
18. Van Hillegersberg R, Boone J, Draaisma WA, et al. First experience with robot-assisted thoracoscopic esophagolymphadenectomy for esophageal cancer. Surg Endosc. 2006;20:1435–9.
19. Kim DJ, Hyung WJ, Lee CY, et al. Thoracoscopic esophagectomy for esophageal cancer: Feasibility and safety of robotic assistance in the prone position. J Thorac Cardiovasc Surg. 2010;139:53–9.
20. Wolfer RS, Krasna MJ, Hasnain JU, McLaughlin JS. Hemodynamic effects of carbon dioxide insufflation during thoracoscopy. Ann Thorac Surg. 1994;58:404–7.
21. Vassiliades TA. The cardiopulmonary effects of single-lung ventilation and carbon dioxide insufflation during thoracoscopic internal mammary artery harvest. Heart Surg Forum. 2002;5:22–4.
22. Tomescu D, Grigorescu B, Nitulescu R, et al. Hemodynamic changes induced by positive pressure capnothorax during thoracoscopic thymectomy. Chirurgia. 2007;102:263–70.
23. Ohtsuka T, Nakajima J, Kotsuka Y, Takamoto S. Hemodynamic response to intrapleural insufflation with hemipulmonary collapse. Surg Endosc. 2001;15:1327–30.
24. El-Dawlatly AA, Al-Dohayan A, Samarkandi A, et al. Right vs left side thoracoscopic sympathectomy: effects of carbon dioxide insufflation on haemodynamics. Ann Chir Gynaecol. 2001;90:206–8.
25. El-Dawlatly AA, Al-Dohayan A, Abdel-Meguid ME, et al. Variations in dynamic lung compliance during endoscopic thoracic sympathectomy with carbon dioxide insufflation. Clin Auton Res. 2003;13(Suppl 1):I94–7.

26. Robicsek F. Robotic cardiac surgery: time told! J Thorac Cardiovasc Surg. 2008;135:243–6.
27. Tatooles AJ, Pappas PS, Gordon PJ, et al. Minimally invasive mitral valve repair using the da Vinci robotic system. Ann Thorac Surg. 2004;77:1978–82.
28. Nifong LW, Chitwood WR, Pappas PS, et al. Robotic mitral valve surgery: a United States multicenter trial. J Thorac Cardiovasc Surg. 2005;129:1395–404.
29. Chitwood WR Jr, Rodriguez E, Chu MW, et al. Robotic mitral valve repairs in 300 patients: a single-center experience. J Thorac Cardiovasc Surg. 2008;136:436–41.
30. Subramanian VA, Patel NU, Patel NC, et al. Robotic assisted multivessel minimally invasive direct coronary artery bypass with port-access stabilization and cardiac positioning: paving the way for outpatient coronary surgery? Ann Thorac Surg. 2005;79:1590–6.
31. Srivastava S, Gadasalli S, Agusala M, et al. Use of bilateral internal thoracic arteries in CABG through lateral thoracotomy with robotic assistance in 150 patients. Ann Thorac Surg. 2006;81:800–6.
32. Argenziano M, Katz M, Bonatti J, et al. Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. Ann Thorac Surg. 2006;81:1666–74.
33. Argenziano M, Oz MC, Kohmoto T, et al. Totally endoscopic atrial septal defect repair with robotic assistance. Circulation. 2003;108(Suppl 1):II191–4.
34. Bonaros N, Schachner T, Oehlinger A, et al. Robotically assisted totally endoscopic atrial septal defect repair: insights from operative times, learning curves, and clinical outcome. Ann Thorac Surg. 2006;82:687–93.
35. Morgan J, Peacock J, Kohmoto T, et al. Robotic techniques improve quality of life in patients undergoing atrial septal defect repair. Ann Thorac Surg. 2004;77:1328–33.
36. Murphy DA, Miller JS, Langford DA. Robot-assisted endoscopic excision of left atrial myxomas. J Thorac Cardiovasc Surg. 2005;130:596–7.
37. Woo YJ, Grand TJ, Weiss SJ. Robotic resection of an aortic valve papillary fibroelastoma. Ann Thorac Surg. 2005;80:1100–2.
38. Jansens JL, Jottrand M, Preumont N, et al. Robotic-enhanced biventricular resynchronization: an alternative to endovenous cardiac resynchronization therapy in chronic heart failure. Ann Thorac Surg. 2003;76:413–7.
39. Loulmet DF, Patel NC, Patel NU, et al. First robotic endoscopic epicardial isolation of the pulmonary veins with microwave energy in a patient in chronic atrial fibrillation. Ann Thorac Surg. 2004;78:24–5.
40. Lehmann A, Zeitler C, Lang J, et al. A comparison of the Arndt endobronchial blocker with a double lumen tube in robotic cardiac surgery. Anasthesiol Intensivmed Notfallmed Schmerzther. 2004;39:353–9.
41. Aybek T, Dogan S, Risteski PS, et al. Two hundred forty minimally invasive mitral operations through right minithoracotomy. Ann Thorac Surg. 2006;81:1618–24.
42. Rodriguez E, Kypson AP, Moten SC, et al. Robotic mitral surgery at East Carolina University: a 6 year experience. Int J Med Robot. 2006;2:211–5.
43. Hatton KW, Kilinski LC, Ramaiah C, et al. Multiple failed external defibrillation attempts during robot-assisted internal mammary harvest for myocardial revascularization. Anesth Analg. 2006;103:1113–4.
44. Sorrell VL, Rajeev AG, Nifong LW, et al. Intraoperative transesophageal echocardiography with a special focus on a patient undergoing advanced robotic-assisted procedures. Echocardiography. 2002;19:583–7.
45. LeVan P, Stevenson J, Develi N, et al. Cardiovascular collapse after femoral venous cannula placement for robotic-assisted mitral valve repair and patent foramen ovale closure. J Cardiothorac Vasc Anesth. 2008;22:590–1.
46. Autschbach R, Onnasch JF, Falk V, et al. The Leipzig experience with robotic valve surgery. J Card Surg. 2000;15:82–7.
47. Reichenspurner H, Detter C, Deuse T, et al. Video and robotic-assisted minimally invasive mitral valve surgery: a comparison of the Port-Access and transthoracic clamp techniques. Ann Thorac Surg. 2005;79:485–90.
48. Jones BA, Krueger S, Howell D, et al. Robotic mitral valve repair: a community hospital experience. Tex Heart Inst J. 2005;32:143–6.
49. Kappert U, Tugtekin SM, Cichon R, et al. Robotic totally endoscopic coronary artery bypass: a word of caution implicated by a five-year follow-up. J Thorac Cardiovasc Surg. 2008;135:857–62.
50. Ishikawa N, Watanabe G, Iino K, et al. Robotic internal thoracic artery harvesting. Surg Today. 2007;37:944–6.
51. Mierdl S, Byhahn C, Lischke V, et al. Segmental myocardial wall motion during minimally invasive coronary artery bypass grafting using open and endoscopic surgical techniques. Anesth Analg. 2005;100:306–14.
52. Caynak B, Sagbas E, Onan B, et al. Robotically enhanced coronary artery bypass grafting: the feasibility and clinical outcome of 196 procedures. Int J Med Robot. 2009;5:170–7.
53. Damiano RJ Jr, Tabaie HA, Mack MJ, et al. Initial prospective multicenter clinical trial of robotically-assisted coronary artery bypass grafting. Ann Thorac Surg. 2001;72:1263–8.
54. Torracca L, Ismeno G, Alfieri O. Totally endoscopic computer-enhanced atrial septal defect closure in six patients. Ann Thorac Surg. 2001;72:1354–7.
55. Gao C, Yang M, Wang G, et al. Totally robotic resection of myxoma and atrial septal defect repair. Interact Cardiovasc Thorac Surg. 2008;7:947–50.
56. Tamim M, Omrani M, Tash A, et al. Carbon dioxide embolism during endoscopic vein harvesting. Interact Cardiovasc Thorac Surg. 2008;7:659–60.
57. Cheema FH, Weisberg JS, Khalid I, et al. Warm beating heart, robotic endoscopic Cox-cryomaze: an approach for treating atrial fibrillation. Ann Thorac Surg. 2009;87:966–8.
58. Abraham WT, Fisher WG, Smith AL, et al. Cardiac resynchronization in chronic heart failure. N Engl J Med. 2002;346:1845–53.
59. Derose JJ Jr, Belsley S, Swistel DG, et al. Robotically assisted left ventricular epicardial lead implantation for biventricular pacing: the posterior approach. Ann Thorac Surg. 2004;77:1472–4.
60. Royse CF. High thoracic epidural anaesthesia for cardiac surgery. Curr Opin Anaesthesiol. 2009;22:84–7.
61. Mehta Y, Arora D, Sharma KK, et al. Comparison of continuous thoracic epidural and paravertebral block for postoperative analgesia after robotic-assisted coronary artery bypass surgery. Ann Card Anaesth. 2008;11:91–6.
62. Folliguet T, Vanhuyse F, Constantino X, et al. Mitral valve repair robotic versus sternotomy. Eur J Cardiothorac Surg. 2006;29:362–6.
63. Campos JH. An update on robotic thoracic surgery and anesthesia. Curr Opin Anaesthesiol. 2010;23:1–6.
64. Bolton JWR, Connally JE. Results of a phase one study on robotically assisted myocardial revascularization on the beating heart. Ann Thorac Surg. 2004;78:154–8.

Part II

Anatomic Lung Resection

3 Robotic Lobectomy

Bernard J. Park

Abstract
This chapter will review the development and technical aspects of anatomic pulmonary resection performed utilizing the da Vinci Surgical System. Indications, patient selection, anesthetic concerns and positioning will be reviewed along with specific information with respect to instrumentation. Step-by-step details of each type of lobectomy will be elucidated in depth, as well as unique considerations for both the Si and the newest Xi system. Extended resections, including concomitant chest wall resection, bronchial and vascular sleeve resections and bilobectomy/pneumonectomy will not be addressed here.

Keywords
Lobectomy • Robotic • VATS • Lymph node dissection • Anatomic

3.1 Development of Robotic Lung Resection

Prior to the 1980s the standard approach for performing major pulmonary resection was rib-spreading thoracotomy. This provided excellent exposure but was associated with potential for exceptional postoperative pain and morbidity in high-risk patients. With the rapid improvements in video technology and development of endoscopic instrumentation like stapling devices, there has been a shift toward a minimally invasive approach to lung resections.

Techniques of minimally invasive video assisted thoracic surgery (VATS) lobectomy were developed more than 20 years ago and have slowly supplanted open approaches for isolated lung lesions in most tertiary centers. The evidence of benefit of this technique over a standard thoracotomy is growing and include improvements in acute postoperative pain, shorter chest tube duration, reduced hospital stay, and lower complications in compromised patients [1–6]. Moreover, with respect to treatment of early stage lung cancer, more recent evidence has shown similar long-term survival in patients having minimally invasive lobectomy versus thoracotomy [7, 8].

However, one major hurdle to more universal adoption has been technical challenges associated with limitation of instrumentation and visualization. Standard endoscopic instruments have only four degrees of freedom resulting in significantly reduced dexterity. Combine this with the operator having to reverse their hand motions, the so-called fulcrum effect, the loss of binocular vision with the standard thoracoscope, and the result is a relatively long learning curve for surgeons unfamiliar with VATS techniques [9, 10].

The development of the da Vinci™ (Intuitive Surgical, Sunnyvale, CA) telerobotic surgical system addressed some of the technical limitations of conventional minimally invasive technology. Since the initial FDA approval of the standard system in 2000 there have been four generations of systems. The latest, the da Vinci Xi system, is currently in use at our institution and has several advantages over conventional thoracoscopy for the operating surgeon:

1. The da Vinci™ visual system provides high definition, stereoscopic binocular vision allowing for depth perception, a big improvement over traditional VATS imaging on a two dimensional display monitor. In addition, the

B. J. Park, M.D., F.A.C.S. (✉)
Department of Surgery, Memorial Sloan Kettering Cancer Center, 1275 York Avenue, Room C-879, New York, NY 10065, USA
e-mail: parkb@mskcc.org

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_3

image can be magnified up to ten times to give unparalleled detail during dissection and mobilization of hilar structures. The other advantage over conventional thoracoscopy is the stable nature of the camera that is under direct control by the operating surgeon.

2. The da Vinci™ Endowrist instruments restore the degrees of freedom lost with conventional VATS instruments. With seven degrees of freedom the robotic instruments recreate the dexterity associated with direct manual dissection. The robotic arm allows three degrees of movement, insertion, external pitch and external yaw. The endowrist allows four more degrees of movement inside the chest cavity, wrist pitch, wrist yaw, rotation and grasp. Together this greatly enhances the surgeon's ability to manipulate the mediastinal and hilar structures.
3. In addition to greater dexterity, the da Vinci™ system has downscaling capability allowing transduction of the surgeon's movements to finer, precise movements at the instruments tips. This with the tremor filter results in an exceptional level of precision in manipulation of the instruments.

3.1.1 Components of the System

The da Vinci™ Surgical System has three main components; the patient cart, surgeon's console and the vision cart (Fig. 3.1). The patient cart contains the four surgical end-effector arms. In the latest Xi model, the endoscope can be controlled by any of the four arms allowing for greater flexibility that increasing the effective working area that can be reached. All four arms including the endoscope are controlled from the surgeon console, which includes the 3D image viewer, the master hand controls, and the multifunction foot pedals that allow application of energy, control of the camera and switching from instrument arms. The endoscope provides a high-definition, binocular view of the surgical field with both 0° and 30° options.

The vision cart contains a touchscreen monitor to provide a view of the operative field to the bedside assistants and OR staff. An electrosurgical unit is integrated into the vision cart providing monopolar or bipolar energy to the various da Vinci™ Xi instruments being utilized. There are a variety of instrument options available for pulmonary resection. Typically, at least three instruments are used for anatomic lung resection: a forceps (Cadiere, Fenestrated Bipolar or Prograsp), an energy dissection device (Maryland bipolar, monopolar spatula, hook cautery) and a retractor (Tip up fenestrated grasper, Thoracic grasper).

3.1.2 Patient Selection and Indications

Selection criteria for robotic lung resection are similar to VATS and most thoracotomy approaches. As with any surgical procedure, there is no substitute for sound judgment and while there are no absolute contraindications for robotic lung resection there are several potential relative contraindications particularly early in one's experience:

- Inability to maintain lung isolation
- Adherent hilar nodal disease (either inflammatory or neoplastic)
- Large, central lesions

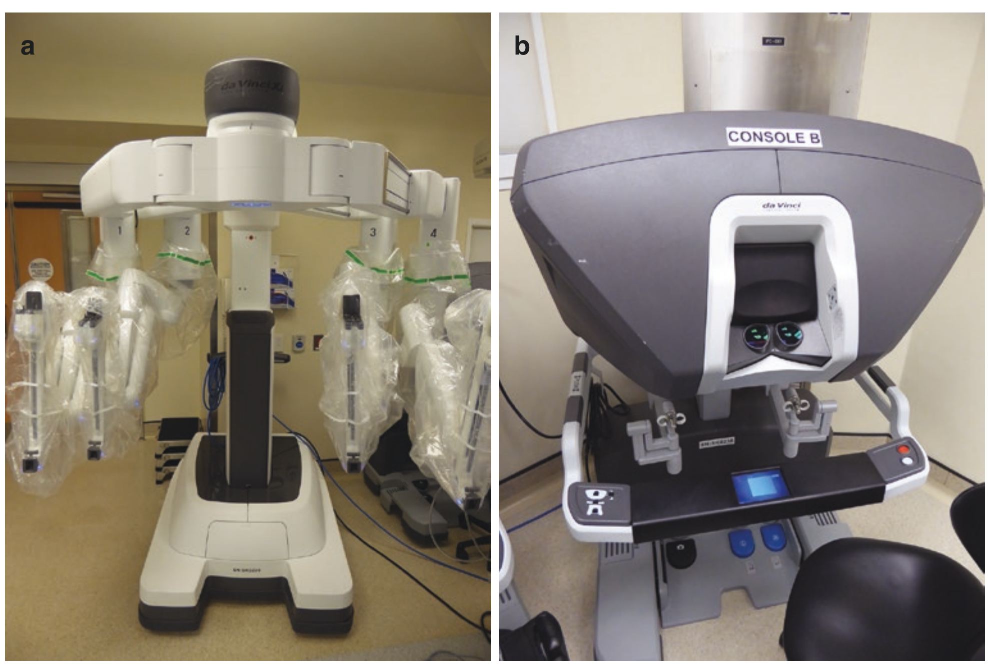


Fig. 3.1 Da Vinci Xi Surgical System

- Need for sleeve (bronchial or vascular) resection
- Locally advanced tumors invading the chest wall or mediastinum

While dense pleural adhesions often have been cited as a relative contraindication for a VATS approach, this is less so for robotic surgery as the visualization and instrument dexterity offered makes extensive adhesiolysis feasible.

3.2 Surgical Technique for Robotic Pulmonary Lobectomy

3.2.1 Preparation of the Robotic System

The nursing and technical staff of the operating set up the robotic system (cart, surgeon's console, visual system) concurrently as the patient is being brought into the room and placed under anesthesia. It is an efficient practice to allow the components of the system to remain in dedicated rooms to minimize setup time and potential for damage. When using the Si system the arms are positioned on the ipsilateral side as the planned resection. This is less critical with the Xi system because of the enhanced targeting feature and ability of the arms to rotate up to 270° theoretically allowing the cart to be positioned virtually anywhere with respect to the operating Table.

3.2.2 Anesthetic Consideration and Patient Positioning

The most common anesthetic strategy involves general anesthesia with endotracheal intubation and lung isolation, but variations include low tidal volume ventilation with or without CO_2 insufflation or intravenous anesthesia with spontaneous ventilation. Standard intraoperative monitoring includes EKG, arterial line for blood pressure monitoring and urinary catheter. We do not routinely place a thoracic epidural for robotic lung resections, instead utilizing multilevel intercostal nerve blocks, peripheral patient-controlled analgesia and liberal used of non-steroidal anti-inflammatory medications.

The patient is positioned in the lateral decubitus position with generous flexion of the operating table to establish a level horizontal surface from the arm to the iliac crest. This is essential, particularly in female patients, to allow for full range of motion of the instruments. This maneuver also aids in opening the intercostal spaces reducing pressure on the intercostal nerve from the trocars.

If one is employing the second (S) or third (Si) generation system, an important step prior to prepping and draping is to move the operating table slightly away from the anesthesia area and to angle the foot of the operating table away from the surgical cart. The smaller the angle of approach of the cart with respect to the longitudinal axis of the patient, the greater the table should be rotated. For example, if one wishes to bring the arms over the patient's head, the table should be angled 90° from the original table position. Care must be taken to insure that there is sufficient length of the circuit tubing available during this positioning, and the anesthesia team must be comfortable that there is adequate access to the patient's airway once docking of the robotic system has taken place.

3.2.3 Port Placement

The same incision strategy may be employed no matter which lung resection is planned. We prefer to place endoscope port in the seventh or eighth intercostal space at the posterior axillary line. If CO_2 insufflation is to be utilized, it may be initiated at 8–10 mmHg. Following initial exploration the remaining ports are placed in the following locations: One accessory port is placed typically in the ninth intercostal space just posterior to a vertical line from the scapula tip; a second posterior port that is useful for retraction of the lung, particularly during the posterior dissection, is placed superiorly and posterior to the ninth interspace port; the final port is placed in the fifth intercostal space in the mid-axillary line. This may be enlarged at any point in the procedure to 3–4 cm to allow for introduction of additional instruments and ultimately for specimen removal (Fig. 3.2). When using one of the older systems (S, Si), an important principle of port placement is to insure that each are spaced roughly 8 cm (one handbreath) apart in order to avoid external instrument arm collisions.

Fig. 3.2 Port strategy for 4-arm robotic lobectomy

3.2.4 Docking the Robotic Cart

Once the incisions have been made the patient cart is ready to be docked.

3.2.4.1 S or Si Systems

The instrument arms should be placed in a neutral position with the instrument arms on either side of the camera arm. For four-arm procedures two instrument arms are positioned on the side of the camera arm corresponding to the side of the planned resection. The cart is then docked from the posterior aspect of the patient with the center column and camera arm in line with the center of the planned field of dissection. For most pulmonary resections a 45-degree angle relative to the long axis of the patient is ideal. It is imperative to position the cart and space the arms to avoid external instrument collisions and insure adequate range of motion of the instruments.

Once the surgical cart is in its final position the camera arm is secured, and the robotic scope is introduced so that the remainder of the ports can be placed under direct vision. If a utility incision is used, the port should be positioned in the middle of the incision to allow for passage of additional non-robotic instruments. Once the instruments are introduced the range of motion of each arm should be tested to confirm there are no major conflicts (Fig. 3.3).

Fig. 3.3 Docking for da Vinci Si procedure

3.2.4.2 Xi System

Two recent innovations in the da Vinci™ Xi system have lead to substantial simplification of the docking process. First, the instrument arms are now mounted on a boom that can rotate 270-degrees. Laser cross hairs from the center of the boom allow rapid positioning of the cart over the camera port. Once the scope is inserted into the chest, it projects its own crosshairs that may be used for targeting the desired anatomic field. In the case of pulmonary resection the superior (upper and middle lobes) or inferior (lower lobe) pulmonary hilum is centered on the endoscope view. The targeting button on the scope is then depressed, and the boom will rotate automatically to maximize the range of motion of each arm and minimize internal and external arm conflicts. Second, the connection mechanism between the arm and port has been re-engineered to allow more a more facile connection. Third, there is a patient clearance feature on each arm that allows maximum spacing between the arms externally while maintaining the internal range of motion of the instruments. At this point, the remaining ports are docked and instruments inserted (Fig. 3.4).

Once the instruments are introduced and visible on the endoscope view, the surgeon can move to the console, and an assistant remains at the table to provide additional exposure and perform instrument exchanges as required. The assistant may also be required to pass and fire endoscopic staplers for division of the hilar structures and fissures as required.

3.2.5 Instrumentation

3.2.5.1 S or Si System

There are a wide variety of instrument choices available. A forceps is most commonly controlled by one hand for grasping tissue, and the options include the Cadiere, Prograsp or Fenestrated Bipolar forceps. The authors favor the Fenestrated Bipolar instrument because of the option to apply bipolar cautery to small vessels when necessary. In another hand there is typically a dissecting instrument, such as the Permanent Spatula, Maryland Bipolar, or Hook Cautery. The authors prefer the spatula as it is blunt and can be used safely to sweep tissue as well as divide tissue with good hemostasis. The fourth arm has either a retraction instrument or suction.

3.2.5.2 Xi System

Similar instruments are utilized for the Xi System. Of note, there are several instruments not currently available on the Xi system, including all 5-mm instruments, the suction irrigator and the Thoracic Grasper. The Tip up Fenestrated Grasper is an excellent, broad-based instrument for lung retraction. This is employed through the most superior posterior port and allows for excellent retraction of the lung.

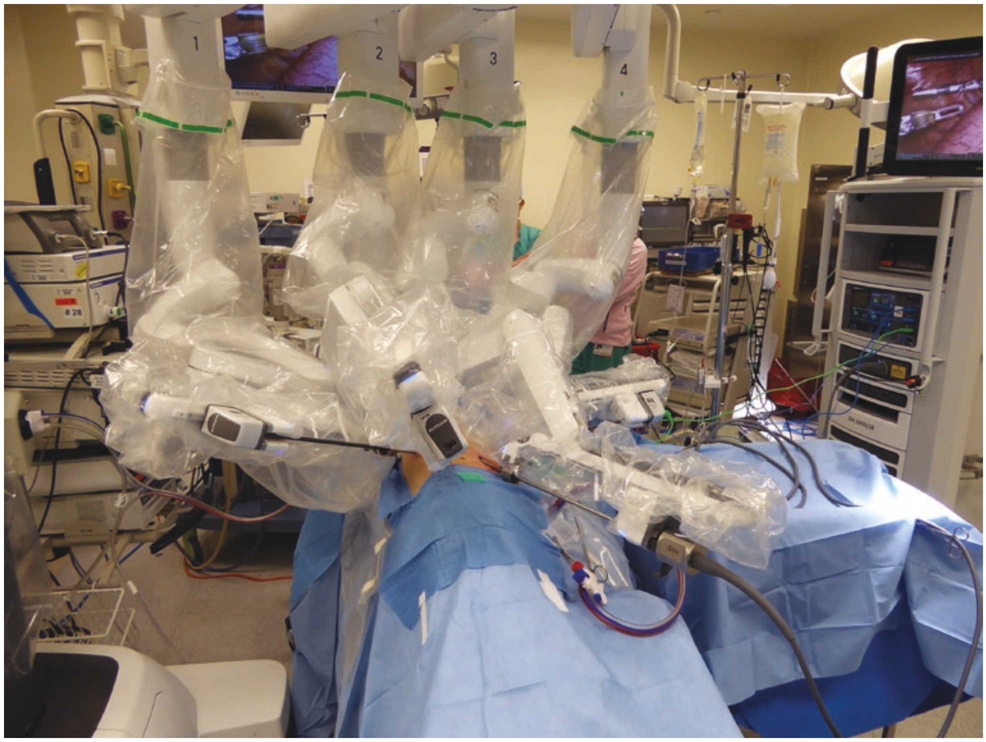


Fig. 3.4 Docking for da Vinci Xi procedure

3.2.6 Posterior Hilar Dissection

In almost every instance of anatomic lung resection it is the authors' preference to begin with posterior hilar dissection. The inferior pulmonary ligament is divided with electrocautery, and the inferior ligament and periesophageal nodes are removed. The superior segment of the lower lobe is then retracted anteriorly, and the posterior pleural is divided at its interface with the lung parenchyma up to the superior hilum. The hilar lymph nodes are individually removed. In the right chest this includes the interlobar "sump" nodes between the right upper lobe and the bronchus intermedius. A subcarinal lymph node dissection is performed (Fig. 3.5). It is critical, particularly on the left side, to have the bedside assistant provide additional exposure of subcarinal space, either through lung retraction or by depressing the inferior vein (left) or pericardium (right).

When performing lower lobectomy, it is advantageous to sweep the posterior parenchymal tissue distally particularly in the areas between the hilar structures and to remove the regional nodes. This will greatly facilitate subsequent isolation and division.

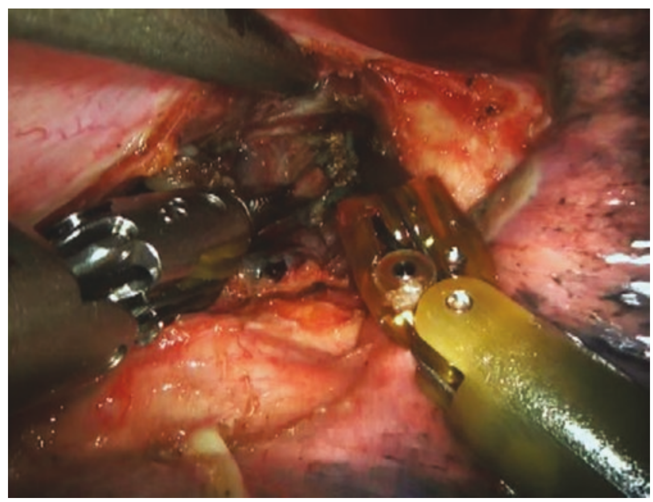


Fig. 3.5 Subcarinal (level 7) node dissection from the right side

3.2.7 Right Upper Lobectomy

The initial posterior hilar dissection is performed as described above. Removal or partial dissection of the sump nodes with identification of the right upper lobe bronchus (Fig. 3.6) greatly enhances division of the bronchus. It is our practice to perform an anterior-to-posterior approach with little or no dissection in the fissure. The superior hilar vessels are placed on tension by retracting the upper lobe laterally, and the pleura is incised above and below the superior vein to expose its entire extent from the takeoff of the middle lobe vein inferiorly to the course of the truncus arteriosus superiorly. Hilar nodes in these two areas should be removed both for oncologic and practice purposes. The middle lobe vein and the ongoing pulmonary artery should be identified and preserved (Fig. 3.7). Once isolated, the upper lobe vein is divided with

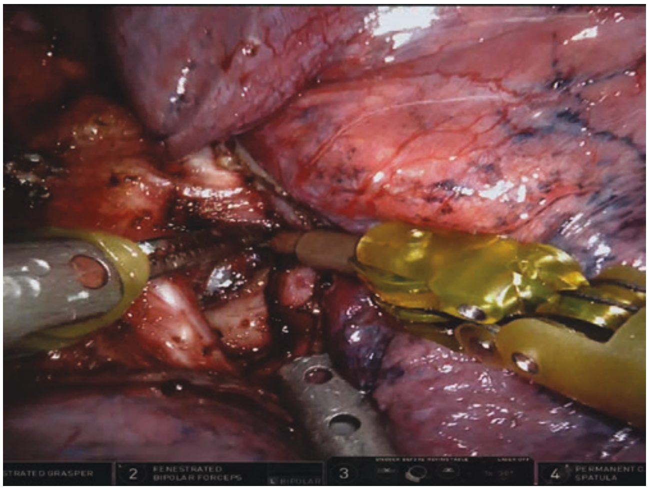


Fig. 3.6 Exposure of right upper lobe bronchus

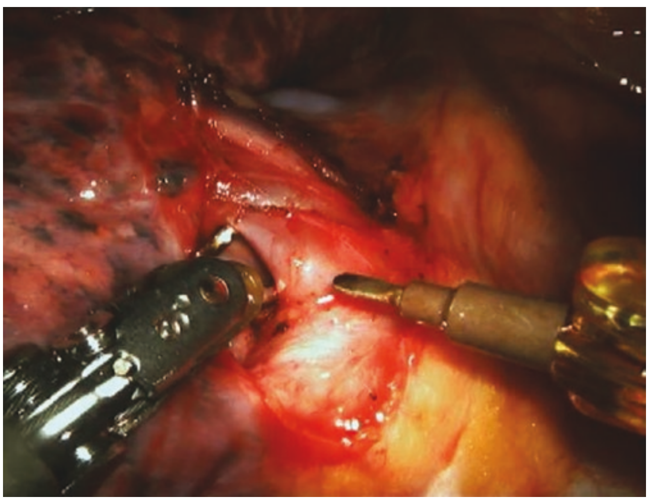


Fig. 3.7 Isolation of the right superior pulmonary vein

an endovascular stapler introduced through the posterior inferior port. This may done with conventional endoscopic staplers (Si) or the robotic stapler (Xi). Use of the robotic stapler requires upsizing to a 12 mm robotic port. Of note all division of the hilar structures may be done by passage of the staplers from the posterior port. Division of the pleural reflection is continued superiorly around the hilum until the right upper lobe bronchus is reached.

Next, the hilar node adjacent to the truncus arteriosus is mobilized sufficiently to allow for isolation and division of the vessel. Once the truncus is divided, the peribronchial lymph nodes and any remaining sump nodes that have not been previously excised should be removed completely. This maneuver will complete the mobilization of the bronchus and will clearly reveal the existence and location of the posterior ascending artery branch. These two remaining structures may then be divided in any order that is convenient. Occasionally, when the posterior ascending branch arises more proximal on the main pulmonary artery, it is necessary to divide this branch first (Fig. 3.8). The bronchus can be divided with a 3.5–4.8 mm stapler or cut sharply and sewn closed with a 3–0 or 4–0 absorbable suture. The horizontal fissure is completely last with multiple fires of the endovascular stapler introduced from the anterior incision.

It is most convenient to perform the right paratracheal lymph node dissection following removing of the lobectomy specimen as it obviates retraction of the lung for exposure. All tissue from the trachea to the superior vena cava the azygos vein to the thoracic inlet and down to the level of the pericardial reflection is removed (Fig. 3.9). Once all dissection is completed and specimens are removed, multi-level intercostal blocks with local anesthetic are performed, and a single 28Fr chest tube is placed posteriorly and apically. The

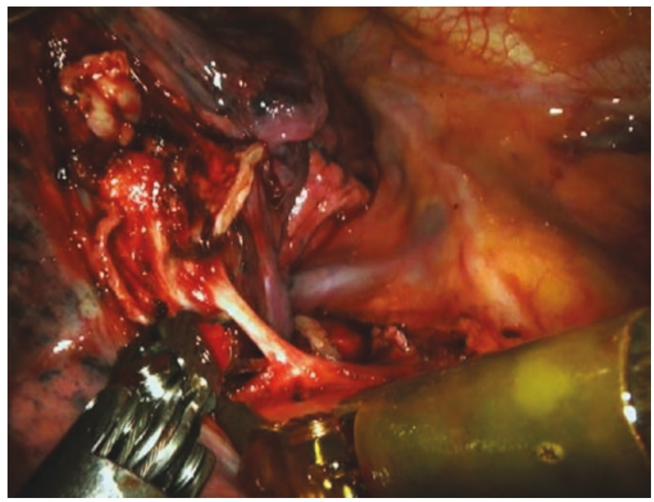


Fig. 3.8 Exposure of the right upper lobe posterior ascending pulmonary artery

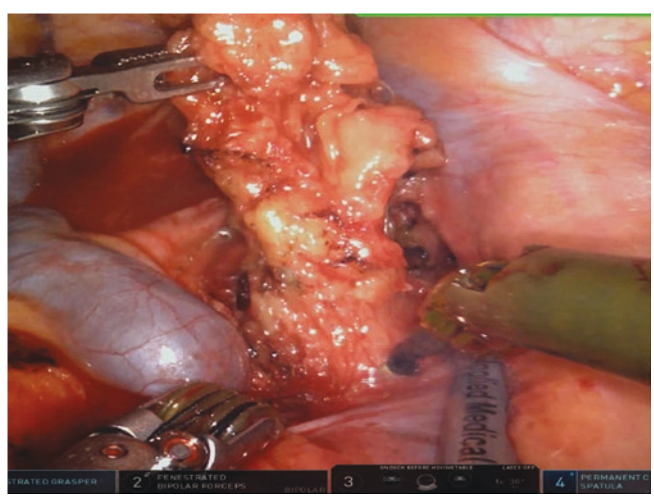


Fig. 3.9 Right paratracheal lymph node dissection

lung is re-expanded under direct vision, and the wounds are closed in a standard fashion.

3.2.8 Lower Lobectomy

The steps for completing a lower lobectomy on either side are nearly identical.

Following the posterior hilar dissection, if the major fissure is entirely or substantially complete, it is advantageous to divide the fissure anteriorly. Usually, there are level 11 interlobar lymph nodes present overlying the basilar artery, and it is advisable to begin fissure dissection in this area. Excising these nodes will expose the artery readily. On the right side these lymph nodes occupy the space between the basilar artery, the lower and middle bronchi and the middle lobe artery. Removing them entirely delineates the anatomic relationships completely (Fig. 3.10). The anterior fissure can then be completed either with cautery or use of an endovascular stapler. On the left side it is imperative to remove the interlobar lymph nodes residing in the secondary carina between the upper and lower lobe bronchi. This again allows for completion of the fissure anteriorly AND it prevents inadvertent division of the entire left mainstem bronchus.

Once the anterior fissure is divided the plane between the basilar artery and lower lobe bronchus is developed through blunt dissection. The authors prefer a gentle sweeping motion alternately using the spatula and the bipolar forceps. With the magnified and binocular vision of the robotic visual system, one can easily separate the plane between the two completely. On the right side it is a little more difficult because of the bronchial anatomy. The posterior fissure may be divided in a manner similar to the anterior portion, either with electrocautery or by stapling. Alternatively, the posterior fissure may be divided last following the hilar structures.

At this point, all the hilar structures should be ready to divide with the endoscopic staplers introduced through the

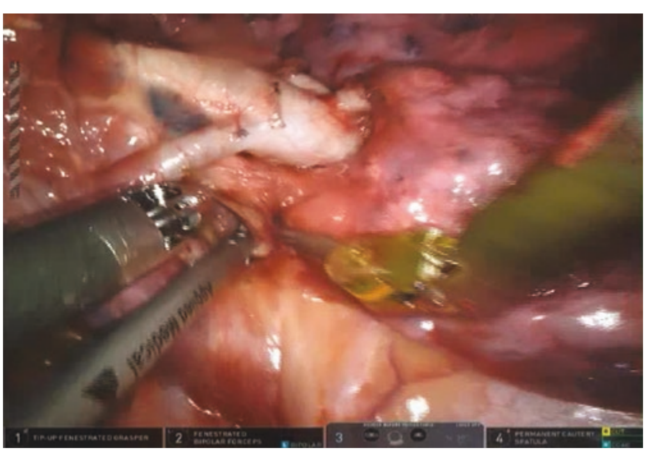


Fig. 3.10 Complete dissection of the anterior major fissure (right side)

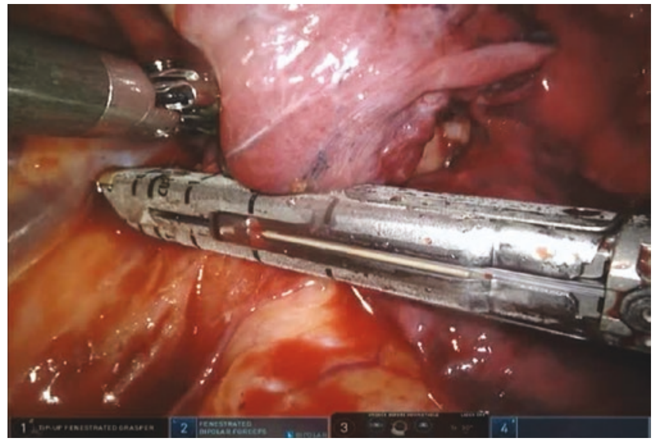


Fig. 3.11 Division of the left inferior pulmonary vein

anterior incision. The lung is retracted superiorly, and the bedside assistant removes the instrument arm from the anterior incision. Use of articulating and curved tip staplers can facilitate passage and division. The inferior vein is divided first (Fig. 3.11) followed by the bronchus, and lastly the basilar artery. Once the hilar structures are sequentially divided, any remaining portion of the posterior major fissure is completed with the endoscopic staplers to complete the lobectomy. The specimen is placed in a polypropylene sac and brought out through a utility incision. The paratracheal or aortopulmonary node dissection is performed.

3.2.9 Middle Lobectomy

The initial steps for a middle lobectomy are identical to that for a lower lobectomy. Following the posterior hilar dissection, the anterior portion of the major fissure is explored and the mediastinal pleural overlying the basilar pulmonary artery is divided to allow identification and excision of the interlobar lymph nodes, exposing the basilar pulmonary artery and the takeoff of the middle lobe bronchus. Once the anterior fissure is divided, the mediastinal pleura overlying the middle lobe vein is divided to isolate the vessel from the remainder of the superior vein. It is then divided with a vascular stapler load introduced through the posterior access incision (Fig. 3.12). The middle lobe bronchus is mobilized by removing the peribronchial nodes and may be divided by stapling either through the posterior or anterior incisions. A curved tip staple load is particularly useful for this. The remaining middle lobe artery branches should be clearly identified, isolated and divided. Most commonly there are two artery branches, and it is important to divide the more anterior branch prior to division of the fissure in order to avoid injury (Fig. 3.13). The horizontal fissure is divided last usually by passing the stapler through the anterior incision.

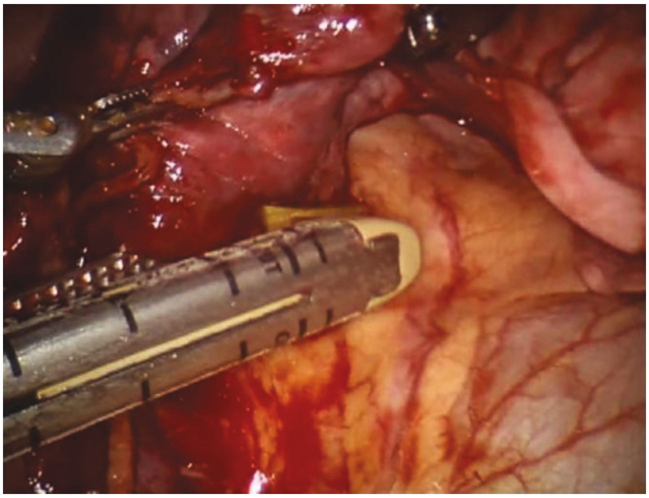


Fig. 3.12 Division of the middle lobe vein

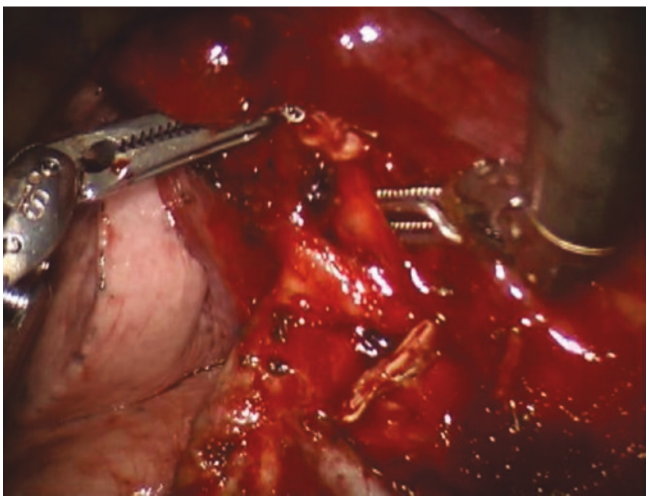


Fig. 3.13 Exposure of the middle lobe arteries

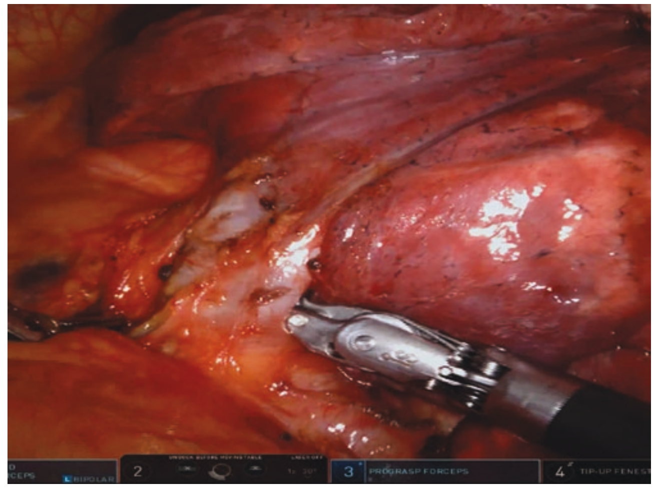


Fig. 3.14 Mobilization of the left superior pulmonary vein

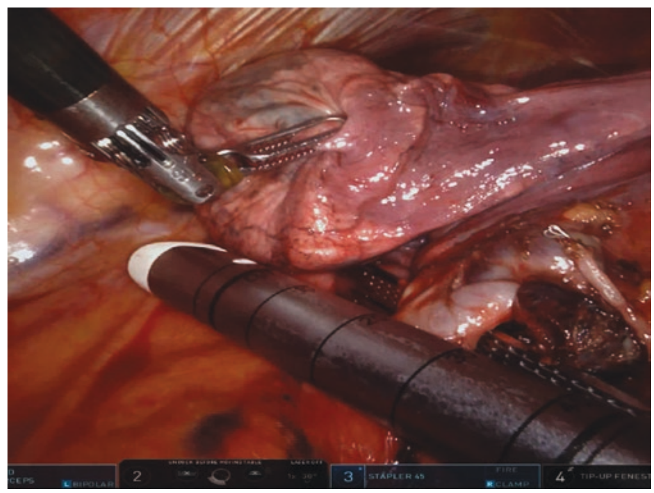


Fig. 3.15 Division of the left anterior/apical pulmonary artery branches

3.2.10 Left Upper Lobectomy

The initial posterior hilar dissection is performed with resection of the posterior hilar and subcarinal lymph nodes. The lung is then retracted laterally in order to place the superior hilar structures on tension. The mediastinal pleura over the superior pulmonary vein is incised from the interlobar area inferiorly to the superior hilum near the aortic arch. The inferior portion of the vein can be mobilized away from the bronchus using blunt dissection, and the superior extent of the vein is separated carefully from the pulmonary artery. The superior vein can then be isolated and divided (Fig. 3.14). The hilar lymph nodes between the upper lobe bronchus and first pulmonary artery branches that should be mobilized away or removed in order to allow the anterior and apical branches to be isolated and divided (Fig. 3.15). As with right upper lobectomy, all of the hilar structures may be resected by stapling through the posterior port. The peribronchial and interlobar lymph nodes between the upper and lower lobe bronchi are removed entirely to allow mobilization and division of the upper lobe bronchus.

Following division of the bronchus, lateral and posterior retraction of the upper lobe will expose the remaining pulmonary branches (Fig. 3.16). Each is mobilized under direct vision and divided sequentially until the lingular and each of the posterior branches have been ligated. The precise sequence in which the vessels are taken can vary depending on their relationship to each other giving the best exposure for stapling. Alternatively, depending on the clinical situation or surgeon preference, the posterior arterial branches

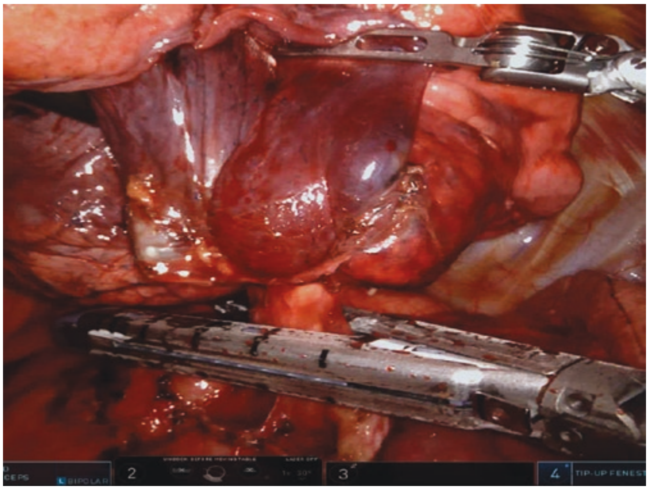


Fig. 3.16 Division of the left upper lobe bronchus

may be isolated and divided prior to dissection of the anterior vessels and bronchus. Once all of the hilar structures have been divided the major fissure can be completed with multiple fires of the endovascular stapler.

3.3 Results and Discussion

Robotic lung resection has been performed by thoracic surgeons for more than a decade with increasingly frequency throughout the world. The first published series appeared in 2002 from Melfi et al. [11]. This heterogenous group of robotic thoracoscopic procedures included five lobectomies and demonstrated the feasibility of using the da Vinci™ system in thoracic surgery with no operative mishaps and appropriate functioning of the robotic arms for the procedure.

Following this landmark report, numerous reports of experience using the robotic system for lung resection followed including our own experience from Memorial Sloan Kettering Cancer Center New York [12]. Our initial series consisted of 34 consecutive patients that underwent attempted robotic lobectomy with four conversions to thoracotomy (12%). All types of lobectomy were performed showing the versatility of the robotic system. No perioperative deaths were observed and a 26% morbidity rate, comparable to techniques of open and VATS lobectomy. Chest tube duration (3 days) and length of hospital stay (4.5 days) were comparable to standard techniques. All patients underwent an R0 resection and had a median of four lymph node stations dissected. Since our series other centers around the world have subsequently reported on their experiences [13–17]. These studies report perioperative mortality rates from 0 to 3%, morbidity rates from 10 to 26%, conversion rates of 0–12% and median length of stay of 2–6 days.

With such reproducible perioperative results, the procedure has gained in popularity in recent years. A recent report reviewing the State Inpatient Databases, in the US, showed robotic lobectomy accounted for 0.2% of total lobectomies in 2008 rising to 3.4% in 2010 [18]. This still remains a small proportion of all patients have lobectomy but represents a rapid growth in the case volume. This same study demonstrated most recent results from many institutions across eight states showing that robotic technique was equivalent or superior to open lobectomy as assessed by mortality, length of stay, routine discharge and complication rate.

A major concern for widespread utilization of robotic lobectomy has focused on cost implications. A cost comparison from our own center has been conducted comparing costs of robotic lobectomy to conventional VATS lobectomy and open thoracotomy [19]. The difference in total average costs was calculated for each group. Within the minimally invasive group, robotic lobectomy was associated with increased cost compared to conventional VATS lobectomy but the average cost of robotic lobectomy was substantially less than thoracotomy, primarily because of a decreased length of stay. With any new technology, the expectation is that as the volume of use goes up, the initial capital costs and disposable costs will reduce as the volume of sales of the robotic system increases nationally and internationally.

Another concern is over the oncologic efficacy of robotic lobectomy. Two recent studies attempt to address this. The first is a multi-institutional retrospective review of patients undergoing robotic lobectomy for early stage lung cancer focusing on long-term outcome [20]. Three hundred twenty-five patients from three separate centers including 123 consecutive patients from our own center were evaluated. The majority of cases were subtypes of adenocarcinoma (73%) and had clinical stage I disease (95.4%). Overall 5 year survival for pathological stages IA, IB and II were 91%, 88% and 49% respectively. These stage-specific survivals were consistent both with the largest recent series of VATS lobectomies and the data used for the seventh edition of the lung cancer staging system, derived largely from cases of conventional open surgery [21–23].

The second study was a recent multi institutional, retrospective study of robotic lobectomy and segmentectomy used the prevalence of pathologic nodal upstaging as a surrogate measure for the completeness of nodal evaluation [24]. The authors concluded the rate of robotic pathologic nodal upstaging for clinically stage I NSCLC appeared to be superior to the VATS approach and similar to the open approach. Overall and disease free survival rates were comparable to open and VATS technique, albeit with a rather short median follow-up of 12.3 months [24]. Together, these studies provide some objective evidence of the oncologic adequacy of robotic lobectomy compared with open and VATS non-robotic techniques. As the previous published series mature with time, more robust long-term oncologic data with become available.

3.4 Summary

The technique of robotic lobectomy is well established and feasible. There are several advantages for the operating surgeon, including superior visualization, instrumentation and ergonomic ease. The greatest overall advantage over VATS may be in the surgeon's ability to control the key aspects of the procedure. Legitimate concerns, such as cost and long-term, patient-centered outcomes, should be addressed with ongoing studies.

References

1. Gottgens KW, Siebenga J, Belgers EH, van Huijstee PJ, Bollen EC. Early removal of the chest tube after complete video-assisted thoracoscopic lobectomies. Eur J Cardiothorac Surg. 2011;39(4):575–8.
2. Nagahiro I, Andou A, Aoe M, Sano Y, Date H, Shimizu N. Pulmonary function, postoperative pain, and serum cytokine level after lobectomy: a comparison of VATS and conventional procedure. Ann Thorac Surg. 2001;72(2):362–5.
3. Paul S, Altorki NK, Sheng S, Lee PC, Harpole DH, Onaitis MW, et al. Thoracoscopic lobectomy is associated with lower morbidity than open lobectomy: a propensity-matched analysis from the STS database. J Thorac Cardiovasc Surg. 2010;139(2):366–78.
4. Petersen RP, Pham D, Burfeind WR, Hanish SI, Toloza EM, Harpole DH Jr, et al. Thoracoscopic lobectomy facilitates the delivery of chemotherapy after resection for lung cancer. Ann Thorac Surg. 2007;83(4):1245–9; discussion 50.
5. Scott WJ, Allen MS, Darling G, Meyers B, Decker PA, Putnam JB, et al. Video-assisted thoracic surgery versus open lobectomy for lung cancer: a secondary analysis of data from the American College of Surgeons Oncology Group Z0030 randomized clinical trial. J Thorac Cardiovasc Surg. 2010;139(4):976–81; discussion 81–3.
6. Whitson BA, Groth SS, Duval SJ, Swanson SJ, Maddaus MA. Surgery for early-stage non-small cell lung cancer: a systematic review of the video-assisted thoracoscopic surgery versus thoracotomy approaches to lobectomy. Ann Thorac Surg. 2008;86(6):2008–16; discussion 16–8.
7. Stephens N, Rice D, Correa A, Hoffstetter W, Mehran R, Roth J, et al. Thoracoscopic lobectomy is associated with improved short-term and equivalent oncological outcomes compared with open lobectomy for clinical Stage I non-small-cell lung cancer: a propensity-matched analysis of 963 cases. Eur J Cardiothorac Surg. 2014;46(4):607–13.
8. Yan TD, Black D, Bannon PG, McCaughan BC. Systematic review and meta-analysis of randomized and nonrandomized trials on safety and efficacy of video-assisted thoracic surgery lobectomy for early-stage non-small-cell lung cancer. J Clin Oncol. 2009;27(15):2553–62.
9. Belgers EH, Siebenga J, Bosch AM, van Haren EH, Bollen EC. Complete video-assisted thoracoscopic surgery lobectomy and its learning curve. A single center study introducing the technique in The Netherlands. Interact Cardiovasc Thorac Surg. 2010;10(2):176–80.
10. McKenna RJ Jr. Complications and learning curves for video-assisted thoracic surgery lobectomy. Thorac Surg Clin. 2008;18(3):275–80.
11. Melfi FM, Menconi GF, Mariani AM, Angeletti CA. Early experience with robotic technology for thoracoscopic surgery. Eur J Cardiothorac Surg. 2002;21(5):864–8.
12. Park BJ, Flores RM, Rusch VW. Robotic assistance for video-assisted thoracic surgical lobectomy: technique and initial results. J Thorac Cardiovasc Surg. 2006;131(1):54–9.
13. Cerfolio RJ, Bryant AS, Skylizard L, Minnich DJ. Initial consecutive experience of completely portal robotic pulmonary resection with 4 arms. J Thorac Cardiovasc Surg. 2011;142(4):740–6.
14. Dylewski MR, Ohaeto AC, Pereira JF. Pulmonary resection using a total endoscopic robotic video-assisted approach. Semin Thorac Cardiovasc Surg. 2011;23(1):36–42.
15. Gharagozloo F, Margolis M, Tempesta B, Strother E, Najam F. Robot-assisted lobectomy for early-stage lung cancer: report of 100 consecutive cases. Ann Thorac Surg. 2009;88(2):380–4.
16. Jang HJ, Lee HS, Park SY, Zo JI. Comparison of the early robot-assisted lobectomy experience to video-assisted thoracic surgery lobectomy for lung cancer: a single-institution case series matching study. Innovations. 2011;6(5):305–10.
17. Melfi FM, Mussi A. Robotically assisted lobectomy: learning curve and complications. Thorac Surg Clin. 2008;18(3):289–95, vi–vii.
18. Kent M, Wang T, Whyte R, Curran T, Flores R, Gangadharan S. Open, video-assisted thoracic surgery, and robotic lobectomy: review of a national database. Ann Thorac Surg. 2014;97(1):236–42; discussion 42–4.
19. Park BJ, Flores RM. Cost comparison of robotic, video-assisted thoracic surgery and thoracotomy approaches to pulmonary lobectomy. Thorac Surg Clin. 2008;18(3):297–300, vii.
20. Park BJ, Melfi F, Mussi A, Maisonneuve P, Spaggiari L, Da Silva RK, et al. Robotic lobectomy for non-small cell lung cancer (NSCLC): long-term oncologic results. J Thorac Cardiovasc Surg. 2012;143(2):383–9.
21. Flores RM, Park BJ, Dycoco J, Aronova A, Hirth Y, Rizk NP, et al. Lobectomy by video-assisted thoracic surgery (VATS) versus thoracotomy for lung cancer. J Thorac Cardiovasc Surg. 2009;138(1):11–8.
22. Goldstraw P, Crowley J, Chansky K, Giroux DJ, Groome PA, Rami-Porta R, et al. The IASLC Lung Cancer Staging Project: proposals for the revision of the TNM stage groupings in the forthcoming (seventh) edition of the TNM Classification of malignant tumours. J Thorac Oncol. 2007;2(8):706–14.
23. Onaitis MW, Petersen RP, Balderson SS, Toloza E, Burfeind WR, Harpole DH Jr, et al. Thoracoscopic lobectomy is a safe and versatile procedure: experience with 500 consecutive patients. Ann Surg. 2006;244(3):420–5.
24. Wilson JL, Louie BE, Cerfolio RJ, Park BJ, Vallieres E, Aye RW, et al. The prevalence of nodal upstaging during robotic lung resection in early stage non-small cell lung cancer. Ann Thorac Surg. 2014;97(6):1901–6; discussion 6–7.

4 Robotic Lobectomy: Hilum First Technique

Kemp Kernstine Sr.

Abstract

Lobectomy of the lung is performed for primary lung cancer with individual ligation of the pulmonary vasculature and bronchus along with division of the fissures. Recent estimates claim nearly 30% of lobectomy cases are performed in a minimally invasive fashion, the robotic approach of the nonrobotic minimally invasive option may have some advantages that includes a potentially more oncologic resection, less instrument movement at the chest wall that may result in less trauma to nerves and, thus, potentially less postoperative discomfort, and a simpler technique to learn and teach, more closely approximating the moves of surgery by thoracotomy. The operative setup and surgical details for each of the five lobes is described and illustrated, outlining the technique to divide the hilar structures first and then to divide the fissures. Over the 15 years of performing the technique, particular learning points are described.

Keywords

Video-assisted thoracoscopic surgery · Robotic · Computer-assisted surgery · Anatomic resection · Thoracotomy · Thoracoscopy · Lung cancer · Neoplasms · Squamous cell Adenocarcinoma · Treatment · Surgical technique · Lobectomy · Segmentectomy Pneumonectomy · Minimally invasive surgery · Pulmonary · Thoracic surgery · VATS NSCLC · Sleeve lobectomy · Lymphadenectomy · Lymph node dissection · Surgical methods

4.1 Background, Specific Indications

Lobectomy is the standard-of-care for the treatment of early stage lung cancer and is defined as an anatomic resection of the lobe with the individual ligation of the artery, vein, and bronchus. Hilar and mediastinal lymph nodes are resected, as well, with sufficient lymphadenectomy to provide at least 2–3 mediastinal lymph node stations and total lymph node count of more than 10 nodes; potentially more than 20 is necessary to provide sufficient staging information.

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Department of Cardiovascular and Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA
e-mail: kemp.kernstine@utsouthwestern.edu

Since the early 1990s, the video-assisted thoracic surgery (VATS) lobectomy has evolved into an efficient oncologic procedure that has been found to have less blood loss, less surgery-related disability, less pain, and reduced hospital length-of-stay/cost compared to the open thoracotomy lobectomy. Robotic technology was introduced in the early 2000 and the first series of robotic lobectomies were reported. The initial equipment was somewhat cumbersome and the techniques used with VATS and the open thoracotomy did not lend themselves to a robotic approach. The length of time for the robotic procedure was long and surgical bleeding obstructed the view. As the technology evolved and with the introduction of robotics into more surgical training programs, greater opportunities were realized with robotic technology in the performance of the anatomic lobectomy.

Lobectomy is particularly suited for robotics; there are restrictive areas within the hilum and mediastinum that are

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_4

difficult to manage with VATS or even open thoracotomy. The degrees of freedom of the instruments and the surgeon-directed magnified view provide a platform to perform intricate maneuvers to resect and, if necessary, repair or reconstruct defects. For the first 10 years after robotic technology was introduced, fewer than 15% of lobectomies were performed in a minimally invasive fashion. In spite of the lack of tactile feedback, the lack of which does not appear to be a major obstacle, there are likely some unproven additional benefits: reduced trocar movement at the chest wall may reduce postoperative pain and improved instrument dexterity may improve the quality of the cancer resection and reduce the likelihood for conversion to open thoracotomy. An additional benefit may be the ability to perform a lobectomy without single lung ventilation. Many other opportunities may be afforded by the surgeon-controlled view and greater dexterity, obstacles such as the shape of the thorax and the presence of the great vessels and the small spaces that would historically prevent resection and reconstructive efforts would now become surgically-capable.

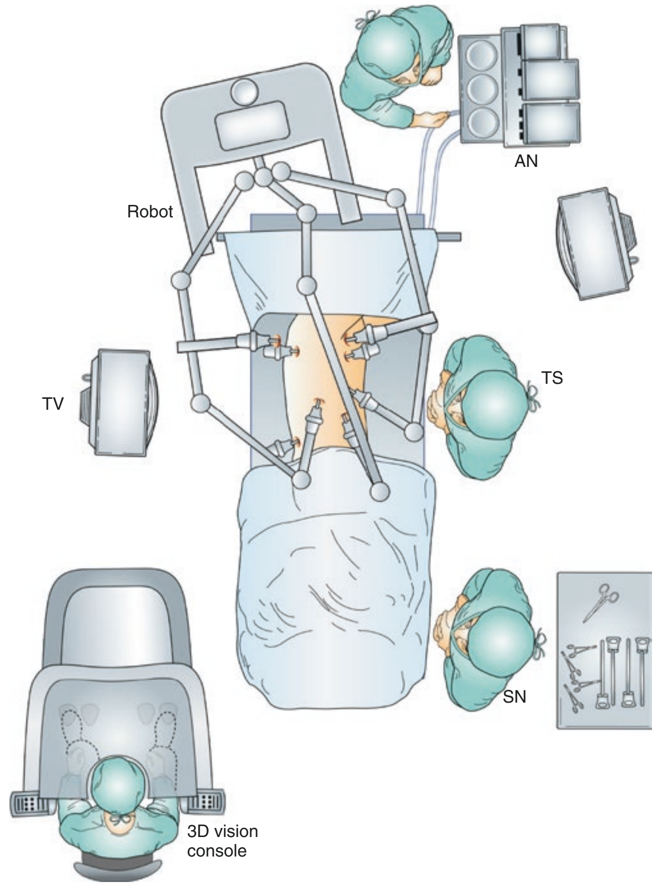


Fig. 4.1 This is an example of an **operating room setup for a robotic case, a robotic right upper lobectomy**. The head of the bed is toward the anesthesiologist (AN) and the bedside cart (Robot) is brought obliquely over the patient's head. The operating console is toward the bottom right of the diagram and the bedside surgeon (TS) and scrub nurse (SN) are toward the front of the patient. Two monitors (TV) or are more often used for viewing the procedure by the team

4.2 Operative Setup

The currently available Food and Drug Administration-approved robotic system has three components, (1) the surgeon console; (2) the "praying mantis-like" robotic arms chassis or "bedside cart;" and (3) the electronic communications tower system between the console and the chassis. These components must be considered prior to bringing the patient into the room, operating rooms often small and unaccustomed to already limited space. The recommendation of the room setup is noted for the right upper lobectomy in Fig. 4.1.

In light of the extra equipment, the following are the steps for the robotic lobectomy: room setup (Fig. 4.1), patient positioning (Fig. 4.3), thoracoport placement marking, port placement (Figs. 4.4, 4.5, 4.6, 4.7, and 4.8), robotic docking and performance of the procedure; hilum-first approach. For the novice team and surgeon, it is recommended that extra time be committed for treatment planning and discussion with the team; surgeon team, anesthesia and nursing. There should be robotic technology knowledgeable individuals on the team. A thoracotomy surgical equipment tray and a sterile sponge-stick with a folded piece of hemostatic collagen-based fabric, such as Surgicel® (Johnson & Johnson) (Fig. 4.2), to serve as a means to compress and hold any possible major bleeding within the mediastinum or hilum.

4.3 Anesthetic Management

The anesthetic management for the robotic lobectomy is not significantly different than the management of the open thoracotomy or VATS lobectomy. Consideration should be given to the patient's co-morbidities and prepare the patient for single lung ventilation whether by double-lumen intubation or bronchial blocker. Fluids should be minimized. Colloid is preferred over crystalloid. Volumes of greater than 1.5 L should be avoided. Transfusions should be avoided, if possible. Once positioned under the robot and the robot docked to the patient's previously placed trocars, the bed cannot be moved. To avoid hemodynamic compromise, sufficient time should be allowed for the patient positioning and the introduction of the intrapleural carbon dioxide (CO_2) that can result in hypotension and hemodynamic instability. Any movement of the bed after the robot is docked could injure the patient. To maintain adequate oxygen saturation, positive end expiratory pressure (PEEP) can be added to the ventilated or dependent lung and the tidal volume adjusted. The anesthesiologist must realize that for an efficient surgical procedure to be performed safety and hemodynamic stability must be the goal of the patient management. The arterial partial pressure of carbon dioxide ($PaCO_2$) is often elevated during the course of the procedure and we attempt to keep it less than 70 mmHg and avoid acidosis by adjusting the minute ventilation and the insufflation CO_2 pressure. The robotic technique may need to be aborted if the patient is unable to tolerate it.

At case completion, we typically provide intravenous ketorolac and/or acetaminophen and provide intercostal bupivacaine blocks to cover the appropriate dermatomes. We have attempted to provide further pain control with extrapleurally and paravertebrally placed catheters infusing bupivacaine. We have found no improvement in postoperative pain by using continuous bupivacaine infusion. Given the fact that the pain management is good to excellent in the vast majority of the patients, epidural catheters are utilized only in those patients that the typical plan for pain management will be compromised, such as those patients that have previously demonstrated in other surgical procedures to be under-treated for pain or those that might have more-than-usual pain, such as with an additional chest wall resection, intercostal muscle flap or particularly large tumors that would be difficult to extract between the ribs, larger than 4–5 cm.

4.4 Stepwise Conduct of the Operation

In preparation for a robotic lobectomy, adequate time should be given for procedure planning, accurate port placement and patient positioning. Failure to address these aspects can result in an inefficient and frustrating case. The chest computed tomogram and the topographical anatomy are used for port position planning. The novice robotic surgical team should make a point to select patients with peripheral lung lesions that are less than 2–3 cm in size and who have had no prior thoracic surgical procedures and no evidence on chest tomogram evidence of pleural symphysis. It is recommended that for the early series of robotic cases, the surgeon should have the same anesthesiologist and scrub/circulator nursing team; the team learns as a group. Prior to the case beginning, there should be a clear plan amongst the team concerning the potential disaster scenario where conversion to open thoracotomy may be necessary. A ring clamp with 2–4 pieces of collagen fabric (Surgicel® is an example) (Fig. 4.2) and a thoracotomy tray should be available should there be an emergency.

We start our cases with flexible bronchoscopy either through a single-lumen endotracheal tube or prior to intubation under conscious sedation prior to the placement of the endotracheal tube. Once we verify that the patient has no untoward finding that would prevent us from performing a minimally invasive lung resection, the patient is prepared for single lung ventilation with an appropriate endotracheal tube. Cervical mediastinoscopy is not uncommonly performed prior to the initiation of the robotic procedure; we have found that robotic upper lobe dissection may be enhanced by mediastinoscopy-directed dissection. After the mediastinoscopy is

Fig. 4.2 Prior to the case initiation, **2–4 Surgicel® pieces are fixed in a surgical ring clamp** in preparation for any bleeding. There should be discussion amongst the team about the worst case scenario, how potential bleeding might be controlled, the robot undocking, and the moving the robot out of the way, the location of the equipment for emergency thoracotomy and who will be the individual to maintain pressure on the bleeding while the thoracotomy is being performed. Should surgical bleeding occur, the robotic surgeon can grasp adjacent lung and compress it over the bleeding site while the bedside surgeon places the ring clamp-Surgicel into the chest for compression of the bleeding. We recommend that the axillary port be the portal of entry for compression, the thoracoport is removed prior to enlarging the incision with Mayo surgical scissors and inserting the ring clamp-Surgicel

completed and it is confirmed that there is no significant mediastinal pathology that would prevent the patient from having a beneficial anatomical lung resection, the patient is placed in the lateral decubitus position (Fig. 4.3). As tolerated, all the patients will be positioned in a reverse Trendelenburg fashion allowing for the diaphragm and the intra-abdominal contents to drop away from the operative field, allowing improved exposure, and allowing for any bleeding that might occur to collect away from the operative filed in the lower aspect of the thorax. For upper and middle lobectomies, the patient position is rotated approximately 30° posteriorly, allowing the lung to fall away from the hilum. For lower lobectomies, rotation is approximately 30° anteriorly to allow the lung to fall anteriorly, exposing the posterior hilum.

The preoperative chest tomogram and the topographical anatomy of the chest wall, the accurate location of the hilum in relation to the sternal angle and the tip of the scapula are identified and marked with indelible ink on the chest wall prior to sterile prepping of the chest. For this robotic lung lobectomy, the target of which the robotic instrumentation is focused is the hilum, typically, a 4 cm circle that covers the distal tip of the scapula. Then, six other marks are made on the chest wall to estimate the location of the thoracoports to be placed (Figs. 4.4, 4.5, 4.6, 4.7, and 4.8).

As described previously, the chest wall is marked prior to prepping the chest and placing the surgical drapes to create the surgical field. Then, after placing the drapes, the ports are placed, the robot is brought into position and the bed position is adjusted as described. For chest wall marking of the upper and middle lobes, see Figs. 4.4 and 4.5 for a diagram and explanation of placement, one for the right and Fig. 4.7 for the left side. For the lower lobes, see Figs. 4.6 (right side) and Fig. 4.8 (left side).

Once the ports are marked with an indelible marking pen, the chest is prepped and draped in the usual sterile surgical fashion. We then place the thoracoports. Prior to placing

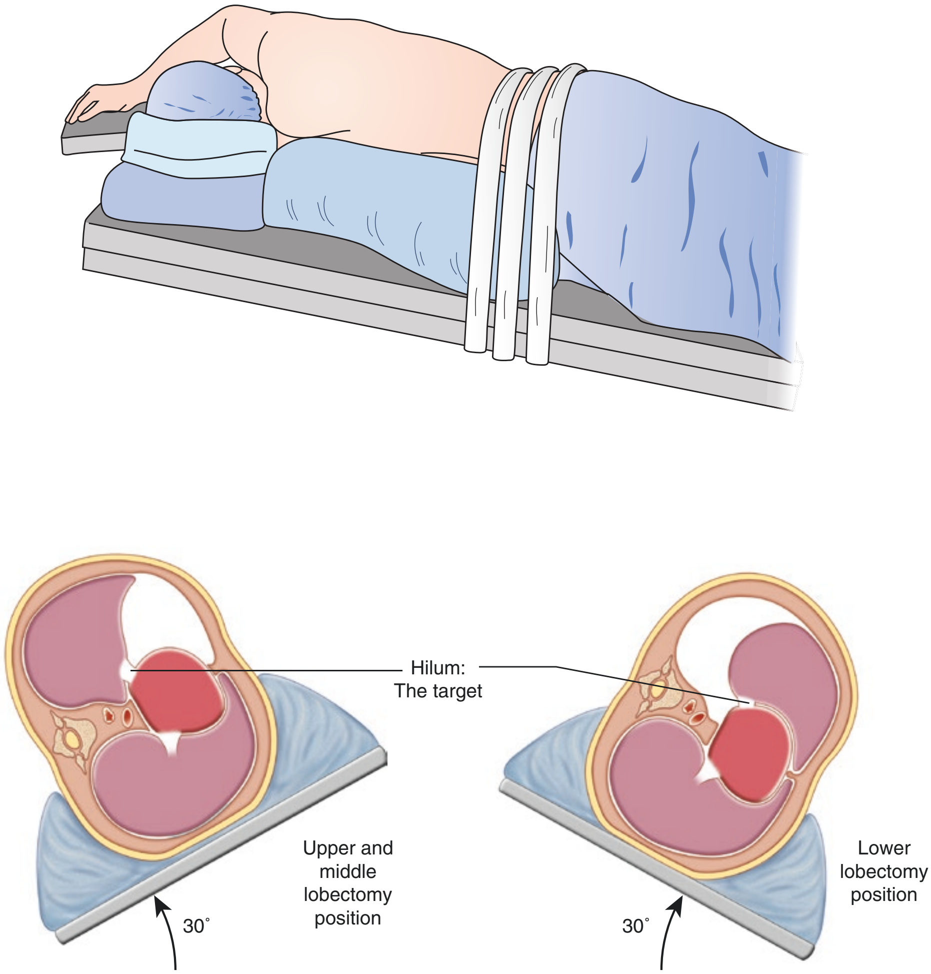


Fig. 4.3 **Patient position for a robotic lobectomy**. For the robotic lobectomy, we place the patients in the lateral decubitus position and strap them to the bed with 3–6 in. adhesive tape wrapped around the table and the patient's greater trochanter to prevent the patient from falling off the bed and maintaining position throughout the case, and, then, in reverse Trendelenburg; for upper and middle lobes, the patient is rotated 30° toward posterior and for the lower lobes, they are rotated 30° anterior. This bed position is often made after the robot chassis or bed side cart is brought over the patient in position, as it may be difficult to bring the robot into position once the patient is in Trendelenburg. For patients with particularly large hips, more Trendelenburg or breaking the table at the waist may help optimize exposure

each of the thoracoports, we inject 0.125% bupivacaine with epinephrine at each site; we believe that it helps to reduce postoperative pain and appears to reduce the local bleeding associated with port placement. We refrain from using electrocautery in these locations as it appears to increase pain and scarring. Among the six port sites marked, the first port to be placed is usually the camera port or **Port A**. However, in the obese patient the diaphragm may be quite high, minimizing the distance between the chest wall and the diaphragm and increasing the likelihood for diaphragm injury during port placement; in which case, we recommend using **Port F** or the axillary port as the first port to be placed. The pathology or CT-guided anatomy may also dictate the first port placement; large anterior tumors may require that the first port to be placed might be posterior port or that instead, a 5-mm thoracoport and thoracoscope might be used to assess the intrathoracic anatomy and guide port placement. After injecting the local anesthetic, as described, we then make an incision typically transversely or within Langer's Lines in the area around the patient's breast. We then use a Tonsil clamp and a very carefully insert the tip of the clamp just over the most cephalad aspect of the adjacent rib while the ventilator has been completely turned off. Wide spreading of the clamp should not be performed reducing the likelihood for intercostal injury and potential bleeding and nerve injury. The thoracoport is then carefully placed into the incision. Before introducing carbon dioxide, the intrathoracic location of the port should be confirmed; there have been reports of inadvertent carbon dioxide insufflation into vascular structures. Once carbon dioxide is insufflated into the pleural space, the videoscope is inserted into the scope and is used to guide further port placement. The remaining ports are placed in a similar fashion with injec-

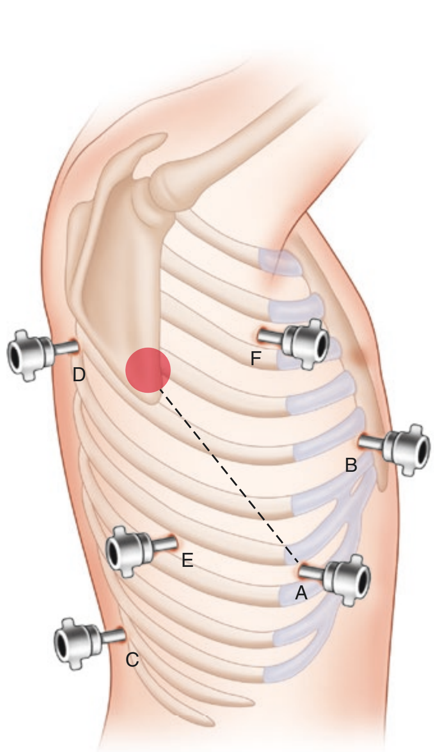


Fig. 4.4 **Port placement for the right upper and middle lobectomy**. Four 12-mm thoracoports are placed in the following fashion (**ports A, C, D, and F**). The Target for the routine lobectomy is the hilum. The topographical approximate location is drawn in the patient's chest wall and is approximately a 4 cm circle is approximately 2 cm cephalad the tip of the scapula. First the camera or video port, port A is in the seventh intercostal space, just cephalad to the eighth rib in the anterior axillary line. We marked a 12 mm indelible mark at this location. A faint indelible line is drawn between the target and this port site. **Port B** is placed in a submammary location just cephalad to the sixth rib, the fifth intercostal space. **Port C** is placed in the seventh intercostal space, just cephalad to the eighth rib in the posterior axillary line to just anterior to the anterior line of the scapula. **Ports B and C**, both 8 mm robotic ports, should be approximately 10–14 cm away from the line between port A and the Target. The second 12 mm port, **port F**, is placed in the second intercostal space, just cephalad of the third rib and in the anterior axillary line, in the same line as **port A**. The third 12 mm port, **port C**, is placed in the ninth intercostal space, just cephalad to the tenth rib and at the most anterior border of the posterior longitudinal muscle of the spine. The final port and the last 12 mm port, **port D**, is located approximately 3–4 cm posterior to the edge of the scapula and at the upper most portion of the level **of the target**. **Port A—Camera Port**, a 12-mm port. **Port B and E**—both 8-mm port, ProGrasp, Cadiere, Bipolar Maryland, Harmonic, Needle holders, Clip Appliers, Hem-o-Loc, hook cautery. **Port D**—a 12-mm port, Forrester Ring Clamp to serve as an atraumatic clamp that can gently and in an atraumatic manner grasp the lung and expose the hilum, otherwise same as **Port F**. **Port C**—12-mm port, 5- and 10-mm minimally invasive Endograspers, Needle Holders for grasping and delivering sutures up to an SH and CT-1 size needles, Endopeanuts, Endosuctioning, endostaplers. **Port F**—The Axillary Port, a 12-mm port, same as Ports C and D, but is chosen because of the particularly wide intercostal space and at the end of the procedure, the interspace pleura is incised with cautery to pull the bagged specimen out of the chest

tion of bupivacaine with epinephrine, an incision and then directly placing the ports under thoracoscopic view to avoid injury the intercostal bundle. Once the ports are placed, the patient is positioned; all patients are positioned in a reverse Trendelenburg fashion and for the upper lobes are rotated towards her back approximately 30° and for lower lobes are rotated towards the front approximately 30° (Fig. 4.3). The robot is then brought in over the head for the lower lobes and for the upper lobe patients approximately 30–40° off center over the head and towards the patients back as noted in Figs. 4.5, 4.6, 4.7, and 4.8. For the S and Si Intuitive Surgical Systems (ISI), the view is between the camera and the base of the robot; the Xi ISI is not as restrictive. The robotic arms should be set to minimize instrument conflict.

Instrument choice is surgeon dependent. For the novice robotic surgeon, it might be helpful to place the ProGrasp or the Cadiere grasper in the leftward or #2 arm and the Harmonic Scalpel or Hooked Cautery in the rightward or #1 arm. We use a Forrester ring clamp or, alternatively a Landreneau ring grasper (Teleflex Medical; Weck Corporation., Triangle Park, NC) to grasp the lobe just laterally to the hilar location where the surgery is to begin, 3–4 cm away from the hilar structures into the pulmonary parenchyma. Once set to the ideal location to provide the best visibility is rarely moved during the case. The weight of the instrument typically provides sufficient traction and is usually unnecessary to provide any additional retraction during the procedure; the assistant should let the clamp sit at rest. For the upper and middle lobes, the grasper is brought through the posterior-superior port or **port D** and, for lower lobes is brought through the upper anterior-superior port or **port F**. The goal is to provide exposure and counter-tension for dissection. Even friable lung can be grasped with the atraumatic graspers with little, if any, damage to the lung.

Once the instrumentation has been placed into the robotic arms, the procedure is ready to be performed. Grasping the lung or hilar structures that are friable with any of the robotic grasping instruments such as the ProGrasp or the Cadiere should be avoided or at least minimized to reduce the risk of injury or bleeding. For the upper lobes, the pulmonary veins are typically taken first. For the right upper lobe the pulmonary artery blood supply branches are taken next, exposing the right upper lobe bronchus. For the lower and middle lobes, the bronchus is taken after the vein is taken. For the left upper lobe, the first main pulmonary artery branch to the upper lobe is taken after the vein that allows exposure of the left upper lobe bronchus; the remaining pulmonary artery branches to the left upper lobe are then taken. Taking the vein first may have some oncologic benefit, reducing the likelihood for pulmonary venous metastasis during lung/tumor manipulation. There is no credible evidence that it results in the pulmonary edema by preventing venous outflow during the course of a lobectomy.

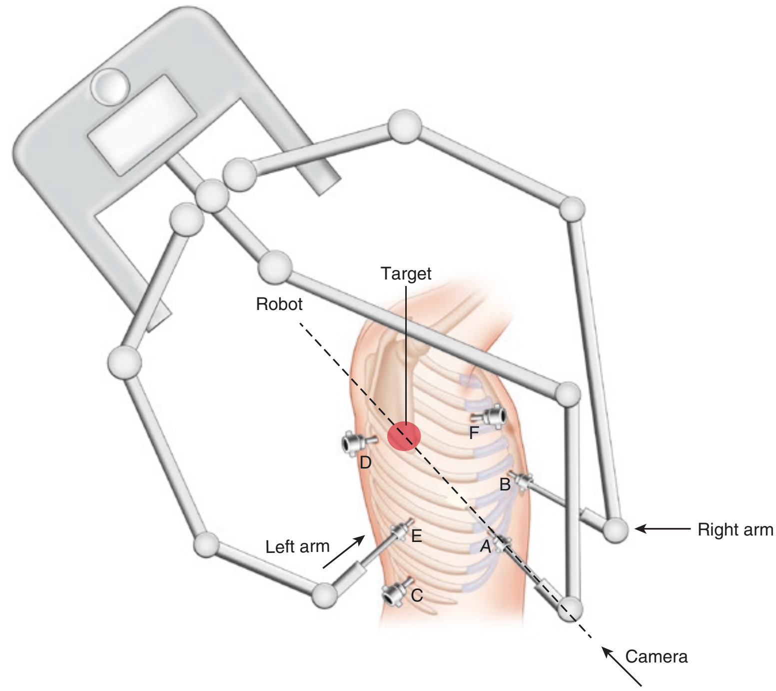


Fig. 4.5 Right upper and middle lobectomy port site setup with the bedside cart in place

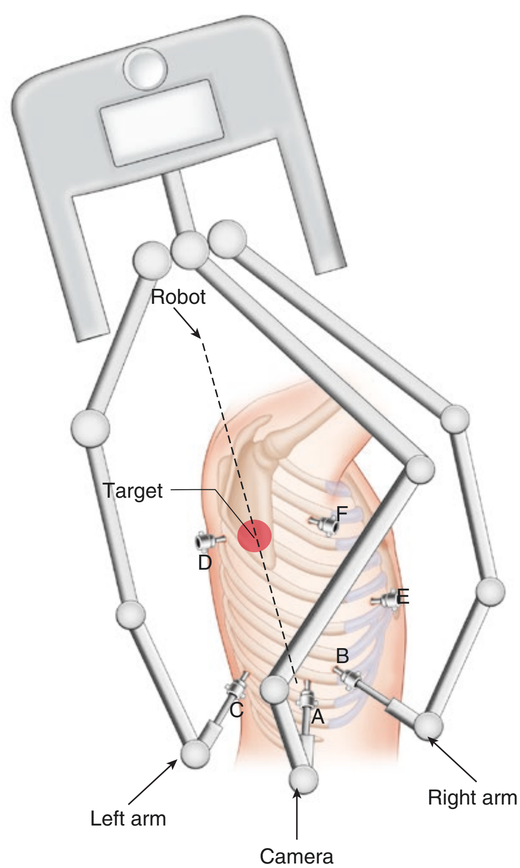


Fig. 4.6 Right lower lobectomy port site setup

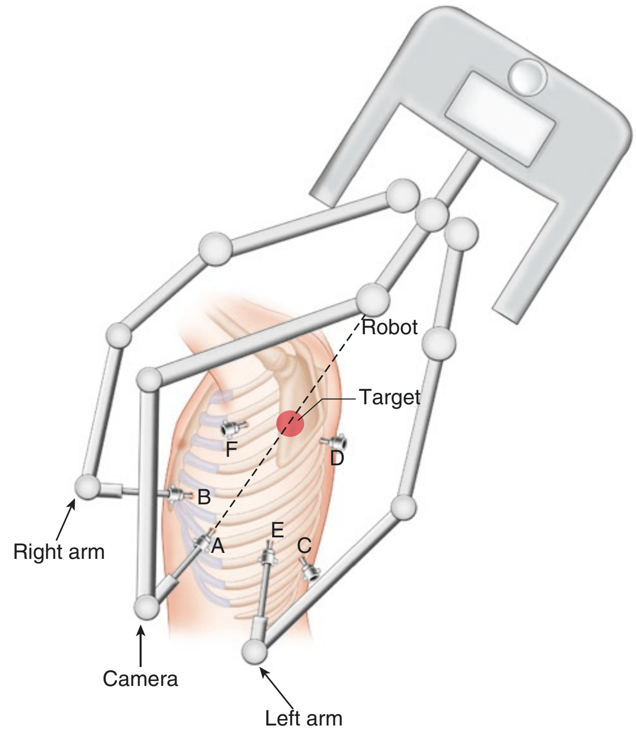


Fig. 4.7 Left upper lobectomy port site setup

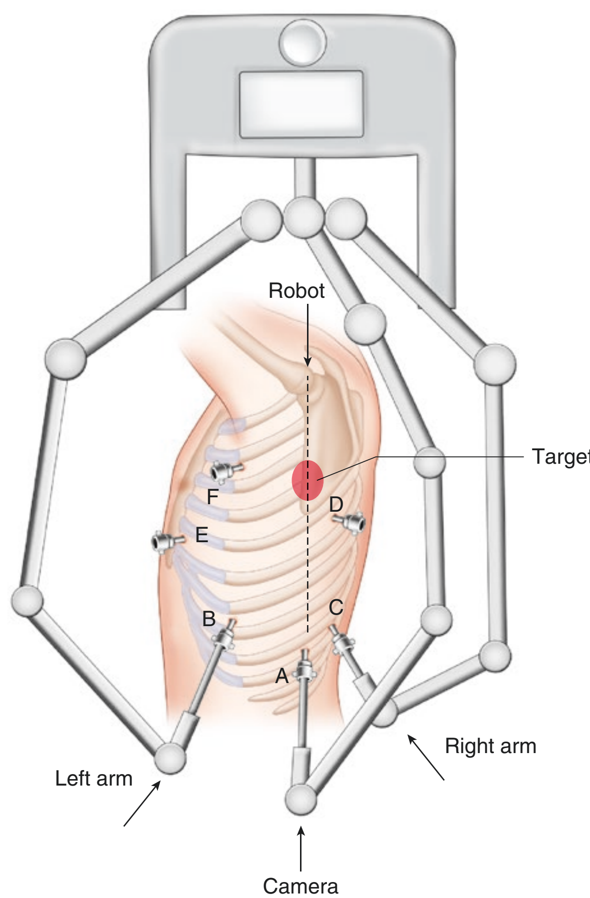


Fig. 4.8 Left lower lobectomy port site setup

4.4.1 Right Upper Lobectomy (Figs. 4.9, 4.10, 4.11, 4.12, and 4.13)

We prefer a 0° scope that allows for a much wider view than the 30° scope. Dependent upon the robot used, the surgeon should set the operating console to a normal view and movement and turned off the "fourth arm" and make certain that the video view is set appropriately to either 0° or 30° down, whichever has been chosen. As stated, in the left arm, the ProGrasp is placed and in the right arm, the Harmonic Scalpel. A general examination of the mediastinum and chest is performed, in addition to what was seen during the placement of the ports and initiation of the procedure. The operative view is then focused on the upper hilum. Once sufficient exposure has been achieved the focus is on the upper mediastinum, avoiding injury to the phrenic nerve and superior vena cava, the harmonic scalpel is used to divide the mediastinal pleura maintaining a distance of approximately 1 cm away from the phrenic nerve and only brief pulses of the harmonic scalpel to avoid lateral heat injury to the nerve. The dissection is continued superiorly along the superior vena cava and azygous vein. A ProGrasp is used to sweep the tissue cleanly away from the proximal pulmonary vein. Effort is made to identify the bifurcation between the right middle and right

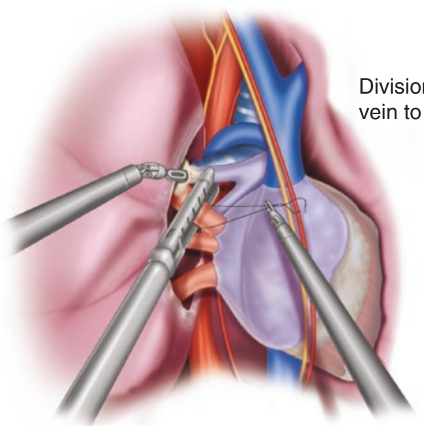


Fig. 4.9 At the start of the upper lobectomy**, the superior pulmonary vein to the right upper lobe is divided** by passing a stapler through **port C** and the adjacent nodal tissue is taken *en bloc* with the lobe. Care should be taken to avoid injury to the middle lobe vein, immediately adjacent to the superior pulmonary vein

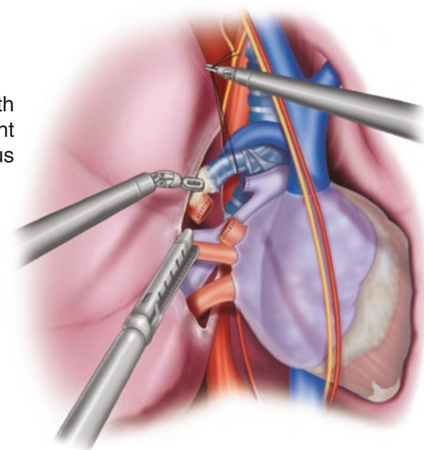


Fig. 4.11 After **division of the recurrent branch of the pulmonary artery to the right upper lobe** and clearing of the hilar tissue between the right upper lobe and the bronchus intermedius, the right upper lobe bronchus is divided with a tissue endostapler flush with the right main stem bronchus and passed through **port C**

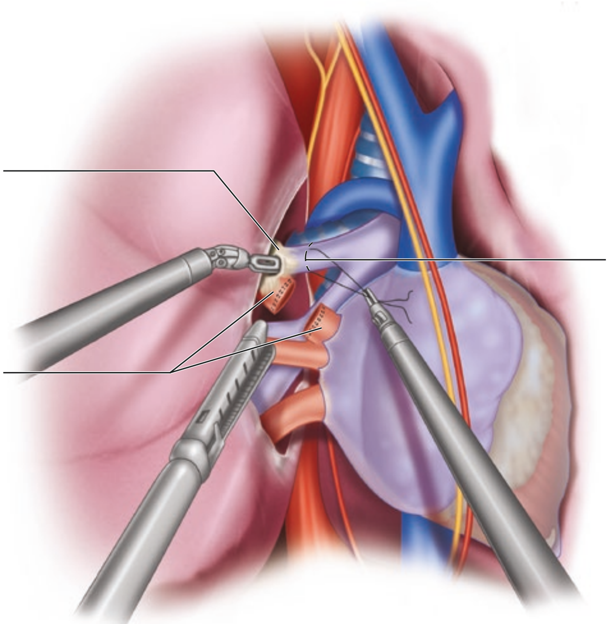


Fig. 4.10 After the lymphatic tissue is dissected away from the pulmonary vasculature, **the pulmonary arteries to the upper lobe are divided with a vascular stapler passed through port C**

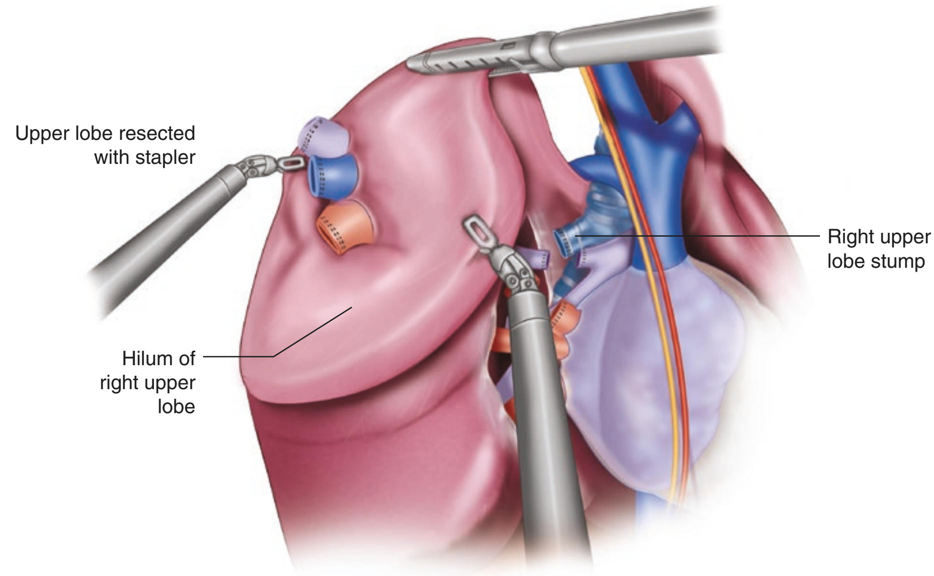


Fig. 4.12 The **minor fissure is divided** between the upper and middle lobe by passing a tissue stapler through **port D** to divide the posterior aspect of the fissure and, if necessary, through **port F** or **port C** to divide the anterior aspect of the fissure. Make certain that the fissure is taken flush with the vasculature in the hilum and the bronchus and any malignant pathology are sufficiently away from the staple line

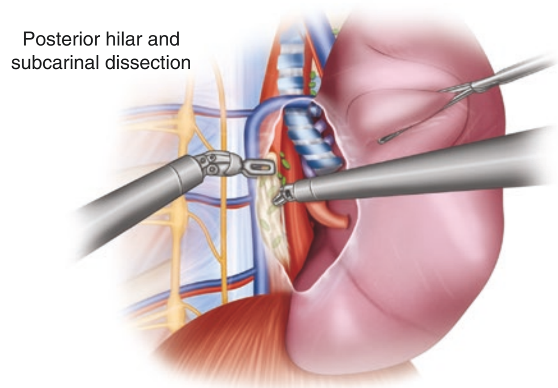


Fig. 4.13 For the lower lobectomy, the **subcarinal tissue is resected** at the start of the case to provide exposure to the main stem bronchus and the pericardium. The lung is retracted anteriorly and the Harmonic scalpel or hook cautery is used. The right paratracheal lymphatic tissue is resected in a similar fashion cleanly from the trachea and the superior vena cava

upper lobe veins within the superior pulmonary vein complex. Using the ProGrasp and harmonic scalpel, hilar tissue is dissected away from the upper lobe vein preserving the middle lobe vein and lifting the vein away from the intermedius and middle lobe pulmonary arteries, grasping the vessels should be avoided. The hilar tissue is bluntly swept toward the resection specimen, clearing the pulmonary artery and the under-aspect of the right upper lobe vein. We strongly encourage that time should be taken to visualize the vein as this is a common site of vascular injury and taking time to perform a thorough posterior dissection will avoid injury and bleeding. Further dissection is performed along the inferior and under aspect of the azygous vein cleaning the adjacent pulmonary arteries and exposing them. The ProGrasp is used like a spatula to push the tissue toward the resection specimen. There are times when the lymphatic tissue is so prominent that it requires complete resection of the lymphatic tissue at those locations to provide better exposure. In that case the completely resected tissue can be removed through **ports D, E, and F**. With the harmonic scalpel the lack of articulations may make it difficult for the novice robotic surgeon to perform the dissection around the pulmonary arteries. Instead, a hook cautery may be used, using it like a right angle to lift the tissue away from the pulmonary artery making certain that it does not injure the pulmonary artery with this maneuver potentially resulting in damage to the pulmonary artery. Then, an 8 cm 0 silk tie is passed into the operative field and placed around the right upper lobe pulmonary vein using it to lift the vessel away from the underlying pulmonary artery. From **port C** a vascular load endostapler is then used to transect the pulmonary vein (Fig. 4.9), one should be especially careful with this maneuver to not partially or completely transect, or narrow the right middle lobe vein. After the pulmonary vein has been ligated, it is not uncommon to need to adjust the upper lobe retracting lung grasper, be it a Landreneau or Forrester clamp. Once this has been completed, the next step is to identify and clean the main pulmonary artery trunk and the right upper lobe branches to expose them for transection. The cephalad aspect of the pulmonary arteries is cleared of hilar tissue and, using the ProGrasp to sweep and grasp non-vascular tissue, the truncus branch pulmonary artery and the recurrent branch are taken back to its junction with the main pulmonary artery, both being cleanly exposed (Fig. 4.10). Each should be identified at its origin and ligated the vascular endostapler (Fig. 4.11), exposing the lymphatic tissue just anterior to the main stem bronchus. In this location it is not uncommon that small tributary pulmonary artery branches may be encountered here; the harmonic scalpel on slow speed may be used to take these vessels. More than one recurrent branch pulmonary artery to the right upper lobe may be encountered as well. The main recurrent branch is located at the inferior aspect of the right upper lobe bronchus and bronchus intermedius junction. Once this vessel is taken, it provides exposure of the right upper lobe and bronchus intermedius junction; cleaning this very well will allow the eventual encircling the proximal right upper lobe bronchus using the ProGrasp. In the rare case that the ProGrasp is not easily passed around the bronchus, the Landreneau or Forrester lung grasper is released and through **port F**, the lung is grasped and retracted anteriorly to expose the posterior aspect of the right upper lobe bronchus. The ProGrasp and the harmonic scalpel are used to identify the posterior pleural and lymphatic tissue, and are taken; bronchial arteries discovered in this location and the blood supply and membranous airway should be preserved if there is no malignancy here. To expose this area, it is sometimes necessary to divide the upper aspect of the major fissure with a tissue endostapler through **port D**. Also in this location, the subcarinal lymph nodes can be identified and cleared from the subcarinal. When taking these nodes, care should be taken to preserve the blood supply to the posterior right main stem and right upper lobe bronchi. Once the airway has been sufficiently cleared, the 8 cm 0 silk is passed around the bronchus as it was for the vessels and clamped at the base of the bronchus with a tissue stapler. It is important not to fire the tissue stapler right away; first, the bronchus intermedius should be examined and if it is not clearly seen, then the right main stem bronchus and bronchus intermedius should be sufficiently exposed to demonstrate that the bronchi are not kinked or narrowed and to make sure that the stapler around the right upper lobe bronchus is flush with the main stem bronchus. The lung can be inflated at this point to demonstrate that the lower and middle lobes are not obstructed. Once divided, the bronchus or adjacent peribronchial tissue is grasped with the ProGrasp and is retracted inferiorly exposing more lymphatic tissue along bronchus intermedius; clearing the tissue from the bronchus to the major fissure. At this location, the major fissure can be hard to discern, the parenchyma of the right upper lobe and the superior segment can seem continuous.

Once the hilar structures are taken and the hilum is thoroughly cleared of lymphatic tissue, the fissure is divided with tissue staplers Fig. 4.12 passed along the angles of presentation through **ports C, D and F**; for patients with friable and/or emphysematous lung tissue, a covered biocompatible mesh endostapler is used to reduce postoperative air leak. Once completely separated, the lobe is placed away from the operative field and remains in the chest until case completion.

Next, further lymph node resection is performed. First, the anterior aspect of the bronchus intermedius and right main stem airway are examined for additional lymphatic tissue. The ProGrasp is used as a spatula to gently retract the pulmonary artery form the main stem bronchus, creating a plane along the pulmonary artery into the mediastinum. Then through the assistant port, a soft endopeanut is inserted through **port C or port F** to retract the pulmonary artery anteriorly. The ProGrasp and the Harmonic are then used to grasp and resect the lymphatic tissue from the anterior aspect of the airway. Once the airway is completely cleaned of lymphatic tissue, the packet of lymphatic tissue is removed. The subcarinal lymphatic tissue can be resected deep in this location, anterior and inferior to the carina. Then, the dissection can be performed in the subazygous location, removing the 10R lymph node packet; beneath the azygous and posterior to the superior vena cava, the lymphatic tissue is grasped and retracted posteriorly, exposing the posterior wall of the superior vena cava. The Harmonic scalpel is used to create a plane along the vena cava well into the mediastinum. Once this is completed, the deep aspect of the dissection along the superior aspect of the right main pulmonary artery and to the leftward side of the mediastinum and then along the anterior and rightward aspect of the trachea. This last maneuver may require switching the ProGrasp and the Harmonic scalpels to achieve the necessary angles of dissection. Complete resection of 4R is accomplished and may be performed with or without division of the azygous vein and the mediastinal pleura. Level 2R or the upper paratracheal lymphatic tissue may be additionally resected, but this should be done with great care to avoid injury of the right recurrent laryngeal nerve where the nerve crosses the origin of the subclavian artery with the innominate artery.

For patients with a nearly complete fissure between the middle and lower lobe and to prevent middle lobe torsion, we perform a pexy using a knifeless tissue stapler through port C stapling together in 1–2 peripheral locations between the peripheral aspect of the inferior aspect of the middle lobe to the periphery of the inferior and lateral aspect of the lower lobe. Too, we do not routinely divide the inferior pulmonary ligament, but do take the pulmonary lymphatic tissue in this location. However, in patients with particularly large right upper lobe tumors, the space left behind may be quite large and result in a persistent pleural space. In those situations taking the inferior pulmonary ligament may allow sufficient mobilization of the lung to fill the apical space avoiding space problems later.

Once all of the lymphatic tissue stations are removed and the lobe completely resected, we place a hook cautery into the left or #2 arm, **port E,** and divide the intercostal pleura and adjacent muscle for an 8–10 cm area along the superior aspect of the rib adjacent to **port F**, the port site planned to remove the lobe; avoid injuring the intercostal bundle and the adjacent periosteum. Once a sufficient intercostal incision has been made, a retrieval bag is passed into the chest through **port F**, there are two of which that we have had significant experience, the Anchor Bag (http://dev.thethreelionsden.com/tissue-retrieval-system/) and the Espiner Bag (http://www.espinermedical.com/). Both bags are made of particularly strong material that does not break or tear and are air and water tight and have a system to completely cover the mouth of the bag for easy removal minimizing the likelihood of spillage. The specimen is placed into the endobag and pulled up into **port F** incision site; the port is often removed prior to this point to allow placement of the endobag. Prior to removal, we suction all debris from the hilum and pleural space and examine for any evidence of bleeding. Once we are satisfied with hemostasis, we fill the pleural space hilum with body temperature saline and ventilate, the bronchial stump is examined for air leak. If there is an air leak, which there rarely is, then we use needle holders in the two robotic arms and place 1–2 simple sutures of 4–0 Prolene on an SH needle or 5–0 Prolene on an RB-1 needle; before passing it into the chest through a port, the suture is cut to 6 cm in length. We recheck the stump for air leak again after performing the repair. The saline is suctioned into a new canister into which 5000 units of heparin has been placed. The canister is sent for post-resection pleural lavage cytology.

In patients in whom we are concerned about the healing and/or blood supply of the bronchial stump or who are likely to receive adjuvant radiation therapy, the stump and adjacent airway is covered with a vascularized pedicle of tissue; our preference is the thymus. Low on the inferior pericardium near the diaphragm using the ProGrasp and the Harmonic scalpel, we clean a wide swath of thymic/anterior mediastinal tissue off of the pericardium and up to the level of the innominate vein. This wide fatty tissue is then used to completely cover the stump and is sewn into place with numerous peribronchially and perihilarly placed 3–0 Vicryl sutures on SH needles in 6–8 cm lengths. As an alternative, we have also performed a wide resection of intercostal muscle and intermammary tissue to provide coverage and extra blood supply to cover the bronchial stump.

The endobags suggested are tough allowing us to remove fairly large tumors. To optimize cosmesis, we attempt to keep the skin incision fairly small, usually 3–5 cm in size, and allow the skin and incision to stretch when removing the bag containing the large specimen. During this time a fair amount of effort is necessary to withdraw the bag, so much so that the anesthesiologist and circulator nurse must hold the patient down onto the operating room table and to prevent dislodging the endotracheal tube. Once removed, the axillary port is packed with a saline soaked laparotomy pad to maintain CO_2 pressure for the remainder of the case.

The robot is undocked at this point. Do not yet remove the sterile covering from the bedside cart. The lung and hilum are again examined for any damage or areas of concern. Once satisfied with the completion of the case, we then inject bupivacaine 0.125% with epinephrine from approximately T2-T10 2–4 cm from the spine using a mediastinoscopy 21 gauge aspirating needle, 5–10 mL into each intercostal space. Then, through two of the port sites, we place a 24 or 28 Fr. French Argyle chest tube to the apex of the chest, accounting for the lung expansion and the curvature of the chest wall, and then through the other chosen port site we place a 19 Fr. round Blake drain, also to the apex of the chest cavity. Both are sutured into place at the skin with 2–0 long nylon that is placed into the port site incision in a vertical mattress fashion, so that when the drain is eventually removed that it pulls the port site incision closed and prevents the egress of pleural effusion and/or entry of air into the chest and provides a good cosmetic approximation of the port site incision. The remaining wounds are closed with 1–2 simple inverting 3–0 Vicryl sutures on SH needles. The port F site or wound where the lobe was removed is closed in 1–2 layers with interrupted and running absorbable sutures. Tegaderm® or Dermabond® dressings are applied to all wounds and Tegaderm® sandwiched around the two drains.

Key features for the immediate postoperative care include keeping the head of the bed elevated at all times. Patients do not eat or drink until the next morning and only when they are able to sit up in a chair and eat under their own volition. There is no drinking or eating in bed to minimize the risk of aspiration. Intravenous and oral fluids are restricted to less than 1.5 L/day for a 70 kg person. Ambulation is initiated early, best on the same day. We give the patient a dose of ketorolac 30–60 mg IV at completion of the case and then 30 mg IV every 6 h. Incentive spirometry is performed every 1–2 h while awake 10–20 times to a target of 1–1.5 L. For patients at risk for bronchospasm, we give them 100 mg of solumedrol at the beginning of the case and routine nebulized bronchodilators afterwards. For patients considered high risk for postoperative supraventricular tachycardia and atrial fibrillation, we give them amiodarone on induction according to the protocol of Tisdale et al. (2009). From the 20 cm H_2O suction the Argyle is placed on water seal at 4 AM and if by 8 AM, there is no dyspnea, no requirement of supplemental oxygen, no enlarging pneumothorax or subcutaneous emphysema on chest x-ray, and if the Blake bulb is holding suction, then the Argyle is removed and the patient is prepared for discharge home that afternoon. If not, the same process is repeated on the second day. If the Argyle is not removed by the third day and the patient is not dyspneic and there is no enlarging pneumothorax or subcutaneous emphysema and the Blake bulb holds suction, then a Heimlich valve is placed on the Argyle and the patient is discharged home. We see our patients in clinic in 5–7 days.

4.4.2 Right Middle Lobectomy (Figs. 4.14 and 4.15)

The patient, table position, ports and instrumentation are all the same as for the upper lobectomy. The Landreneau or Forrester ring clamp is brought through **port D** as for the

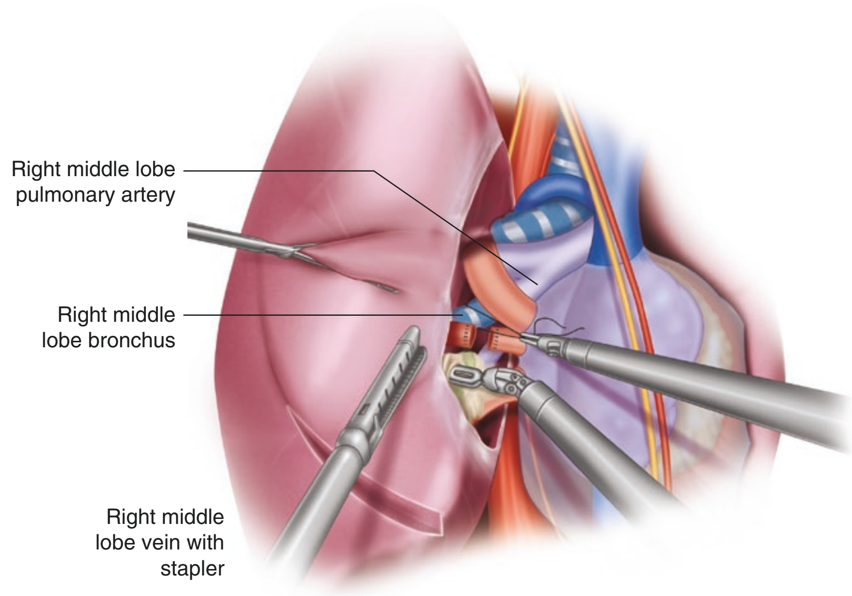


Fig. 4.14 At the beginning of the **right middle lobectomy**, the right middle lobe vein (RMLV) is identified and the lymphatic tissue is dissected away toward the middle lobe to be resected. A vascular endostapler is passed through **port C** to divide the vein. The right middle lobe bronchus (RMLB) and right middle lobe pulmonary artery (RMLA) can be seen deep to the divided vein

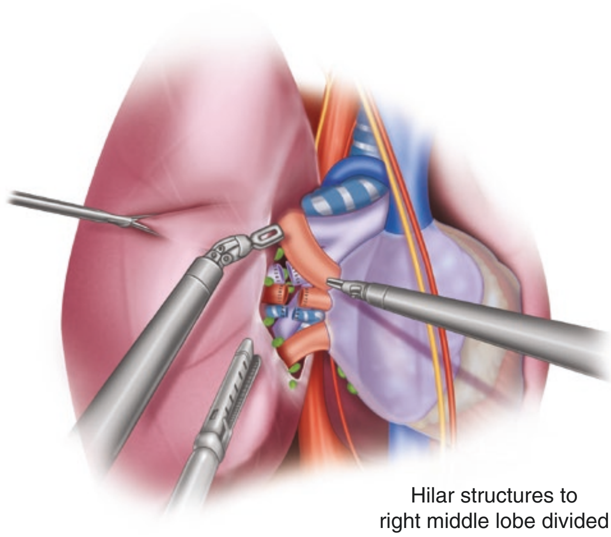


Fig. 4.15 The **right middle lobe vein is divided** first, then the bronchus and then, the pulmonary artery. All staplers for this resection is passed through **port C**. The fissure is divided by passing tissue staplers through **ports C and D**

right upper lobe and the lung parenchyma of the middle lobe is grasped to retract the lung away from the hilum and mediastinum, exposing the right middle lobe hilar structures. The phrenic nerve is identified and the hilar mediastinal pleura is incised with the Harmonic scalpel and then using sharp and blunt dissection the middle lobe vein is identified, it is usually the lowest aspect of the superior venous drainage complex. For the middle lobe, there is a single vein in almost all cases, but in patients with particularly large middle tumors there may be more veins, some draining to the upper lobe vein which should be carefully examined before division to avoid damaging the upper lobe venous drainage. The lymphatic tissue between the middle lobe and upper lobe veins is carefully dissected away to expose the veins. During the dissection of the lymphatic tissue in the hilum, the tissue is dissected toward the pulmonary parenchyma with great care taken to avoid injury to the middle lobe pulmonary artery traversing along the superior aspect of the pulmonary artery to the lower lobe. The dissection is continued into the hilum encircling the middle lobe vein. Hilar tissue from the middle lobe vein is cleaned from the pericardium. Once the middle lobe vein has been completely dissected away from surrounding structures, an 8 cm piece of 0 silk suture is passed around the vein and the vein divided with a vascular endostapler passed through **port C** (Fig. 4.14). Division of the vein exposes the middle lobe bronchus which is directly behind it and is orientated in the same direction as the vein. Resection of the hilar lymphatic tissue adjacent to the middle lobe bronchus and the adjacent lower lobe pulmonary artery exposes distal bronchus intermedius. At the upper rightward aspect of the exposure and coming from the main pulmonary artery is the middle lobe pulmonary artery obliquely heading into the parenchyma from that location. The ProGrasp and the Harmonic scalpel are used to dissect out the vessels and the bronchus and encircle the bronchus with the 0 silk suture. The middle lobe bronchus is then transected with a tissue endostapler passed through **port C** (Fig. 4.15). In some patients exposure to the bronchus may be difficult through **port C** and it may be necessary to divide with a tissue endostapler the most inferior aspect of the major fissure. At this point it may be necessary to adjust the Landreneau or Forrester ring clamp passed through **port D** to provide sufficient retraction to assess the remaining structures in the hilum. Lymphatic and areolar tissue is then dissected away from the pulmonary artery to the lower lobe potentially exposing 1–3 more pulmonary artery branches to the middle lobe, most major one that had been previously identified just posterior and inferior to the remaining upper lobe pulmonary vein. Each of these arteries is then ligated in the same fashion with a vascular endostapler, resecting the hilar tissue cleanly from the lower lobe/intermedius pulmonary artery. Once the pulmonary vasculature has been completely taken, the fissure is then completed as is described for the right upper lobe. Once the specimen has been completely separated, it is placed away from the operative area. As with the right upper lobe, the hilum and mediastinum are then examined and further lymphatic tissue is resected. Once an adequate lymphadenectomy has been performed, a bronchial leak test is then performed, as previously described. The mediastinum is covered with saline and the lung inflated. If any bronchial stump leak is found a 6 cm length stitch of 4–0 Prolene sutures on an SH needle or a 5–0 Prolene on an RB-1 needle is used to provide further support to the bronchial stump recheck for air leak and add more sutures as necessarily. The specimen is brought out through an endobag in the same fashion as with the right upper lobe.

4.4.3 Right Lower Lobectomy

Using the body position in Fig. 4.3, port placement is performed for the lower lobe as described in Fig. 4.6. In contrast to the upper lobe, the Landreneau ring clamp or the Forrester ring clamp is passed through **port F** rather than **port D**. The most inferior lateral aspect of the lower lobe is then grasped with the ring clamp pulling the lower lobe up exposing the inferior pulmonary ligament and keeping it on tension (Fig. 4.16). In the rightward arm of the robot, the harmonic scalpel is passed and in the leftward arm a ProGrasp, as it is for the upper lobe. The inferior pulmonary ligament is divided with all of the adjacent nodal tissue, completely cleaning the pericardium at this location and avoiding injury to the esophagus and the Vagus and phrenic nerves. The lung is then retracted anteriorly to expose the posterior aspect of the right lower lobe and its adjacent mediastinal and hilar lymphatic tissue and pleural reflection (Fig. 4.17). The tissue along the esophagus and the Vagus nerve is resected taking the hilar/mediastinal tissue with the intended specimen and exposing the inferior pulmonary vein along its posterior aspect. Some of the dissection is then performed anteriorly avoiding injury to the phrenic nerve. Once the inferior vein is encircled by an 8 cm 0 silk suture and the

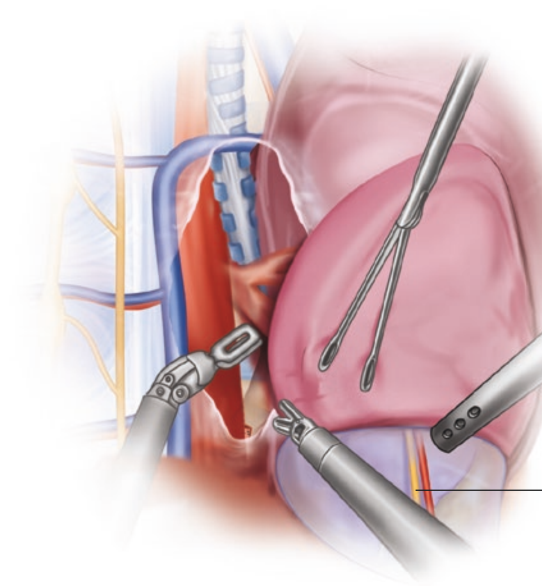


Fig. 4.16 **Right lower lobectomy**. Grasping with ring clamp through **port F** (from Fig. 4.6) of the lateral aspect of the lower lobe and exposing, on tension, the inferior pulmonary ligament. The Harmonic in the R arm (**port B**) is taking the inferior pulmonary ligament close and flush with the esophagus and the pericardium and the ProGrasp in the L arm (**port C**) pushing the tissue up toward the specimen to be removed

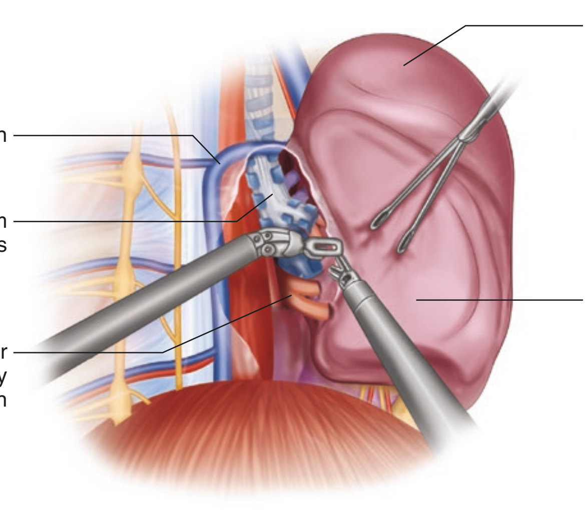


Fig. 4.17 **Right lower lobectomy. Exposure of the posterior hilum of the lower lobe**. The left arm is pushing the pleural reflection away from the bronchus, exposing the pulmonary parenchymal aspect of the lower lobe bronchus and a Harmonic being used to incise and create this plane separating the edge of the pulmonary artery just in the view from the airway

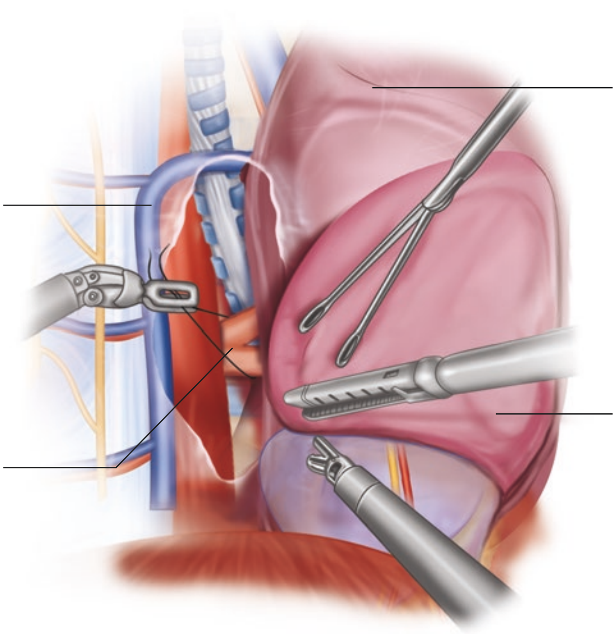


Fig. 4.18 **Right lower lobectomy**. **Division the inferior pulmonary vein** by passing a vascular stapler from **port E**. Both robotic arms working to lift the lung away from the pericardium assisting the passage of the stapler

right middle lobe vein confirmed, a vascular endostapler is passed through **port E** to divide the inferior vein (Fig. 4.18). Then, the subcarinal lymph nodes are resected by dissecting along the inferior aspect of the right bronchus intermedius up to the carina and deep along the pericardium, avoiding injury to the esophagus and the left main stem bronchus. Once resected, the subcarinal tissue is removed from the pleural space through one of the available thoracoports. The parenchymal envelope that covers the distal bronchus intermedius, superior segment and basilar segment bronchus is then dissected off the airway, exposing the medial aspect of the airway just cephalad to the superior segment bronchus. This dissection is continued well into the hilum so that the parenchyma and lymphatic tissue are off the bronchus. The degree of this dissection will set up the next maneuver, encircling the right lower lobe bronchus.

The ring clamp through **port F** is used to retract the lung posteriorly exposing the anterior hilum to allow complete resection of all of the lower anterior hilar tissue toward the lower lobe and to correctly identify the inferior aspect of the major fissure. This further releases the lower lobe from the pericardium. The lung is then retracted laterally and superiorly, toward the apex of the chest. This often exposes significant lymphatic tissue between the most cephalad aspect of the inferior pulmonary vein and the airways. This lymphatic tissue is then dissected off the airways exposing the bifurcation between the basilar segment airways of the lower lobe which in this location to straight up with the middle lobe bronchus is now to the right of the operative field at a right angle. There is often an enlarged lymph node (s) just at the bifurcation between the basilar segment bronchus and the middle lobe bronchus. Using the ProGrasp and the Harmonic scalpel the node is dissected off; inferiorly clearing and exposing the bifurcation between the two airways (Fig. 4.19). Once completely cleared it exposes the pulmonary artery to the lower lobe. Then, the dissection is performed between the basilar segment lower lobe airway and the lower lobe pulmonary artery carefully separating the two under direct vision with the Harmonic scalpel. After this is then completed, a ProGrasp is replaced in the location where the Harmonic scalpel had been, the rightward arm. The two ProGrasps are used to carefully pass along the plane between the bronchus and the pulmonary artery. A slow rocking motion will assist in this maneuver and avoid any injury. It is also possible to use the ProGrasp to retract the bronchus into position so as to see the plane that is being developed. A slow and continued movement will allow the passage of the rightward arm ProGrasp to pass around the bronchus and a silk suture is placed around it encircling the distal bronchus intermedius (Fig. 4.20). Once completed a tissue endostapler is then passed from **port E** to transect the right lower lobe bronchus, both the superior segment and the basilar segment bronchi. Once this is completed, it is often necessary to replace the ring clamp in **port F** so as to expose the right lower lobe pulmonary artery. The Harmonic scalpel is placed in the right arm again and any lymphatic tissue is dissected away from the pulmonary artery to expose it. Once the remaining pulmonary arteries are sufficiently exposed and encircled with the 0 silk, 1–2 vascular endostapler firings are necessary to resect these vessels (Fig. 4.21). The remaining major fissure is then completed in the same fashion as with the right upper lobectomy (Fig. 4.22). Again as with the right upper lobectomy the bronchial stump is covered with irrigant and

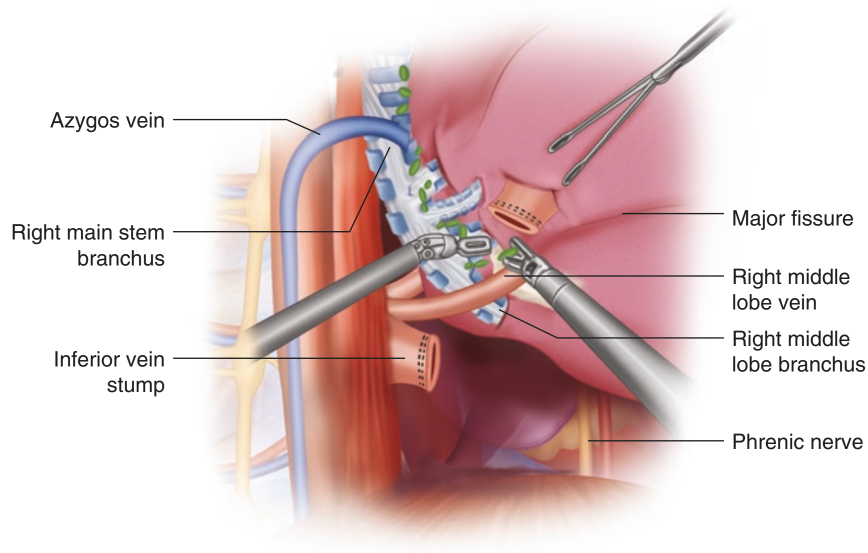


Fig. 4.19 **Right lower lobectomy**. Shows the under aspect of the lobe after the vein had been divided showing lymphatic tissue under the inferior pulmonary vein stump, exposure of the basilar bronchus coming to a right angle with the middle lobe bronchus. There is a lymph node station at the bifurcation of the lower lobe basilar segment and middle lobe bronchi covering the pulmonary artery. The lung grasper is used to expose this area. The ProGrasp in the left arm is used to grasp the lymph tissue covering the bronchi and the Harmonic scalpel in the right arm is used to tease the lymph tissue away from the bronchi and pulmonary artery beneath the covering lymph tissue avoiding heat or mechanical injury to the bronchi or the pulmonary artery

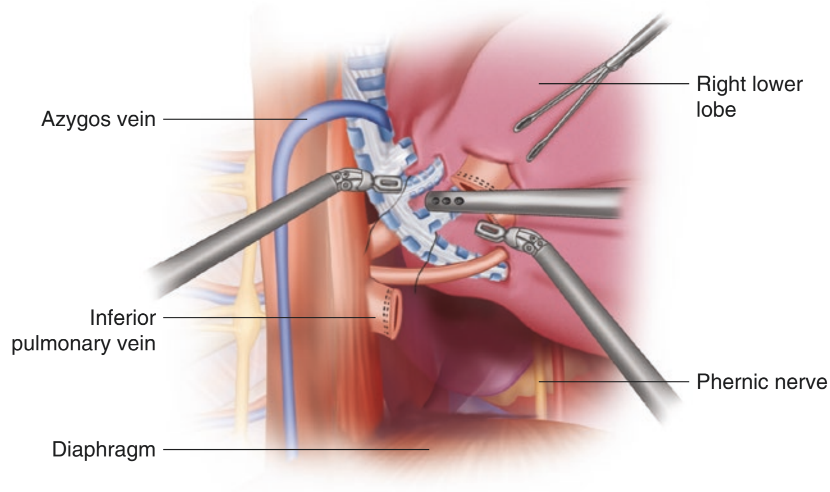


Fig. 4.20 **Right lower lobectomy**. **Isolation of the basilar and superior segment bronchi for division**. The right robotic arm is exchanged for a ProGrasp replacing the Harmonic that was there and under direct vision the blunt tip of the ProGrasp is used to tease the basilar and superior segment bronchi away from the pulmonary artery. A 0-silk suture is passed around the superior segment and basilar segment bronchus for division

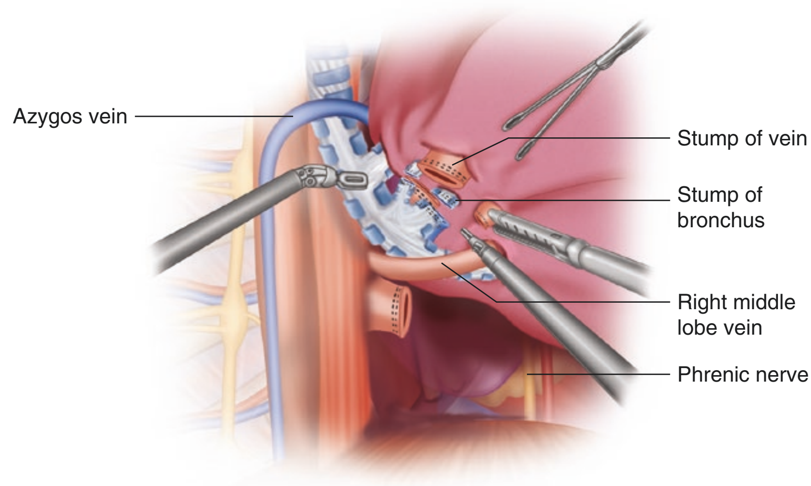


Fig. 4.21 **Right lower lobectomy**. A silk stitch around the two arteries to the lower lobe, the basilar segment and superior segment pulmonary artery branches taken with an endostapler from **port E**

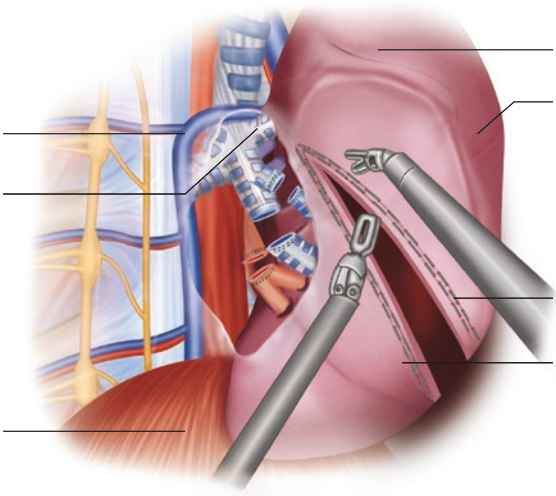


Fig. 4.22 **Right lower lobectomy**. **Fissure being completed** by a stapler being passed from **port E**

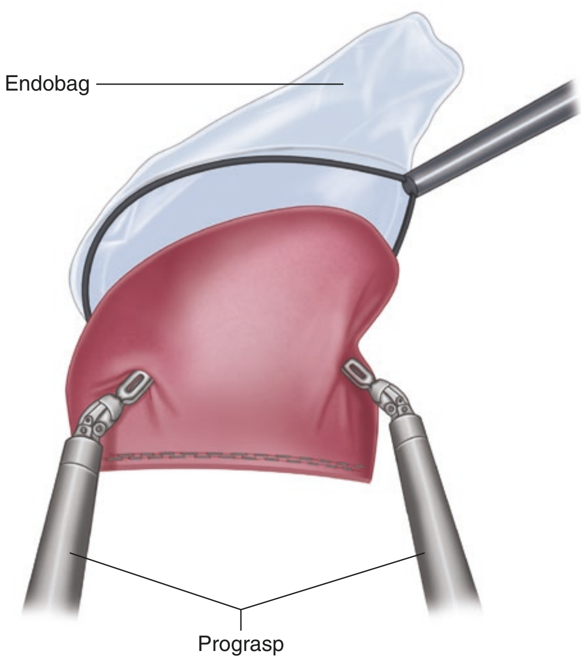


Fig. 4.23 **Right lower lobectomy**. The bag is closed and is pulled partially up into the **port F** incision and the mediastinum is covered in saline looking for an air leak in the bronchial stump

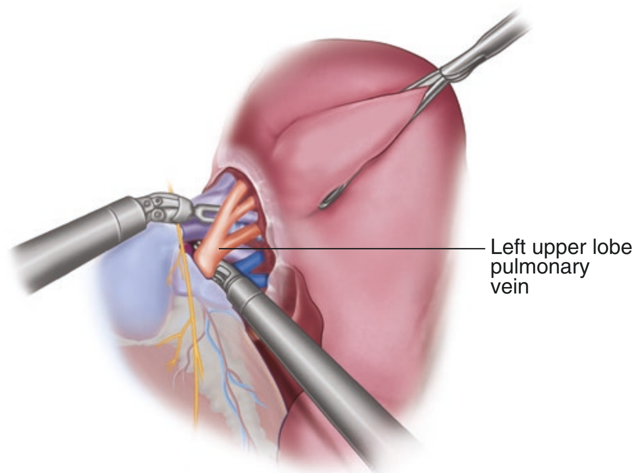


Fig. 4.24 **Initiation of the left upper lobectomy**. After resection of the aortopulmonary window lymphatic tissue avoiding injury to the phrenic and recurrent laryngeal nerves (being aware that the recurrent laryngeal nerve may not be intimately associated with the under aspect of the aortic arch and the nerve can come very close to the upper aspect of the pulmonary artery), the left upper lobe pulmonary vein is isolated by dissecting the circumference with a Harmonic scalpel. Before taking the upper lobe vein, confirm that there is a lower lobe vein by dissecting the lower lobe vein from surrounding tissue

managed in the same fashion as with the right upper lobectomy. Further lymphatic resection is performed as with the upper lobectomy (Fig. 4.23).

4.4.4 Left Upper Lobectomy (Figs. 4.24 and 4.25)

Using the left upper chest port placement as outlined in Fig. 4.7 and with the ProGrasp in the left robotic arm and a Harmonic scalpel in the right, the dissection is initiated along and 1 cm posterior to the phrenic nerve and the incision is continued to the aorta pulmonary window exposing the under aspect of the aortic arch. A Landreneau ring clamp or Forrester ring clamp is brought through the posterior-superior thoracoport or **port D** to grasp the pulmonary parenchyma just adjacent and lateral to the hilum placing the hilar tissue on some tension. Then, the tissue in the aorta pulmonary window is completely resected, avoiding injury to the phrenic nerve and the recurrent laryngeal nerves. There is often so much tissue resected that it is necessary to remove the tissue in a small endobag.

Using blunt dissection, the origin of the superior pulmonary vein is dissected cleanly, identifying the bifurca-

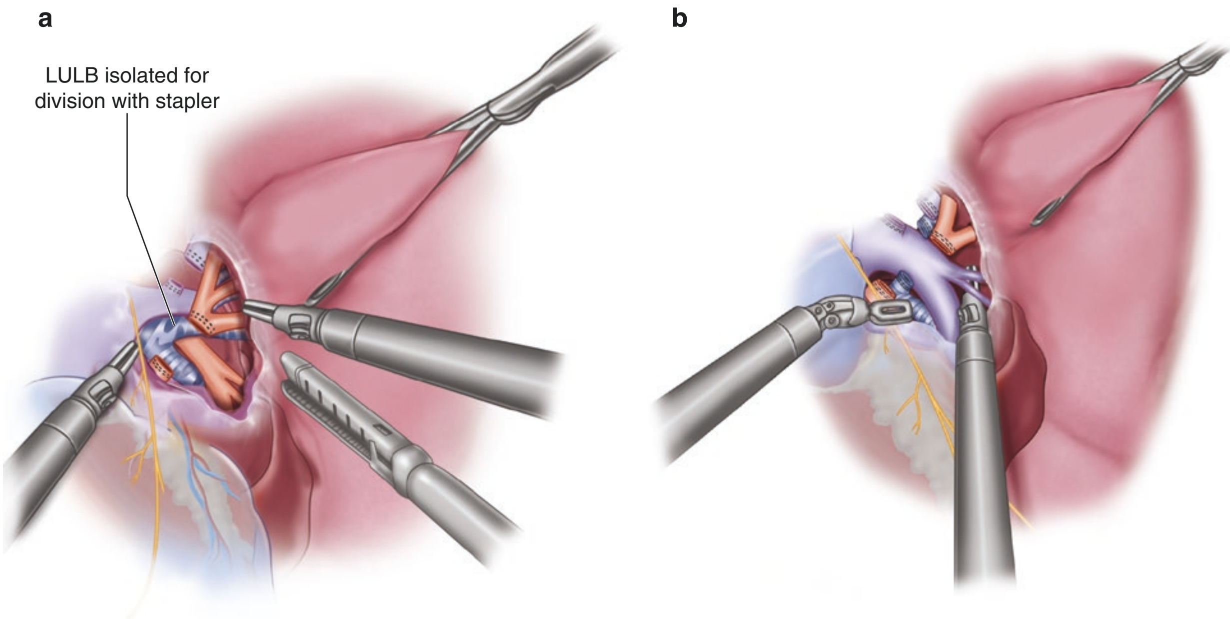


Fig. 4.25 After division of the first branch of the pulmonary artery, the left upper lobe bronchus (LULB) is identified by dissecting away areolar and lymphatic tissue beneath the divided pulmonary vein. The cartilaginous portion of the bronchus, should be readily visible. At the bifurcation of the left upper and lower lobe bronchi, there is lymphatic tissue present that is removed to expose the pulmonary artery beneath it. Once the nodal tissue is removed, the left upper lobe bronchus is dissected away from the pulmonary artery behind it using the ProGrasp from the leftward arm and a Harmonic from the right arm. The Forrester ring clamp can be used to exert tension on the bronchus by grasping the lung and holding the bronchus away from the pulmonary artery. Once the left upper lobe bronchus is sufficiently teased away from the pulmonary artery, the Harmonic scalpel in the right arm is exchanged for a ProGrasp and the right or left arm ProGrasp is carefully passed behind the left upper lobe bronchus to place a 0-silk suture, 8 cm in length. Once completed a tissue endostapler is passed through **port C** and clamped down on the upper lobe bronchus. Then a test inflation of the left lower lobe is performed and once confirmed that the left lower lobe inflates and deflates, the bronchus is divided. To complete the left upper lobectomy, the Forrester retracting grasper exposes the pulmonary artery to the lower lobe and the remaining pulmonary artery branches to the upper lobe it and the areolar tissue is divided with the Harmonic scalpel in the right arm. This exposes the remaining left upper lobe and lingular pulmonary artery branches which are divided with a vascular endostapler passed through **port C**. The fissure is divided with an endostapler and the lobe is placed in an endobag brought through **port F** after the intercostal space has been widened with the Hook cautery in the right arm. The stump is submerged in saline to make certain that there is no bronchial stump leak. If there is a leak, it may be repaired as described for the right upper lobectomy

tion between the upper and lower lobe pulmonary veins and dissecting tissue from the posterior and anterior aspect of the main pulmonary artery at the upper most aspect of the hilum (Fig. 4.24). Time and effort should be taken to be absolutely certain that the inferior pulmonary vein has been identified; it may require division of the anterior and posterior hilar pleura. Then, the superior pulmonary vein is carefully lifted away to expose structures posterior to the vein, not grasping the superior vein by the ProGrasp, but using it like a spatula to expose the underlying left upper lobe bronchus and pulmonary artery. The Harmonic scalpel is used for this posterior dissection of the lymphatic tissue that is often encountered. Once the superior pulmonary vein is completely encircled, a 0 silk suture is passed around it and the vein is divided with a vascular endostapler passed through **port C**. Once transected, the ring clamp in **port D** is repositioned on the anterior aspect of the left upper lobe to a closer location to the hilum to expose the bronchus. Often significant lymphatic tissue is encountered and is resected with the specimen. Since the most cephalad aspect of the bronchus is difficult to identify as it is often partially covered by the first major pulmonary artery branch, it is best to divide the pulmonary artery branch first. Adjacent lymphatic tissue is dissected off of the origin of this branch and the adjacent main pulmonary artery. Once this has been completed, a 0 silk is placed around the pulmonary artery and a vascular endostapler brought in through **port C** can be used to transect the pulmonary artery. Once this has been completed, the lymphatic tissue from the anterior aspect of the distal left main bronchus and the upper and lower lobe bronchi is resected. This is a very important maneuver as it will help to identify the left lower lobe bronchus. There is significant lymphatic tissue just at the bifurcation between the upper lobe and lower lobe bronchi. Once this is then resected the main pulmonary artery to the lower lobe becomes visible. This then allows the plane to be developed along the posterior aspect of the upper lobe bronchus. Then under direct vision and using a Harmonic scalpel the plane is created between the pulmonary artery and the upper lobe bronchus. The silk is passed around the airway and the bronchus divided with a tissue endostapler (Fig. 4.25). The ring clamp through **port D** is reattached closer on the hilum, in some cases grasping the specimen side bronchus, to expose the main pulmonary artery to the lower lobe and the remaining pulmonary artery branches to the upper lobe. The adjacent lymphatic and areolar tissue are taken with a Harmonic scalpel and the remaining pulmonary artery branches taken with vascular endostapler. The fissure is then completed as it is for the right upper lobe bronchus. The specimen is placed away from the area of dissection and further lymphatic tissue is then resected as necessary as described in the sections on the other lobes. In the same fashion as with the other lobes, **port F** is then prepared and an endobag is placed through that site and into which the upper lobe is placed. The upper lobe is removed in the same fashion as described in the right upper lobectomy in the case completed in the same fashion.

4.4.5 Left Lower Lobectomy (Figs. 4.8, 4.26, 4.27, 4.28, 4.29, 4.30, 4.31, and 4.32)

The patient, table position, and the thoracoport sites are as shown in Fig. 4.8. As with the other robotic lobectomies, a 0° scope is used. The dissection is initiated after the Landreneau ring clamp or Forrester ring clamp is passed through the anterior-superior thoracoport site or **port F** and grasped on the lower most lateral portion of the left lower lobe. This exposes and places on tension the inferior pulmonary ligament (Fig. 4.26). In the left robotic arm is the ProGrasp and in the right robotic arm the Harmonic scalpel. The inferior pulmonary ligament is taken cleanly from the pericardium avoiding injury to the esophagus, the Vagus and phrenic nerves. The dissection is continued to the inferior pulmonary vein at its origin. The lung is retracted anteriorly to expose the posterior hilum and the region of the subcarina (Fig. 4.27). This dissection is continued into the subcarina and all of the adjacent lymphatic tissue is resected preserving, if possible, the adjacent bronchial artery blood supply (Fig. 4.28).

Then, the parenchymal envelope is dissected off of the distal airway up to the takeoff of the superior segment bronchus exposing the distal main stem bronchus at this location so that the most superior aspect of the lobe has been detached from the bronchus, exposing the pulmonary artery to the lower lobe. The lobe is then retracted posteriorly and the dissection is continued to along the pericardium up to the superior pulmonary vein, identifying the superior pulmonary vein before any resection of the inferior vein is performed. Adjacent lymphatic tissue is taken with the specimen. The inferior pulmonary vein is then encircled with a 0 silk suture (Fig. 4.29). The inferior or lower lobe vein is then divided with a vascular endostapler passed through **port E**. This exposes the left lower lobe bronchus at the bifurcation with the lower lobe bronchus. Adjacent lymphatic tissue is taken off the bronchus and along the leftward aspect of the bronchus the bifurcation between the upper lobe and lower lobe bronchus can be identified at this location (Fig. 4.30). This lymphatic tis-

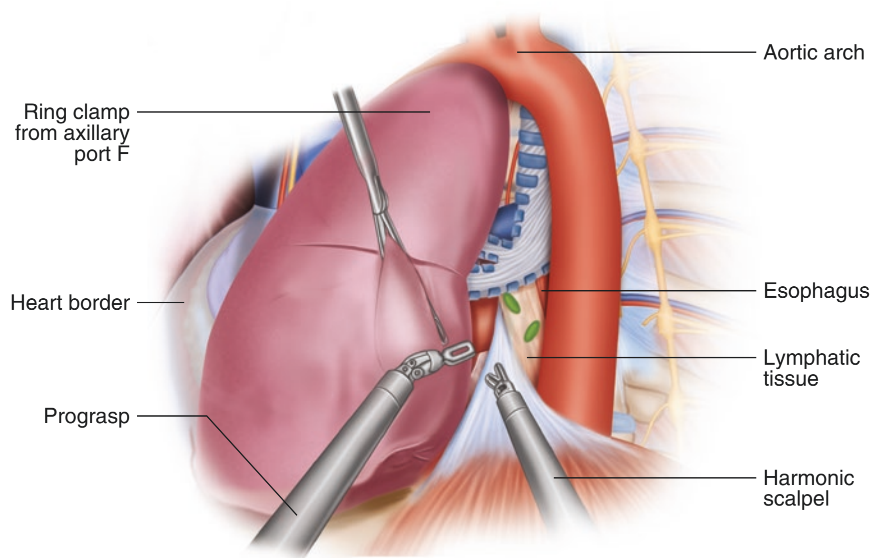


Fig. 4.26 **Robotic left lower lobectomy**. **Dissection of the inferior pulmonary ligament of the left lower lobe**. Through **port F** grasp the lateral or basilar aspect of the left lower lobe resulting in exposure and tension of the inferior pulmonary ligament. In the right arm the Harmonic scalpel is used to incise the ligament with lymphatic tissue at the base, adjacent to the pericardium and the esophagus; yet, avoiding injury to the esophagus and the Vagus nerve, taking a wide section of tissue with the specimen

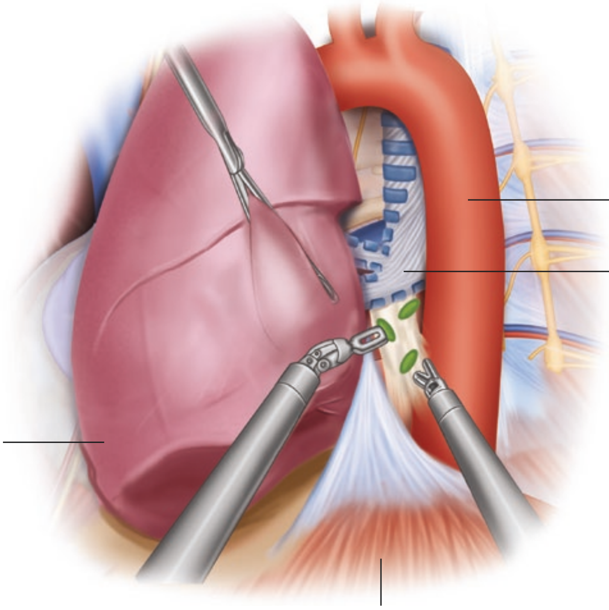


Fig. 4.27 **Robotic left lower lobectomy**. Retract the lobe anteriorly **exposing the posterior aspect of the lobe and hilum**. The ProGrasp in the left arm and the Harmonic in the right arm are used to remove the subcarinal tissue and clearing of the under aspect of the left main stem bronchus

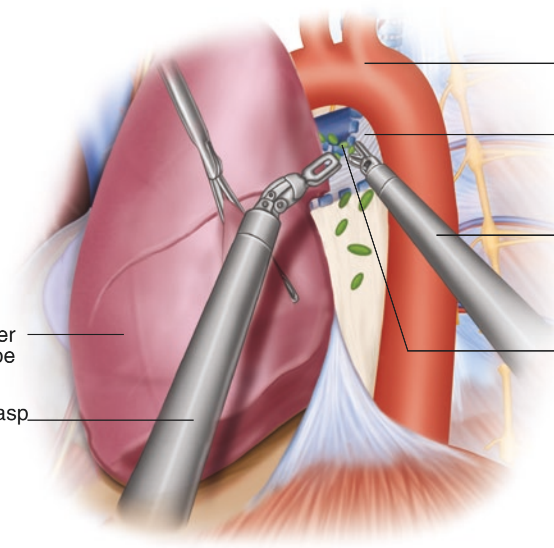


Fig. 4.28 **Robotic left lower lobectomy**. **Clearing of the upper aspect of the left mainstem bronchus** exposes the main pulmonary artery just cephalad to the superior segment bronchus and allows development of a plane between the pulmonary artery and the bronchus at this location. Avoid taking any bronchial arterial branches that will be important in blood supply to the healing bronchial stump

sue is carefully teased away from the bifurcation and once achieved the ProGrasp in the leftward arm is then used to carefully pass around the origin of the lower lobe bronchus. A 0 silk is then passed around it and a tissue endostapler is used to divide it. The ring clamp through **port F** is then adjusted so as to expose the pulmonary arteries beneath it (Fig. 4.31). There are at least two pulmonary arteries present, the basilar segment and the superior segment arteries and others identified are divided separately or together with a vascular endostapler through **port E**. The fissure is then completed in the same fashion as with the right upper lobe (Fig. 4.32). The course of the remaining case is then completed in the same fashion as with the right upper lobe.

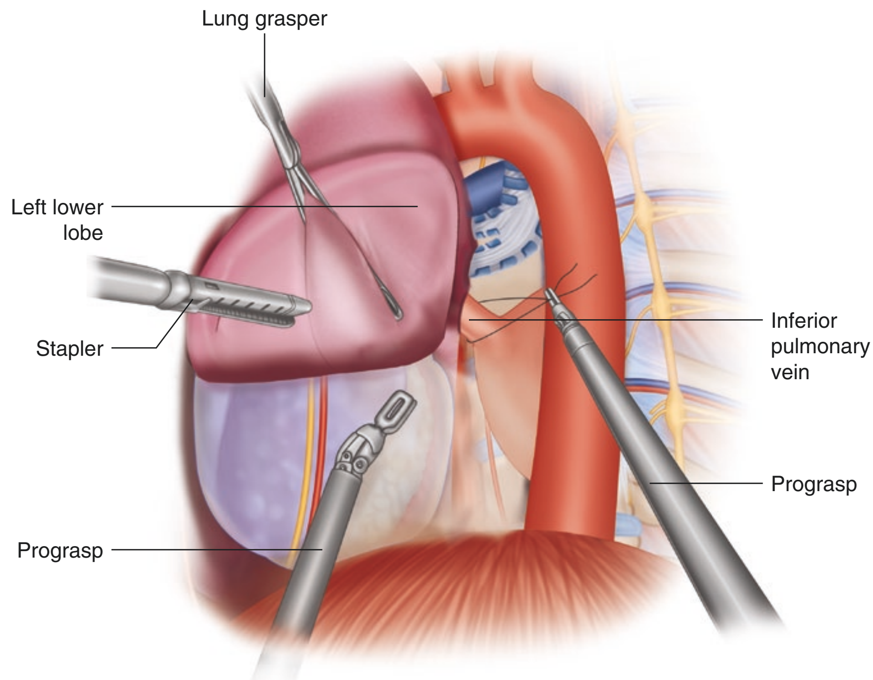


Fig. 4.29 **Robotic left lower lobectomy**. **Division of the inferior pulmonary vein** by passing a stapler from **port E** with ProGrasps used to expose the area and lift the 0-silk suture around it

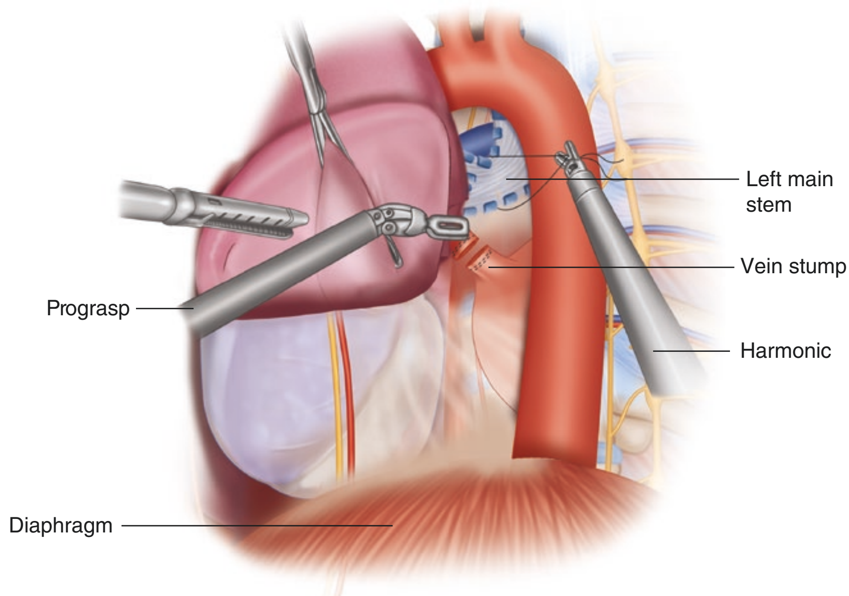


Fig. 4.30 **Robotic left lower lobectomy**. **Exposure and Division of the Left Lower Lobe Bronchus**. The left arm ProGrasp is used to identify the lymphatic tissue around the bifurcation of the left lower lobe and the upper lobe bronchi. The Forrester ring clamp is positioned to allow optimal exposure of this portion of the hilum. Once achieved, the lymphatic tissue is dissected away from the bifurcation to expose the pulmonary artery beneath it and then the ProGrasp is carefully passed behind the lower lobe bronchus to the posterior hilum, a silk suture is passed around the bronchus for retraction purposes. The stapler is passed from **port E** and in the same fashion with the left upper lobe, a test clamp is performed making certain that the left upper lobe inflates and deflates. Once confirmed the bronchus is divided

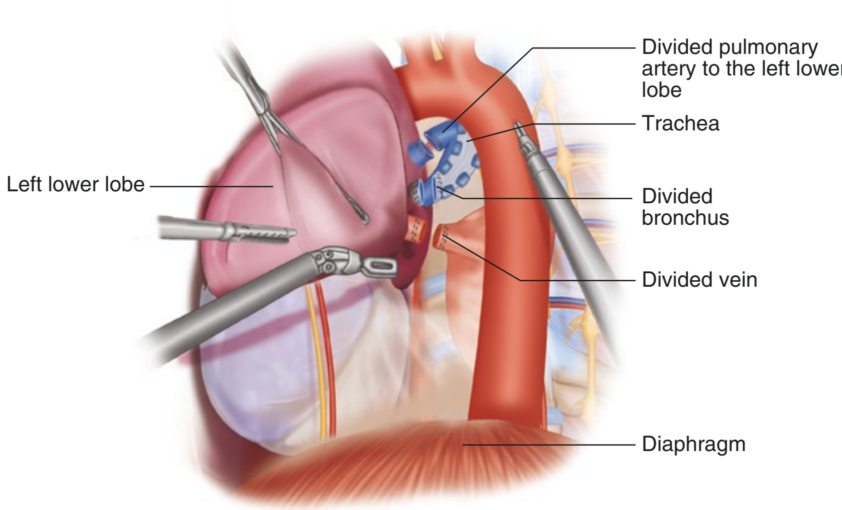


Fig. 4.31 **Robotic left lower lobectomy**. **Division of the left lower lobe pulmonary artery branches**. Shown are the divided stumps of the bronchus and pulmonary vein and the unresected pulmonary arteries, the left arm ProGrasp is shown passing around the pulmonary arteries. A 6–8 cm 0-silk is passed around the pulmonary artery and the arteries are divided with a vascular load stapler from **port E**

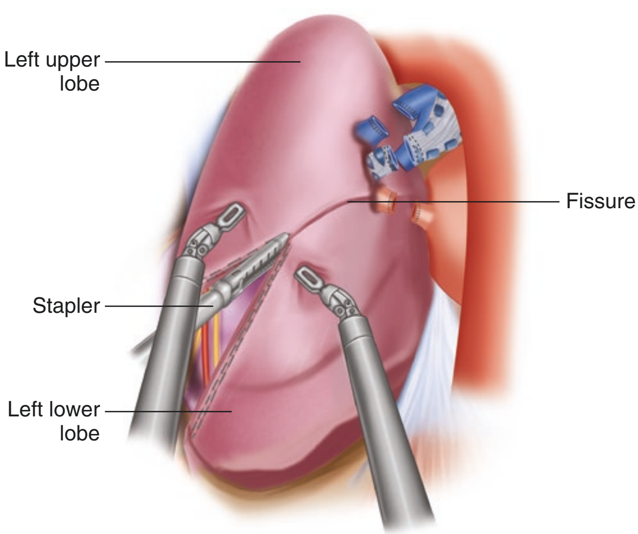


Fig. 4.32 **Robotic left lower lobectomy**. **Division of the Fissure** ProGrasps in both arms expose the major fissure and the stapler being passed through **port E**

4.5 Tips and Pitfalls

- Continuous carbon dioxide insufflation (CO_2) should be kept at a pressure of less than 10–15 mmHg. It is used to assist in compressing the lung and pushing the mediastinum away from the operative area and assisting in clearing any surgical smoke or vapor. We recommend a gradual increase rather than sudden increase in intrapleural CO_2 pressure to allow the patient to hemodynamically adjust to the increased intrapleural pressure.
- With the currently available robotic equipment, it is recommended that grasping the lung, any hilar structures, or the airway with the robotic instrumentation should be avoided to minimize the risk of injury and/or bleeding. Robotic instrumentation is better used for sweeping and very precise grasping of areolar tissue adjacent to the major structures. We recommend using instead instruments used in video-assisted thoracoscopic surgery as these are less traumatic to these structures than the robotic instrumentation.
- Avoid using in the chest cavity any operating sponges. Instead, we use tightly rolled swathes of Surgicel® 3-0 Vicryl sutures to mop or pack bleeding areas. Free operating sponges can be lost, even when the sponge count is correct at the end of the case. Making a habit of not having them on the table eliminates a potential complication and although, uses material that might be expensive, provides hemostasis and will dissolve if lost within a couple of weeks.
- It is critical to identify anomalous bronchial, pulmonary vascular, and azygous vein anatomy prior to dividing any structures. Often, these anomalies can be inferred by the appearance on the computed tomogram, but tumor and disease may alter the operative anatomy so much so that it may be difficult to clearly identify the anomalies. Commonly encountered anomalous structures:

  - Common pulmonary vein, rather than a superior and inferior pulmonary vein
  - Right middle lobe vein that comes off the upper lobe vein complex late
  - High riding main pulmonary artery potentially confused with the pulmonary artery blood supply to the upper lobe.
  - Replacement of the inferior vena cava with the azygous vein, all inferior venous return comes through the azygous vein
  - Right upper lobe take off from the distal trachea rather than the right main stem bronchus
  - Azygous lobe
  - Left lower lobe take off is more distal than expected, taking what is presumed to be the upper lobe bronchus can potentially injure the distal main stem bronchus
- Vascular staplers, rather than tissue staplers, should be used for the pulmonary vasculature. When taking the bronchus and normal appearing airways, tissue staplers should be used. Inexperienced teams can sometimes mistake tissue staplers for vascular staplers and vice versa.
- In the emphysematous and/or friable lung tissue, we recommend using covered staplers; examples include Surgisis® (Cook Medical)
- Thick tissue staplers may be necessary in the particularly thick and often incomplete fissures. Be prepared to use them.
- After using stitches with swedged-on needles, cut the suture to leave at least a 1–2 cm segment of suture on the needle for suture/needle removal and use a nonrobotic minimally invasive needle holder to grasp the suture rather than the needle for removal of the needle.
- In patients that have had or are likely to have hilar or mediastinal irradiation or in those where the blood supply to the stump is of concern, perform a vascular pedicled tissue coverage of the bronchial stump with either thymic tissue, adjacent mediastinal tissue, intercostal muscle or internal mammary blood supply-tissue.
- Always keep your eye on the phrenic nerve. Carbon dioxide pressure in the pleural space can distend the diaphragm and raise the phrenic nerve from the normal location along the mediastinum and like a violin string can be quite taut and raised off the mediastinum sufficiently that it can be injured during the dissection and/or passage of the stapler.
- In patients with fairly brittle ribs or in patients with particularly large tumors, it is often better to "shingle" or resect a 1–2 cm segment of the rib or ribs adjacent to the planned removal of the endobag.

4.6 Outcomes in Brief

We have performed over 600 robotic lung lobectomies since 2002, the majority of which were performed using the hilum-first technique as outlined in this chapter. We have learned that both the fissure-first and the hilum-first techniques may be used dependent on the pathology and the anatomy of the given situation. Dependent upon the anesthesia and surgical team's experience, the procedure rarely takes longer than 3 h, even when cardiothoracic surgery trainees are the console surgeon. Conversion rates are less than 1%. Blood loss is rarely more than 100 mL. The rate of positive surgical margins of malignancy is less than 3%. Fewer than 5% of patients with cancer have less than 20 lymph nodes counted by our pathology team. The average size of the primary tumor is approximately 4.3 cm with the largest being 21 cm. Median length of stay in the hospital is 2 days with 20% being discharged on day 1. Unless chest wall resection is performed, we do not use epidural anesthesia. Although we discharge patients with narcotics, nearly a third are off the narcotics by the first postoperative visit and over half are off narcotics by the end of 2 weeks. Less than 1% of patients had any pain from the procedure beyond 1 month and if working nearly all returned to work within the month. Overall complication rate is less than 8%. Persistent air leak beyond 3 days occurs in fewer than 5%. In a propensity-matched analysis of 65 robotic lobectomies with the SEER database, there appeared to be at least an equivalent long term survival and potentially superior survival for the robotic lobectomy patients; 80% at 3 years with 15% of the patients having stage IIB or greater.

Selected References

Anderson CA, Hellan M, Falebella A, Lau CS, Grannis FW, Kernstine KH. Robotic-assisted lung resection for malignant disease. Innovations (Phila). 2007;2:254–8.

Braumann C, Jacobi CA, Menenakos C, Ismail M, Rueckert JC, Mueller JM. Robotic-assisted laparoscopic and thoracoscopic surgery with the da Vinci system: a 4-year experience in a single institution. Surg Laparosc Endosc Percutan Tech. 2008;18:260–6.

Cao C, Manganas C, Ang SC, Yan TD. A systematic review and meta-analysis on pulmonary resections by robotic video-assisted thoracic surgery. Ann Cardiothorac Surg. 2012;1:3–10.

Cerfolio RJ. Total port approach for robotic lobectomy. Thorac Surg Clin. 2014;24:151–6, v.

Cerfolio RJ, Bryant AS. Perspectives on robotic pulmonary resection: it's current and future status. Ann Cardiothorac Surg. 2012;1: 59–60.

Dylewski MR, Ohaeto AC, Pereira JF. Pulmonary resection using a total endoscopic robotic video-assisted approach. Semin Thorac Cardiovasc Surg. 2011;23:36–42.

Kent M, Wang T, Whyte R, Curran T, Flores R, Gangadharan S. Open, video-assisted thoracic surgery, and robotic lobectomy: review of a national database. Ann Thorac Surg. 2014;97:236–42; discussion 42–4

Kernstine KH, Anderson CA, Falabella A. Robotic lobectomy. Oper Tech Thorac Cardiovasc Surg. 2008;13:204.e1–e23.

Kocher GJ, Schmid RA, Melfi FM. Robotic lobectomy: tips, pitfalls and troubleshooting. Eur J Cardiothorac Surg. 2014;46:e136–8.

Lee BE, Shapiro M, Rutledge JR, Korst RJ. Nodal upstaging in robotic and video assisted thoracic surgery lobectomy for clinical N0 lung Cancer. Ann Thorac Surg. 2015;100:229–33; discussion 33–4

Melfi FM, Fanucchi O, Davini F, Romano G, Lucchi M, Dini P, Ambrogi MC, Mussi A. Robotic lobectomy for lung cancer: evolution in technique and technology. Eur J Cardiothorac Surg. 2014;46:626–30; discussion 30–1

Park BJ. Robotic lobectomy for non-small cell lung cancer: long-term oncologic results. Thorac Surg Clin. 2014;24:157–62, vi.

Park BJ, Flores RM. Cost comparison of robotic, video-assisted thoracic surgery and thoracotomy approaches to pulmonary lobectomy. Thorac Surg Clin. 2008;18:297–300, vii.

Park BJ, Flores RM, Rusch VW. Robotic assistance for video-assisted thoracic surgical lobectomy: technique and initial results. J Thorac Cardiovasc Surg. 2006;131:54–9.

Park BJ, Melfi F, Mussi A, Maisonneuve P, Spaggiari L, Da Silva RK, Veronesi G. Robotic lobectomy for non-small cell lung cancer (NSCLC): long-term oncologic results. J Thorac Cardiovasc Surg. 2012;143:383–9.

Tisdale JE, Wroblewski HA, Wall DS, Rieger KM, Hammoud ZT, Young JV, Kesler KA. A randomized trial evaluating amiodarone for prevention of atrial fibrillation after pulmonary resection. Ann Thorac Surg. 2009;88(3):886–95.

Veronesi G, Galetta D, Maisonneuve P, Melfi F, Schmid RA, Borri A, Vannucci F, Spaggiari L. Four-arm robotic lobectomy for the treatment of early-stage lung cancer. J Thorac Cardiovasc Surg. 2010;140:19–25.

Wilson JL, Louie BE, Cerfolio RJ, Park BJ, Vallieres E, Aye RW, Abdel-Razek A, Bryant A, Farivar AS. The prevalence of nodal upstaging during robotic lung resection in early stage non-small cell lung cancer. Ann Thorac Surg. 2014;97:1901–6; discussion 6–7

5 Robotic Pancoast and Chest Wall Resection

Robert B. Cameron

Abstract

Robotic chest wall resection is relatively uncommon compared to other thoracic procedures; however, in many circumstances, there exist definite advantages to robotic resection over standard thoracoscopic and open resection. The advantages are particularly relevant for smaller to moderate sized tumors in the posterior portion of the thorax as well as in the apex particularly where reconstruction may not be necessary. Distinct advantages include the increased degrees of freedom and resulting flexibility in instrument angulation as well as the ability to avoid division of large chest wall muscles, thereby facilitating recovery and postoperative functional status. Haptic feedback remains a significant challenge as does instrumentation for bony rib division, although the use of endoscopic burrs can greatly facilitate this portion of the procedure. Chest wall reconstruction often can be accomplished with less difficulty than one initially may think and can include even rigid reconstruction using methylmethacrylate if necessary. Like any technique of chest wall resection, postoperative pain management is key.

Keywords

Lung cancer • Sarcoma • Chest wall • Superior sulcus • Pancoast • Surgery • Thorascopic • Minimally-invasive • Rib

When compared to other robotic procedures, chest wall robotic resection has been slow to develop. This, in part, may be due to the lower overall incidence of surgical chest wall problems, the complex nature of some accompanying chest wall reconstruction techniques, a perception of the chest wall is a "superficial" surgical target, and the lack of robotic instrumentation to handle bone. While some chest wall problems, i.e., simple small segmental rib biopsies in the anterior/lateral lower chest and large full-thickness chest wall tumors from recurrent breast cancer following chemotherapy and radiation requiring complex resections with muscle flap reconstruction, probably are treated best with standard open surgical approaches; there are nonetheless a number of potential uses for robotic chest wall resection.

Factors that should be considered in the decision to use robotic technology include the extent of the resection, location of the target, additional required procedures, available equipment, and surgeon experience. Large, full-thickness chest wall resections (skin to pleura), like the example noted above with recurrent extensive breast cancer in a previously highly irradiated field, by their very nature, require large open incisions and should not be considered appropriate indications for robotic resources. Similarly, small limited rib biopsies particularly in the lower anterior and lateral chest can be performed with small surgical incisions directly over the lesion and therefore would not be expected to benefit from robotic technology (for exceptions see discussion of location, below). Moderate sized, partial thickness chest wall resections, particularly in the apical and posterior chest walls may be considered as more ideal although resections of long

R. B. Cameron, M.D. (✉)
Division of Thoracic Surgery, Department of Surgery, West Los Angeles Veterans Administration Medical Center, David Geffen School of Medicine at UCLA, Los Angeles, CA, USA
e-mail: RCameron@mednet.ucla.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_5

single ribs also lend themselves to robotic approaches since the resected rib, albeit long, can be extracted from one end to the other through a very small "port" incision not much bigger than the width of the rib/specimen. Beyond extent of resection, the location is an important factor. Chest wall resections in the lower anterior and lateral chest are fairly well-tolerated open procedures, accomplished with reasonably limited incisions, often require rigid reconstruction, and therefore likely devoid of a significant cost/benefit ratio for robotic surgery. Lesions in the posterior and apical chest wall (i.e., superior sulcus/Pancoast tumors) typically have the greatest robotic benefit due to the resulting pain and debility from overlying structures that are disrupted/retracted with the requisite extended open incisions, including large chest wall muscles (trapezius, lattisimus dorsi, rhomboids, and serratus) and bone (scapula). Avoidance of the significant morbidity solely resulting from open incisions in these areas is the prime source of robotic benefit, even when the chest wall being removed is relatively small. Furthermore, the position in the posterior or apical chest wall generally makes reconstruction of the resulting defect unnecessary thereby further simplifying the procedure and enhancing the robotic potential. This is not to imply that chest wall reconstruction also cannot be performed by robotic methods, but rigid reconstruction using methylmethacrylate or other similar method is certainly challenging in these areas when attempted robotically.

One additional factor to be considered in robotic chest wall resections is the nature and extent of other required simultaneous procedures. For instance, *en bloc* chest wall resection of a small area of posterior sub-scapular chest wall (or even apical chest wall as in classic Pancoast tumors) with an advanced lung cancer requiring pulmonary lobectomy is a good indication for robotic resection. If the same patient, however, has extensive hilar involvement making robotic/thoracoscopic lobectomy difficult and an open lobectomy or even pneumonectomy advisable, then little rationale would exist to pursue a robotic resection for the chest wall portion of the procedure. Finally, access to the necessary surgical instruments and surgeon experience, as always, plays a critical role in the decision to attempt a robotic chest wall resection. Each surgeon must be generally comfortable using the robotic system available and must have some familiarity with the instruments, approaches, and specific techniques employed during chest wall resections.

Generally, adept thoracoscopic surgeons can accomplish chest wall resections, as described above, without the use of robotic instrumentation; however, robotic assistance offers some very distinct advantages: first, the use of a "fourth arm" can help with retraction on the chest wall for better exposure. Precise and stable control of this retraction by the operating surgeon enhances visualization during the procedure. Secondly, the articulations of the instrument arms are invaluable when the "rigid" chest wall cannot be completely retracted and angulation is required to divide the appropriate attachments. Unlike softer more flexible organs like the lung, which can be easily retracted in a number of ways, chest wall segments are relatively fixed with limited motion, particularly early in the procedure. Angulation is not possible with standard thoracoscopic instruments and additional ports in those situations are often required. One major persistent limitation of robotic systems, however, remains the lack of haptic feedback. Retraction on a rigid portion of chest wall may apply far more pressure than what the surgeon realizes. Tissue displacement and other visual clues utilized by robotic surgeons as tactile surrogates to judge tension on tissues in a wide variety of circumstance and procedures does not occur to the same extent with resection of rigid portions of chest wall. In these procedures, the surgeon has to be particularly careful of the potential damage not only to the patient's tissues but also to the robotic instruments, themselves.

5.1 Anesthetic Management

The anesthetic management of patients undergoing robotic chest wall resection follows standard thoracic anesthetic methods, including management of double lumen tubes and/or bronchial blockers, arterial cannulation, foley catheter bladder drainage, and adequate peripheral venous access. Central venous access is reserved for those patients with difficult intravenous access problems or severe peripheral vascular or coronary artery disease (see also Chap. 2). Blood is generally not required unless there are specific indications. Some surgeons prefer to limit the use of relaxants when working around large peripheral motor nerves like in the apex of the chest near the brachial plexus so that electrocautery-mediated nerve stimulation can alert the surgeon to the nerves' proximity; thereby, more reliably, avoiding nerve damage. Most often, however, a clear view of the anatomy is the most important factor in avoiding inadvertent both nerve and blood vessel injury.

5.2 Operative Set-Up

The standard set-up for robotic chest wall resection should include simple thoracoscopic instruments, such as peanut dissectors, a long thin "on/off" irrigation/suction cannula as well as a Yankaur suction tip, extension tips for electrocautery, standard thoracoscopic instruments including a Maryland dissector (used to control small bleeding vessels), and standard curved lung clamps (either Duval-type or ringed clamps). Other equipment that should be present and immediately available, but not necessarily removed from the sterile packaging include 5- and 10 mm clip appliers, Hem-O-Lok® clip appliers and Hem-O-Lok® cartridges, and a thoracotomy tray and thoracotomy instruments for emergent use.

Robotic instrumentation preferences varies between surgeons, but should include a Prograsp®/Cadiere® or similar grasper, bipolar grasper, robotic and thoracoscopic scissors, hook cautery, Harmonic scalpel, two robotic needle holders, and any other individual surgeon preferred robotic instruments.

One unique aspect of chest wall resection is the bony rib cage. "Thoracoscopic" rib division has been described for minimally-invasive thoracic procedures, but most often is accomplished with standard open bone instruments through an incision directly overlying the area [1, 2]. This certainly is not satisfactory for most advanced bony/chest wall procedures. An endoscopic drill with a long bur attachment is a nice instrument to address the bony points of attachment. I use the Stryker Maestro® pneumatic drill system (http://www.stryker.com/en-us/products/NeurosurgicalSpineENT/HighSpeedDrills/MaestroDrill/index.htm) with an XXL either straight or angled SP/PD attachment (see Fig. 5.1). A variety of straight to round burs can be used from the TPS, MIS, Elite, and Zyphr lines. Designs are available that are side/tip cutting or only side cutting. The latter is my preference for better control and less risk of injury to structures just outside of the target ribs. One may also use the similar Medtronic Midas Rex MR7/Legend® system. (http://www.medtronic.com/us-en/healthcare-professionals/products/ear-nose-throat/powered-ent-instruments/midas-rex-legend-ehs-stylus-high-speed-surgical-drill.html).

Patient positioning can greatly impact the ease and potentially the success of the entire operation (see Chap. 1). Furthermore, achieving optimal operating table position is critical before the robot is docked. Generally, the patient is positioned in the standard lateral decubitus position with normal padding and axillary "lift;" however, this can be modified if warranted. Maximum table flexion (point of flexion slightly below the nipple) and tilting/reverse Trendelenburg positioning is highly recommended to keep the operative field's position generally higher than the surrounding area to allow any fluid/blood to spontaneously drain away from the operative field by gravity.

One difficult management issue for many of these cases, particularly the apical chest wall lesion, is airway safety and security since the bedside robotic cart is positioned over the patient's head and this along with the need to position the arms together in front of the face limits the anesthesiologist's field of access for airway management. Some critical space can be created by angling the bedside robotic cart to come in slightly posterior to the patient's midline and turning the operating room table at an angle so that the patients forehead faces directly toward the anesthesiologist. Generally, a single small 5- or 7-mm port for the operating assistant should be marked in all patients but not placed unless necessary.

5.3 Stepwise Conduct of the Operation

After proper patient positioning, sterile skin preparation and draping, the ipsilateral lung is a taken out of the ventilatory circuit and allowed to deflate. Although some surgeons prefer to explore the chest with a standard thoracoscopic camera and instruments prior to docking and using the robot, I prefer to proceed directly to the robotic portion of the procedure. I do place a small 7-mm Applied Medical 5 mm × 100 mm Kii® first entry access port at the site of the robotic camera as the initial port to safely enter the chest under direct visualization and allow a pneumothorax to develop prior to inserting the large 12-mm camera port. As a general rule, the camera port should be placed in the fifth intercostal space at the mid-axillary line for apical lesions and the instrument ports are

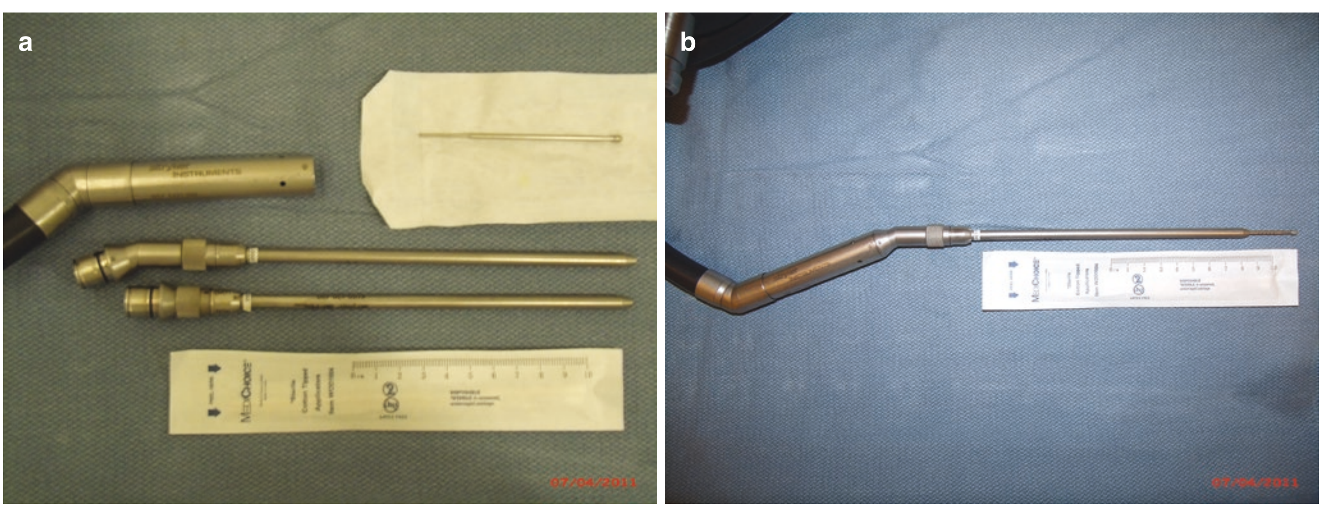


Fig. 5.1 A collection of parts of the Stryker Maestro Pneumatic Drill System used for chest wall resection both disassembled (**a**) and assembled (**b**)

placed to either side in the fourth intercostal space at the anterior axillary line (right) and the sixth or seventh intercostal space either at the posterior axillary line or in the auscultatory triangle (left). For posterior chest wall resections, the camera port is again placed in the fifth intercostal space but at the anterior axillary line and the instrument ports are placed also at the anterior axillary line, but in the third intercostal space (right) and the seventh intercostal space (left). The setup and port locations for both approaches are demonstrated in Fig. 5.2. Once the camera port is in place, the robotic camera can be used (even before docking) to place the secondary ports. Once all ports have been placed the robot is docked. Generally, a single small 7-mm port for the operating assistant to use for suction or retraction should be marked in all patients but not placed unless warranted.

The procedure itself is begun by exploring the entire surgical area and gaining proper orientation to all anatomic landmarks and structures. Once the area of chest wall to be resected has been determined, the first goal is to mark the limits of the resection including the exact locations for each rib division by opening the overlying pleura and periosteum and exposing the rib cortex itself. Next, the Stryker Maestro® pneumatic drill with XXL straight or angled attachment and bur (Fig. 5.1) are used to divide all necessary rib locations. This often requires use of irrigation/suction instruments to clear the bony debris. Subsequently, the soft tissue attachments can be divided with the surgeon's choice of instrumentation, e.g., hook cautery, Harmonic scalpel, bipolar scissor or grasper, etc. The specimen, once freed from all attachments, can be placed into the extraction bag and oriented for removal.

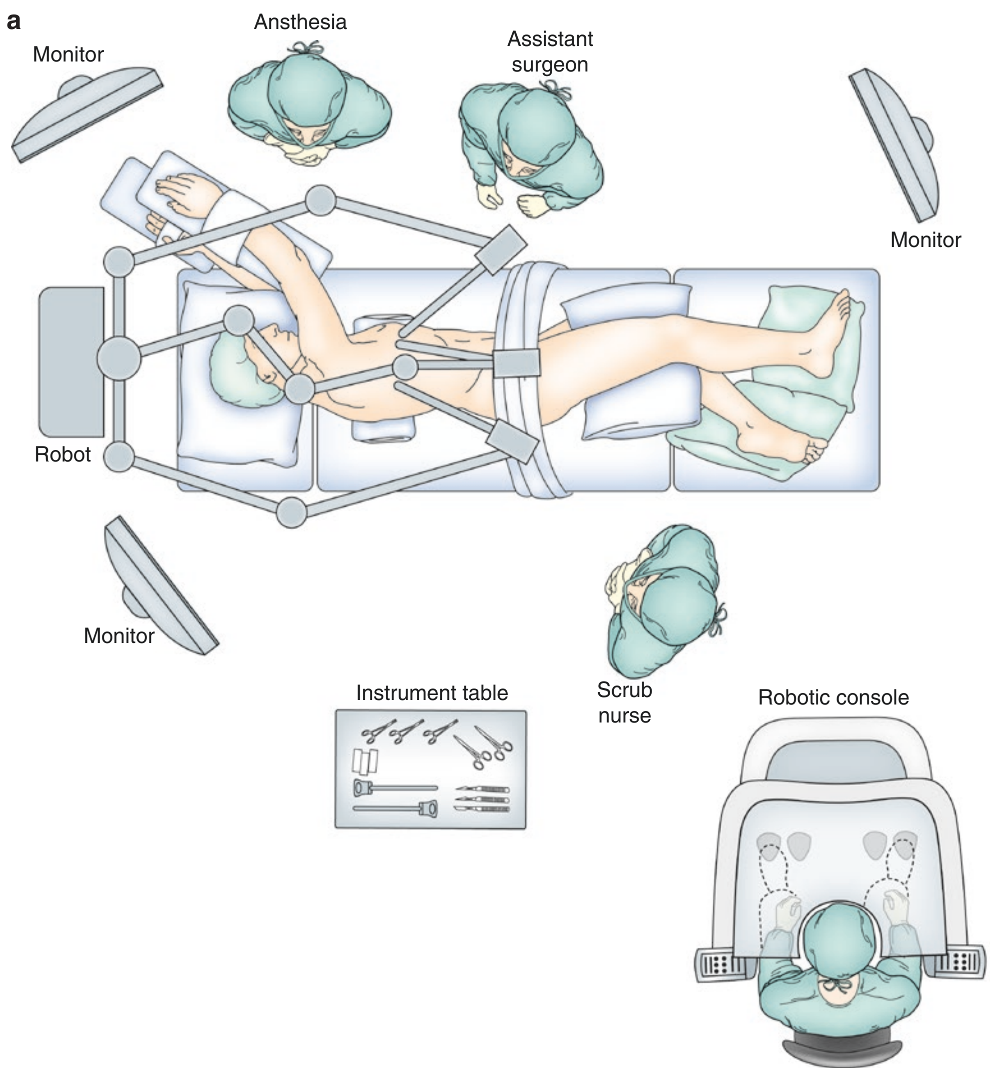


Fig. 5.2 Positioning of the operating room and robotic consols for apical (**a**) and posterior (**b**) chest wall tumors

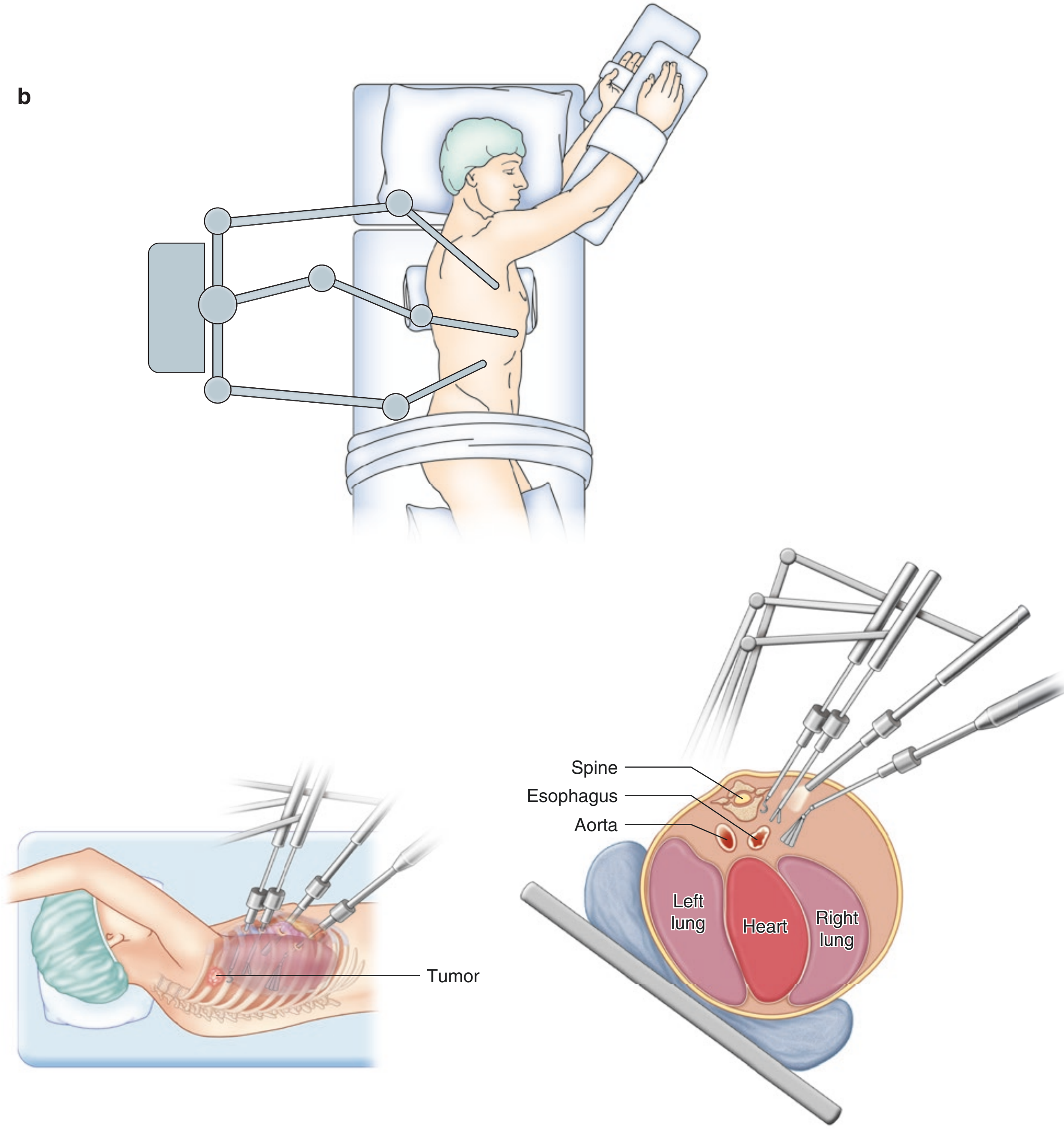


Fig. 5.2 (continued)

5.4 Tips and Pitfalls

There are several key elements to remember and a couple to avoid when performing robotic chest wall resections. First, it is imperative that the attachments of the chest wall segment to be removed to the bony thorax be divided as early as possible. Secondly, when traction is placed on the chest wall, the surgeon must remember that the lack of haptic feedback and normal soft tissue displacement makes judging the amount of tension on skeletal elements significantly harder. Thirdly, when dividing the rib, make sure the rib ends are as blunt as possible to avoid injury to soft tissues (i.e., vascular, neurologic and pulmonary tissues) during retraction of the chest wall segment; particularly, when combining chest wall with other procedures, like lung resections. Fourthly, use a ultra-heavy weight extraction bag to prevent perforation of the bag by the rib segments during extraction. This can also be aided by orienting the ribs lengthwise for extraction whenever possible.

5.5 Postoperative Management Issues

Postoperative pain management techniques vary widely from surgeon to surgeon. Although minimally-invasive thoracic techniques are associated with less pain, there still can be quite substantial acute pain in the first 1–2 days; particularly, following chest wall procedures. For this reason, I prefer to use an epidural catheter even when performing a robotic surgery case if it is anticipated that the patient will stay in the hospital for more than 2 days. This can be placed pre-operatively and removed on the day of discharge while transitioning the patients to oral pain medication (usually oxycodone or hydromorphone). For patients with straight forward chest wall resections who have no problems with bleeding during the procedure, I forgo the placement of any chest drainage catheters and most often discharge the patients within 24 h although an occasional stay of 1–2 days is reasonable. For patients with anticipated short stays, an intercostal block using 10 cm^3 of 1/4% bupivacaine with epinephrine solution performed under direct vision at the time of the operation combined with a patient-controlled analgesia (PCA) systems work well. As mentioned, patients with straight-forward surgical procedures do not require chest drainage catheters at all and can have their lung re-expanded and the chest simply closed at the end of the procedure. Patients with chest drains otherwise can have them removed according to the usual institutional/surgeon criteria. I always obtain a chest radiograph (postero-anterior and lateral views) before discharge and at the time of a post-operative office visit which occurs usually 2 weeks following surgery.

5.6 Outcomes

Most patients undergoing a chest wall resection should have few problems. If post-operative pain is controlled, there is no pulmonary procedure, and no chest drains are left, complications are distinctly unusual. When combined with lung resections, the outcomes are essentially identical to those of standard lung resections.

References

1. Gera PK, La Hei E, Cummins G, Harvey J. Thoracoscopy in chest wall Ewing's sarcoma. J Laparoendosc Adv Surg Tech A. 2006;16(5):509–12.
2. Widmann MD, Caccavale RJ, Bocage JP, Lewis RJ. Video-assisted thoracic surgery resection of chest wall en bloc for lung carcinoma. Ann Thorac Surg. 2000;70(6):2138–40.

Part III

Mediastinum

6 Robotic Anterior Mediastinal Mass/Cyst and Thymectomy

Jens C. Rückert, Marc Swierzy, Ralph-Ingo Rückert, and Mahmoud Ismail

Abstract

Thymectomy is necessary for thymic tumors and an essential part of the therapeutic strategy for myasthenia gravis. Within a century, the history of thymectomy has been characterized by the development of minimally-invasive surgical techniques. The latest refinement is robotic-assisted thymectomy. The perioperative management including anesthesia is described. The stepwise operative technique starts with special positioning of the patient. The preferred conduct of the operation is provided. For anatomical reasons the left side is preferred for the unilateral approach. The extended thymectomy is necessary to achieve the best outcome. This includes resection of the contralateral cardiophrenic tissue. Tips for performing the operation are included and pitfalls are described. All essential steps of the operation are illustrated. The advantages of robotic technology optimized by the described approach and consist of surgeon-directed 3-D vision, magnification, multiple arcs of instrument movement, tremorless precision, and potentially the most thorough mediastinal dissection of all minimally invasive surgical options. The review of the supportive literature for thymectomy in the treatment of myasthenia gravis is described; especially the recently published prospective randomized trial comparing medical therapy to thymectomy, showing superiority of thymectomy. It is likely that the impact will increase the number of patients seeking thymectomy.

Keywords

Thymectomy • da Vinci • Robotic surgery • Myasthenia gravis

6.1 Background/Specific Indications

Historically, surgery was found to be the first means to improve myasthenia gravis (MG) symptoms. At that time, MG was thought to be connected with thymic tumors given the association of MG symptoms and thymic pathology, tumors and hyperplasia [1]. The first reported operation was performed by Sauerbruch in an 18-year-old women in Zurich in 1911 [2]. The patient was suffering from a combination of Grave´s disease and MG. At the time there was a certain notion of a possible connection between thyroid diseases and the appearance of muscular weakening MG. In a two stage procedure Sauerbruch went through the neck for the thymectomy and partial thyroid vessel ligation first and a second intervention for the thyroid resection. Because the operation technique was a transcervical approach, it might be seen as a minimally invasive operation; not only the first thymectomy, but the first minimally invasive approach as well. The patient reportedly significantly improved. The discovery of symptomatic treatment for MG was, yet, 23 years away [3]. In 1944 Blalock published the first series of 20 patients with

J. C. Rückert (✉)
Competence Center for Thoracic Surgery, Surgical Clinic Campus Mitte, Virchow Clinic, Charité–University Medicine Berlin, Charitéplatz 1, 10117 Berlin, Germany
e-mail: jens.c.rueckert@charite.de

M. Swierzy • M. Ismail
Department of Thoracic Surgery, University Medicine Berlin (Charité), Clinic for Surgery, Berlin, Germany

R.-I. Rückert
Department of Surgery, Franziskus-Krankenhaus Berlin, Berlin, Germany

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_6

thymectomy for MG based on his own successful case history of a 19-years-old patient in 1939 [4, 5]. Though symptomatic treatment for MG was available, a 25% mortality rate for his transsternal technique was reported [5]. Blalock pointed out that there should always be a comprehensive view of the anterior mediastinal compartment, necessitating a sternotomy.

In 1950, thymectomy was most comprehensively analyzed by the British surgeon Keynes. He reported on a personal experience of 250 cases [6, 7]. He was the first to postulate not only the significant importance of thymectomy to improve MG, but also the significance of the prognostic factors such as the interval between the diagnosis and thymectomy and the special role of thymoma. This period of our understanding of the pathophysiology and treatment of MG and the role of thymectomy was largely via median sternotomy. By elucidating the outcome difference of thymoma and non-thymomatous MG, Keynes correctly elucidated the difference and the contribution of thymectomy to the therapeutic success [6, 7].

The next stage in the evolution of MG treatment and, historically, the last debate before the age of surgical thoracoscopy began was around 1970. A renewed interest in refinement of the transcervical thymectomy was accompanied by the findings of potential ectopic thymic tissue in the anterior mediastinal area [8–11]. Even today, it seems most instructive to compare the arguments for either transcervical approach or most extensive forms of median sternotomy [12, 13]. Basic and clinical research during the 1970s discovered the autoimmune nature of MG; yet, there was no randomized trial support for thymectomy for MG. The diversity of MG patients in the degree of severity and presence or absence of anti-acetylcholine-receptor-antibodies resulted in a relative indication for non-thymomatous MG; whereas, there was a clear indication for the treatment of thymoma or suspected thymoma without MG [14, 15].

Around 1990 the technical development of surgical thoracoscopy significantly influenced the performance of thymectomy. The first thoracoscopic approach was published by Landreneau in 1992 who excised a small thymoma from the thymic gland [16]. During the next decade, various thoracoscopic operative techniques for thymectomy have been developed and performed [17–20]. As a result, there were 14 different minimally invasive techniques for thymectomy all claiming radicality. The results of MG improvement were reported with limited direct comparisons. Therefore, with the intention to better analyze the role of thymectomy, Jaretzki suggested and introduced a MG task force in 1997 [21]. Comprehensive decision making included the neurological societies and led, again, to the role of thymectomy for the treatment of MG [22].

At the same time, surgical innovation opened quite a new era with the development of robotic surgical platforms. In contrast to other minimally invasive approaches, robotics offers greater precision, potentially providing the most radical thoracoscopic thymectomy. Interestingly enough, as with the thoracoscopic approach, the first description was a non-radical simple excision of a thymoma in 2001 [23]. Many surgeons adopted robotic thymectomy [24–26]. This latest step in the development of thymectomy was followed be worldwide acceptance of minimally-invasive thymectomy not only for non-thymoma MG, but also for anterior mediastinal tumors, namely thymoma [27, 28]. While there were already more than 1000 robotic thymectomies that had been performed worldwide in 2012 [27], the low level of evidence to support the role of thymectomy for the treatment of MG was analyzed and provided confirmation that thymectomy is beneficial to patients with nonthymomatous MG [29].

6.2 Operative Set-Up

Removal of the thymus is warranted in patients with myasthenia gravis and those suspicious of malignancy. Specifically, we resect patients with a diagnosis of stages I–IIb MG (Ossermann Classification) and those with confirmed or suspicious for thymoma that is less than 2 cm. All patients undergo a preoperative chest radiograph, a recent chest computed tomogram (Fig. 6.1), baseline pulmonary function testing, and a thorough neurological examination, inclusive of serological testing.

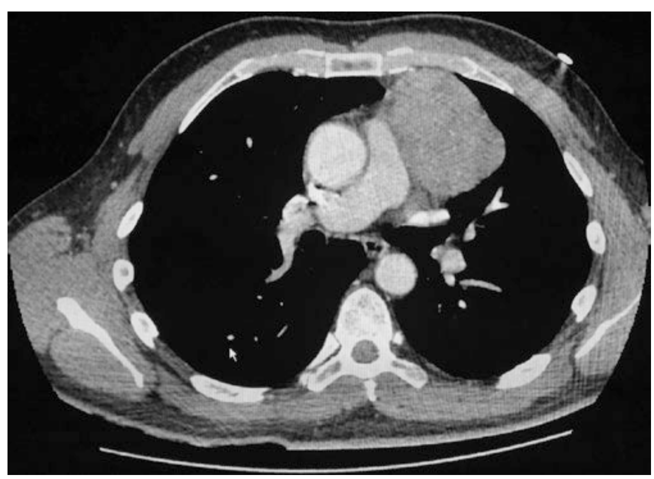


Fig. 6.1 Contrast-enhanced chest computed tomogram of a large left-sided thymoma on axial image

6.3 Anesthetic Management

6.3.1 Preoperative Preparation

The preoperative optimization of therapy should be done by neurologists. The medication for most stable situation as to MG symptoms should be maintained and represents a major factor for perioperative risk reduction. Any form of immunosuppressive therapy has not to be changed. Possibly a premedication with promethazine of 1 mg/kg is given.

6.3.2 Operative Phase

An intra-arterial blood pressure monitoring catheter, two peripheral intravenous infusion catheters, and a bladder catheter are all placed. A perioperative single shot antibiotic prophylaxis is given and we choose a second generation cephalosporin (we commonly choose cefuroxime). Total intravenous anesthesia is conducted with continuous application of propofol and remifentanil. For intubation, a left-sided double-lumen tube for right single lung ventilation is used after relaxation with cis-atracurium (0.1 mg/kg). During the surgery, pressure-controlled ventilation is used. To accommodate for the hemodynamic interference of CO_2-insufflation or intermittent arrhythmia due to direct pericardial dissection a close contact between surgeons at the console and at the table and anesthesiology is essential. At the end of the operation, metimazole and piritramide are given before primary extubation of the wake patient on the operation table.

6.4 Stepwise Conduct of the Operation

Mainly for anatomical reasons, we prefer and recommend to approach the thymus from the left thorax. Our operation technique is a unilateral left-sided three trocar approach.

The patient is brought into a special position on the operating table; we call it the semilateral right-sided position. It is created from a supine position with the patient on a vacuum mattress with elevated left shoulder. The left arm is positioned as low as possible, for that purpose the patient is positioned slightly over the left edge of the operation table (Fig. 6.2). The patient is always prepared for a conversion to median sternotomy. The trocar positions are as follows: the camera trocar is placed first in the fourth intercostal space. The criterion for correct placement is the direct view at the left phrenic nerve with the 30° optic looking down. The two

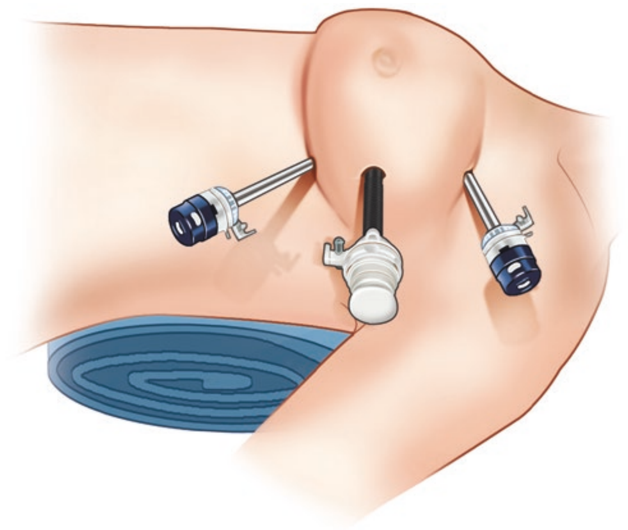


Fig. 6.2 Left-sided approach for a robotic thymectomy. The patient is placed on the edge of the operating table with arm below the table. The patient is positioned and prepared for a potential sternotomy and for the potential placment of an extra trocar from the right side in case of necessity to check the radicality to make certain that the entire thymus is being removed.. The bedside cart is brought from the patient's right side. A roll is placed under the mid upper chest allowing the left shoulder to fall down toward the floor. The patient's left side is rotated approximately 10–15° up. All three trocars are placed along the mammary fold forming a triangle. The trocars are initially inserted with the help of a conventional thoracoscope. For obese patients, we prefer the use of the extra-long trocars

working trocars are placed in the third and fifth intercostal space and in the midclavicular and anterior to midaxillary line, respectively, under direct vision using a simple thoracoscopic camera. The three trocars should form a symmetric triangle with the connection between both working trocars just parallel to the sternum. Our preferred instruments are the Bipolar Maryland® for the left hand and Ultracision™ Harmonic Scalpel for the right hand. In our opinion, two grasping instruments are necessary. The dissection starts in the middle part of the pericardial area adjacent to the phrenic nerve (Fig. 6.3). We incise the pleura anterior to the left phrenic nerve and continue the dissection cranially until the pleural fold where the pleural incision turns left and proceeds to the right pleural space (Fig. 6.4). At this point in the dissection, it is important to dissect directly left from the left phrenic inside the neck to identify and free the innominate vein. Clearing the innominate vein is the landmark prior to entering the neck and completely mobilizing the left (Fig. 6.5) and afterwards the right upper thymic poles (Fig. 6.6). Gentle traction and meticulous dissection of the capsule is essential (Fig. 6.7). Here, both grasping instruments

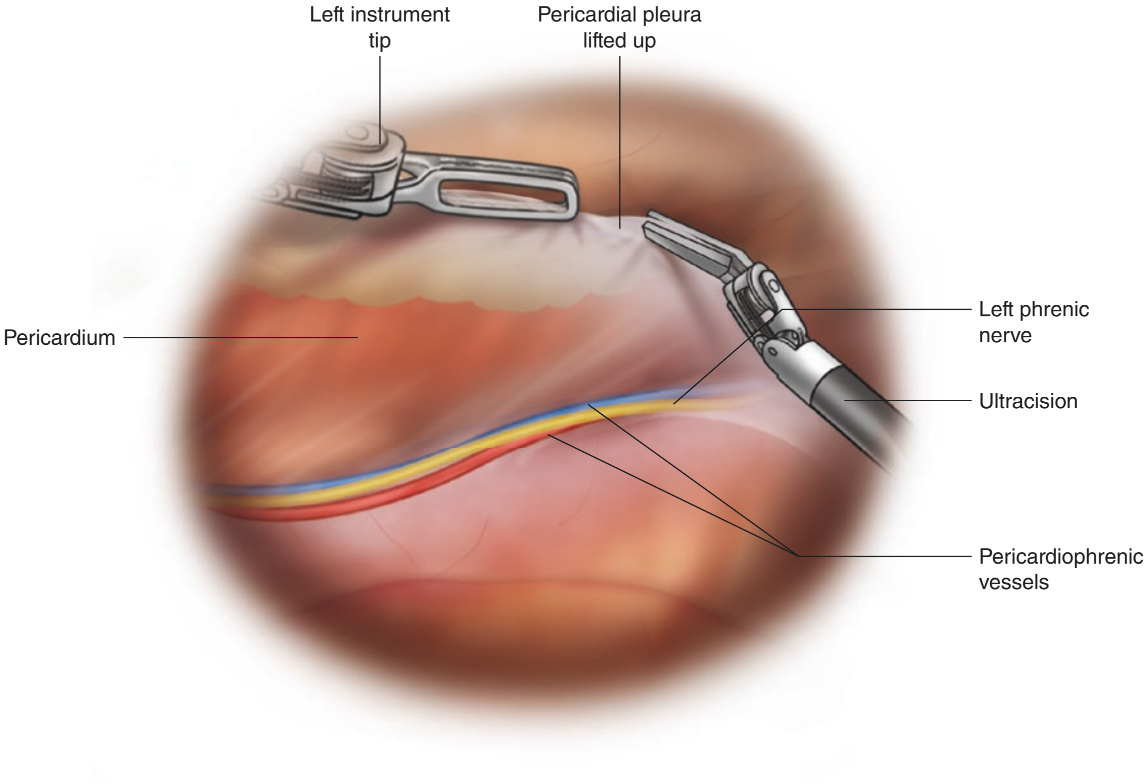


Fig. 6.3 Initiation of the left-sided approach to a thymoma. The dissection is started directly above the phrenic nerve in an area free of fatty tissue. This area is seen in almost all patients

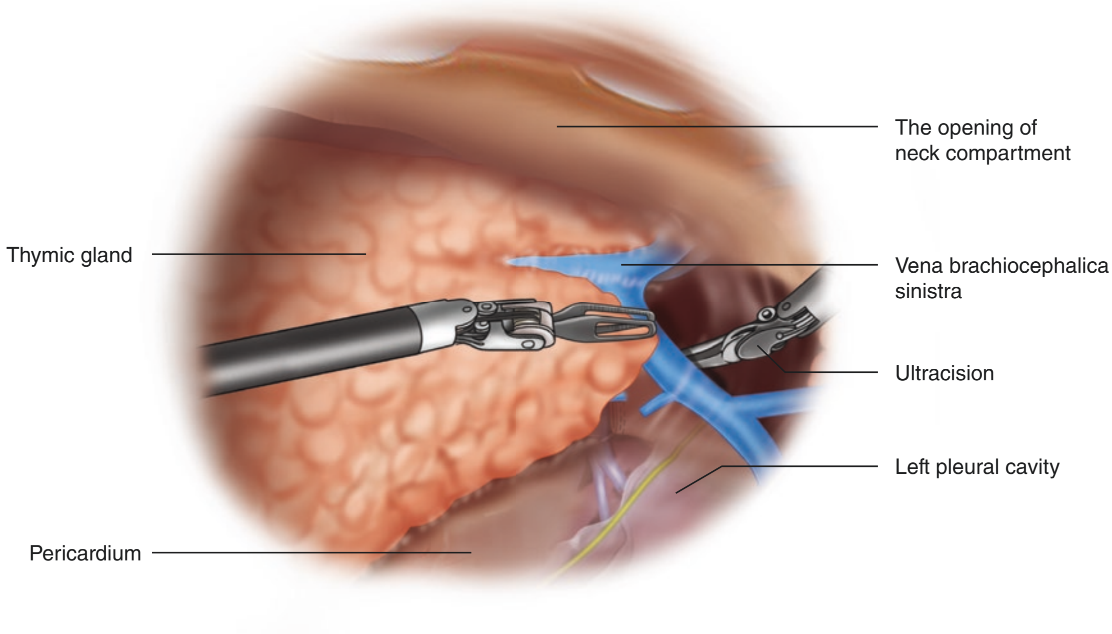


Fig. 6.4 Dissection of the thymus from the phrenic nerve to the upper aspect of the mediastinum. The dissection is continued along the left phrenic nerve. After dissection of the tissue in the aortopulmonary window, the left innominate vein is shown

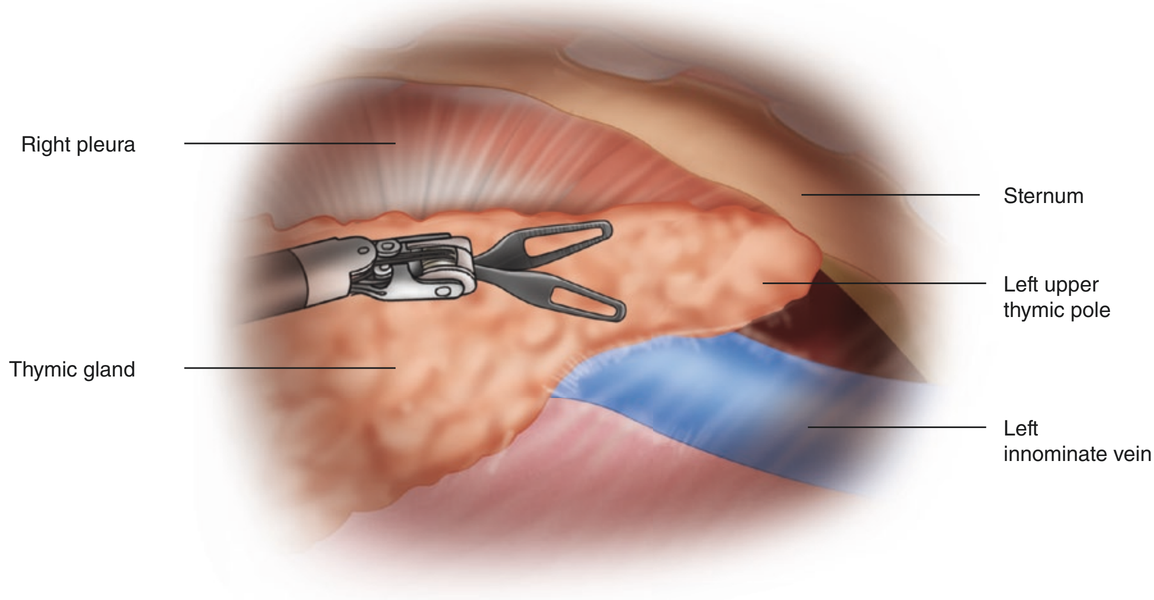


Fig. 6.5 Dissection of the left upper thymic pole away from the left innominate vein. The fascial planes of the neck are entered and the upper thymic poles are completely removed after dissection of the thymo-thyroid ligament

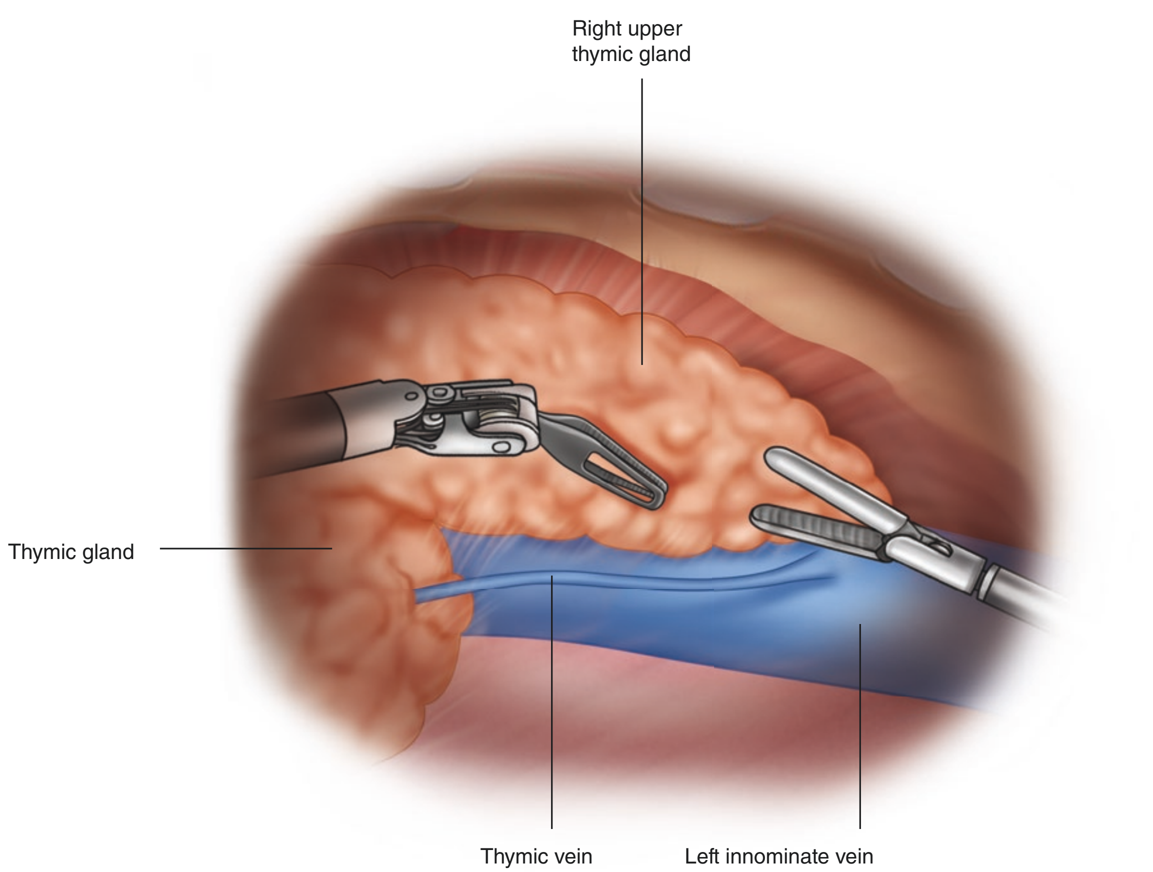


Fig. 6.6 Dissection of the right upper thymic pole away from the attachments in the neck and upper mediastinum. The right upper thymic pole is dissected in a similar way as the left upper pole. The thymic vein is dissected with the Ultracision, but in some cases where the vein is more than 2–3 mm in size, we prefer the use of endoclips

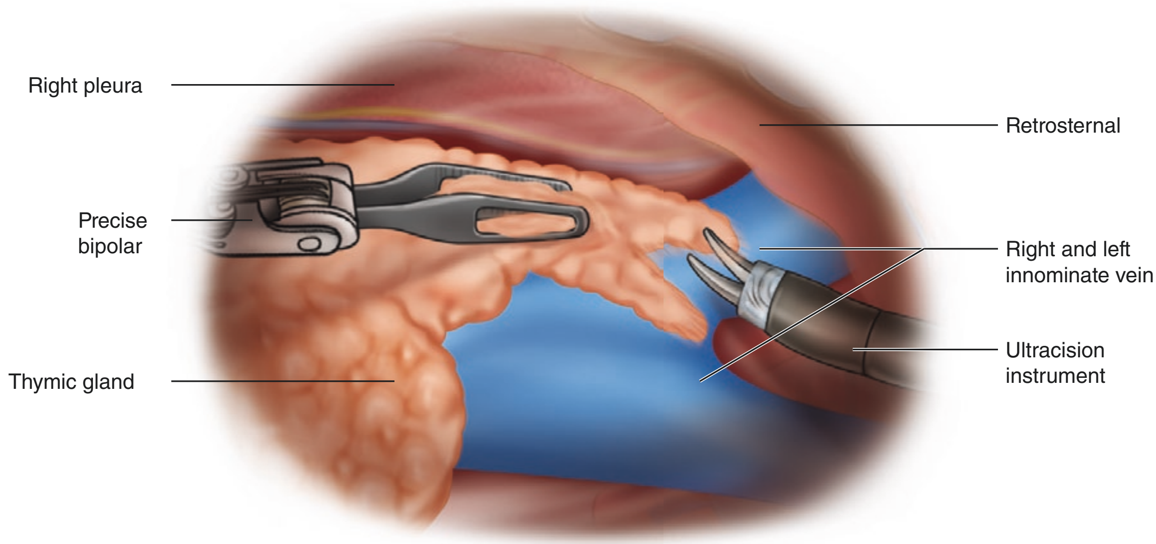


Fig. 6.7 Dissection of the thymus away from the pericardium to expose the right mediastinal pleura. The tissue above the right innominate vein is dissected. This allows a better view of the right mammary vein and right phrenic nerve

are used to identify vascular supply for ligation most effectively. The thymic veins can be expected to be variable from one large sampling vessel (vein of Keynes) to more than four smaller vessels distributed between left area of the phrenic nerve and even SVC on the right side. The dissection does not require clips or ligation, but can always be done by Ultracision. We try to preserve the left mediastinal pleura as much as possible to allow for effective CO_2 insufflation. It is at this point that the CO_2 insufflation is started. After isolation of the left phrenic bundle and dissection of the tissue portion in the aortopulmonary window, the main thymic lobes are mobilized on the pericardium. We dissect until the right pleura is shown. The venous confluence is completely dissected free. The right brachiocephalic vein as well as the right mammary vein must be demonstrated. The entrance of the right mammary vein into the venous confluence is the anatomical landmark for searching for the right phrenic nerve (Fig. 6.8). It can always be found here at the lateral side of the superior vena cava. Then, the right phrenic verve is completely dissected free; thus, enabling complete mobilization of the tissue portion in the aorto-caval groove down to the entrance of the SVC into the right atrium. We then turn the camera down to the left side to mobilize the whole tissue of the left cardiophrenic area (Fig. 6.9). If completed, one of the most important steps is the final portion of *en bloc*-thymic dissection; at the subxiphoid location, we open-up the right pleural mediastinal pleura and dissect the right cardio-phrenic fat pad (Fig. 6.10). This dissection is performed from caudal to cranial position without danger for the right phrenic nerve being under vision until its turn down away from dissection line at the right diaphragm. For all unilateral thoracoscopic operation techniques for thymectomy this dissection of the contralateral cardiophrenic fatty tissue is a key step to confirm anatomical radicality (Fig. 6.11).

After *en bloc* resection the specimen is brought into a retrieval bag and removed through the middle incision after changing the camera for the lower trocar. The specimen is always measured for size and weight and will be placed on the International Thymic Malignancy Interest Group (ITMIG) scaffold after photo-documentation to the pathologist for review (Fig. 6.12). After inspection of the operative field, a chest tube is placed in the left pleural cavity. After reinflation of both lungs, all trocars are removed and the incisions closed.

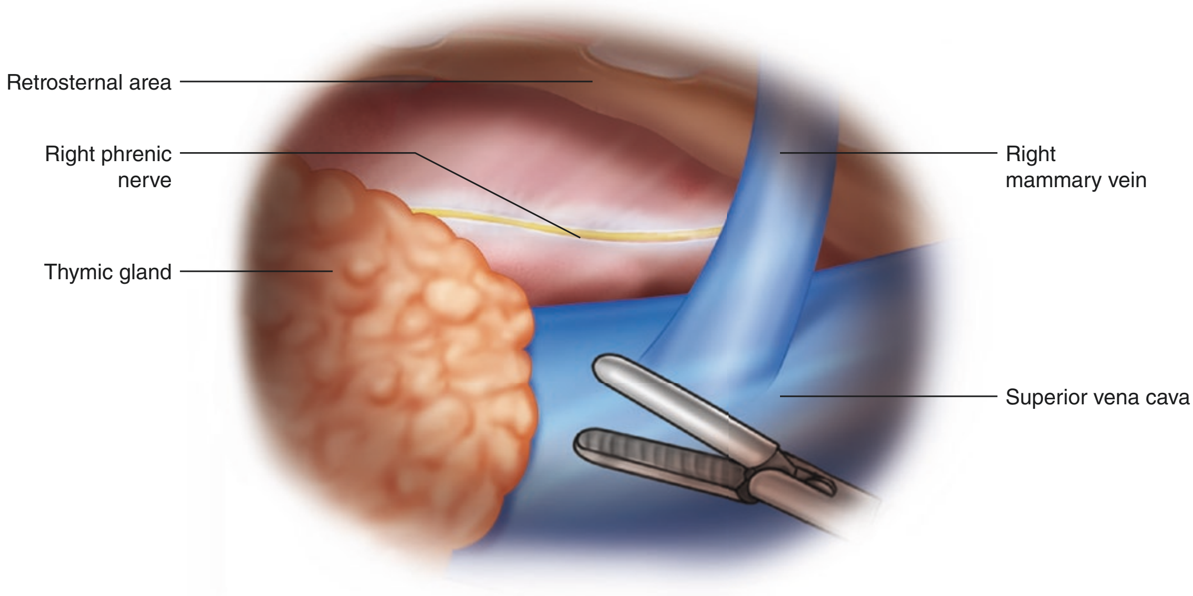


Fig. 6.8 Exposure of the right mediastinal pleura with exposure of the right phrenic nerve. The right pleura is kept intact at the beginning this can help demonstrating the right phrenic nerve

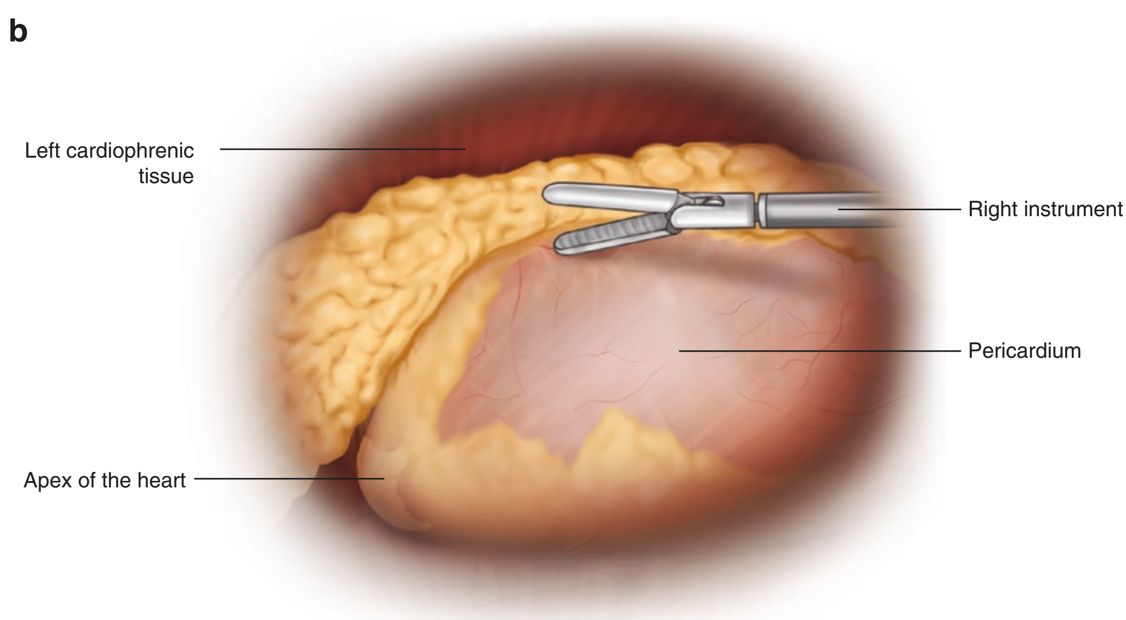


Fig. 6.9 *En Bloc* dissection of the left lower anterior mediastinal perithymic tissue away from the phrenic nerve, pericardium, and the subxiphoid diaphragm. The left pericardial fatty tissue in the left cardiophrenic region is dissected. At this point attention should be given to left phrenic nerve and it's branches

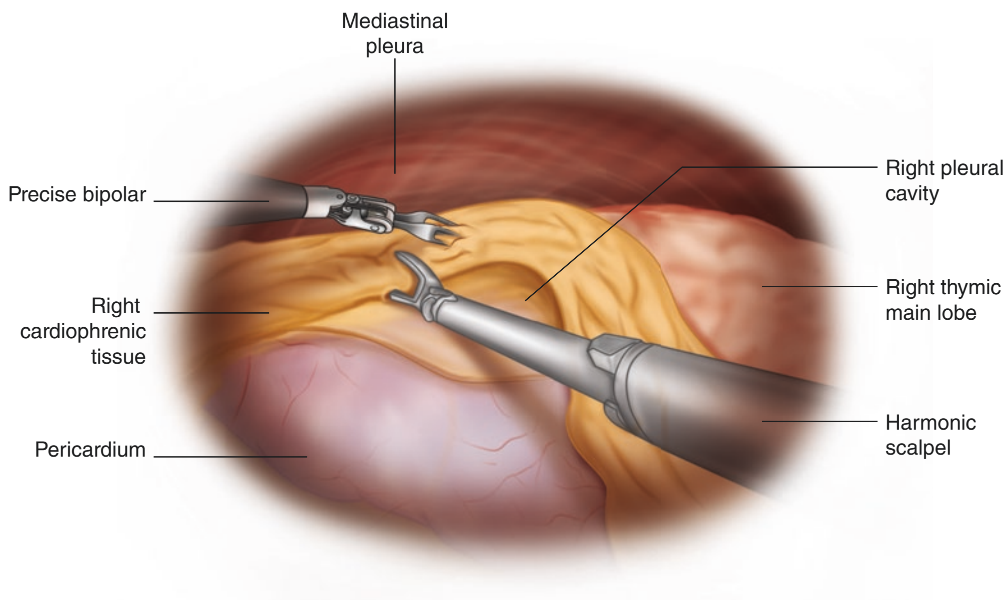


Fig. 6.10 En Bloc dissection of the right lower anterior mediastinal peri-thymic tissue away from the right lower inferior mediastinum. The retrosternal pleura is opened and the right cardiophrenic fatty tissue is completely dissected en bloc with the rest of the thymus and perithymic tissue

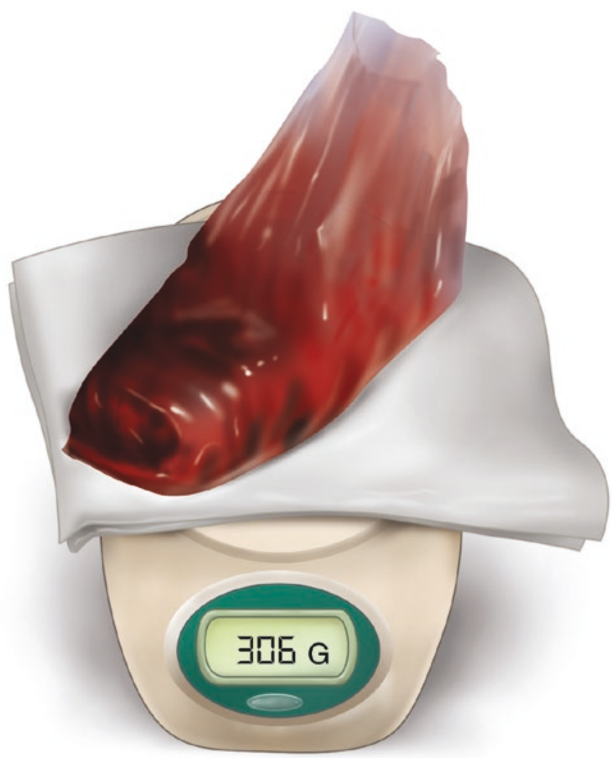


Fig. 6.11 Dissection of the right lower cardiophrenic area. After dissection of the right cardiophrenic tissue the right phrenic nerve is demonstrated. During this step is the right pleural cavity opened

6.5 Postoperative Phase

The preoperative myasthenia gravis medication is continued. Patients are most frequently sent to the ward, but always consider ICU/IMCU or PACU for the exceptional case where the preoperative MG is unstable. There is a range as to pleural drainage from no drainage at all to one large tube. We recommend 18–20 Fr. single left-sided drainage for approximately 24 h.

6.6 Tips and Pitfalls

- The table position is important for an efficient procedure. Turning and tilting the operating table approximately 15° left side up to improve the positioning of the table cart and the three robotic arms.
- Use a simple thoracoscopic camera and optic instead of the robotic camera for placing the three special trocars.
- If the intrapleural space is insufficient, such as with higher body mass index, use CO_2 insufflation from the beginning.

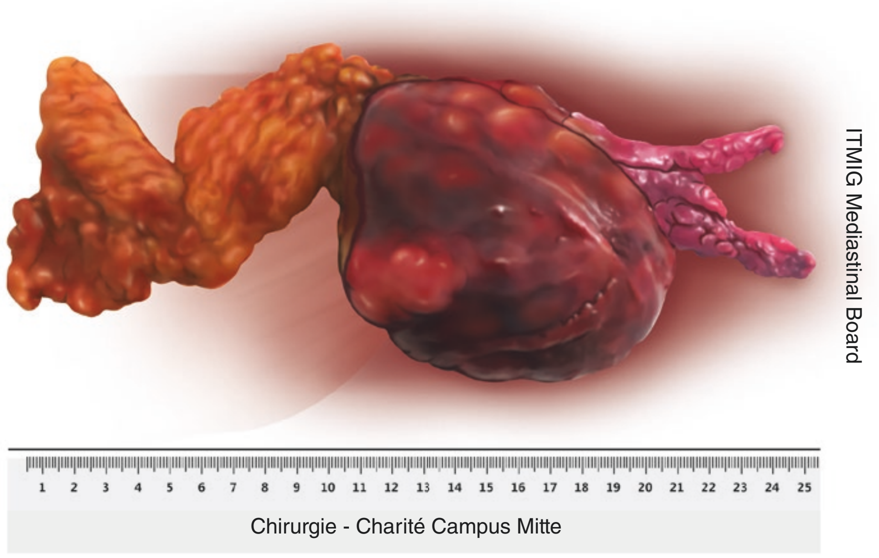


Fig. 6.12 Specimen weighing after removal in an endobag and preparation of the specimen prior to histological evaluation using the International Thymic Malignancy Interest Group (ITMIG) Anatomical Map. The specimen is always measured for size and weight and is placed on the ITMIG-scaffold after photo documentation

- The use of two grasping instruments is essential for an efficient dissection, especially in the anatomical regions of aortopulmonary window, both upper thymic poles, and the contralateral cardiophrenic fat pad.
- If the lower mediastinal area at the cardiophrenic location cannot be addressed without instrument interference, take out all the instruments and the camera, disconnect the robotic arms and reposition the bedside cart. After reconnection the dissection of the lower mediastinal tissue will be much more easily performed.

6.7 Brief Outcome Analysis

The performance of this technique of robotic thymectomy, we believe is one of the most radical minimally-invasive techniques. The three-trocar unilateral robotic approach leads to one of the most acceptable cosmetic results with minimal pain. Patients usually recover quickly. Due to different national health care systems and depending on the individual severity of MG and the co-morbidity most patients are treated in the hospital between 0 and 2 days after the operation. The procedure may be more radical than non-robotic median sternotomy thymectomy translating into better outcome for MG [30]. The procedure has become the most frequent indication for robotic thoracic surgery; worldwide there have been more than 3500 robotic thymectomies performed (Intuitive Surgical, Sunny Vale, CA). By 2012 over 100 institutions had performed robotic thymectomy [27]. By 2014, there were 13 publications each reporting on at least 20 robotic thymectomies per publication. The largest single-center series comprises 650 robotic thymectomies. It is anticipated that there will be further adoption of robotic thymectomy as a result of the recent publication of the prospective randomized trial demonstrating superior outcomes of complete thymectomy for MG compared to medical therapy alone [29]. This information should encourage others to evaluate the result of thymectomy in MG, as few adequately assess the postoperative improvement of MG post-thymectomy [26]. For thymoma, the robotic technique appears to be sufficient when compared to sternotomy (Table 6.1) [27, 30–39].

Table 6.1 Literature summary of robotic thymectomy series including 30+ cases

Author year	Country	Study interval	Total	MG	Thymoma	Approach	Ports	Complete remission rate (%)	Thymoma remission rate (%)
Ismail 2013 [27]	Germany	2003–2012	317	273	56	Left	3	57	0
Keijzers 2013 [31]	Netherlands	2004–2012	138	NA	37	Right	3	NA	2.7
Marulli 2013 [32]	Italy	2002–2010	100	100	8	Left	3	28.5	0
Freeman 2011 [33]	USA	6-years	75	75	Excluded	Left	3	28	NA
Schneiter 2013 [34]	Switzerland	2004–2011	58	25	20	Left	3	NA	11.1
Jun 2014 [35]	China	2010–2012	55	NA	21	Left + right	3–4	NA	NA
Melfi 2012 [36]	Italy	2001–2010	39	19	13	Left	3	NA	0
Seong 2014 [37]	Korea	2008–2012	37	NA	11	NA	NA	NA	NA
Augustin 2008 [38]	Austria	2001–2007	32	32	9	Right	3	NA	0
Cerfolio 2011 [39]	USA	2009–2010	30	30	NA	Right	3	NA	NA

NA not announced

References

1. Lacquer L, Weigert C. Beitrage zur Lehre von der Erb'schen krankheit ueber die Erb-sche krankheit (myasthenia gravis). Neurol Zentralblatt. 1901;20:594–601.
2. Schumachter E, Roth J. Thymektomie bei einem Fall von Morbus Basedowi mit Myasthnie. Grenzgeb d Med u Chir. 1912;25:746–65.
3. Walker MB. Treatment of myasthenia gravis with physostigmine. Lancet. 1934;223(5779):1200–1.
4. Blalock A, Mason MF, Morgan HJ, Riven SS. Myasthenia gravis and tumors of the thymic region: report of a case in which the tumor was removed. Ann Surg. 1939;110(4):544–61.
5. Blalock A. Thymectomy in the treatment of myasthenia gravis. Report of twenty cases. J Thorac Surg. 1944;13:316–39.
6. Keynes G. The results of thymectomy in myasthenia gravis. Br Med J. 1949;2(4628):611–6.
7. Keynes G. Surgery of the thymus gland: second (and third) thoughts. Lancet. 1954;263(6824):1197–202.
8. Kark AE, Kirschner PA. Total thymectomy by the transcervical approach. Br J Surg. 1971;58(5):321–6.
9. Kark A, Papatestas A. Some anatomic features of the transcervical approach for thymectomy. Mt Sinai J Med. 1971;38(6):580–5.
10. Masaoka A, Nagaoka Y, Kotake Y. Distribution of thymic tissue at the anterior mediastinum. Current procedures in thymectomy. J Thorac Cardiovasc Surg. 1975;70(4):747–54.
11. Jaretzki A 3rd, Penn A, Younger D, Wolff M, Olarte M, Lovelace R, Rowland L. "Maximal" thymectomy for myasthenia gravis. Results. J Thorac Cardiovasc Surg. 1988;95(5):747–57.
12. Jaretzki A III, Wolff M. "Maximal" thymectomy for myasthenia gravis. Surgical anatomy and operative technique. J Thorac Cardiovasc Surg. 1988;96(5):711–6.
13. Cooper JD, Al-Jilaihawa AN, Pearson FG, Humphrey JG, Humphrey HE. An improved technique to facilitate transcervical thymectomy for myasthenia gravis. Ann Thorac Surg. 1988;45(3):242–7.
14. Rückert JC, Ismail M, Badakhshi H, Meisel A, Swierzy M. Thymektomie bei Myasthenie und/oder Thymom. Zentralblatt für Chirurgie-Zeitschrift für Allgemeine, Viszeral-, Thorax-und Gefäßchirurgie. 2014;139(01):121–34.
15. Gronseth GS, Barohn RJ. Thymectomy for Myasthenia gravis. Curr Treat Options Neurol. 2002;4(3):203–9.
16. Landreneau RJ, Dowling RD, Castillo WM, Ferson PF. Thoracoscopic resection of an anterior mediastinal tumor. Ann Thorac Surg. 1992;54(1):142–4.
17. Mack MJ, Landreneau RJ, Yim AP, Hazelrigg SR, Scruggs GR. Results of video-assisted thymectomy in patients with myasthenia gravis. J Thorac Cardiovasc Surg. 1996;112(5):1352–9; discussion 1359–60
18. Mineo TC, Pompeo E, Ambrogi V, Bernardi G, Iani C, Sabato AF. Video-assisted completion thymectomy in refractory myasthenia gravis. J Thorac Cardiovasc Surg. 1998;115(1):252–4.
19. Novellino L, Longoni M, Spinelli L, Andretta M, Cozzi M, Faillace G, et al. "Extended" thymectomy, without sternotomy, performed by cervicotomy and thoracoscopic technique in the treatment of myasthenia gravis. Int Surg. 1994;79(4):378–81.
20. Rückert J, Gellert K, Einhäupl K, Müller J. Thoracoscopic thymectomy for treatment of myasthenia gravis. Zentralbl Chir. 1997;123(5):506–11.
21. Jaretzki A III. Thymectomy for myasthenia gravis: analysis of the controversies regarding technique and results. Neurology. 1997;48(Suppl 5):S52–63.
22. Gronseth GS, Barohn RJ. Practice parameter: thymectomy for autoimmune myasthenia gravis (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology. 2000;55(1):7–15.
23. Yoshino I, Hashizume M, Shimada M, Tomikawa M, Tomiyasu M, Suemitsu R, Sugimachi K. Thoracoscopic thymomectomy with the da Vinci computer-enhanced surgical system. J Thorac Cardiovasc Surg. 2001;122(4):783–5. https://doi.org/10.1067/mtc.2001.115231.
24. Ruckert JC, Ismail M, Swierzy M, Sobel H, Rogalla P, Meisel A, et al. Thoracoscopic thymectomy with the da Vinci robotic system for Myasthenia gravis. Ann N Y Acad Sci. 2008;1132:329–35.
25. Rea F, Marulli G, Bortolotti L, Feltracco P, Zuin A, Sartori F. Experience with the "da Vinci" robotic system for thymectomy in patients with myasthenia gravis: report of 33 cases. Ann Thorac Surg. 2006;81(2):455–9.
26. Castle SL, Kernstine KH. Robotic-assisted thymectomy. Semin Thorac Cardiovasc Surg. 2008;20(4):326–31.
27. Ismail M, Swierzy M, Ruckert JC. State of the art of robotic thymectomy. World J Surg. 2013;37(12):2740–6. https://doi.org/10.1007/s00268–013–2250-z.
28. Marulli G, Maessen J, Melfi F, Schmid TA, Keijzers M, Fanucchi O, et al. Multi-institutional European experience of robotic thymectomy for thymoma. Ann Cardiothorac Surg. 2016;5(1):18–25. https://doi.org/10.3978/j.issn.2225-319X.2015.08.13.
29. Wolfe GI, Kaminski HJ, Aban IB, Minisman G, Kuo HC, Marx A, et al., MGTX Study Group. Randomized trial of thymectomy in Myasthenia gravis. N Engl J Med. 2016;375(6):511–22. doi:https://doi.org/10.1056/NEJMoa1602489.

30. Rückert JC, Swierzy M, Ismail M. Comparison of robotic and nonrobotic thoracoscopic thymectomy: a cohort study. J Thorac Cardiovasc Surg. 2011;141(3):673–7.
31. Keijzers M, Dingemans AM, Blaauwgeers H, van Suylen RJ, Hochstenbag M, van Garsse L, et al. 8 years' experience with robotic thymectomy for thymomas. Surg Endosc. 2014;28(4):1202–8. https://doi.org/10.1007/s00464–013–3309–5.
32. Marulli G, Schiavon M, Perissinotto E, Bugana A, Di Chiara F, Rebusso A, Rea F. Surgical and neurologic outcomes after robotic thymectomy in 100 consecutive patients with myasthenia gravis. J Thorac Cardiovasc Surg. 2013;145(3):730–5; discussion 735–6. doi:https://doi.org/10.1016/j.jtcvs.2012.12.031.
33. Freeman RK, Ascioti AJ, Van Woerkom JM, Vyverberg A, Robison RJ. Long-term follow-up after robotic thymectomy for nonthymomatous myasthenia gravis. Ann Thorac Surg. 2011;92(3):1018–22; discussion 1022–3. doi:https://doi.org/10.1016/j.athoracsur.2011.04.054.
34. Schneiter D, Tomaszek S, Kestenholz P, Hillinger S, Opitz I, Inci I, Weder W. Minimally invasive resection of thymomas with the da Vinci(R) Surgical System. Eur J Cardiothorac Surg. 2013;43(2):288–92. https://doi.org/10.1093/ejcts/ezs247.
35. Jun Y, Hao L, Demin L, Guohua D, Hua J, Yi S. Da Vinci robot-assisted system for thymectomy: experience of 55 patients in China. Int J Med Robot. 2014;10(3):294–9. https://doi.org/10.1002/rcs.1577.
36. Melfi F, Fanucchi O, Davini F, Viti A, Lucchi M, Ambrogi MC, Mussi A. Ten-year experience of mediastinal robotic surgery in a single referral centre. Eur J Cardiothorac Surg. 2012;41(4):847–51. https://doi.org/10.1093/ejcts/ezr112.
37. Seong YW, Kang CH, Choi JW, Kim HS, Jeon JH, Park IK, Kim YT. Early clinical outcomes of robot-assisted surgery for anterior mediastinal mass: its superiority over a conventional sternotomy approach evaluated by propensity score matching. Eur J Cardiothorac Surg. 2014;45(3):e68–e73; discussion e73. https://doi.org/10.1093/ejcts/ezt557.
38. Augustin F, Schmid T, Sieb M, Lucciarini P, Bodner J. Video-assisted thoracoscopic surgery versus robotic-assisted thoracoscopic surgery thymectomy. Ann Thorac Surg. 2008;85(2):S768–71. https://doi.org/10.1016/j.athoracsur.2007.11.079.
39. Cerfolio RJ, Bryant AS, Minnich DJ. Starting a robotic program in general thoracic surgery: why, how, and lessons learned. Ann Thorac Surg. 2011;91(6):1729–1736; discussion 1736–7. doi:https://doi.org/10.1016/j.athoracsur.2011.01.104.

Further Reading

Sonett JR, Jaretzki A III. Thymectomy for nonthymomatous myasthenia gravis: a critical analysis. Ann N Y Acad Sci. 2008;1132(1):315–28. https://doi.org/10.1196/annals.1405.004.

Park BJ, Yang HX, Woo KM, Sima CS. Minimally invasive (robotic assisted thoracic surgery and video-assisted thoracic surgery) lobectomy for the treatment of locally advanced non-small cell lung cancer. J Thorac Dis. 2016;8(Suppl 4):S406–13. https://doi.org/10.21037/jtd.2016.04.56.

7 Robotic Anterior Mediastinal Mass Resection: Belgium

Jeroen M.H. Hendriks, Patrick Lauwers, Rudy Mercelis, Senne Van Donink, Pieter Mertens, and Paul E.Y. Van Schil

Abstract

Tumors of the anterior mediastinum are relatively rare and most of them are thymic tumors, lymphomas, germinal cell tumors and thyroid tumors. As a reference centre for these tumors, both open and VATS techniques are used for surgical resection for more than three decades. Since 2004, these tumors are removed with the da Vinci robot as a minimal invasive procedure. Initially with the 3-arm da Vinci S and since 1 year with the 4-arm da Vinci Xi. Technique and results are presented in this paper. Outcome is excellent and robotic resection will stay our technique of choice.

Keywords

Anterior mediastinum • Thymic tumors • Thymoma • RATS • Robotic, da Vinci • Myasthenia gravis

7.1 Neurological Aspects of Anterior Mediastinal Tumors

Tumors of the anterior mediastinum are relatively rare. Most of them are thymomas, lymphomas, germinal cell tumors and thyroid tumors [1, 2]. The diagnosis is suspected on medical imaging with contrast enhanced computed tomography (CT) being the preferred method [3], while magnetic resonance imaging (MRI) and positron emission tomography (PET) may provide additional information in selected cases [4].

A particular phenomenon of thymomas is the association with autoimmune diseases. This has not only been described for several neurological disorders such as myasthenia gravis, Lambert-Eaton myasthenic syndrome, neuromyotonia, stiff person syndrome, rippling muscle disease, autonomic neuropathy and inflammatory myopathy, but also for hematological syndromes as pure red cell aplasia, pancytopenia, thrombocytopenia and hypogammaglobulinemia or Good syndrome, dermatologic disorders such as alopecia, vitiligo and pemphigus, and other diseases as systemic lupus eythematosus, glomerulonephritis and ulcerative colitis [5, 6].

While the association of most of these conditions with thymoma is rare, a lot of information is available about the association with myasthenia.

In patients with myasthenia gravis, a thymoma is discovered in about 15% including both young adults and late onset patients above the age of 60. Patients with thymoma generally have a more severe form of myasthenia than non-thymoma patients and almost all of them have detectable antibodies against the acetylcholine receptor [7, 8].

On the other hand, a diagnosis of myasthenia gravis can be made in about 50% of thymoma patients. While most patients have already symptoms and signs of myasthenia at the time of diagnosis, others develop myasthenia months to years after thymectomy. In most of them, the presence of acetylcholine receptor antibodies can already be detected at the time of the operation [5].

J. M. H. Hendriks, M.D., Ph.D. (✉) • P. Lauwers • S. Van Donink
P. E. Van Schil
Department of Thoracic and Vascular Surgery, Antwerp University Hospital, Wilrijkstraat 10, 2650 Edegem, Belgium
e-mail: jeroen.hendriks@uza.be

R. Mercelis
Department of Neurology, Antwerp University Hospital, Edegem, Belgium

P. Mertens
Department of Anesthesiology, University Hospital Antwerp, Edegem, Belgium

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_7

The high incidence of myasthenia in thymoma patients and the special care required by myasthenia patients during anesthesia and postoperative period, make that every thymoma patient should be evaluated by a neurologist familiar with myasthenia before surgery [2].

Myasthenia most often begins with ocular symptoms as diplopia and ptosis. In almost all patients symptoms are variable and more pronounced with visual fatigue, e.g. after car driving for a long time. Typically, symptoms are more severe in the evening than in the morning.

A second group of patients present with bulbar symptoms: dysarthria, chewing difficulties and dysphagia. Also in this instance symptoms are aggravated by fatigue, e.g. dysarthria increases while the patient is speaking aloud for some time or chewing is still possible at the beginning of a meal but after some time the chewing muscles get weak and the chin drops. Patients with pronounced bulbar symptoms are at high risk for respiratory problems and should be treated for their myasthenia before surgery. Generalized weakness without ocular or bulbar symptoms is rather unusual. Weakness is also induced by exercise and is most common in the proximal arm muscles but can involve individual finger extensors. Fatigue as only complaint is not specific for myasthenia.

The diagnosis of myasthenia is based upon history and clinical findings and can be confirmed by electromyography (EMG) or by the presence of antibodies against the acetylcholine receptor [9]. In some acetylcholine receptor antibody negative patients antibodies against muscle specific kinase (MUSK) are detected. However, MUSK myasthenia appears not to be associated with thymoma [10].

Diagnosis of myasthenia is rather easy in severe generalized disease but can be difficult in limited ocular involvement with intermittent symptoms and no clinical abnormalities. In those cases, single fiber EMG of the facial muscles is the most sensitive diagnostic test [11, 12]. In some patients the response to a rapid acting acetylcholinesterase inhibitor such as edrophonium chloride can be helpful.

The treatment of myasthenia usually starts by symptomatic relief with acetylcholinesterase inhibitors such as pyridostigmine. In our own series, nearly half of the patients do not require any other therapy. Some need immunomodulating therapies with steroids, azathioprine and sometimes other drugs such as cyclosporine, mycophenolate mofetil and tacrolimus [13, 14]. Plasmapheresis and intravenous human immunoglobulins are effective as short term therapy in severely disabled patients with bulbar and respiratory problems. A particular treatment for myasthenia gravis is thymectomy. It is always indicated in patients with radiological suspicion of thymoma, but it is generally accepted that its influence on the course of myasthenia is better in young patients with generalized myasthenia and thymic hyperplasia without the presence of a thymoma [9]. An international controlled trial to confirm the superiority of thymectomy plus prednisolone to prednisolone alone is ongoing [15].

7.2 Thymectomy by Minimally Invasive Techniques

7.2.1 General Principles

Resection of anterior mediastinal masses by thoracoscopic techniques has been introduced in the early 1990s as a minimally invasive alternative for sternotomy [16]. The use of robotic systems for resection of tumors in the anterior mediastinum started at the beginning of the twenty-first century [17]. Most authors describe the use of the da Vinci surgical robotic system for thymic hyperplasia and thymoma in patients with myasthenia gravis [17–20] although resection of other mediastinal tumors has also been reported [21]. Today, there is an ongoing debate whether the da Vinci robotic system really has an added value to thoracoscopic resection of anterior mediastinal masses regarding its high costs, and provides a valuable alternative to obtain a complete resection in case of thymomas when compared to transcervical or transsternal thymectomy or a combination of these approaches. The da Vinci robot is also used by the subxiphoid approach for extended thymectomy. This technique, better described as the trans-subxiphoid robotic thymectomy or TRT, has been evaluated in a human cadaver as an alternative to the lateral thoracoscopic approach in 2009 and evaluated clinically in 2016 by Suda [22, 23]. So far, no randomized controlled trials between different techniques for resection of anterior mediastinal masses have been performed, but advantages of the videoscopic approach include less pain and scarring, less risk of wound infection, fewer transfusions, and shorter hospital stay.

The use of the da Vinci robot for the resection of tumors in the mediastinum, including the anterior compartment, was introduced in the Antwerp University Hospital in 2004 and until now, robotic expertise for this indication is limited in other Belgian centers of thoracic surgery. The robot has been used in our service to resect different kind of mediastinal tumors including neurinomas, neurofibromas, mediastinal cysts, mediastinal metastases, ectopic parathyroid adenomas and thymomas. It is currently also used for pulmonary resections, thoracic selective sympatectomy and aortic surgery.

Size of the tumor is an important parameter to choose between resection by sternotomy or robot-assisted thoracoscopy. Initially 4 cm was our upper limit but larger tumors have been resected. Besides this, histology, previous thoracic surgery, the body habitus of the patient, cardiopulmonary morbidity and the patient's preference also determine the final approach. In general, the da Vinci surgical robotic system provides a superb three-dimensional view of the operative field and gives superior handling of the surgical instruments when compared to the classic thoracoscopic technique. With 7 degrees of freedom in movement of the instrument tip and a possible rotation of 360°, it is even superior to a surgeon's hand in open surgery. Therefore, a precise dissection within a small, fixed and remote area is possible. For this reason, dissection of the upper horns is also possible in most cases of thymectomy without an additional cervical incision.

7.2.2 Anesthesia

The anesthesiologist needs to have a thorough knowledge of thoracic anesthesia since the principles of robotic assisted thoracic surgery are essentially the same as those for thoracoscopic and open thoracic surgery. Single lung ventilation is essential for a successful procedure.

Due to the positioning and necessary working space for the robotic system, patient and table positions are often far from routine. This makes access to the airway of the patient by the anesthesiologist often difficult. Therefore, positioning of the patient and single lung ventilation have to be optimal when the robot is put over the patient. Before draping of the patient, prevention of pressure from the robotic arms upon the patient is of utmost importance. When the exposition of the area of interest is not optimal, CO_2 insufflation is used.

Even with only moderate pressures (7 mmHg) significant negative effects on circulation and ventilation might be possible. Reduced venous return can cause hemodynamic instability. Because altering the table position to change filling pressures of the heart is not possible during the procedure, more liberal use of hemodynamic active drugs might be necessary. Ventilation can be impaired by the higher intrathoracic pressure while at the same time absorbed CO_2 has to be eliminated. This might introduce respiratory acidosis and even desaturation, especially when both pleural cavities are opened.

The technique used in our hospital has been described by several authors with specific modifications whenever needed. After general anesthesia is initiated, patients are intubated with a double-lumen tube for selective single-lung ventilation. Standard patient positioning is an incomplete right lateral decubitus with the left side elevated upwards at a 30° angle (Fig. 7.1). The head is also tilted superiorly and slightly to the right. It is important to place the left arm alongside the body but on a lower level than the table not to obstruct movements of the robotic arms. Only patients with myasthenia gravis are transferred to the intensive care unit while all other patients are admitted at the postoperative anesthesia care unit (PACU) and dismissed to the ward several hours later.

Fig. 7.1 Body position for anterior mediastinal mass removal

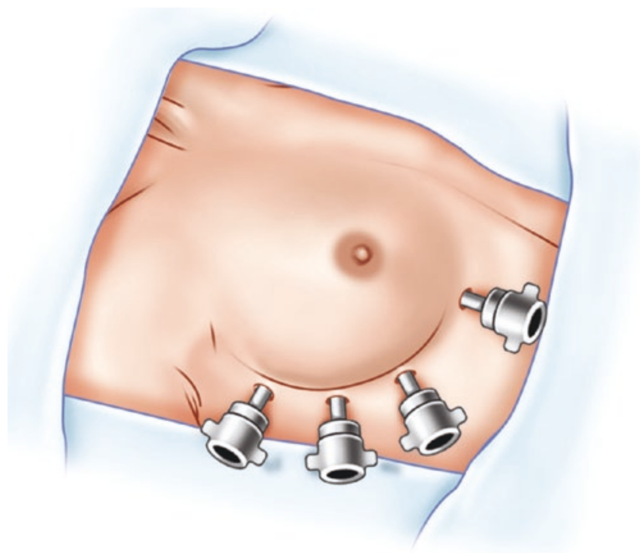


Fig. 7.2 Port placement for right chest approach

7.2.3 Surgical Technique

In our center most resections are performed from the left side of the thorax except for tumors located on the right side of the anterior mediastinum Four trocars are placed as soon as single lung ventilation is initiated by the anesthesiologist: Before 2015 we used the older da Vinci S system with only three ports. These three robotic ports were handled by the first surgeon at the console, while one additional fourth trocar was for the second surgeon at the operating table (Fig. 7.2). For operations on the right side the robot is coming over the left shoulder with ports positioned along the right mammary fold while from the anterior side with the patient in lateral decubitus (Fig. 7.3).

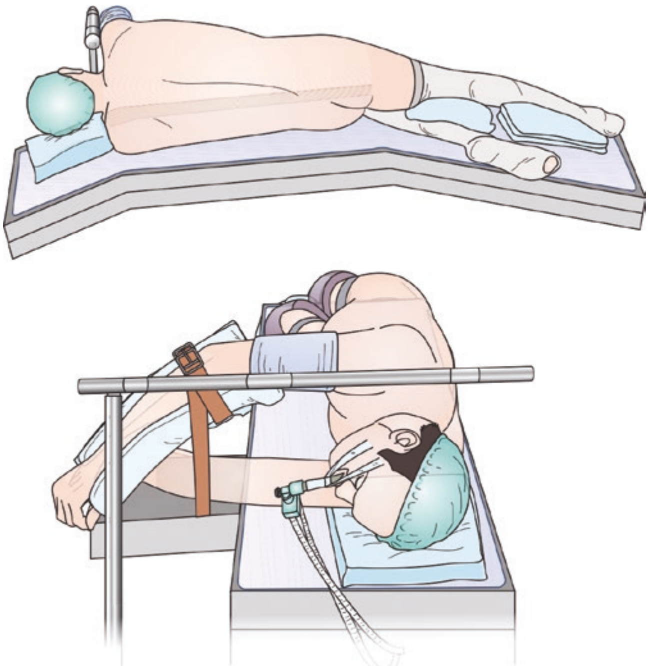


Fig. 7.3 Right chest approach, left lateral decubitus position

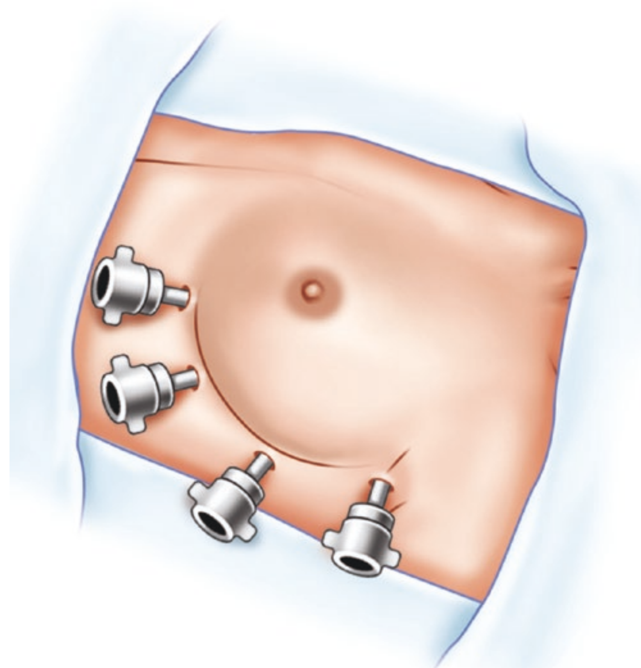


Fig. 7.4 Port placement for left chest approach

Since 2015, we use the da Vinci Xi four-arm surgical robot. This makes handling of all four 8 mm ports possible at the console by the first surgeon. The robot can access the patient from the lateral side (instead of the shoulder approach) and easily rotated once over the patient. Arms will be corrected a second time after the target is defined with the camera inside the patient. This makes the approach easier while not obstructing the working space of the anaesthesiologist. The camera can also be changed easily between ports during the procedure whenever necessary. The second surgeon or table surgeon can choose between placing all robotic ports in the left pleura around the breast with one hand's breadth between them (Fig. 7.4) or placing three ports around the breast while the fourth port is placed more posteriorly, outside this circle as used with the older da Vinci system. In the latter case, the fourth arm is not placed. When all four da Vinci ports are used, the fourth port is also used by the console surgeon but can be easily disconnected whenever the second surgeon needs to suction blood, to apply clips, and for removal of the specimen. Afterwards, the fourth arm is reconnected. The table surgeon is also present to change the instruments and stays at the operating table during the whole procedure in case urgent conversion to a sternotomy or anterior thoracotomy is needed. Since we usually operate close to the phrenic nerve, bipolar cautery is always installed. All non-thymic tumors are resected by a direct approach unless they are not visible within the thymic fat in which case they are resected by an extended thymectomy. Mostly, a 30° camera is used. Once CO_2 insufflation of 7 mmHg is installed, dissection starts at the left lower corner, anterior and medial to the phrenic nerve, and from here upwards alongside the nerve into the cervical region. Special attention is paid to the left innominate vein and its thymic tributaries. These small veins are usually clipped through the fourth port by the second surgeon. The upper thymic poles are mobilized from the left to the right side of the mediastinum and during this dissection, the innominate vein is compressed downwards by the second surgeon in order not to hurt it during dissection. In most cases, the right pleura is opened in order to locate the phrenic nerve at the other side and to accomplish a complete extended thymectomy. The lower parts are dissected at the end and subsequently, the resected specimen is placed in an endobag and removed through the fourth trocar incision. A pleural drain is inserted through one of the ports crossing the mediastinum from the left side with its tip in the right pleura, draining both thoracic cavities and the mediastinum. After re-inflation of the left lung, trocar incisions are closed and patient is extubated immediately on the table whenever possible.

7.3 Outcomes

From 2004 to April 2016 a total of 75 robotic assisted operations for tumors in the anterior mediastinal compartment were performed in the Antwerp University Hospital, Belgium. These represent 70% of our total of robotic assisted operations for mediastinal tumors.

Median age was 42 years (range, 14–79 years). Myasthenia gravis was present in 37 patients (61%). The majority of patients (n = 69) were operated through the left hemithorax (64%). A CO_2 insufflation was used in all patients since 2006. Resection of the tumor was macroscopically complete in all patients. There was no significant intra-operative blood loss in any of the patients and no major surgical complications occurred except for a phrenic nerve paresis in 3 patients. The robotic system itself did not show any technical failure. Chest tubes were removed on postoperative day 3 (range, 1–6). Pathology revealed 17 thymomas (five type A, three type B1, nine type B2), 41 thymic hyperplasias, and three thymic cysts. Other resections included pericardial cysts and parathyroid adenomas.

References

1. Duwe BV, Sterman DH, Musani AI. Tumors of the mediastinum. Chest. 2005;128(4):2893–909.
2. Casey EM, Kiel PJ, Loehrer PJ Sr. Clinical management of thymoma patients. Hematol Oncol Clin North Am. 2008;22(3):457–73.
3. Tomiyama N, Honda O, Tsubamoto M, et al. Anterior mediastinal tumors: diagnostic accuracy of CT and MRI. Eur J Radiol. 2009;69(2):280–88.
4. Endo M, Nakagawa K, Ohde Y, et al. Utility of 18FDG-PET for differentiating the grade of malignancy in thymic epithelial tumors. Lung Cancer. 2008;61(3):350–5.
5. Evoli A, Minicuci GM, Vitaliani R, et al. Paraneoplastic diseases associated with thymoma. J Neurol. 2007;254(6):756–62.
6. Tormoehlen LM, Pascuzzi RM. Thymoma, myasthenia gravis, and other paraneoplastic syndromes. Hematol Oncol Clin North Am. 2008;22(3):509–26.
7. Maggi L, Andreetta F, Antozzi C, et al. Thymoma-associated myasthenia gravis: outcome, clinical and pathological correlations in 197 patients on a 20-year experience. J Neuroimmunol. 2008;201–202:237–44.
8. Maggi L, Andreetta F, Antozzi C, et al. Two cases of thymoma-associated myasthenia gravis without antibodies to the acetylcholine receptor. Neuromuscul Disord. 2008;18(8):678–80.
9. De Baets MH, Oosterhuis HJGH, editors. Myasthenia gravis. Boca Raton: CRC Press; 1993.
10. Pasnoor M, Wolfe GI, Nations S, et al. Clinical findings in MuSK-antibody positive myasthenia gravis: a U.S. experience. Muscle Nerve. 2010;41(3):370–4.
11. Sanders DB. Clinical impact of single-fiber electromyography. Muscle Nerve. 2002;11(Suppl):S15–20.
12. Mercelis R. Abnormal single-fiber electromyography in patients not having myasthenia: risk for diagnostic confusion? Ann N Y Acad Sci. 2003;998:509–11.
13. Sanders DB, Evoli A. Immunosuppressive therapies in myasthenia gravis. Autoimmunity. 2010;43(5-6):428–35
14. Skeie GO, Romi F. Paraneoplastic myasthenia gravis: immunological and clinical aspects. Eur J Neurol. 2008;15(10):1029–33.
15. Newsom-Davis J, Cutter G, Wolfe GI, et al. Status of the thymectomy trial for nonthymomatous myasthenia gravis patients receiving prednisone. Ann N Y Acad Sci. 2008;1132:344–7.
16. Sugarbaker DJ. Thoracoscopy in the management of anterior mediastinal masses. Ann Thorac Surg. 1993;56(3):653–6.
17. Augustin F, Schmid T, Sieb M, Lucciarini P, Bodner J. Video-assisted thoracoscopic surgery versus robotic-assisted thoracoscopic surgery thymectomy. Ann Thorac Surg. 2008;85(2):S768–71.
18. Ismail M, Swierzy M, Rückert RI, Rückert JC. Robotic thymectomy for myasthenia gravis. Thorac Surg Clin. 2014;24:189–95.
19. Jun Y, Hao L, Demin L, Guohua D, Hua J, Yi S. Da Vinci robot-assisted system for thymectomy: experience of 55 patients in China. Int J Med Robot. 2014;10:294–9.
20. Keijzers M, De Baets M, Hochstenbag M, et al. Robotic thymectomy in patients with myasthenia gravis: neurological and surgical outcomes. Eur J Cardiothorac Surg. 2015;48:40–5.
21. Marulli G, Maessen J, Melfi F, et al. Multi-institutional European experience of robotic thymectomy for thymoma. Ann Cardiothorac Surg. 2016;5:18–25.
22. Ishikawa N, Sun YS, Nifong LW, Oda M, Watanabe G, Chitwood WR Jr. Thoracoscopic robot-assisted extended thymectomy in human cadaver. Surg Endosc. 2009;23(2):459–61.
23. Suda T, Kaneda S, Hachimaru A, et al. Thymectomy via a subxiphoid approach: single-port and robot-assisted. J Thorac Dis. 2016;8:S265–71.

Robotic Thymectomy: China

8

Innes Y.P. Wan and Michael K.Y. Hsin

Abstract

Surgical resection of thymus gland has been established as an effective treatment in selected patients with myasthenia gravis (MG). Since April 2006, we have started our robotic thoracic surgical program at the Prince of Wales Hospital, the Chinese University of Hong Kong, Hong Kong (SAR), China. We reported our initial experience of using da Vinci robotic system for complete thymectomy in 12 patients with myasthenia gravis. The mean operative time was 140 min and there was no major complications with mean hospital stay of 4 days. All patients have symptomatic improvement (DeFillipi class) on follow-up. Robotic thymectomy is a safe procedure and is associated with satisfactory clinical outcomes.

Keywords

Thymectomy • Myasthenia gravis • Robotics • Minimally invasive surgery • Mediastinum

8.1 Background

Surgical resection of the thymus as a treatment for myasthenia gravis (MG) was first proposed by Buckingham, and currently thymectomy has been established as an effective treatment option in selected MG patients [1]. In our locality, thymectomy for MG has a 70% response and a 33% remission rate [2].

Traditional methods of surgical access include the transsternal, transcervical and combined approaches. The more recent development of video-assisted thoracoscopic surgery (VATS) and robotic surgery provide further options, with the potential to decrease post-operative pain, shorten hospital stay, and improve cosmesis.

Several case series have been published in recent years [3–10] proving the safety and feasibility of using robotic assisted surgical system to perform thymectomy with good results. Here we describe our early experience using the da Vinci Robotic system, available to our division since 2006, for complete thymectomy in patients with myasthenia gravis, and to share the challenges encountered during the early implementation of the system in our unit.

With increasing popularity of robotic surgery technology, a foreseeable surge in its use in cardiothoracic surgery is anticipated. One main attraction of robotic-assisted surgery over conventional VATS technique is that it provides extra dexterity in a confined space when compared to conventional VATS. This was made possible by the extra wrist action of the instruments which provide 7 degrees of movement. Furthermore, the system provides a stereo-visual representation of the surgical field as opposed to a 2-D image in conventional VATs, providing the surgeon with an accurate sense of depth during the operation. Scale motion with tremor filtering provides better surgical accuracy. One major disadvantage of using the robotic system is the lack of tactile feedback.

However, practicing robotic surgeons have found that the loss of this sense can be compensated by the superior 3-D

I. Y. P. Wan, MBChB, FCSHK, FRCSEd, FHKAM (✉)
The Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong, China
e-mail: innesw@surgery.cuhk.edu.hk

M. K. Y. Hsin, MBBChir, MA, FRCS, FHKAM
Department of Cardiothoracic Surgery, Queen Mary Hospital, Hong Kong, China

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_8

image [3, 5–10, 11]. The use of robotic system enabled precise and accurate dissection of the superior mediastinal structures, the upper horns of the thymic gland together with all the cervical portions of the thymus. A more complete and radical resection can be performed within that limited space by the robotic instrument. The peri-thymic fat over the contralateral hemithorax can easily be dissected free resulting in a more complete thymectomy when compared with unilateral VATS approach [8–10].

Most experts agree that the learning curve for robotic thymectomy is relatively short [3, 5–7, 11]. This has been shown again in our series, with a rapid drop in operative time from 165 to around 100 min just after the first four cases.

There is no consensus on which is the best route for thymectomy in MG. Even in minimally invasive approaches, options of right, left, bilateral, or combined with transcervical incision have all been demonstrated to be feasible and comparable. The right-sided approach is our preference, because the surgical team and operating room staff involved were familiar with this approach when we performed the video-assisted non-robotic thoracoscopic approach (VAT), and that the prior research done in our center confirmed that right sided VAT thymectomy produces satisfactory results [12]. Advocates of the left-sided approach may be concerned about possible incomplete excision of accessory thymic tissue in the aorto-pulmonary window, which has been reported to be present in up to 24% of patients [13]. Some argue that the left phrenic nerve is better exposed in a left-sided approach while the right phrenic nerve is partially protected by the superior vena cava [3]. Experience in this center showed that left phrenic nerve injury has not been a problem with either VATs or robotic thymectomy [12]. Evidence of superiority of a left-sided approach is still lacking.

The use of the appropriate instruments is essential in performing robotic-assisted thymectomy. The Cadiere® forceps are placed within the left-sided port for the manipulation of the relatively fragile thymic tissue. The diathermy blade is useful both for cutting and blunt dissection of tissue. It is crucial to achieve accurate positioning of the bedside cart and docking of the robotic arms. Our experience shows that if the bedside cart is positioned too far away from the operating table, the efficiency and the range of movement of the robotic arms will be reduced. This will result in "crowding" and "fighting" of the robotic arms. Once the operation has started with the ports inserted, change of position of the patient cart becomes very difficult, and re-calibration of the instruments after changing position also takes up a lot of the operating time. Optimal positioning of the patient side-cart with the help of the operating surgeon is essential.

Previously published series on robotic-assisted mediastinal tumor or thymic excision have shown similar [3, 5–6, 11] or even superior results [6] in terms of DeFillipi classification of remission when compared with VATs procedures. Because of the small number of patients and the short follow-up period in our series, direct comparison between robotic surgery versus VATS thymectomy cannot be made. Our initial findings suggest that robotic thymectomy is promising; when compared to VATS thymectomy for non-thymomatous thymectomy in this center [12], the mean operative time was 43 min longer in the robotic group (mean 107 versus 138 min). The mean hospital stay was similar between the two groups. The length-of-hospital stay was determined by the status of the MG as two patients in our series required postoperative intravenous immunoglobulin (IVIG) for MG crisis without any active surgical problems. Complication rate in the VATS group was 11% (including Pneumonia/Chest wall parasthesia) versus 0%. Need for wound extension was 5.5% in VATs, 0% in robotic thymectomy. On follow-up improvement in MG was 99.6% in VATs, 100% in the robotic group (De Filipi 1–3). However, the follow-up time is short when compared with our VATS series.

Robotic thymectomy seems comparable, if not superior to VATS thymectomy. The results of our small series appear to be comparable to the other world larger series [8–10] in terms of operating time and postoperative outcomes.

The initial costs of setting up a robotic surgical service is substantial and its maintenance can be costly. By sharing this technology across all surgical specialties in the hospital, the cost can be significantly reduced. Considering the small number of robotic thymectomy cases performed in Hong Kong, China at the present moment, we expect there is room for improvement and better results may be achieved in the near future.

8.2 Anesthetic Technique

General anesthesia is achieved with Propofol and Fentanyl. Left sided double–lumen endotracheal tube is placed for selective one-lung ventilation of left lung. As all patients undergoing robotic-assisted thymectomy had myasthenia gravis, no muscle relaxant are used during anesthesia. General anesthesia is maintained with isoflurane and nitrous oxide in oxygen. Ventilation is adjusted to maintain normocapnia. Since MG patients are usually more susceptible to the neuromuscular blocking effect of vtolatile gases, non-depolarizing muscle relaxants are not used. Routine pulse oximetry and non-invasive hemodynamic monitoring are employed during the procedure.

8.3 Surgical Technique

All patients are operated on by a team of thoracic surgeons with extensive VATS experience, using the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA). All patients are positioned with right side up at 30°, using a silicon gel wedge to support the right shoulder and upper back. The right arm of the patient is then positioned to the side of the patient resting on the operating table with the right shoulder arm slightly extended (Fig. 8.1). The bedside-cart with the robotic arms is positioned on the left side of the operating table (Fig. 8.2). A 30-degree upward endoscope is inserted through a thoracoport via a 15 mm incision at the fifth intercostal space at the mid-axillary line. Two 8-mm accessory ports are then inserted at the third intercostals space/ mid-axillary line and the fifth intercostals space/mid-clavicular line. The two robotic arms of the da Vinci System are then attached to the two accessory ports, while another arm is attached to the

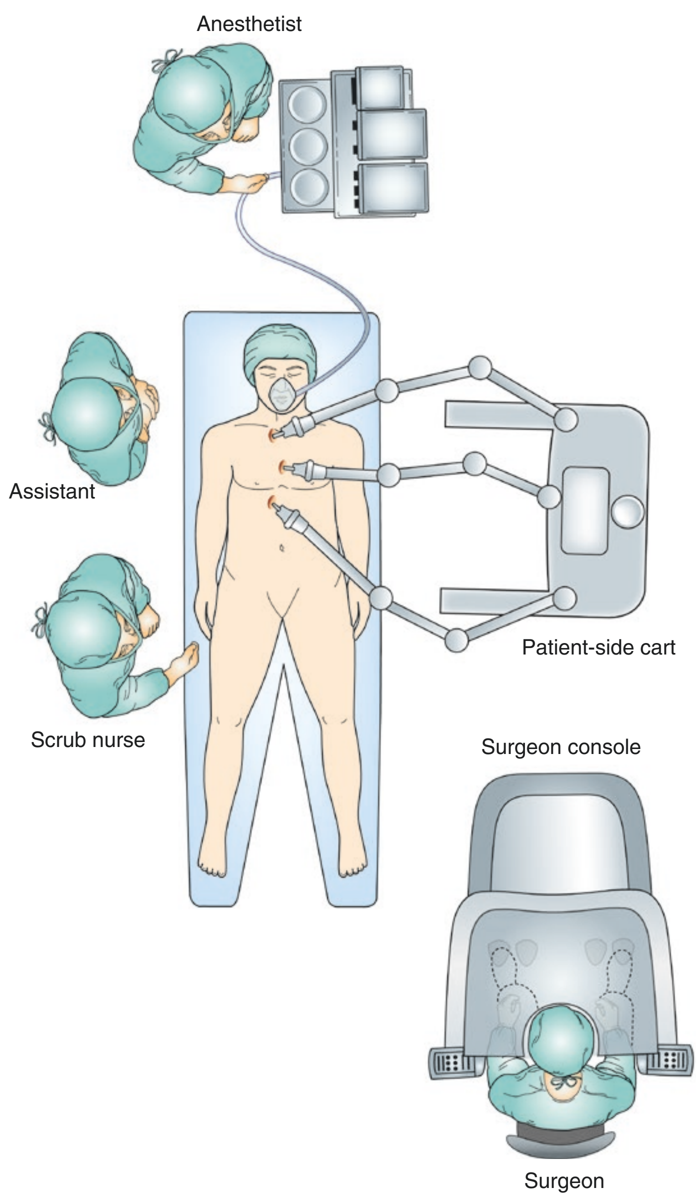


Fig. 8.1 Patient position: camera port (fourth ICS anterior axillary line), Left instrument port (third ICS mid-axillary line) and right instrument port (fifth ICS mid-axillary line)

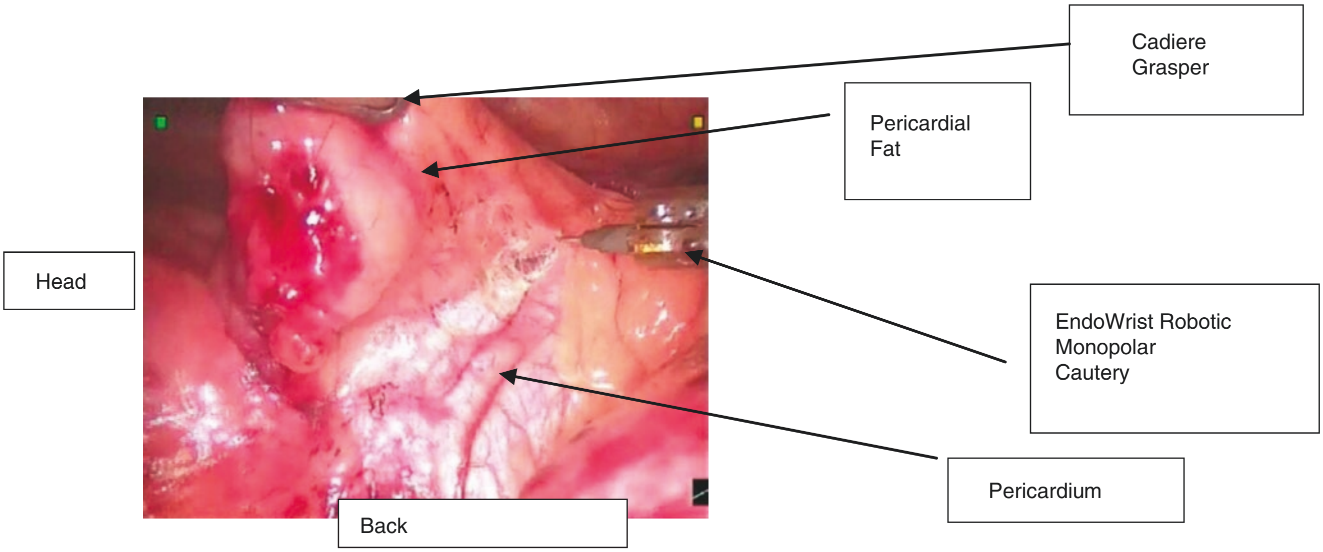


Fig. 8.2 Room set-up for right-sided approach thymectomy

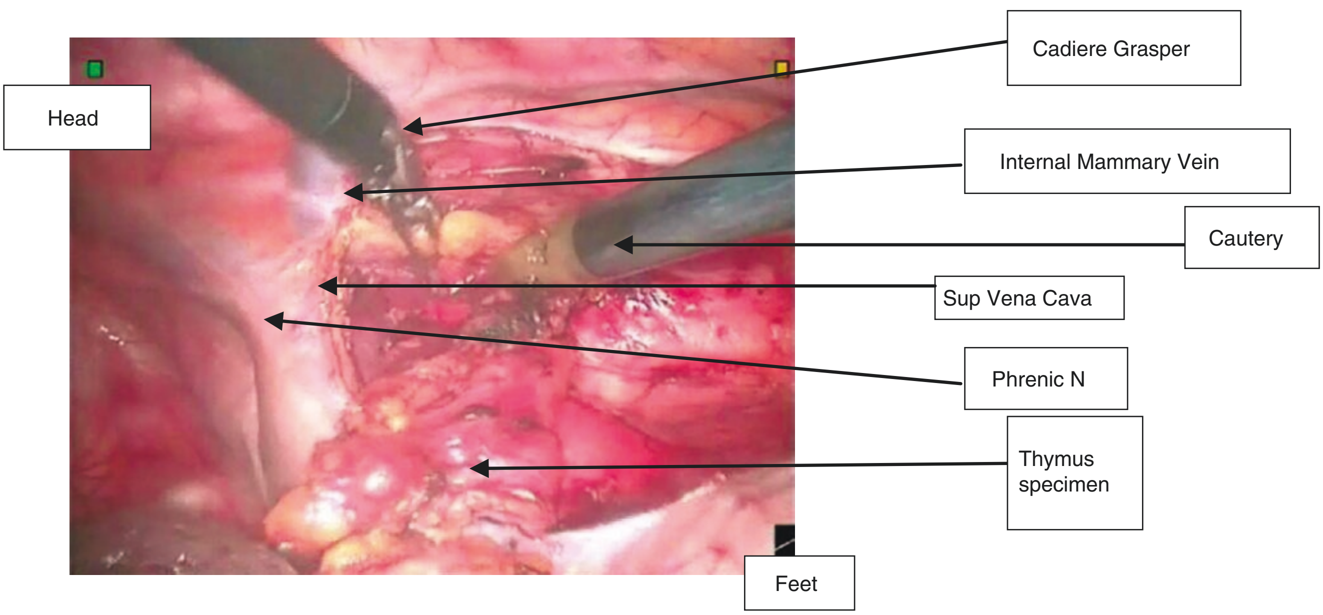


Fig. 8.3 Initiation of right-sided approach thymectomy. Lower mediastinal dissection: Dissection of the right inferior horn (RIH) of the thymus from the diaphragm and the pericardium anterior to the right phrenic nerve (PN)

port-inserted endoscope. There is no need to use the fourth arm of the robot to perform a thymectomy. The right lung is then deflated and CO_2 insufflation is started at 10 mmHg through the camera port.

Cadiere forceps are used through the left port in all except the first case in the series, where a Debakey forceps with Endowrist action was used. Electrocautery blades with Endowrist action were used via the right port, acting as a dissecting instrument. The right inferior pole of the thymus is first dissected off the right pericardium and diaphragm (Fig. 8.3), continuing cranially along the anterior border of the phrenic nerve and the superior vena cava up to the level of the right internal mammary vein (Fig. 8.4). The retrosternal plane is developed with dissection of the mediastinal fat and tissue at the anterior mediastinum. The dissection is continued over the retrosternal space until the left mediastinal pleura and left inferior horn are identified (Fig. 8.5). After further dissection the innominate vein is then exposed by mobilizing the lower part of the thymus upwards (Fig. 8.6a). Thymic veins from the innominate vein are clipped and cut

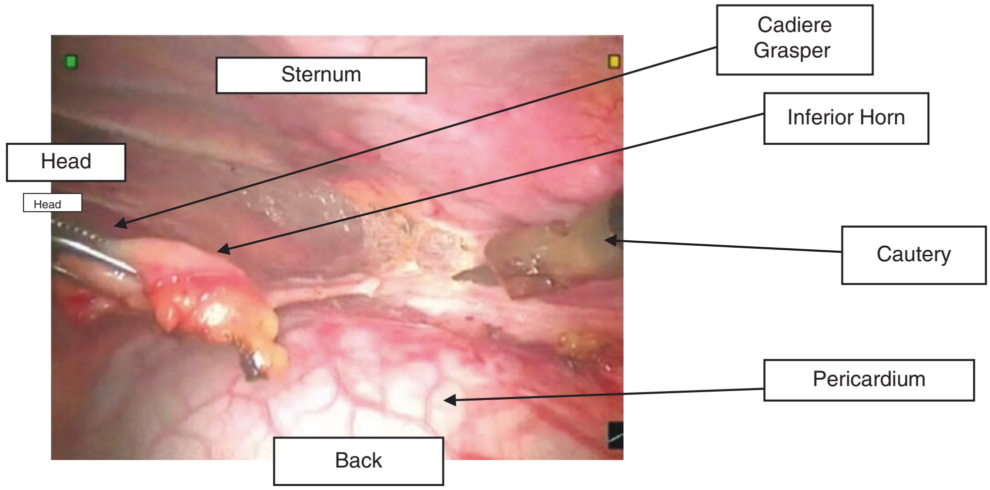


Fig. 8.4 Right-sided aspect of thymectomy completed

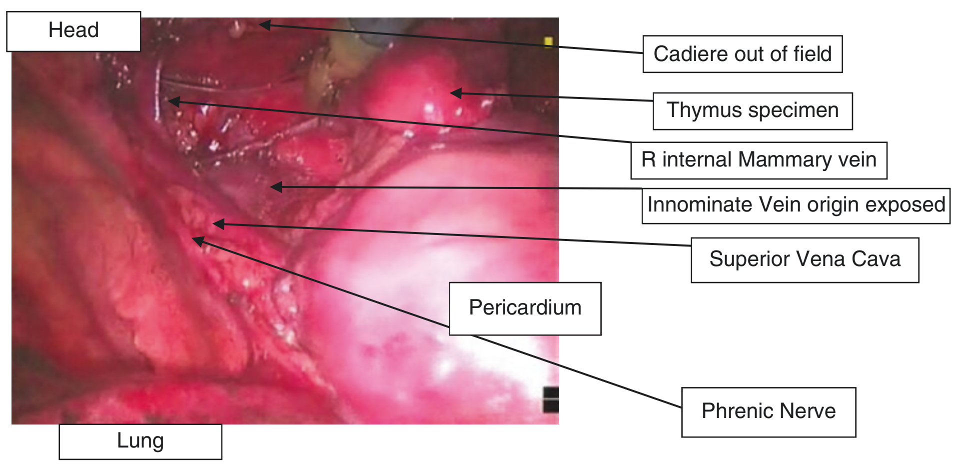


Fig. 8.5 Dissection of the left inferior horn

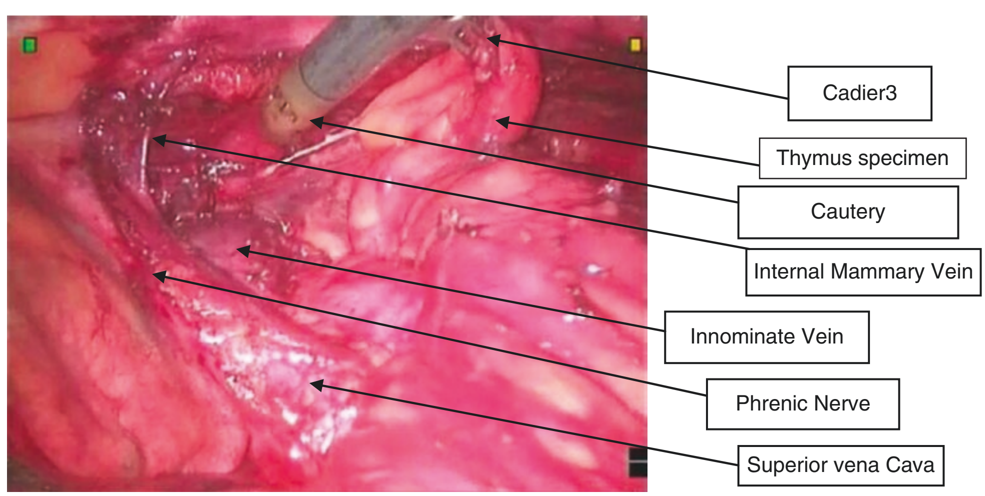


Fig. 8.6 (**a**, **b**) Exposure of the innominate vein by lifting the thymus cephalad. Upper mediastinum. The thymus was dissected from the innominate vein with venous thymic tributaries and left upper horn of thymus can be mobilized. The right internal mammary vein is preserved

using a robotic clip applicator and scissors with Endowrist action via the right assess port. Change of instruments during the surgery is facilitated by the scrub nurse and the assistant, sitting on the right of the patient. The right superior horn was dissected and freed from the innominate vein. The left upper horn could be dissected and excised in a similar manner and detached from the thyroid gland by blunt dissection (Fig. 8.6b).

The excised specimen was placed in a “Zip-lock” bag and delivered through the inferior port/camera port after the trochars were removed. A 24 Fr chest tube is inserted through the most inferior port after hemostasis and wounds are closed in layers. All patients are extubated in the operating room and transferred to the intensive care unit for observation overnight.

8.4 Outcomes

From April 2006 to Nov 2009, 12 patients with myasthenia gravis underwent right-sided thoracoscopic thymectomy using the da Vinci Robotic system (Table 8.1) [14]. Nine were females and 3 were male, aged 21–53 years old. MG was diagnosed using clinical criteria and positive results: the Tensilon test, circulating acetylcholine receptor antibodies, or electromyography. All patients had pre-operative computed tomography (CT) performed. Two patients had a pre-operative diagnosis of a small thymoma (less than 2 cm), while the other ten patients had normal-sized thymus on CT scan.

Twelve robotic-assisted complete thymectomy procedures were performed with no conversion to other approaches (Table 8.2) [15]. Operative time ranges from 100 to 200 min (mean time 140 min), with a trend of decreasing operative time with accumulating experience. The operative time was longer for patients with thymoma (200 and 170 min, respectively) since that involved resection of a relatively bulky thymic gland with exploration of the left pleural space via the right side. There were no intra-operative or post-operative complications. Nearly all chest drains were removed on post-operative day 1 and the mean hospital stay was 4.0 days only. The excised specimens showed thymic hyperplasia except for two patients with type B1 thymoma. The follow-up period ranges from 2 to 44 months. Early post-operative evaluations showed 1 patient had complete remission in symptoms (DeFillipi class 1), eleven patients became asymptomatic or less symptomatic with decreasing medication requirement (DeFillipi class 2 and 3).

Table 8.1 Patient characteristics

Age	21–53 (mean: 41)
Sex M:F ratio	1:3
Osserman Class	
I	2
IIa	3
IIb	5
III	2
IV	0

Osserman Classification: I Occular MG: Involvement of extra ocular muscles, with diplopia or ptosis; IIa Mild generalised MG: occular symptoms are associate to slow involvement of bulbar and skeletal muscles; IIb Moderately generalised MG: Progressive onset of symptoms with significant manifestation of weakness; III Acute MG: Rapid onset (6 months) of severe bulbar and skeletal muscles with important weakness. Respiratory muscles involved; IV Late severe MG: progressive in severity for 2 or more years

Table 8.2 Outcomes

Operative time (min)	100–200 (mean 140)
Intra-operative blood loss (mL)	10–100 (mean 40)
Chest drain removal (days)	1–3 (mean 2)
Hospital stay (days)	3–6 (mean 4)
Follow-up (months)	2–44 (mean 21)
DeFilippi Class on follow-up	
1	1
2	7
3	4
4	0

DeFilippi Postop Classification: 1 Complete remission. No medication; 2 Asymptomatic, decreased medication; 3 Improved, decreased symptoms or decreased medication; 4 No change; 5 Worsening symptoms

References

1. Buckingham JM, Howard FM Jr, Bernatz PE, Payne WS, Harrison EG Jr, O’Brien PC, Weiland LH. The value of thymectomy in myasthenia gravis: a computer-assisted matched study. Ann Surg. 1976;184(4):453–8.
2. Kay R, Lam S, Wong KS, Wang A, Ho J. Response to thymectomy in Chinese patients with myasthenia gravis. J Neurol Sci. 1994;126(1):84–7.
3. Rea F, Marulli G, Bortolotti L, Feltracco P, Zuin A, Sartori F. Experience with the “da Vinci” robotic system for thymectomy in patients with myasthenia gravis: report of 33 cases. Ann Thorac Surg. 2006;81(2):455–9.
4. Bodner J, Wykypiel H, Greiner A, Kirchmayr W, Freund MC, Margreiter R, Schmid T. Early experience with robot-assisted surgery for mediastinal masses. Ann Thorac Surg. 2004;78(1):259–65.
5. Savitt MA, Gao G, Furnary AP, Swanson J, Gately HL, Handy JR. Application of robotic-assisted techniques to the surgical evaluation and treatment of the anterior mediastinum. Ann Thorac Surg. 2005;79(2):450–5.

6. Cakar F, Werner P, Augustin F, Schmid T, Wolf-Magele A, Sieb M, Bodner J. A comparison of outcomes after robotic open extended thymectomy for myasthenia gravis. Eur J Cardiothorac Surg. 2007;31(3):501–4.
7. Ro C, DeRose JJ Jr, Connery CP, Balaram SK, Ashton RC Jr. Three-year experience with totally endoscopic robotic thymectomy. Innovations. 2006;1(3):111–4.
8. Augustin F, Schmid T, Sieb M, Lucciarini P, Bodner J. Video-Assisted Thoracoscopic surgery versus robotic–assisted thoracoscopic surgery thymectomy. Ann Thorac Surg. 2008;85:S768–71.
9. Ruckert J, Ismail M, Swierzy M, Sobel H, Rogalla P, Meisel A, Wernecke K, Ruckert R, Muller J. Thoracoscopic thymectomy with the da Vinci Robotic System for Mysathenia gravis. Ann N Y Acad Sci. 2008;1132:329–35.
10. Fleck T, Fleck M, Muller M, Hager H, Klepetko W, Wolner E, Wisser W. Extended videoscopic robotic thymectomy with the da Vinci telemanipulator for treatment of myasthenia gravis: the Vienn experience. Interact Cardiovasc Thorac Surg. 2009;9(5):784–7.
11. Bodner JC, Zitt M, Ott H, Wetscher GJ, Wykypiel H, Lucciarini P, Schmid T. Robotic-assisted thoracoscopic surgery (RATS) for benign and malignant esophageal tumors. Ann Thorac Surg. 2005;80(4):1202–6.
12. Manlulu A, Lee TW, Wan I, Law CY, Chang C, Garzon JC, Yim A. Video-assisted thoracic surgery thymectomy for nonthymomatous myasthenia gravis. Chest. 2005;128(5):3454–60.
13. Jaretzki A 3rd, Barohn RJ, Ernstoff RM, Kaminski HJ, Keesey JC, Penn AS, Sanders DB. Myasthenia gravis: recommendations for clinical research standards. Task Force of the Medical Scientific Advisory Board of the Myasthenia Gravis Foundation of America. Ann Thorac Surg. 2000;70(1):327–34.
14. Osserman KE, Genkins G. Studies in myasthenia gravis: review of a twenty-year experience in over 1200 patients. Mt Sinai J Med. 1971;38(6):497–537.
15. DeFilippi VJ, Richman DP, Ferguson MK. Transcervical thymectomy for myasthenia gravis. Ann Thorac Surg. 1994;57(1):194–7.

9 Robotic Applications to the Mediastinum

Michael A. Savitt

Abstract

The mediastinum can present a surgical challenge for patients and their surgeons. In some situations, to obtain sufficient diagnostic tissue or to completely resect relatively small lesions requires sizeable incisions that can result in unnecessary pain and debility. Minimally invasive techniques have not consistently provided the needed angles of approach, dexterity within the confined space of the mediastinum, and the surgeon-directed visibility necessary to perform a thorough and safe procedure. The robotic surgery platform meets those demands. The special considerations for an efficient procedure are reviewed.

Keywords

Mediastinum • Robotic surgery • Minimally invasive • Thymectomy • Thymoma • Parathyroid adenoma • Thymic cyst • Anterior mediastinal tumor • Germ cell tumor • Robotic assisted • Thoracoscopic surgery • Thymus hyperplasia • Extended thymectomy • Surgical technique

The mediastinum is the site of a wide spectrum of diseases. The diagnosis and treatment of benign and malignant diseases of the mediastinum remains a challenge to thoracic surgeons. A reasonable differential diagnosis can often be made on the basis of clinical history, physical examination, and radiologic workup; however, in the majority of cases a precise diagnosis can not be made without histologic examination of the tissue. Traditional surgical applications to the mediastinum involve both diagnostic and therapeutic procedures. Diagnostic procedures have been used principally for the evaluation of unknown masses and conformation of suspected hematopoietic malignancies, such as lymphoma and Hodgkin's disease. Therapeutic resections have been primarily applied to patients with thymoma, myasthenia gravis, neurogenic tumors, and cysts [1–5].

Diagnostic surgery of the mediastinum includes thoracoscopy and mediastinoscopy (anterior and cervical). The prevailing gold standard for resectional therapy of thymoma, with or without myasthenia gravis, has generally been median sternotomy, with thoracoscopy advocated as an alternative for the treatment of known benign cystic diseases [3–5]. The introduction of robotic-assisted technologies provided an improvement in visualization and surgical dexterity over thoracoscopy. The authors believe that the robotic-assisted technology is optimally suited for resectional therapy of most mediastinal disease [1, 2].

The mediastinum is among the most complex anatomical regions of the human body. A thorough understanding of its anatomic components and their three-dimensional relationships is a precursor to the effective application of robotic-assisted surgery. From a surgical perspective the mediastinum is divided into three separate compartments: anterior, middle (visceral), and posterior (para-vertebral). The anterior compartment extends from the thoracic inlet to the diaphragm and is bounded by the posterior aspect of the sternum anteriorly, the pericardium posteriorly, and by the pleura laterally. From a practical surgical standpoint the most important anatomic boundary of the anterior mediastinum is the posterior lateral extent which is bounded on either side by the right

M. A. Savitt, M.D., M.S.E. (✉)
Department of Cardiothoracic Surgery, Indiana University Health System, Muncie, IN, USA
e-mail: mike.savitt@att.net

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_9

and left phrenic nerves. The middle compartment is bounded by the pleura laterally, the diaphragm and thoracic inlet proximally and distally, the vertebral bodies posteriorly, and the phrenic nerve anteriorly. The middle compartment contains the heart, great vessels, lymphatics, pulmonary hilum, and esophagus. The posterior compartment extends from the anterior surface of the vertebral bodies to the para-vertebral sulci, and primarily contains neural structures and the sympathetic chain.

The therapeutic decisions on how to manage a mediastinal mass depend on location, the expected histopathologic diagnosis, clinical presentation, patient age and co-morbidities. Generally patients with cystic lesions or well encapsulated solid masses without signs of invasiveness, complete resection of the lesion is advisable, being diagnostic as well as therapeutic. This is the case for most lesions in the posterior mediastinum, and for cystic lesions of the middle mediastinum. This also applies to cystic lesions of the anterior mediastinum as well as encapsulated thymomas and teratomas. Resection of most masses in the mediastinum which fit these characteristics can be safely and effectively carried out with the aide of robotic-assisted technologies, and it is the authors' preference to use robotic-assisted technologies for all resectional mediastinal masses which meet the above criteria. Large lesions (>7 cm), and especially extra-capsular thymomas (where the risk of tumor speeding is high) remain an indication for an open procedure.

9.1 Operative Technique

All cases are performed with selective single-lung ventilation with a radial artery and central venous catheters. For anterior and middle mediastinal lesions the patient is placed supine with either the right or left chest elevated 30°, with the ipsilateral shoulder retracted and depressed, the arm internally rotated and elbow flexed and at the patients side (Fig. 9.1). This position allows accesses to anterior and midaxillary lines without brachial plexus traction and free motion of the robotic instrumentation. Laterality is determined by the anatomic predominance of the mediastinal mass. However, it is the authors' preference to approach all anterior mediastinal masses from a right-sided approach. The left-sided approach is difficult owing to diminished mediastinal working space secondary to the cardiac mass. The heart impairs the reach of the lowest robotic arm into the superior-most anterior mediastinum, and visualization of the right phrenic nerve across the midline. If predominance of an anterior mediastinal masses is left of the left phrenic nerve, then the lesion is generally approached in either an open fashion, or if it is a small lesion (<5 cm) it is treated as a left-sided middle mediastinal lesion (described below).

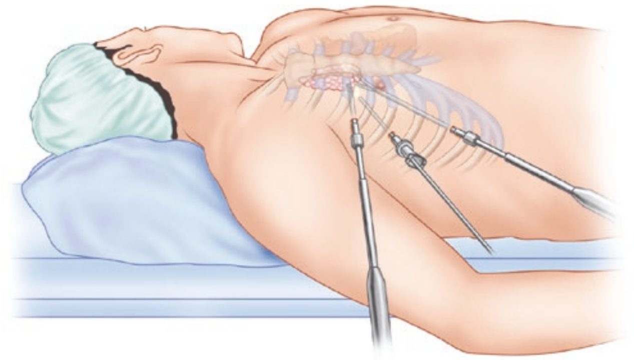


Fig. 9.1 Right-side approach for anterior mediastinal masses. A 10–12-mm port is placed in the fifth intercostal space in the midaxillary line (Port Site A) and the other ports placed according to the visual findings with a 30-degree 5-mm thoracoscope. Typically, the other ports are placed in the anterior axillary line in the third (Port B) and seventh (Port C), respectively. The robot or bedside cart is brought from the opposite side of the operating room table

All port sites are infiltrated with a local anesthetic agent (0.25% bupivacaine). A 30-degree 5 mm telescope is placed through a 10-mm port placed in the fifth intercostal space in the midaxillary line. For the left-sided approaches all port sites in general should be placed 1–2 cm more posterior than their respective right-sided locations. The mediastinum is evaluated and the feasibility of resection and location of additional port sites is determined. For an anterior mediastinal lesion if an anterior mediastinal mass is noted to be extra capsular, a biopsy is taken. Frozen section results are then used to determine feasibility and type of resection. The robotic surgical system is brought up to the table from the patients left side (right side for left sided approaches) for right sided port placement. A 30-degree telescope is used and the additional robotic instruments are introduced through generally the third and seventh intercostals spaces, in the anterior axillary line. These port placements can be adjusted based on their optimal position as determined during the initial thoroscopic evaluation of the lesion to be resected and its respective location to anatomic structures. In young female patients the camera port is generally placed strategically in the sub-mammary fold for improved cosmetics.

In general exposure is facilitated by right lung (or left in a left sided approach) deflation and CO_2 insufflation to a pressure of 10–15 mmHg. The radial arterial and central venous pressures are monitored to ensure adequate hemodynamics during CO_2 insufflation. Maximizing the pressure of insufflation helps create space and facilitates visualization especially for anterior mediastinal resections.

Resections of lesion in the middle mediastinum are generally straight forward and are facilitated by gentle counter traction usually through the most superior port and a gentle blunt dissection technique sweeping the mass or cyst away from the corresponding phrenic nerve and adjacent structures in the pulmonary hilum, generally the pulmonary vein and or artery. The base of the mass or cyst is generally clipped and then the entire specimen is removed with an endoscopic bag thru the most inferior port.

All masses to be resected in the anterior mediastinum are resected by complete thymectomy, and all are approached by the author from the right side. The thymic dissection is begun at the right pericardiophrenic angle and continued up along the right phrenic nerve to the superior vena caval innominate junction the corresponding phrenic nerve is the most important anatomic structure to identify in all anterior and middle resections of the mediastinum. The thymus is then resected free from the retro sternal area to beyond the left internal mammary artery, extending superiorly until the innominate vein is exposed. The thymus is then retracted rightward, and with rotation of the scope caudally and towards the left chest. The left phrenic nerve can generally be identified. The leftward thymic extent can be dissected in a cephalad manner. If the left phrenic nerve cannot be identified, the left pleural space is entered and the scope passed across the midline into the left chest. The scope can then be used to look down and back while ventilation is temporarily interrupted so that the exact position of the left phrenic nerve may be verified.

Exposure of the thymic cords is facilitated by the CO_2 insufflation, and each pole is grasped and dissected bluntly in its entirety. The thymic venous tributaries that drain the innominate vein are identified, clipped, and divided. The thymus is then placed in an endoscopic bag and removed through the lower port. If the contra-lateral space was entered a small chest tube is placed across the midline, aspirated, and removed. The robotic instruments are removed, and rib bocks of 0.25% bupivicaine are placed, and a small chest tube is left postoperatively. The lung is re-inflated under direct vision, and the incisions are closed in multiple layers.

Posterior mediastinal lesions are approached the same as middle mediastinal masses except that the patient is placed in a full lateral position, exactly as the patient would be positioned for a posterior lateral thoracotomy. Laterality is determined by the anatomic predominance of the mediastinal mass. The robot is positioned anterior to the patient (from the left-side of the table for a right sided lesion). The initial 10-mm camera port is placed in the fifth intercostal space at the mid-axillary line, and the determination of the additional robotic ports is determined by inspecting the exact location of the mass relative to the two operative robotic instruments. Theses ports are generally placed in the third and seventh interspace in the posterior axillary line. Port placement is the most important technical aspect of resecting a position mediastinal mass, and therefore it is facilitated by placing the ports in a position that allows each arm to reach the mass, without creating internal collisions. While the author generally prefers to use a 30-degree scope looking backwards towards the area of interested, in many cases a 0-degree scope can facilitate visualization of the posterior mediastinum. A traction stitch is then passed thru the posterior mediastinal mass and gentle traction thru the most inferior port helps facilitate gentle sharp and blunt dissection of the base of the masses. Once the stalk is encountered it is doubly clipped, and the stalk is divided and the mass is removed with an endoscopic bag.

9.2 Tips and Pitfalls

The most important technical aspect of orbit-assisted mediastinal resection is port placement. We have attempted to provide the reader with a basic port placement strategy, however it should be noted that with experience all ports other than the initial camera port are positioned under direct vision. The ports should be placed in such a way to facilitate the operation and to avoid collisions with the robotic instruments and camera.

It is the authors' opinion that robotic technologies are best suited to resection of anterior mediastinal masses, and new users should focus on this area first. With experience each surgeon will develop their own unique methodology to assure optimal port placement, which is of utmost importance when tackling lesions in the posterior mediastinum.

The authors also feel that each and every lesion should be assessed thorascopicly to determine the feasibility of resection. This is particularly important with thymomas. The authors feel that thymomas with their propensity to seed the mediastinum and pleural space should only be resected with robotic-assisted techniques if the masse is not extra capsular, and all efforts should be made to avoid grasping the thymoma directly. If an extra capsular lesion is seen then the procedure should be converted to an open (median sternotomy is the author's preference) procedure.

9.3 Outcomes

Robotic-assisted techniques allow optimal exposure of the entire mediastinum and allow for precise and meticulous dissection. Robotic-assisted surgery has generally been applied to thymectomies, with excellent results [4, 5], but there have been sporadic reports on it's usage in the middle and posterior mediastinum. The robotic-technique clearly is a safe and effective means of resectional therapy to mediastianl masses. For thymectomies it allows for the ability to perform extensive and complete thymectomies from a single-sided approach, and hence has become the authors preferred approach to all respectable masses in the anterior mediastinum.

The robotic-assisted technique provides access to all parts of the mediastinum, with excellent exposure, provides a diagnosis if necessary, an excellent cosmetic result, and allows for complete resection and staging of mediastinal lesions. The ability to both diagnosis and treat from the same port sites makes robotic-assisted surgery a vital and perhaps ideal tool in the treatment of complex mediastinal lesions.

References

1. Savitt MA, Gao G, Furnary AP, et al. Application of robotic-assisted techniques to the surgical evaluation and treatment of the anterior mediastinum. Ann Thorac Surg. 2005;79:450–5.
2. DeRose JJ Jr, Swistel DG, Safavi A, et al. Medistinal mass evaluation using advanced robotic techniques. Ann Thorac Surg. 2003;75:557–73.
3. Duwe BV, Sterman DH, Musani AI. Tumors of the Mediastinum. Chest. 2005;128:2893–909.
4. Takeda S, Miyoshi S, Minami M, et al. Clinical spectrum of mediastinal cysts. Chest. 2003;124:125–32.
5. Yim AP, Kay RL, Ho JK. Video-assisted thoracoscopic thymectomy for myasthenia gravis. Chest. 1995;108(5):1440–3.

Check for updates

Difficult Mediastinal Mass Resections: Robotic Approach and Solutions—Austria

10

Johannes Bodner, Florian Augustin, and Thomas Schmid

Abstract

Approaching the narrow mediastinum with its various vulnerable structures by conventional Video Assisted Thoracoscopic Surgery (VATS) is technically challenging. The daVinci robotic system was developed to overcome the limitations of VATS by providing a 3-dimensional vision of the operating field, an intuitive and extended manoeuvrability of the instruments as well as motion scaling with tremor filtering. These features come to advantage particularly in difficult to reach anatomical regions like the mediastinum. Both, the anterior and the posterior mediastinum are easily accessible by a robotic approach allowing to perform all common procedures of the thymus, the thoracic esophagus, (para-) thyroids and tumors of lymphatic or neurogenic origin. The anaesthetic management as well as surgical-technical aspects of robotic procedures within the mediastinum are discussed in detail, potential pitfalls are elaborated and tips to prevent complications are given.

Keywords

Robotic assisted thoracoscopic surgery • daVinci • Mediastinum • Thymectomy • Myasthenia gravis • Ectopic (para)thyroid adenoma • Neurinoma

10.1 Background and Specific Indications

Video-assisted thoracoscopic surgery (VATS) has been performed for more than 25 years. Starting with technically rather simple procedures like pleural biopsies, increasing experience and evolution of minimally invasive instruments led to a broader application of the technique [1]. However, when facing the narrow and difficult to reach area of the mediastinum, a minimally invasive approach using conventional instruments with limited manoeuvrability is still challenging for many surgeons [2].

J. Bodner, M.D., M.Sc., F.E.B.T.S. (✉)
Department of Thoracic Surgery, Klinikum Bogenhausen, Munich Community Hospital, Munich, Bayern, Germany
e-mail: Johannes.bodner@i-med.ac.at

F. Augustin, M.D. • T. Schmid, M.D.
Department of Visceral, Transplantation and Thoracic Surgery, Center of Operative Medicine, Innsbruck University Hospital, Innsbruck, Tirol, Austria

To overcome limitations of the conventional minimally approach, micromechanic robotic systems have been introduced in the late 1990s. The da Vinci system offers 3-dimensional vision, improved manoeuvrability with 7 degrees of freedom (Endowrist® Technology) as well as motion scaling and tremor filtering. All of these advances improve surgical dexterity within the mediastinum [3]. Thoracic surgeons, therefore, soon focused their interest in robotic applications on the diagnostic and therapeutic approach to mediastinal masses [4, 5].

Robotic applications for diagnostic and therapeutic procedures for mediastinal masses are described in this chapter, reviewing the recent literature.

The mediastinum is the central department of the thoracic cavity, extending from the sternum in front to the vertebral column behind; it contains all the thoracic viscera except the lungs.

For the purpose of description, the mediastinum is divided into two parts (Fig. 10.1):

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_10

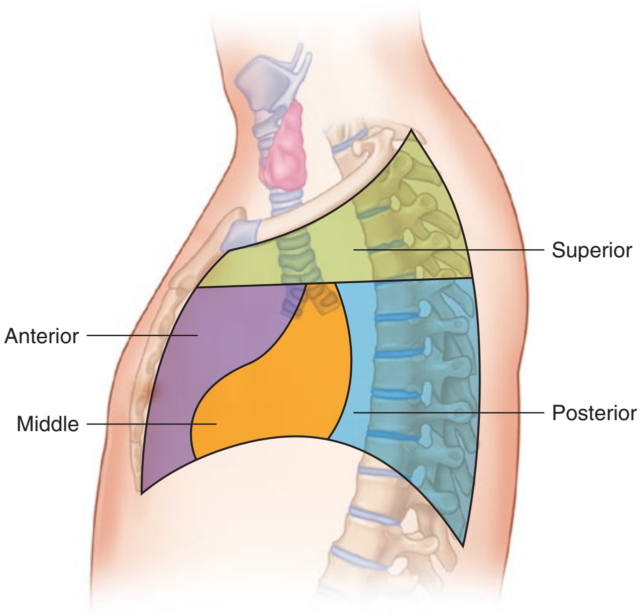


Fig. 10.1 Anatomic location of the four compartments of the mediastinum

- The upper mediastinum is bounded by the thoracic inlet and the plane from the sternal angle to the disc of T4–T5
- The lower mediastinum can be subdivided into three parts
  - anterior mediastinum in front of the pericardium
  - middle mediastinum containing the pericardium and its contents
  - posterior mediastinum behind the pericardium

10.2 Surgery of the Mediastinum

Diseases of the thymus, the esophagus, and the lymphatic tissue are the main indications for surgery of the mediastinum, more rarely, ectopic thyroid and parathyroid glands. A variety of benign as well as primary and secondary (metastatic) malignant lesions indicates surgical biopsy or resection (Table 10.1). While in open surgery the mediastinum is approached either transcervically or via a sternotomy, for most minimally invasive video-assisted procedures the approach is transthoracic with incision of the mediastinal pleura.

It has turned out that both, the anterior and the posterior mediastinum are accessible by a robotic approach. It is, thus, not the anatomic location, but the underlying disease that determines whether a robotic approach is indicated or not. Lesions larger than 5–7 cm in diameter are difficult to grasp and handle with the robotic instruments and the vision might be impaired. Potential infiltration of surrounding tissue has still been considered a contraindication for any minimally invasive approach, though the robot specific technical advances (3-D imaging, multi-articulating instruments) allow for meticulous dissection.

Table 10.1 Surgically relevant diseases of the mediastinum and corresponding (minimally invasive) procedures

Disease	Procedure
Thymoma, thymic cyst, myasthenia gravis	(Extended) thymectomy
(paravertebral) neurinoma	Extirpation
Lymph node metastasis	Biopsy, sampling, oncologic dissection
Foregut cyst	Extirpation
Esophageal leiomyoma	Extirpation
Esophageal cancer	Dissection, resection, reconstruction
(Ectopic) parathyroid tissue	Extirpation
(Ectopic) thyroid tissue	Extirpation
Lymphoma	Biopsy, (extirpation)
Germ cell tumors including teratoma	Extirpation

10.3 Anesthetic Management

The anesthetic management does not significantly differ from a conventional video-assisted thoracoscopic approach. Since all procedures are trans-thoracic through one pleural cavity, single lung ventilation achieved by a double lumen tube is standard. The earlier the single lung ventilation is set, the faster the excluded lung collapses, thus opening space for the robotic instruments and videoscope. Intense collaboration and communication with the anesthesiologists are of utmost importance since their working space is significantly limited by the robotic arm cart which is positioned cephalad in most thoracic robotic procedures. An arterial as well as a central venous line are recommended.

10.4 Operative Set-Up

The procedures are performed with a limited range of robotic instruments: DeBakey® and Cadiere® forceps, needle holder, scissors, cautery hook and robotic clip applier are used. Dissection is mainly performed with electrocautery, alternatively with scissors or ultrasonic energy instruments (harmonic curved shears). Robotic clips are used for small vascular structures (e.g. thymic veins) while larger structures may alternatively be controlled by conventional stapler devices introduced through an auxiliary port by the table-site assistant.

We have the scrub nurse warming the binocular robotic scope in a sterilized thermos bottle to prevent it from recurrent fogging during the initial phase. Both, surgeons and scrub nurses should be well-prepared for immediate conversion to an emergency thoracotomy in case of a major bleeding. Therefore, a set of instruments for thoracotomy is always prepared in our operating room. It is highly advisable to establish a dedicated team for robotic surgery.

Patient positioning is procedure specific:

- Posterior mediastinal interventions (paravertebral neurinoma, cyst, esophageal dissection, lymph node dissection) positioning is extreme lateral decubitus;
- Anterior mediastinal lesions standard lateral decubitus position is applied;
- Thymectomies, incomplete lateral decubitus (30°–45°) position is of advantage.

The site of incision might differ from the ones listed below based on tumor location.

Padding and taping do not differ from those for conventional thoracoscopic procedures. Specific attention must be paid by the bedside-assistant surgeon to avoid injuries to the patient from movements of the robotic arms. The primary surgeon on the console is not aware of range and power of motions that are transmitted from the handles of his console to the robotic arm cart.

At the end of a procedure a chest tube is placed in the pleural cavity.

10.5 Stepwise Conduct of the Operation

10.5.1 Extended Thymectomy

Extended thymectomy is performed with en bloc resection of the anterior mediastinal fat tissue including the thymus as described by Masaoka et al. [6]. All adipose tissue around the upper poles of the thymus, around both brachiocephalic veins and on the pericardium is dissected meticulously. Borders of dissection are the diaphragm caudally, the thyroid gland cranially, and the phrenic nerves laterally.

In our setting, which is a right-sided approach (unless there is a far left sided thymoma), the patient's right arm is positioned at the side as far back as possible to gain enough space for the robotic arms (Fig. 10.2). The port for the robotic endoscope is positioned in the fifth to sixth intercostal space in the mid-axillary line. A more ventral position would facilitate contralateral preparation but hamper ipsilateral dissection. The camera is inserted and under vision control the two robotic instrument ports are placed in the third and sixth intercostal spaces, one hand's breadth left and right of the camera trocar, respectively, in the submammary fold. (Fig. 10.3). The three ports enclose an angle of 70°–90° to

Fig. 10.2 Patient positioning for a robotic thymectomy

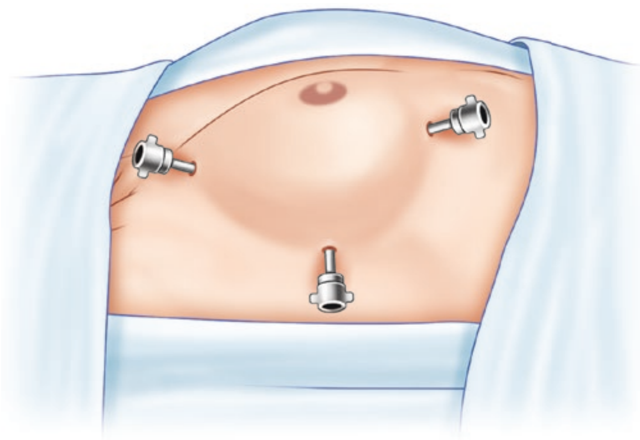


Fig. 10.3 Incisions for robotic thymectomy in a right sided approach

prevent extra-corporal collision of the robotic arms. An auxiliary port is inserted latero-dorsal to the camera trocar one intercostal space cranially, if needed. The robotic arm cart is moved towards the patient's ventral side (Fig. 10.4). Dissection starts ventral to the right phrenic nerve from cranial to caudal and is performed with the robotic cautery hook in the right and the Cadiere forceps in the left robotic instrument arm (Fig. 10.5). En-bloc extirpation of fat tissue in the lower anterior mediastinum may be hindered by collision of the left robotic arm with the patient's shoulder. In this situation a curved thoracoscopic grasper is inserted via the auxiliary port to achieve better exposure. Dissection continues to the substernal region where the left parietal pleural is incised along, but medially to the intrathoracic (mammaric) bundle. The thymus is dissected free from the pericardium and preparation proceeds cranially up to the thymic and innominate veins. Before the thymic veins are controlled, the right and left upper horns are freed. This allows for better mobility of the specimen and thus for better dissection of the (usually one to three) thymic veins. The vessels are clipped; however, very smaller ones are controlled by electrocautery. The da Vinci system enables the surgeon to also dissect the left thymic lobe accurately from a right-sided access in most patients. This is facilitated by the thoraco-lift, meaning that the chest wall is actively lifted by the robotic arms along the three trocars. This allows in addition with the multi-articulation of the robotic instruments for a dissection along the curved shape of the heart and the great vessels over to the left phrenic nerve. Once the specimen is completely freed, it is removed in an endobag that is either inserted via one of the robotic ports or an auxiliary port. A specimen of a robotic assisted thymectomy is shown in Fig. 10.6.

When looking at the current literature, right- and left-sided approaches have been used. According to the authors, a left-sided approach facilitates the accurate dissection at the level of the left phrenic nerve and the aorto-pulmonary window as a frequent site of ectopic thymic tissue is easier to reach [7, 8]. Savitt et al. favor a right-side approach, because the heart impairs the reach of the lower robotic arm into the superior mediastinum [9]. This might be one reason why this right-sided approach is described one intercostal space lower than the left-sided approach. A bilateral approach may be even more accurate. However, it is more time consuming and should only be used when exposure of the contralateral phrenic nerve is insufficient and appropriate dissection is not possible, especially in myasthenia gravis patients. Also, a subxiphoid robotic approach for thymic resection in a cadaver was described. However, no application of this approach in a clinical setting was reported.

In patients with thymoma, the dissection does not differ from thymus resection for myasthenia gravis. However, based on our experience, the robotic approach is not recommended in thymic tumors larger than 5 cm in diameter. Handling of the specimen with small robotic instruments is impaired, removal of the usually hard lesions through the small incisions bears the risk of harm to the lesion and affects pathological examination negatively; finally, oncologic concerns exist [5].

10.5.2 Extirpation of a Posterior Mediastinal Paravertebral Tumor (Neurinoma, Cyst, Sympathetic Chain Lesion)

For posteriorly located masses, the camera port is positioned in the anterior axillary line. Locations of the incisions are highly dependable on tumor location. The ports for the two working arms are placed symmetrically one hand's breadth right and left of the camera trocar. The cart is then approached from dorso-cranial (Fig. 10.7). An auxiliary port is usually not needed in these procedures. Dissection is carried out using a Cadiere forceps in one and the cautery hook in the other hand. The tumor is excised en bloc with the covering parietal pleura. It is removed in an endobag through the most anterior port site where the intercostal space is wider.

10.5.3 Resection of a Benign Esophageal Tumor (Leiomyoma, Foregut Cyst, Esophageal Diverticulum)

The robotic cart is situated at the right upper side of the patient. The trocars are placed far caudally (camera trocar in the ninth intercostal space in the mid-axillary line, left robotic arm in the ninth intercostal space in the posterior-axillary line, right robotic arm in the eighth intercostal space in the anterior-axillary line). One auxiliary port for suction and retraction of the deflated lung is positioned between the left robotic arm and the camera arm. Dissection starts with

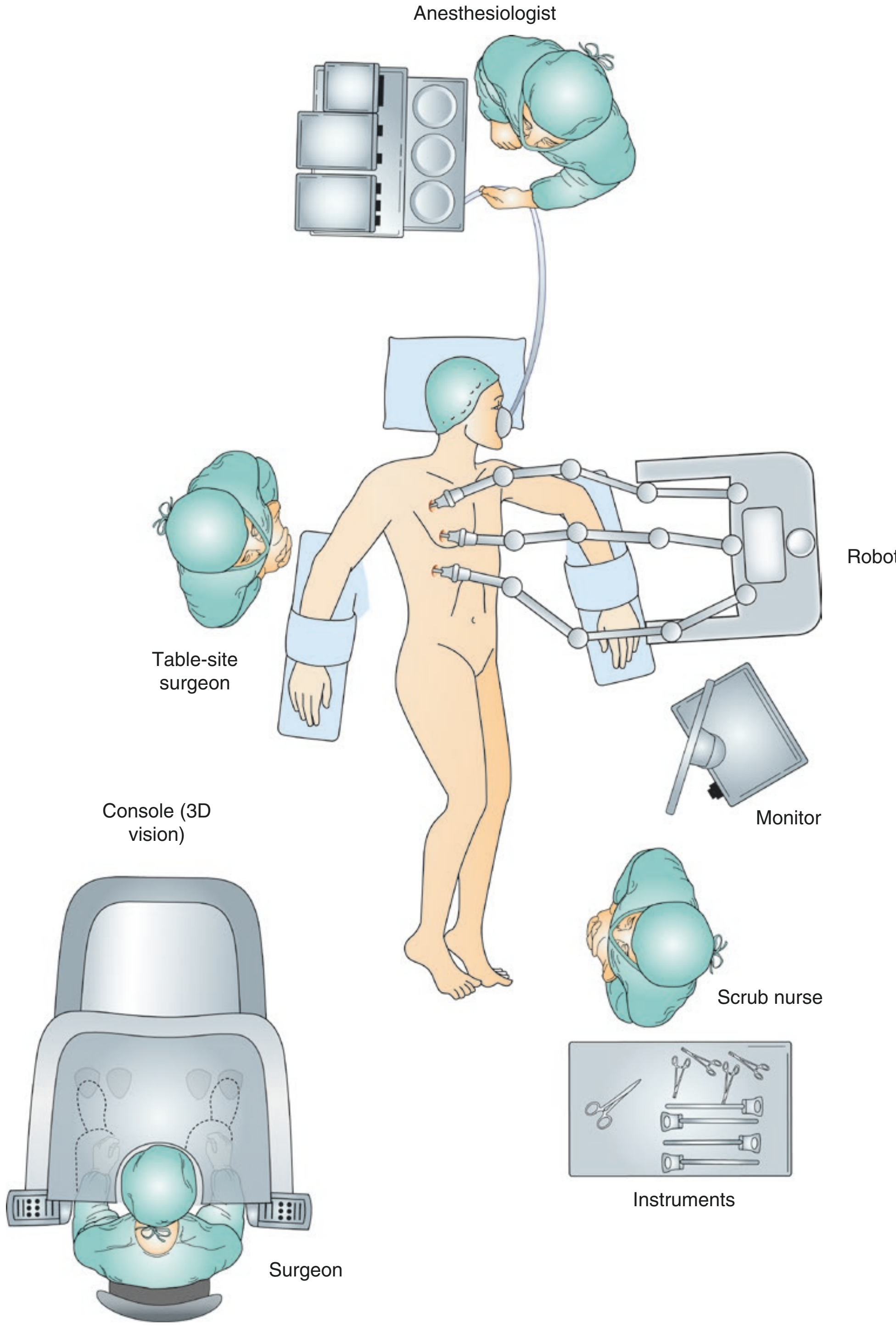


Fig. 10.4 OR setting for a robotic thymectomy

the incision of the parietal pleura to expose the esophagus. If the tumor is located deep to the azygos vein, the azygos vein is divided using a vascular endostapler introduced through the auxiliary port. A 270°–360° mobilisation of the esophagus over a distance of at least 10 cm (corresponding to the location of the tumor) is performed using the robotic hook cautery. An esophageal myotomy for resection of an intramural tumor of approximately 6 cm (depending of the size of the lesion) is performed. The tumor is dissected with the hook cautery including control of small feeding vessels. After complete resection, the integrity of the mucosa is confirmed by intraoperative upper endoscopy with gas insufflation. The tumor is removed in an endobag and the esophageal myotomy is closed using interrupted sutures. If the lesion is located in the lower esophagus in the posterior phrenicocostal sinus, the diaphragm gets intermittently fixed to the

Fig. 10.5 Intraoperative view during robotic thymectomy

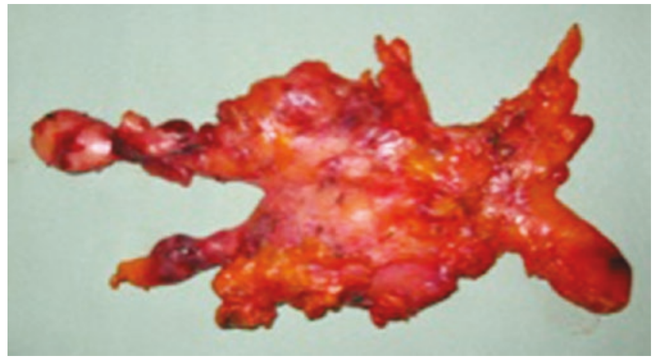


Fig. 10.6 Specimen of robotic assisted thymectomy

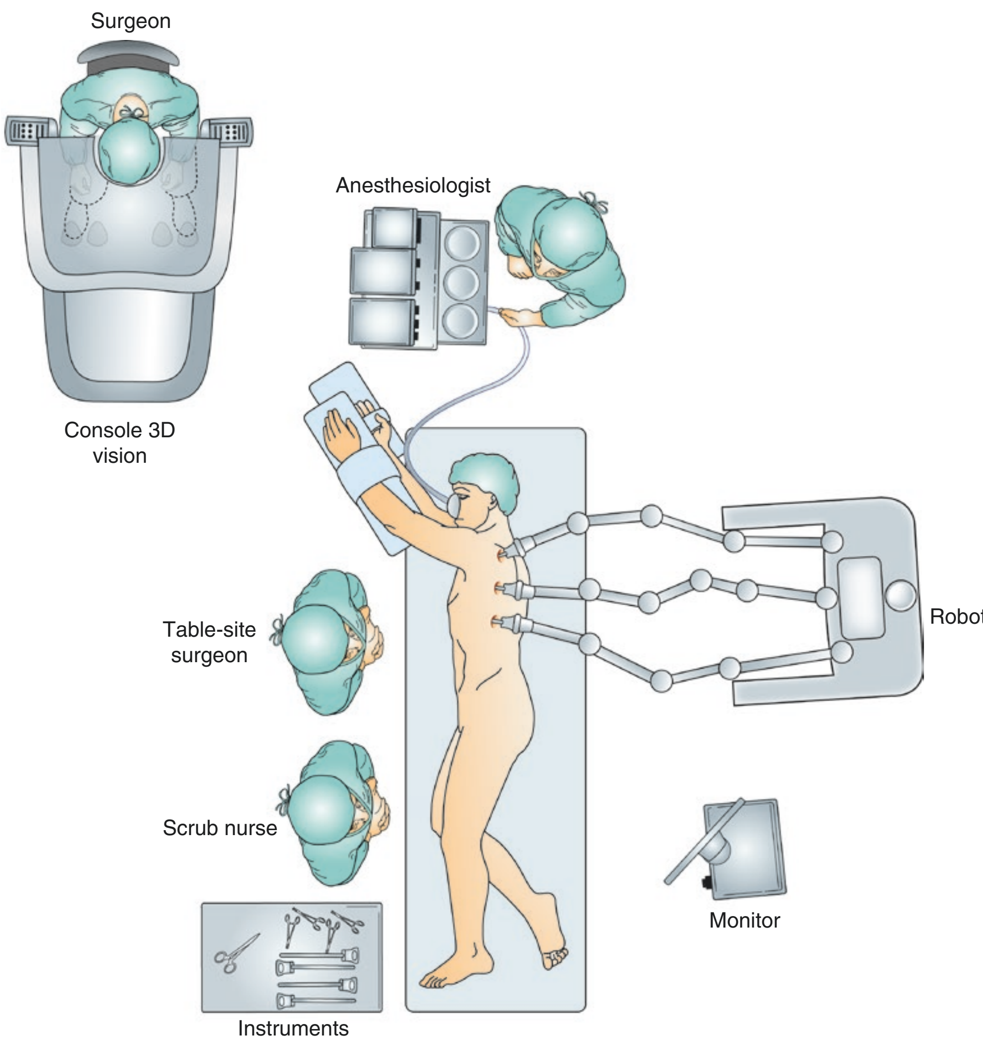


Fig. 10.7 OR setting for a robotic dorso-cranial approach

thoracic wall and the pulmonary ligament is divided with the cautery hook, both for better exposure. Again, the lesion is enucleated and the esophageal muscular layer is repaired in an interrupted stitch fashion. An esophageal diverticulum is excised followed by the closure of the esophageal defect in a two layer single stitch fashion.

10.5.4 Extirpation of Masses in the Aortopulmonary Window (Ectopic Parathyroids, Lymph Nodes)

The camera port is inserted in the sixth intercostal space in the anterior axillary line and the two instrument ports are both placed in the fourth intercostal space one hand's breadth right and left, respectively [10]. A first auxiliary port flexible is placed in the medio-clavicular line of the sixth intercostal space and the upper lobe of the left lung is pushed caudally with a retractor by the table site assistant. Suction is provided via a second auxiliary port, positioned in the posterior axillary line of the sixth intercostal space. Dissection starts by incising the parietal pleura covering the aortopulmonary window. Care must be taken not to injure the left vagal and recurrent laryngeal nerves. The mass is carefully dissected from the aortic arch, the trunk of the pulmonary artery, and the trachea with the hook cautery. If present, vascular pedicles are controlled with clips.

10.5.5 Resection of an Ectopic Mediastinal Goiter

The trocar for the robotic endoscope is positioned in the eighth intercostal space in the posterior axillary line and the two 8-mm robotic operating trocars are placed one handbreadth to the right and left of the first incision, respectively. Lung retraction is performed by the bedside assistant with a flexible retractor inserted via an auxiliary port in the anterior axillary line of the sixth intercostal space. Resection is performed using the robotic Cadiere forceps and the robotic cautery hook. Dissection starts with incision of the parietal pleura at the upper margin of the azygos vein. The tumor is freed beginning from caudally and dissection proceeds upwards along but lateral to the superior vena cava. When dissection posterior to the superior vena cava is necessary, care must be taken not to injure the phrenic nerve. In ectopic goiters, the blood supply derives from cephalad from one or more arteries and several small veins draining into the innominate veins. Control of these structures is achieved using robotic clips or coagulation.

10.6 Tips and Pitfalls

These have been mentioned in the previous chapter when the different procedures were described and are here listed in a summary fashion:

- place the three robotic ports in a way that they enclose an angle of at least 70°–90° to prevent extra-corporal collision of the robotic arms
- in robotic thymectomy, position the patient's right arm at the side as far back as possible to gain enough space for the robotic arms
- in robotic thymectomy, dissection in the far low anterior mediastinum may be hindered by collision of the left robotic arm with the patient's shoulder. If experiencing this situation insert a curved thoracoscopic grasper via the auxiliary port to achieve better exposure
- prior dissection of the upper thymic horns allows for better mobility of the specimen and thus for safer dissection of the thymic veins
- the thoraco-lift (the active lifting of the chest wall by the robotic arms along the three trocars) provides more space and allows for dissection of the left thymic lobes from a single right sided approach (and vice versa)
- do not approach thymic tumors larger than 5 cm in diameter robotically for safety and oncologic reasons
- remove the mass always through the most anterior port site where the intercostal spaces are wider.
- fix the diaphragm intermittently to the thoracic wall and divide the pulmonary ligament if a mass is located in the posterior phrenico-costal sinus
- the console surgeon should be aware of range and power of motions which are transmitted from the handles of his console to the robotic arm cart

10.7 Postoperative Management Issues

Once the procedure has been completed and hemostasis has been controlled, the robotic instruments are removed and the robotic arms are detached from the ports. Usually one chest drain is inserted under vision but with manual control of the robotic camera. After the lung is reinflated, the camera is removed. Extubation in the operating room is routinely performed unless specific contraindications exist.

Postoperative management is not robotic-specific and does not differ from the conventional VATS regime. Patients start drinking when fully awake and get mobilized the evening of the procedure. Drains are removed when no air-leak is present and output is less 300 cm^3. Chest x-rays are performed in the recovery room and after chest tube removal.

10.8 Outcomes

Favorable outcomes for robotic resections of mediastinal masses were reported by different groups [3, 8, 11–13]. The robot facilitates and enables more technically advanced surgical procedures by means of a minimally invasive approach. The main concern of robotic surgery—when starting a program—is operative time which has a proven negative impact on patient outcome if excessively prolonged. Thus, surgeons are encouraged to work with a dedicated team specially trained in robotic set up and to convert to an open approach if no surgical progress has been made over a period of time.

References

1. Roviaro GC, Varoli F, Vergani C, Maciocco M. State of the art in thoracoscopic surgery. A personal experience of 2000 videothoracoscopic procedures and an overview of the literature. Surg Endosc. 2002;16:881–92.
2. Dieter RA, Kuzycz GB. Complications and contraindications of thoracoscopy. Int Surg. 1997;82:232–9.
3. Schurr MO, Arezzo A, Buess GF. Robotics and systems technology for advanced endoscopic procedures: experiences in general surgery. Eur J Cardiothorac Surg. 1999;16:97–105.
4. Morgan JA, Kohmoto T, Smith CR, Oz MC, Argenziano M. Endoscopic computer-enhanced mediastinal mass resection using robotic technology. Heart Surg Forum. 2003;6:164–6.
5. Balduyck B, Hendriks JM, Lauwers P, Mercelis R, Ten Broecke P, Van Schil P. Quality of life after anterior mediastinal mass resection: a prospective study comparing open with robotic-assisted thoracoscopic resection. Eur J Cardiothorac Surg. 2011;39(4):543–8.
6. Masaoka A, Yamakawa Y, Niwa H, et al. Extended thymectomy for myasthenia gravis patients: a 20-year review. Ann Thorac Surg. 1996;62:853–9.
7. Rea F, Marulli G, Bortolotti L, Feltracco P, Zuin A, Sartori F. Experience with the “Da Vinci” robotic system for thymectomy in patients with myasthenia gravis: report of 33 cases. Ann Thorac Surg. 2006;81:455–9.
8. Rückert JC, Swierzy M, Ismail M. Comparison of robotic and nonrobotic thoracoscopic thymectomy: a cohort study. J Thorac Cardiovasc Surg. 2011;141:673–7.
9. Savitt MA, Gao G, Furnary AP, Swanson J, Gately HL, Handy JR. Application of robotic-assisted techniques to the surgical evaluation and treatment of the anterior mediastinum. Ann Thorac Surg. 2005;79:450–5.
10. Bodner J, Profanter C, Prommegger R, Greiner A, Margreiter R, Schmid T, et al. Mediastinal parathyroidectomy with the da Vinci robot: presentation of a new technique. J Thorac Cardiovasc Surg. 2004;127:1831–2.
11. Augustin F, Schmid T, Sieb M, Lucciarini P, Bodner J. Video-assisted thoracoscopic surgery versus robotic-assisted thoracoscopic surgery thymectomy. Ann Thorac Surg. 2008;85:768–71.
12. Meehan JJ, Sandler AD. Robotic resection of mediastinal masses in children. J Laparoendosc Adv Surg Tech A. 2008;18:114–9.
13. Goldstein SD, Yang SC. Assessment of robotic thymectomy using the Myasthenia Gravis Foundation of America Guidelines. Ann Thorac Surg. 2010;89:1080–5.

Part IV

Esophagectomy

Robotic Transhiatal Esophagectomy

11

Ozanan R. Meireles and Santiago Horgan

Abstract

The first published report of robotic esophagectomy was in 2002, the transhiatal approach. Patients with severe dysplasia and early stage esophageal cancer, end-stage achalasia, severe refractory reflux disease, and other end-stage esophageal diseases that have resulted in a severely diseased nonfunctioning esophagus appear amenable to this approach. The anesthetic and surgical management are described along with the lessons learned from the surgical team. Each step of the procedure is illustrated and the outcomes of the procedure described. The outcomes from this procedure demonstrate an efficient technique that has great potential.

Keywords

Robot-assisted • Minimally invasive surgery • Esophagectomy • End stage achalasia • End stage gastroesophageal reflux disease • Computer-assisted surgery • Esophageal neoplasms • Thoracoscopy • Laparoscopy

11.1 Background and Specific Indications

Esophagectomy is among the most complex and traumatic operations in gastrointestinal surgery, and has been associated with major postoperative morbidity and mortality [1]. The indications for esophagectomy range from benign conditions, such as megaesophagus and severe strictures to premalignant and malignant lesions.

Currently, the major indication for this operation is carcinoma of the esophagus, with incidence of 5 per 100,000 people in the United States. In 2009, The National Cancer Institute estimated that yearly, 13,200 Americans would be diagnosed with esophageal cancer and 12,500 would die from it [2]. Adenocarcinoma accounts for about 50% of all new cases of esophageal cancer in the US [3, 4], it is usually located in the lower esophagus or at the gastroesophageal junction. The most important risk factor associated with this disease is gastroesophageal reflux disease (GERD). Approximately 15% of patients with GERD develop intestinal metaplasia and 1% of these develop esophageal cancer. Moreover, it has been shown that Barrett's with high-grade dysplasia (HGD) harbors unsuspected adenocarcinoma in 60% of the cases [5].

The first successful esophagectomy with gastric pull-up was performed through the left chest in 1933 [6]. Since then the technique evolved from open to laparoscopic to robotic procedures. Minimally invasive surgical techniques were introduced in an effort to lessen the invasiveness of the open approaches [7, 8]. In 1990s De Paula [9] and Swanstrom [10] reported the first trans-hiatal laparoscopic esophagectomy (THE), reporting excellent visualization up to the level of the inferior pulmonary vein, with minimal blood loss, shorter operative times and hospital stay [7]. However, the

O. R. Meireles, M.D. (✉)
Department of General and Gastrointestinal Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, MA, USA
e-mail: OzMeireles@mgh.harvard.edu

S. Horgan, M.D.
UC San Diego Health—La Jolla, 4520 Executive Drive, San Diego, CA 92121, USA
e-mail: shorgan@ucsd.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_11

shortcoming of laparoscopy, such as lack of stereoscopic view, unstable camera platform, straight laparoscopic instruments with limited degrees of freedom, and poor ergonomics, made it difficult to perform an adequate middle and upper esophageal dissection and mediastinal nodal harvesting [11]. Some surgeons have adopted hybrid laparoscopic and thoracoscopic approaches in order to overcome the limitations of laparoscopy, and consequently purely laparoscopic esophagectomy has failed to become widely adopted as the treatment of choice for esophageal cancer. For those reasons many esophageal surgeons still debating over the most beneficial approach and no surgical technique has prevailed over the others [12].

In 2003, we described the very first robotic assisted transhiatal esophagectomy [13], followed by several reports that confirmed the feasibility and safety of the technique. The robotic system allows the surgeon to work in the narrow space of the mediastinum, overcoming spatial limitations experienced during standard laparoscopy. It offers stereoscopic view and utilizes instruments that are 7.5 cm longer than standard laparoscopic instruments; therefore, allowing more proximal mobilization, reaching sometimes beyond the level of the carina. Furthermore, the dissection in the vicinity of the pulmonary veins, aorta, parietal pleura and pericardium can be accomplished safely due to the articulated instruments tip, the three dimensional visualization and the magnification of the operative field. It has also been shown that this approach maintains the oncological principles without the need of concomitant thoracoscopy when compared with standard laparoscopic trans-hiatal esophagectomy (THE) [14–16].

11.2 Operative Set-Up

A dedicated large operating room for the robotic equipment is highly recommended, where enough room can be provided for the anesthesia equipment, the da Vinci robotic system, the standard laparoscopic towers and the endoscopic tower.

The anesthesia machine and monitors must be positioned away from the patient due to the position of the da Vinci® surgical system over the patient's head.

11.3 Anesthetic Management

The anesthesiologist must understand the special implications on the management of patients undergoing robotically-assisted THE. Some important concern related to the procedure are the patient positioning, duration of the procedure, development of hypothermia, and the well-known hemodynamic and respiratory effects related to the pneumoperitoneum.

The induction of general anesthesia takes place with the patient in supine position, where a single-lumen endotracheal tube is utilized. The use of invasive hemodynamic monitoring, pneumatic compression stockings on both legs and preoperative antibiotics are recommended routinely. Due to the extreme positioning, the possibility of patients sliding off the operating room table increases, therefore restraints must be used. Also a foam egg crate mattress should be placed in between the patient pressure points and the operating room table to avoid tissue and nerve impingement. Finally, careful attention should also be given to the robotic arms location and motion to prevent them from contacting the patient and cause pressure or crush injuries.

Another important consideration is the access of the patient's airway by the anesthesiologist when the robot is docked. Due to the substantial size of the robot and it's cephalad position over the patient during the procedure, significant draping on both the robot and patient is required, additionally the patient's airway has to be located at an increased distance from the anesthesiologist and the anesthesia machine, therefore making access the patient head rather difficult.

11.4 Stepwise Conduct of the Operation

The aims of this operation are to resect the esophagus, perform lymphadenectomy when indicated, create a gastric conduit and perform a cervical anastomosis. The surgical steps are:

1. Perioperative EGD
2. Positioning
3. Port placements
4. Exposure of the Hiatus and mobilization of the Stomach
5. Ligation of the left gastric artery
6. Trans-mediastinal esophageal dissection
7. Open cervical dissection
8. Creation of the gastric tube and resection of the specimen
9. Cervical anastomosis

11.4.1 Upper Flexible Endoscopy

After endotracheal intubation, Esophagogastroduodenoscopy is performed to assess endoluminal anatomy and reconfirm the nature and location of the esophageal lesion.

11.4.2 Positioning

The patient is placed in low dorsal lithotomy position, and the abdomen, chest, and neck are prepared and draped in the usual sterile fashion. It is important to acknowledge that repositioning the patient on the operating room table after the robotic arms have been docked is extremely cumbersome, therefore the patient must be optimally positioned before the robotic portion of the operation begins. To allow proper placement of the robotic arms and optimal access to the upper abdomen and hiatus the patient should be positioned in steep reverse Trendelenburg, where the gravitational effect assists on the displacement of the small bowel and omentum from the surgical field (Fig. 11.1).

11.4.3 Port Placement

The peritoneal cavity access is obtained with the insertion of a 12-mm trocar under direct visualization, using an ENDOPATH Optiview® trocar (Ethicon Endosurgery, Cincinnati, OH) with a 0° laparoscope, in the left side of the

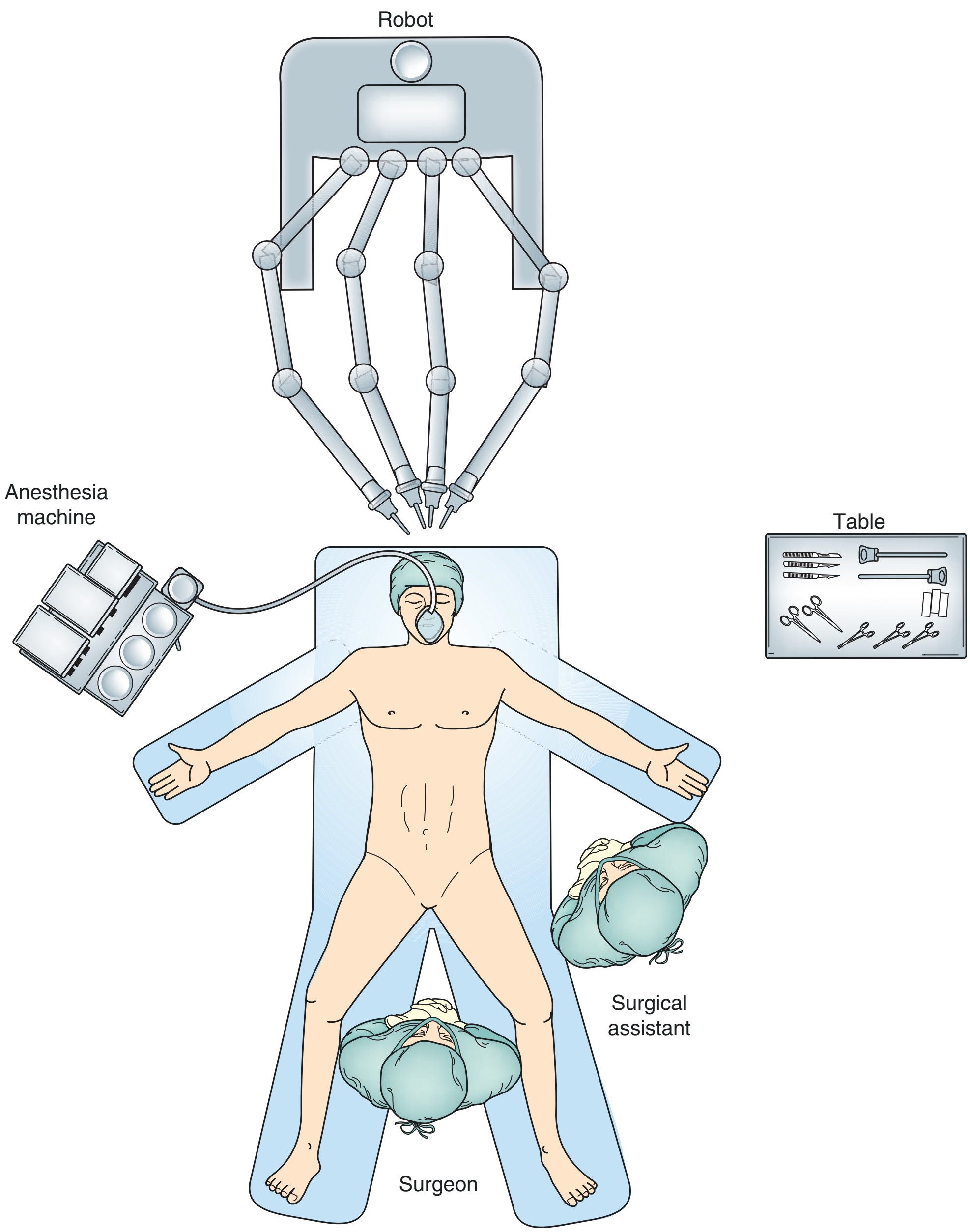


Fig. 11.1 Patient position for the robotic transhiatal esophagectomy. The patient is placed in low dorsal lithotomy position, and the abdomen, chest, and neck are prepared and draped in the usual sterile fashion. It is important to acknowledge that repositioning the patient on the operating room table after the robotic arms have been docked is extremely cumbersome; therefore, the patient must be optimally positioned before the robotic portion of the operation begins. The patient is then placed in steep reverse Trendelenburg position. The surgeon stands in between the patient's legs and the first assistant on the patient's left side

mid-abdomen, two fingerbreadths lateral to the umbilical scar and one palm width inferior to left subcostal margin, to allow optimal visualization of the gastroesophageal junction. This 12-mm trocar will be later utilized by the robotic system's camera. After successful access to the peritoneal cavity, pneumoperitoneum is accomplished at 15 mmHg using CO_2. The peritoneal cavity is then surveyed to rule out carcinomatosis. Under direct visualization two 8-mm ports are individually placed at the left and right mid-subcostal margin. Through a subxyphoid 5 mm incision, a Nathanson retractor is introduced to retract the left lobe of the liver anteriorly. Finally a 10-mm assistant port is placed at the patient's left midabdomen at the level of the anterior axillary line for the use of suction and passage of sutures during the operation. The patient is then placed in steep reverse Trendelenburg position. The surgeon stands in between the patient's legs and the first assistant on the patient's left side (Fig. 11.2).

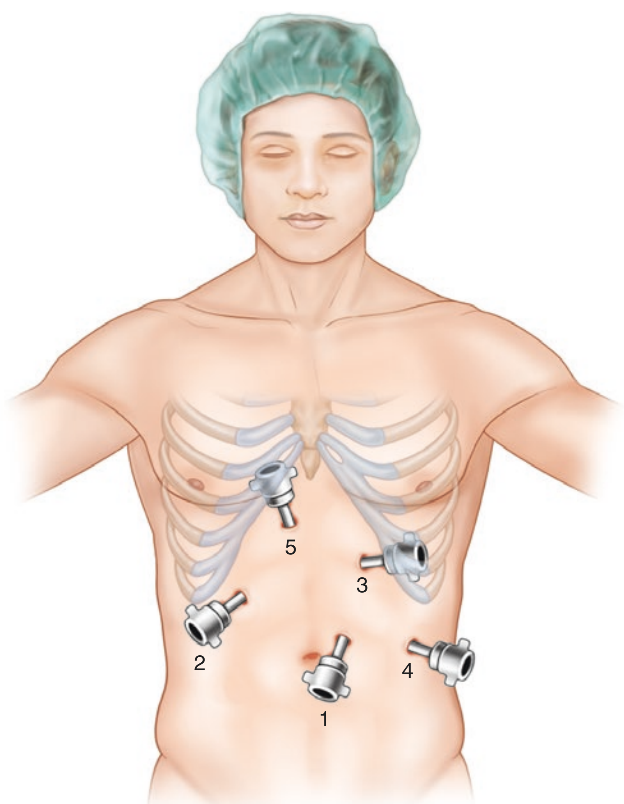


Fig. 11.2 Port placement for the robotic transhiatal esophagectomy. (1) 12-mm optical trocar, in the left side of the mid-abdomen, two fingerbreadths lateral to the umbilical scar and one palm width inferior to left subcostal margin. (2 and 3) 8-mm ports placed at the left and right mid-subcostal margin. (4) 10-mm assistant port placed at the patient's left midabdomen at the level of the anterior axillary line for the use of suction and passage of sutures. (5) 5 mm subxyphoid incision for placement of a Nathanson® retractor

11.4.4 Exposure of the Hiatus and Mobilization of the Stomach

The operation starts with standard laparoscopic instrumentation. The left crus is identified and freed from the phrenoesophageal membrane using ultrasonic shears, followed by blunt dissection to separate the former from the esophagus. The stomach's greater curvature is then mobilized by transecting the gastrocolic ligament and short gastric vessels, starting at the level of the distal gastric body and extending cephalad to the previously dissected left crus. The gastrohepatic ligament is then opened, and the hepatic branch of the Vagus nerve is divided, allowing identification of the right crus, which is freed from the phrenoesophageal attachments using electrocautery or ultrasonic shears. A retroesophageal window is created to permit passage of a Penrose drain, which is used to encircle the gastroesophageal junction and allow further manipulation of the esophagus during the remaining of the operation (Fig. 11.3).

11.4.5 Ligation of the Left Gastric Artery

Additional mobilization of the stomach is attained by transecting the left gastric artery and vein with linear EndoGIA stapler device (Endo-GIA Ethicon Endosurgery, Cincinnati, OH) using vascular load. The dissection of the gastrocolic ligament is extended along the greater curvature toward the antrum, where the pylorus is adequately dissected and the posterior gastric attachments within the lesser space are free. During this part of the operation, particular attention should be paid to avoid iatrogenic injuries to the right gastroepiploic artery, since it will be responsible for the vascular supply to the gastric tube. Kocher maneuver and pyloroplasty are not necessary in cases where adequate mobilization of the stomach is attained the Vagus nerves are preserved.

11.4.6 Trans-Mediastinal Esophageal Dissection

After the hiatus has been exposed and the stomach mobilized laparoscopic, the da Vinci Surgical System is then positioned cephalad to the patient and docked to the optic and to working trocars. A Cadiere® forceps (Intuitive Surgical, Inc. Sunnyvale, California) is placed at the surgeon's left hand, and an articulated hook cautery at the surgeon's right hand. During the robotic portion of this procedure, the assistant surgeon remains at the patients' left side. Trans-hiatal dissection of the esophagus is carried cephalad through the

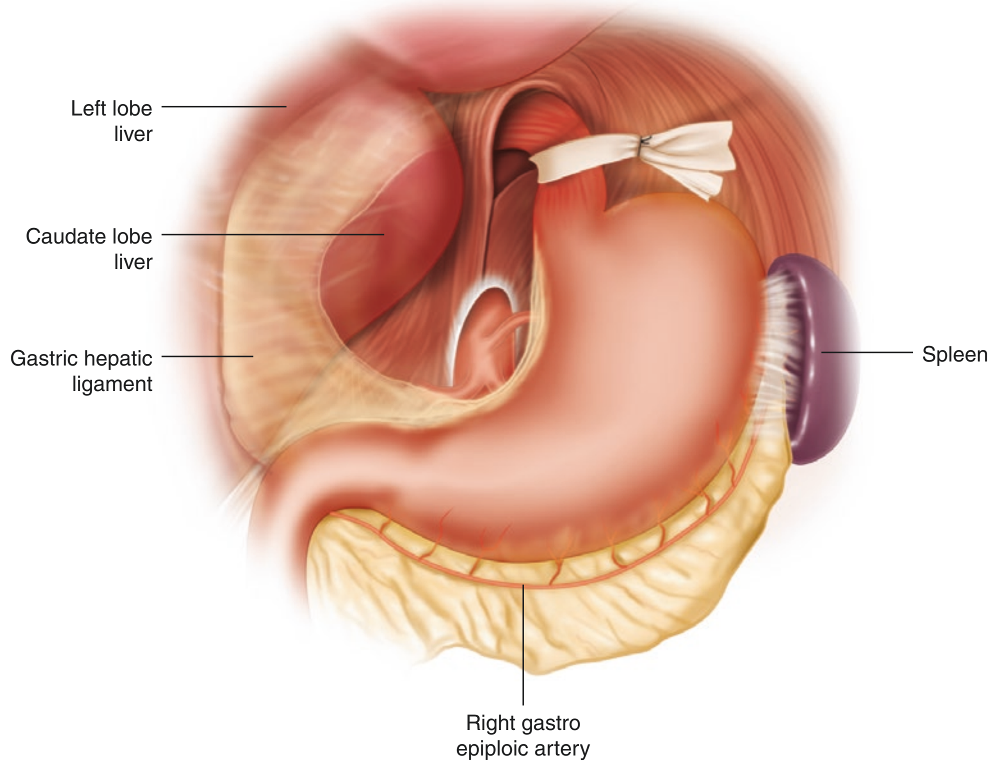


Fig. 11.3 Exposed esophageal hiatus. A Penrose drain is placed around the distal esophagus and used for retraction of the stomach by the assistant or bedside surgeon. The left gastric artery is dissected with the adjacent lymph nodes and divided with a vascular stapler

mediastinum along the circumferential borders of the esophagus. During this step the precise moments of the robotic instruments are fundamental to accomplish accurate circumferential dissection of the esophagus and proper lymph node harvesting, and at the same time to avoid injuries to the pleura and the pericardium and reach the thoracic inlet. Once the upper mediastinum is reached the robotic dissection is finalized, and the da Vinci Surgical System is undocked (Figs. 11.4 and 11.5).

11.4.7 Cervical Dissection

After the trans-hiatal dissection has been successfully completed up to the level of the upper mediastinum, a cervical incision along the anterior border of the left sternocleidomastoid muscle is performed, and cervical esophageal dissection is undertaken to free the proximal esophagus. During this step, esophageal intubation with an NG tube or flexible gastroscope greatly facilitates the circumferential mobilization of the esophagus. A Penrose drain is then passed around the cervical esophagus, and finger dissection is taken down to the superior or mid mediastinum to connect the cervical and transhiatal dissection. It is important to mention that care must be taken to preserve and avoid injuries the recurrent laryngeal nerves.

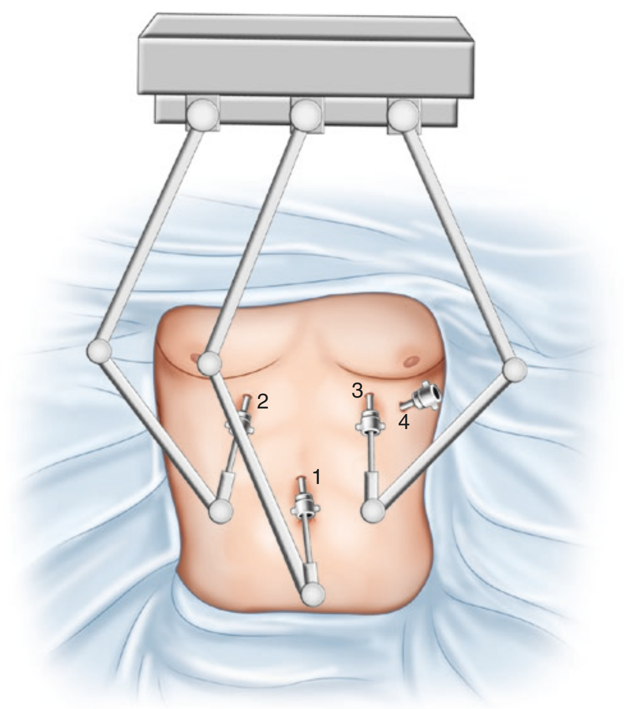


Fig. 11.4 Transhiatal dissection of the thoracic esophagus. After the hiatus has been exposed and the stomach mobilized laparoscopically, the da Vinci Surgical System is then positioned cephalad to the patient and docked to the optic and to the working trocars. (1) Robotic optical trocar; (2) Articulated Hook Cautery; (3) Cadiere® forceps; (4) Assistant's surgeon port

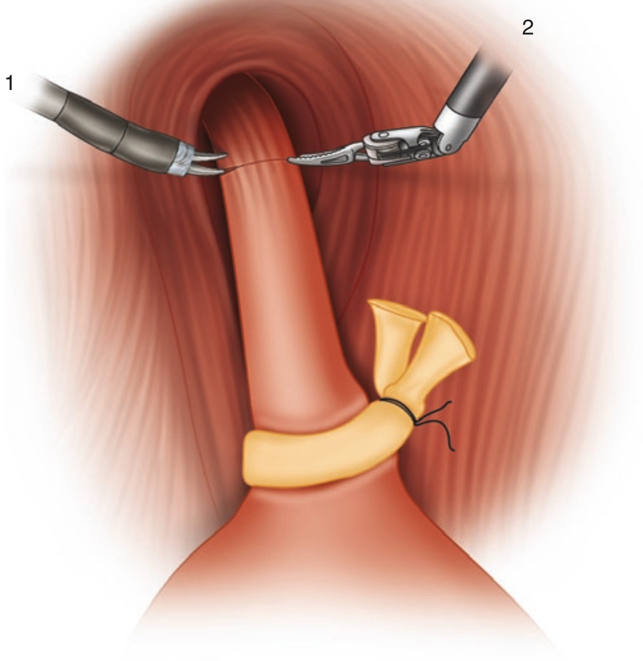


Fig. 11.5 Deep transhiatal dissection. The Assistant is retracting the stomach and esophagus using the Penrose drain. (1) Cadiere® forceps; (2) Articulating hook cautery or other energy device of choice

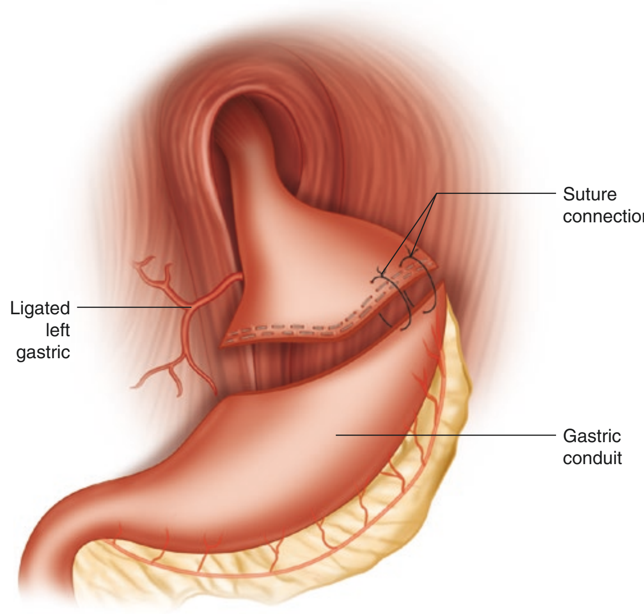


Fig. 11.6 Gastric tube sutured to the specimen. After the trans-hiatal dissection has been successfully completed up to the level of the upper mediastinum, the cervical esophageal dissection is undertaken to free the proximal esophagus through a left neck incision. The robot is undocked and laparoscopy is resumed, and the gastric conduit is created along the greater curvature of the stomach with several sequential staple loads. From the cervical incision, the specimen is removed and the gastric tube is pulled into the mediastinum to perform the anastomosis

11.4.8 Gastric Tube Formation and Resection of the Specimen

After the cervical mobilization of the esophagus is completed, the laparoscopy is resumed and the gastric conduit is created along the greater curvature of the stomach with several sequential staple loads, using a 3.5 mm EndoGIA stapler device (Endo-GIA Ethicon Endosurgery, Cincinnati, OH). From the cervical incision, the specimen is removed and the gastric tube is pulled through the mediastinum to perform the anastomosis (Fig. 11.6).

11.4.9 Cervical Anastomosis

Two different techniques can be used to complete the esophagogastric anastomosis. The classic two-layer hand-sewn anastomosis or the stapled technique, where a 3.5-mm GIA stapler device is used for the posterior wall, and a TA 55 stapler device is used for closure of the anterior wall. Finally a single 7-mm drain is placed at the mediastinal dissection bed lateral and posterior to the anastomosis and laparoscopic feeding jejunostomy are routinely performed.

11.5 Tips and Pitfalls

11.5.1 Tips

- Patients with BMI greater than 30 m^2/kg should be placed on liquid diet for 2 weeks before surgery to reduce the size of the liver and improve working space.
- The bedside cart should be positioned over the head of the patient, and the anesthesiologist with the anesthesia equipment positioned on the right side of the patient.
- The assistant should remain standing at the patients left side during the entire operation
- Steep reverse Trendelenburg position for surgery is preferred to optimize visualization of the hiatus and mediastinum.
- A specialized energy dissecting device, such as the harmonic scalpel or EndoWrist® One Vessel Sealer are essential to minimize blood loss and expedite the operation, especially during the gastric mobilization
- Left gastric artery should be ligated, as proximal as possible to its take off from the aorta to ensure optimal lymphadenectomy.

- During the mediastinal dissection, the robotic zero degree laparoscope is preferred
- The gastric tube should not be wider the normal esophageal caliber
- Pyloroplasty is not recommended on a routine basis
- The placement of feeding jejunostomy should be based on individual institution's protocol. This step is not considered mandatory for us.

11.5.2 Pitfalls

- Avoid dissecting to close to stomach to minimize injury to the gastroepiploic arteries and veins and therefore devitalize the gastric tube.
- Use stapler loads with greater heights in the distal stomach, such as green load (4.1 mm) or gold load (3.8 mm), and moderate height, blue load (3.5 mm), in the proximal stomach to avoid leaks.
- Avoid dissection in close proximity to the aorta in the mediastinum to avoid vascular iatrogenic injuries.
- The pleura openings should always be closed, to avoid residual pneumothoraxes.
- Thoracoscopy may be indicated during robotic THE when dealing with tumors located in mid esophagus.

11.6 Outcomes

Esophagectomy is one of the most complex operations of the gastrointestinal tract and it is associated with considerable postoperative morbidity and mortality. The unique characteristics of the da Vinci surgical system, including the longer and articulated instruments with 7 degrees of freedom, 3 dimensional visualization, stable camera platform, and improved ergonomics, provide fine and accurate movements in the narrow and confined mediastinum space, overcoming spatial and visual limitations experienced during standard thoracoscopic or laparoscopic techniques.

The robotic platform distinct features allows us to perform precise dissection during critical portions of the esophageal mobilization, especially near to the pulmonary veins, aorta, parietal pleura and pericardium, resulting in minimal cardiac and pulmonary complications, and significant decrease in blood loss when compared with laparoscopic THE [17]. Furthermore, the longer instruments on this stable platform make possible proximal esophageal mobilization beyond the level of the carina and adequate dissection of the mid and upper thoracic esophagus with enhanced lymph node harvesting accuracy. Hence, the da Vinci robotic system is capable to enhance dexterity by nearly 50% when compared with standard laparoscopy [18].

Additionally, the transhiatal route overcomes some of the disadvantages observed during thoracoscopic esophagectomy, such as the need of repositioning of the patient after the gastric mobilization, and the morbidities associated with prolonged one-lung ventilation [19]. Those advantages translated in zero 30-day mortality in one of our published series, which in our opinion was due to lessen cardiopulmonary complications and reduction of the perioperative stress.

Our experience also demonstrated that the operative time improves with the OR robotic team familiarity with the equipments and steps of the operation. In a series of cases performed in our institution, the initial mean operative time including the robotic setup time was 267 min, which decreased to a mean of 210 min in the last five cases [17].

In conclusion, robotically assisted Trans-Hiatal Esophagectomy is a safe and elegant operation with minimal blood loss, minimal respiratory complications, and minimal hospital mortality. The current robotic surgical system capabilities, particularly the three-dimensional visualization with magnification of the operative field and the articulated wristed instruments enhance the surgeon's ability to perform minimally invasive Trans-Hiatal Esophagectomy with fine and precise dissection in the very narrow mediastinum surgical field. Those enhancements is dexterity permit accurate esophageal dissection with optimal proximal and distal resection margins and a mean number of harvested lymph nodes comparable to thoracoscopic esophageal mobilizations, hence preserving the oncological surgical principles [20–22].

Finally, as an increasing number of surgical robotic systems populate the markets and more adequately trained esophageal surgeons become available, this type of operation will potentially supplant laparoscopic/thoracoscopic esophagectomy as the preferred surgical technique for the treatment of esophageal cancer. Certainly multi-institutional trials with long-term survival and oncological outcomes are necessary to add statistical power and validate those initial observations, and ultimately determine if robotic Trans-Hiatal Esophagectomy has better or at least comparable oncological outcomes to the historical results of open transhiatal or transthoracic techniques.

References

1. Birkmeyer JD, Siewers AE, Finlayson EV, et al. Hospital volume and surgical mortality in the United States. N Engl J Med. 2002;346:1128–37.
2. American Cancer Society. Cancer facts and figures 2009. Atlanta, GA: American Cancer Society; 2009. Last accessed 6 Jan 2010.

3. Devesa SS, Blot WJ, Fraumeni JF Jr. Changing patterns in the incidence of esophageal and gastric carcinoma in the United States. Cancer. 1998;83(10):2049–53.
4. Blot WJ, McLaughlin JK. The changing epidemiology of esophageal cancer. Semin Oncol. 1999;26(5 Suppl 15):2–8.
5. Korst RJ, Altorki NK. High grade dysplasia: surveillance, mucosal ablation, or resection? World J Surg. 2003;27:1030–4.
6. Ohsawa T. Esophageal surgery. J Jpn Surg Soc. 1933;34:1318–950.
7. Nguyen NT, Roberts P, Follette DM, Rivers R, Wolfe BM. Thoracoscopic and laparoscopic esophagectomy for benign and malignant disease: lessons learned from 46 consecutive procedures. J Am Coll Surg. 2003;197:902–13.
8. Luketich JD, Schauer PR, Christie NA, Weigel TL, Raja S, Fernando HC, Keenan RJ, Nguyen NT. Minimally invasive esophagectomy. Ann Thorac Surg. 2000;70:906–11. Discussion 911–902.
9. De Paula AL, Hashiba K, Ferreira EA, de Paula RA, Grecco E. Laparoscopic transhiatal esophagectomy with esophagogastroplasty. Surg Laparosc Endosc. 1995;5:1–5.
10. Swanstrom LL, Hansen P. Laparoscopic total esophagectomy. Arch Surg. 1997;132:943–7. Discussion 947–949.
11. Espat NJ, Jacobsen G, Horgan S, Donahue P. Minimally invasive treatment of esophageal cancer: laparoscopic staging to robotic esophagectomy. Cancer J. 2005;11:10–7.
12. Oelschlager BK, Pellegrini CA. Role of laparoscopy and thoracoscopy in the treatment of esophageal adenocarcinoma. Dis Esophagus. 2001;14:91–4.
13. Horgan S, Berger RA, Elli EF, Espat NJ. Robotic-assisted minimally invasive transhiatal esophagectomy. Am Surg. 2003;69(7):624–6.
14. Luketich JD, Alvelo-Rivera M, Buenaventura PO, Christie NA, McCaughan JS, Litle VR, Schauer PR, Close JM, Fernando HC. Minimally invasive esophagectomy: outcomes in 222 patients. Ann Surg. 2003;238:486–94. Discussion 494–485.
15. Kawahara K, Maekawa T, Okabayashi K, Hideshima T, Shiraishi T, Yoshinaga Y, Shirakusa T. Video-assisted thoracoscopic esophagectomy for esophageal cancer. Surg Endosc. 1999;13:218–23.
16. Law S, Wong J. Use of minimally invasive oesophagectomy for cancer of the oesophagus. Lancet Oncol. 2002;3:215–22.
17. Galvani CA, Gorodner MV, Moser F, Jacobsen G, Chretien C, Espat NJ, Donahue P, Horgan S. Robotically assisted laparoscopic transhiatal esophagectomy. Surg Endosc. 2008;22(1):188–95.
18. Moorthy K, Munz Y, Dosis A, Hernandez J, Martin S, Bello F, Rockall T, Darzi A. Dexterity enhancement with robotic surgery. Surg Endosc. 2004;18(5):790–5.
19. Law S, Fok M, Chu KM, Wong J. Thoracoscopic esophagectomy for esophageal cancer. Surgery. 1997;122:8–14.
20. Nguyen NT, Follette DM, Wolfe BM, Schneider PD, Roberts P, Goodnight JE Jr. Comparison of minimally invasive esophagectomy with transthoracic and transhiatal esophagectomy. Arch Surg. 2000;135:920–5.
21. Bodner J, Wykypiel H, Wetscher G, Schmid T. First experiences with the da Vinci operating robot in thoracic surgery. Eur J Cardiothorac Surg. 2004;25:844–51.
22. Okushiba S, Ohno K, Itoh K, Ohkashiwa H, Omi M, Satou K, Kawarada Y, Morikawa T, Kondo S, Katoh H. Handassisted endoscopic esophagectomy for esophageal cancer. Surg Today. 2003;33:158–61.

12 Robot-Assisted Thoracolaparoscopic Esophagectomy: The Netherlands

Roy J.J. Verhage, Christiaan Kroese, and Richard van Hillegersberg

Abstract

For locally advanced esophageal cancer, radical surgical resection is the mainstay of treatment. Lymph node metastases occur along the entire tract of the esophagus in an early stage. Optimal treatment involves neo-adjuvant chemoradiotherapy followed by a two field thoraco-abdominal en bloc esophagectomy with an extensive mediastinal and truncal lymph node dissection.

Techniques for minimally invasive esophagectomy have been introduced to reduce surgical trauma and morbidity of traditional open esophagectomy. However, conventional endoscopic surgery is limited by 2-dimensional vision, reduced dexterity and limited degrees of freedom. Robotic systems were developed to overcome such limitations, enabling the surgeon to perform complex minimally invasive surgical procedures. Advantages include reduced blood loss and fast postoperative recovery.

This chapter describes the indications and preoperative considerations for robot-assisted thoracolaparoscopic esophagectomy. Furthermore, anesthesiological management is discussed, addressing important intraoperative issues such as single lung ventilation and fluid management.

The three-stage operative procedure is described in detail. The thoracoscopic phase is performed using the robotic DaVinci Si system (Intuitive Surgical Inc., Sunnyvale CA, USA). The laparoscopic phase is performed with conventional laparoscopy. A gastric conduit is created extracorporally and a cervical esophagogastric anastomosis is formed.

Additionally, the clinical care of patients after esophagectomy is discussed with a specific focus on anastomotic leakage and chylous leakage.

Keywords

Esophagectomy • Thoracoscopy • Single lung ventilation • Laparoscopy • Gastric conduit • Lymph node dissection • Thoracic duct • Anastomotic leakage • Chylous leakage

Esophageal cancer is the eighth most common type of malignancy and the sixth most common cause of cancer mortality in the world [1]. In 2002, approximately 462,000 patients were newly diagnosed with esophageal cancer [1]. The two most common histologic subtypes are esophageal squamous cell carcinoma (ESCC), arising from dysplastic squamous epithelium of the esophagus and esophageal adenocarcinoma

R. J. J. Verhage, M.D., Ph.D.
R. van Hillegersberg, M.D., Ph.D. (✉)
Department of Surgical Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
e-mail: r.vanhillegersberg@umcutrecht.nl

C. Kroese, M.D.
Department of Anesthesiology, Intensive Care and Emergency Surgery, University Medical Center Utrecht, Utrecht, The Netherlands

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_12

(EAC), originating from dysplasia in columnar-lined esophagus with intestinal metaplasia (i.e. Barrett's esophagus) [2, 3]. The incidence of esophageal cancer has rapidly increased over the past decades, particularly due to a rise in EAC [4]. Worldwide the incidence of ESCC is highest [1].

Radical surgical resection is the mainstay of treatment for patients diagnosed with locally advanced esophageal cancer, combined with neo-adjuvant chemoradiotherapy, offering the best chance of cure [5]. Symptoms, such as dysphagia and retrosternal discomfort, arise only when the tumor is large enough to obstruct the esophageal lumen. Therefore, patients are frequently diagnosed at an advanced stage of disease. Consequently, less than half of patients are eligible for surgery due to tumor ingrowth into adjacent structures or due to the presence of distant metastases.

As the esophagus has a unique longitudinal lymphatic drainage system in the submucosal layer, lymph node metastases of esophageal cancer can occur along the entire tract of the esophagus from the cervical to the abdominal part. Optimal treatment for esophageal cancer, therefore, consists of transthoracic en bloc esophagectomy (TTE) with an extensive mediastinal lymph node dissection (LND). This approach through thoracotomy is accompanied by significant morbidity, mainly consisting of cardiopulmonary complications.

To reduce surgical trauma and morbidity of open transthoracic esophagectomy, less invasive surgical techniques such as transhiatal esophagectomy (THE) and minimally invasive esophagectomy (MIE) have been introduced. A randomized controlled trial by Hulscher et al. comparing the transthoracic versus transhiatal esophagectomy has shown the latter to have a lower complication rate [6]. However in the transhiatal approach a limited lymph node dissection is performed, with no dissection of the upper mediastinal lymph nodes [7, 8]. Approximately 30% of lymph node metastases in patients with cancer of the distal esophagus or gastro-esophageal junction (GEJ) are located in the upper mediastinum [9]. The transhiatal approach does not include these nodes leading to a trend towards a better survival for transthoracic over transhiatal esophagectomy [10, 11]. Other studies have mixed results, not clearly demonstrating superiority of the transthoracic approach [12–14].

Recent analyses of the MIE to date have shown a decreased operative blood loss, complication rate and hospital stay [15–17]. However, conventional endoscopic surgery has important limitations, such as a 2-dimensional view, a cumbersome hand-eye-coordination and limited degrees of freedom due to the rod-like, inflexible instruments. Robotic systems have been developed to overcome these limitations [18, 19]. During esophagectomy, the robotic platform enables the surgeon to perform an accurate mediastinal dissection. It allows *en bloc* resection of the esophagus with its surrounding mediastinal fat and lymphatic tissue, which often harbour metastatic disease. The available space for this dissection is often limited. In this particular aspect, the robotic approach excels in comparison with open thoracotomy or other MIE techniques. Robot-assisted thoracoscopic esophagectomy (RTE) in conjunction with conventional laparoscopy has shown to be technically feasible [9, 20]. Moreover, it provides sufficient oncological resection and is associated with low blood loss [9, 21].

12.1 Indications

Appropriate patient selection is essential to a successful esophageal surgery program. Depending on tumor stage and extent of comorbidities, 30–40% of esophageal cancer patients is eligible to undergo esophagectomy. The risk of postoperative complications is associated with advanced age and comorbidity. Additionally, prolonged single-lung ventilation during the thoracic phase may further increase the risk of pulmonary complications. Although the minimally invasive approach may offer a potentially curative surgical resection to a greater percentage of patients, careful patient selection remains critical. The presence and degree of comorbidities such as cardiovascular and pulmonary diseases and diabetes must be assessed in each individual case.

Furthermore, for distal tumors (lower third of the esophagus) and cardiac tumors, a laparoscopically-assisted transhiatal may be considered, rather than a robotic transthoracic approach. Other candidates for a laparoscopic transhiatal approach include patients with distal early stage (T1) tumors without evidence of distant adenopathy and absent to minimal local adenopathy on endoscopic ultrasonography (EUS) in whom endoscopic mucosal resection (EMR) did not achieve a complete resection.

12.2 Preoperative Considerations

Routine preoperative diagnostic investigations include esophagogastroscopy with tumor biopsy, endoscopic ultrasound (EUS), computed tomography (CT) of the chest and abdomen, ultrasonography of the neck with fine-needle aspiration of suspicious of cervical nodes, electrocardiography and lung function testing. Bronchoscopy is performed if airway involvement is suspected and [18F]fluorodeoxyglucose (FDG) positron emission tomography (PET) with CT fusion when metastases beyond the surgical field or organ metastases are suspected on CT. Any FDG-avid lesions are biopsied to confirm the presence of metastatic disease.

The proximal and distal borders of the tumor in the esophagus circumferential involvement, degree of obstruction, skip lesions and their location and the health of the remaining mucosa is determined by gastroscopy or EUS. Tumors are considered upper esophageal when they were located between 18 and 24 cm from the incisor teeth, mid oesophageal when located between 24 and 32 cm, and lower esophageal (including tumours of the GEJ) when located between 32 and 40 cm [22].

12.3 Anesthesia Management

Perioperative management involves a multi-specialty team consisting of surgical, anesthetic, critical care, physiotherapy, dietetic and nursing specialists. Standardized perioperative clinical protocols provide a framework for patient management aiming to improve efficiency and outcome. However, there is little evidence from randomized clinical trials to guide management of anaesthesia for esophagectomy. The section below highlights the anaesthesia for robot-assisted thoracoscopic esophagectomy (RTE) conducted in the University Medical Center Utrecht.

12.3.1 Preoperative

All patients planning to undergo RTE are seen by an anaesthesiologist in the Preoperative Clinic. The physical status of the patient is assessed and preoperative testing is guided by institutional guidelines. Patients with comorbidity and increased risk of perioperative complications (e.g. cardiovascular and pulmonary) will be referred for additional specialty care, and treatment as directed by the anaesthesiologist.

12.3.2 Perioperative

Thoracic epidural analgesia (TEA) and its effects during the postoperative period have been studied extensively. TEA most likely decreases the risk of postoperative respiratory failure and results in improved pain control [23, 24]. Furthermore, TEA may increase the blood supply to the esophago-gastric anastomosis area after esophagectomy [25]. Although there are no specific publications on the effects of TEA during minimally invasive esophagectomy, the advantages of TEA in the postoperative course of open esophagectomy is extrapolated to thoracoscopic esophagectomy.

Normally, the epidural catheter is placed between the fifth and the eight thoracic vertebrae. After insertion of the catheter, a test dose of lidocaine with epinephrine is administered to exclude subarachnoid or intravasal placement of the catheter. To avoid the risk of sympathicolysis, no additional boluses of local anaesthetics are given. Epidural sufentanil is used intraoperatively and a continuous infusion of bupivacaine and morphine is applied postoperatively. To enable selective deflation of the right lung during the thoracoscopic phase, patients are intubated with a left-sided double-lumen tube. Patients receive two large-bore peripheral cannulae, a central venous line in the right internal jugular vein, an arterial line, a urinary catheter and a nasogastric tube. Furthermore ASA standards for basic anaesthetic monitoring are applied [26]. Antibiotic prophylaxis is provided by i.v. administration of 2000 mg cefazolin and 500 mg metronidazole. Thirty minutes before incision, 10 mg/kg methylprednisolone is administered to minimize postoperative pulmonary complications [27].

Patients receive either propofol or volatile anaesthesia at the discretion of the attending anaesthesiologist. During the thoracoscopic phase of the operation patients are positioned in the left lateral decubitus position, and selective ventilation of the left lung is instituted. Continuous intravenous muscle relaxation is used to facilitate dissection of the esophagus along the trachea, azygos vein, aorta and pulmonary veins as sudden, unexpected movements of the patient could have detrimental effects. The patient must be protected against inadvertent contact from the motions of the robotic arms. After the instruments are connected to the arms of the robot and are placed inside the patient, the body position cannot be modified unless the instruments are disengaged and removed from the body cavity.

When the robotic system is in place, access to the patient in case of emergency is limited. Therefore, the surgical team should be capable of rapidly removing the robot if required.

12.3.3 Management of One-Lung Ventilation in RTE

The management of one-lung ventilation (OLV) remains challenging. Common problems include hypoxemia, failure to isolate the lungs properly and the potential for causing acute lung injury. To install OLV, a left-sided double-lumen tube (DLT) is used. Positioning of the DLT is most reliably achieved with a fiberoptic bronchoscope. It has been shown that left DLTs, when positioned only by inspection and auscultation, were in fact malpositioned in more than 33% of the cases [28]. After positioning the patient from supine to lateral, the position of the DLT is checked again routinely. Cuff pressure is measured to prevent high intracuff pressures and possible mucosal damage. Patients with a difficult airway present an extra challenge. Airways that are difficult for placement of a single-lumen tube (SLT) are even more difficult for placing a DLT because of its size and shape. Oral fiberoptic intubation with a DLT has been described in both awake and anesthetized patients [29]. Alternatives include the use of a bronchial blocker as well as the use of a tube exchanger. The latter may be used for inserting a DLT or changing a SLT for a DLT. As mentioned earlier, the development of hypoxemia is a problem. During OLV both lungs are perfused. Perfusion of the nonventilated lung inevitably leads to transpulmonary shunting, impairment of oxygenation and possible hypoxemia. Another important problem is the risk of acute lung injury, caused by volume or pressure induced stress of the ventilated lung. To decrease the incidence of hypoxemia and the risk of acute lung injury, a good ventilation strategy is important. In our institution, during OLV a protective lung ventilation (PLV) protocol is applied. This consists of a pressure-controlled ventilation strategy with a maximum pressure of 20 cm H_2O. Tidal volume is reduced to 6 ml/kg predicted body weight. Furthermore, 5 cm H_2O PEEP is routinely used. Although hypoxemia is a constant threat, the lowest possible fraction of inspired oxygen (FiO_2) is delivered to prevent oxidative damage and postoperative ALI [30].

In case of hypoxemia, the first treatment is an increase in FiO_2. If no improvement occurs, the surgeon is informed and the nonventilated lung is expanded with 100% oxygen. Our clinical experience suggests that dislocation of the DLT, atelectasis or bronchial occlusion of the ventilated lung with blood or secretions are the most occurring causes of hypoxemia. Therefore, immediate fiberoptic bronchoscopy is performed to rule out or even correct dislocation of the DLT and occluded bronchi. Once these are ruled out, a recruitment manoeuvre is performed to open possible atelectasis.

When hypoxemia persists, the administration of oxygen with or without CPAP to the nonventilated lung is a valuable option. Clear communication with the surgeon is necessary in these circumstances as both manoeuvres may have a negative impact on the surgical exposure during thoracoscopy. When applying CPAP, the nonventilated lung is first reinflated as CPAP alone does not inflate an atelectatic lung. At the end of the thoracoscopic phase, the nonventilated lung is reinflated under direct vision and extensive recruitment manoeuvres are performed after which two-lung ventilation is restarted and 10 cm H_2O PEEP is added. There is no more need for lung separation during the rest of the operation and usually the DLT is exchanged for a SLT. The risks and benefits of changing the DLT should be carefully considered. After large fluids shifts and an extended surgical procedure, swelling in the upper airways occurs relatively often. Exchanging the DLT for an SLT should be done under direct vision if possible. If adequate exposure is not possible, an airway exchanger may be used.

12.3.4 Fluid Management

Much has been written about intraoperative fluid administration. Several publications suggest that a restrictive fluid management reduces length of hospital stay, cost and complication rates. In our institution fluid strategy during RTE is aimed at a mildly positive fluid balance of approximately 500–1000 ml at the end of the procedure. Additional information is obtained from the use of FloTrac/Vigileo which calculates continuous cardiac output and stroke volume variation from arterial pressure waveform characteristics. These values can be used to predict the effect of extra boluses of fluid. Although not validated for thoracoscopic procedures, it has been validated for laparoscopic operations in pigs [31]. Therefore, FloTrac/Vigileo can be of assistance in the laparoscopic phase of the operation especially to predict fluid responsiveness and distinguish those patients with low cardiac output from hypovolemia and the patients that are in need of inotropic support. The use of central venous oxygen saturation may have additional value in particular in patients with decreased cardiac function. However, at the moment no large scale randomized trials are available.

12.3.5 Perioperative Complications

The most common complications encountered perioperatively include arrhythmias, most often seen as the result of manipulation of the heart during the thoracoscopic phase of the operation. Usually these arrhythmias are self-limited after interruption of the surgical manipulation. Another complication regularly seen is the development of a pneumomediastinum as a result of the opening of the hiatus during the laparoscopic phase of the operation. Hemodynamics may show the characteristics of a tension pneumothorax. Again the surgeon should be informed immediately and asked to lower the pressure of the pneumoperitoneum. If indicated, thoracic drains are inserted to relieve the pneumomediastinum.

12.3.6 Postoperative Care

Postoperatively all patients remain under general anaesthesia and are intubated until they are transferred to the intensive care unit. Extubation is aimed for the same day. Although immediate extubation in the operating room has been described and considered safe [32], we consider it appropriate to ventilate patients postoperatively until chest X-ray is obtained. When the X-ray shows no significant atelectasis, weaning from ventilation is started. As stated earlier, thoracic epidural analgesia improves pain control and decreases pulmonary complications. In order to ensure analgesia is satisfactory enough to enable mobilization and physiotherapy, each patient is visited on a daily basis by a pain service as long as the epidural catheter remains in place.

12.4 Procedures

12.4.1 Robot-Assisted Thoracoscopic Dissection

12.4.1.1 Instruments

- Hook
- Cadiere
- Needle driver
- Long tip forceps
- optional: Large Hem-o-lok® Clip Applier

12.4.1.2 Positioning

The patient is positioned in the left lateral decubitus position, tilted 45° towards the prone position. The operating table is flexed, lowering the legs and upper thorax (the patient is positioned with the xyphoid above the pivoting point of the table). This extends the thorax and widens intercostal space for introducing trocars. The bedside cart of the robotic system (DaVinci Si system, Intuitive Surgical Inc., Sunnyvale CA, USA) is brought into the operative field from the dorso-cranial side of the patient (Fig. 12.1). Before incision, the right lung is desufflated. A 10-mm camera port is placed at the sixth intercostal space, posterior to the posterior axillary line. Two 8-mm ports are placed just anterior to the scapular rim in the fourth intercostal space and more posterior in the eighth intercostal space. Two thoracoscopic ports are used in the fifth and seventh intercostal spaces just posterior to the posterior axillary line. These ports are used for conventional thoracoscopic assistance such as suction, traction, and clipping. CO_2 insufflation of the thoracic cavity permits excellent vision, without the need for retracting the lung from the operative field. In case of a none-compliant lung, a retractor can be used.

12.4.1.3 Operative Steps

After division of any pulmonary adhesions and a proper overview of the operating field is achieved, the pulmonary ligament is divided. The parietal pleura is dissected at the anterior side of the esophagus from the diaphragm up to the azygos arch (Fig. 12.2). The azygos arch is carefully dissected and ligated using Hem-o-lok® clips (size Large, Teleflex Medical, Limerick PA, USA) applied with the robot. Then dissection of the parietal pleura is continued above the arch for a right paratracheal lymph node dissection. The right vagal nerve is dissected below the level of the carina. Subsequently, the parietal pleura is dissected at the posterior side of the esophagus cranially to caudally along the azygos

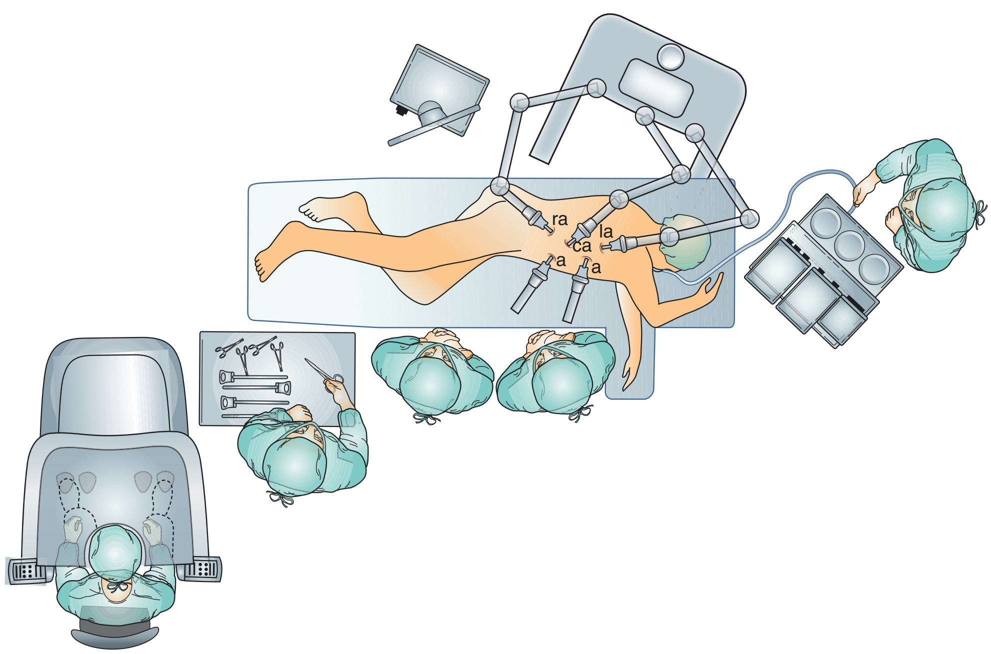


Fig. 12.1 Room organization and port site locations for the chest portion. Patient is positioned in the left lateral decubitus position, tilted 45° towards the prone position. The operating table is flexed, lowering the legs and upper thorax (the patient is positioned with the xyphoid above the pivoting point of the table). The bedside cart of the robotic system is brought from the dorsocranial side of the patient. Five chest ports are placed in the following manner: a 10-mm camera port (ca) is placed at the sixth intercostal space, posterior to the posterior axillary line. Two 8-mm ports are placed just anterior to the scapular rim in the fourth intercostal space and more posterior in the eighth intercostal space (ra and la). Two thoracoscopic ports (a) are used in the fifth and seventh intercostal spaces just posterior to the posterior axillary line. These ports are used for conventional thoracoscopic assistance such as suction, traction, and clipping

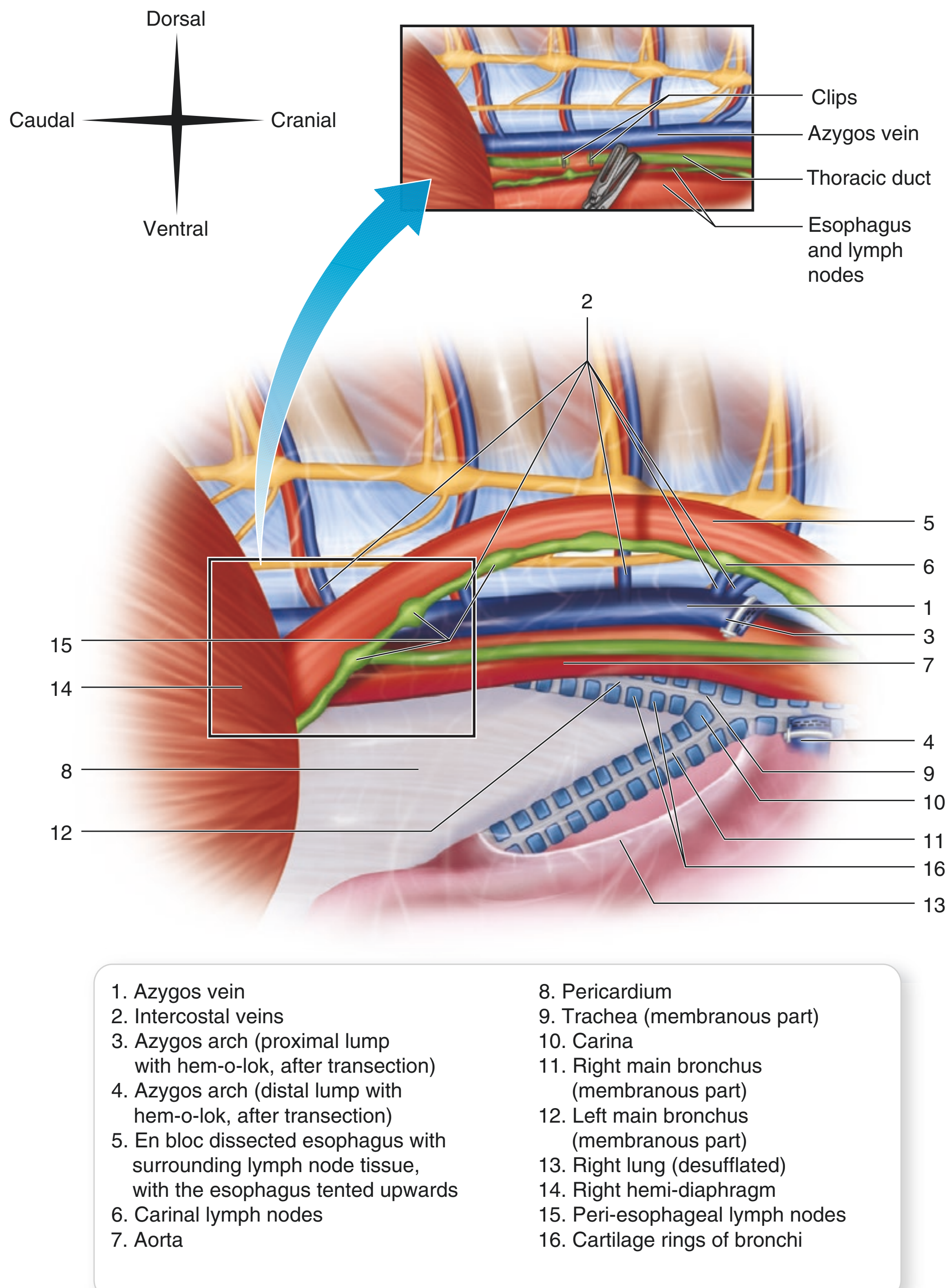


Fig. 12.2 Initiation of the thoracic esophagectomy. The pulmonary ligament is divided. The parietal pleura is dissected at the anterior side of the esophagus from the diaphragm up to the azygos arch

vein, including the thoracic duct. At the level of the diaphragm, the thoracic duct is clipped with a 10-mm endoscopic clipping device (EndoclipTM II; Covidien, Mansfield, Massachusetts, USA) to prevent postoperative chylous leakage (Fig. 12.3).

At the level of the diaphragm, a Penrose drain is placed around the esophagus to provide traction, which facilitates esophageal mobilization. The esophagus is then resected en bloc with the surrounding mediastinal lymph nodes and the thoracic duct from the diaphragm up to the thoracic inlet. Aortoesophageal vessels are identified and clipped by the assisting surgeon. The extensive lymphadenectomy includes the right-sided paratracheal (lymph node station 2R), tracheobronchial (lymph node station 4), aortopulmonary window (station 5), carinal (station 7) and peri-esophageal (station 8) lymph nodes. A 24-Fr chest tube is placed, and the lung is insufflated under direct vision.

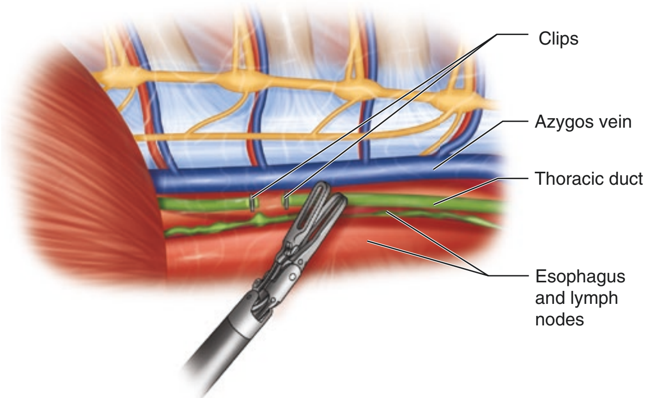


Fig. 12.3 Dissection of the mid-thoracic esophagus. The azygos arch is ligated. The parietal pleura is dissected at the posterior side of the esophagus cranially to caudally along the azygos vein, including the thoracic duct. At the level of the diaphragm, the thoracic duct (TD) is clipped with a 10-mm endoscopic clipping device to prevent postoperative chylous leakage

12.4.2 Laparoscopic Dissection

12.4.2.1 Instruments

- Harmonic scalpel
- 2× fenestrated bowel clamps
- Endopaddle
- Clipper

12.4.2.2 Positioning

After completion of the robot-assisted thoracoscopic esophageal mobilization, the patient is put in supine position. An 11-mm camera port is introduced left paraumbilically, and an 11-mm working port is placed at the left midclavicular line at the umbilical level. A 5-mm working port is placed more cranially at the right midclavicular line. A 5-mm assisting port is placed in the left subcostal area, and a 12-mm port is placed pararectally right for the liver retractor (Fig. 12.4). The abdomen is insufflated to a carbon dioxide pressure level of 15 mmHg.

12.4.2.3 Operative Steps

The hepatogastric ligament is opened. The greater and lesser curvatures are dissected with ultrasonic harmonic scalpel. The hiatus is opened, and the distal esophagus is dissected from the right and left crus. The carbon dioxide pressure level is reduced to 6 mmHg to avoid excessive intrathoracic pressure and a chest tube is placed in the left pleural sinus. Dissection and lymphadenectomy then continues around the celiac trunk (Fig. 12.5). The left gastric artery and vein then are transected at their origin. Abdominal lymphadenectomy

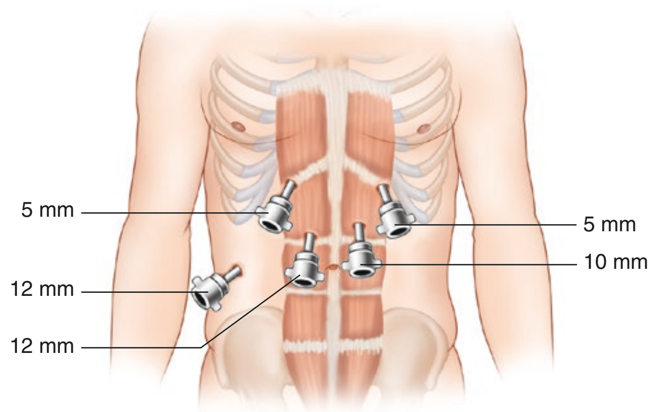


Fig. 12.4 Port placement for the abdominal laparoscopic portion. The patient is put in supine position. An 11-mm camera port is introduced left paraumbilically, and an 11-mm working port is placed at the left midclavicular line at the umbilical level. A 5-mm working port is placed more cranially at the right midclavicular line. A 5-mm assisting port is placed in the left subcostal area, and a 12-mm port is placed to the right of the rectus for the liver retractor. Using a matt retractor, the stomach and adjacent omentum is lifted anteriorly, exposing the retroperitoneum and celiac axis. Dissection and lymphadenectomy then continues around the celiac axis. The left gastric artery and vein then are transected at their origin. Abdominal lymphadenectomy includes lymph nodes surrounding the left gastric artery and the lesser omental lymph nodes

includes lymph nodes surrounding the left gastric artery and the lesser omental lymph nodes.

The cervical esophagus is mobilized through a left-side longitudinal neck incision along the sternocleidoid muscle. No formal cervical lymph node dissection is carried out, but cervical lymph nodes are dissected if lymph node metastases are suspected macroscopically during the cervical phase of esophagectomy. The esophagus is dissected and a cord is attached to the proximal part of the specimen to enable pull-up of the gastric conduit along the anatomical tract of the esophagus.

The esophagus and surrounding lymph nodes are pulled into the abdomen under laparoscopic vision. A 7-cm transverse incision is made at the level of the left paraumbilical port for extraction of the specimen and stomach using a wound protector.

Outside the abdomen, a 5-cm-wide gastric tube is constructed with staplers (GIATM 80, 3·8 mm; Covidien, Dublin, Ireland), and the stapled line is oversewn with 3–0 polydioxanone. Routine extracorporal oversewing was reintroduced as two serious complications occurred when the staple line was not oversewn [20, 33]. The specimen consisting of the esophagus and cardia of the stomach is sent for pathological examination. After the gastric tube has been

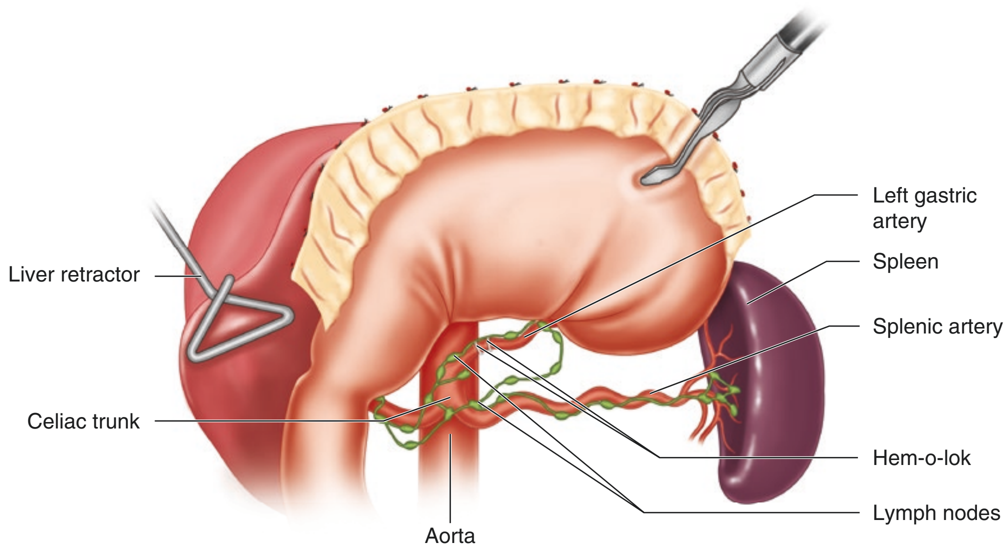


Fig. 12.5 Laparoscopic ligation of the left gastric artery and celiac axis lymphadenectomy. Using a matt retractor, the stomach and adjacent omentum is lifted anteriorly, exposing the retroperitoneum and celiac axis. Dissection and lymphadenectomy then continues around the celiac axis. The left gastric artery and vein then are transected at their origin. Abdominal lymphadenectomy includes lymph nodes surrounding the left gastric artery and the lesser omental lymph nodes

pulled to the neck, a hand-sewn end-to-side esophagogastrostomy is performed in the neck using 3–0 polydioxanone single-layer running sutures. Excess gastric tubing is removed using a GIA stapler.

A feeding jejunostomy is placed at the level of the transverse incision (Freka® FCJ-Set, Fresenius Kabi AG, Bad Homburg vd H., Germany).

12.5 Postoperative Care

12.5.1 Clinical Care

Postoperatively, patients are transferred to the intensive care unit (ICU). After leaving the operating room, mechanical ventilation is continued briefly usually extubating later that evening. After 1 day in the ICU patients are transferred to a medium care (MC) ward.

Important for postoperative care are a nasogastric tube, feeding jejunostomy and an epidural catheter. The nasogastric tube is used for gastric decompression and to provide a splinting in case of anastomotic dehiscence. Fixation of the tube is imperative, as re-introduction can cause damage to the anastomosis.

No oral intake is allowed for 7 days minimum. During that first week, feeding is provided by the feeding jejunostomy. After 7 days without any indication of anastomotic dehiscence sips of water are initiated. If there is no evidence of anastomotic leak, oral intake is gradually supplemented to solid foods under close supervision of a clinical nutritionist. The feeding jejunostomy is left *in situ* up to 6 weeks after discharge from the hospital. Only after sufficient intake is maintained, the jejunostomy is removed at the outpatient clinic.

Pain medication through the epidural catheter is required to improve postoperative ventilation and coughing. Other strategies to prevent postoperative pulmonary complications include elevation of the bed by 15°–30°, physical respiratory therapy and early mobilization.

12.5.2 Points of Interest

12.5.2.1 Anastomotic Leakage

Leakage of the esophago-gastrostomy can present itself in various ways. Possible clinical signs are fever, swelling, erythema or fluctuations in the neck, subcutaneous emphysema and pneumothorax. In case of anastomotic leakage, the neck wound is re-opened to enable drainage. Frequent cleaning and flushing of the wound is required. Leakage can occasionally drain to the mediastinum. This causes fever and mostly pleural effusion and atelectasis. The pleural cavity should be drained. The mediastinum is drained through the neck.

12.5.2.2 Chylous Leakage

The diagnosis of chylous leakage is based on excessive drainage of milk-like fluid from a thoracic drain containing an elevated level of triglycerides and increased concentration of chylomicrons. Long chain triglycerides (LCT) are drained through the thoracic duct. By eliminating LCTs from the diet less triglycerides will be drained, reducing chylous production. To sustain energy intake, medium chain triglycerides which are absorbed directly through the portal system, can be added to the patient's diet.

When a clinical suspicion of chylous leakage arises, concentrations of triglycerides and cholesterol in both serum and drain fluids need to be examined. A triglyceride drainfluid-serum ratio of more than 10 and a cholesterol drainfluid-serum ratio of less than 1 is typical for chylous leakage.

Mild chylous leakage (<500 cm^3/24 h) is conservatively treated with adapted enteral feeding (MCT) and ceasing oral intake. Mild to serious leakage (500–1000 cm^3/24 h) requires MCT feeding or total parenteral feeding (TPF). Serious leakage of more than 1000 cm^3/24 h is treated with TPF without any enteral or oral type of feeding.

12.5.3 Outpatient Care

After discharge from hospital, patients are seen frequently every 2–4 weeks to make sure their weight is stable and eating is tolerated. In case of weight loss of more than 2 kg, tube feeding is started through the jejunostomy. After the initial visits, patients are seen every 3–4 months in the first year, at 6-month intervals in the second year, and annually thereafter. At each visit, a medical interview and physical examination are carried out. Diagnostic modalities such as gastroscopy with biopsy, CT, FDG-PET or magnetic resonance imaging are only performed if tumour recurrence is suspected, in accordance with the 2006 National Comprehensive Cancer Network Esophageal Cancer Clinical Practice Guidelines [34].

References

1. Kamangar F, Dores GM, Anderson WF. Patterns of cancer incidence, mortality, and prevalence across five continents: defining priorities to reduce cancer disparities in different geographic regions of the world. J Clin Oncol. 2006;24:2137–50.
2. Stoner GD, Gupta A. Etiology and chemoprevention of esophageal squamous cell carcinoma. Carcinogenesis. 2001;22:1737–46.
3. Marsman WA, Tytgat GN, ten Kate FJ, van Lanschot JJ. Differences and similarities of adenocarcinomas of the esophagus and esophagogastric junction. J Surg Oncol. 2005;92:160–8.
4. Holmes RS, Vaughan TL. Epidemiology and pathogenesis of esophageal cancer. Semin Radiat Oncol. 2007;17:2–9.
5. Mariette C, Piessen G, Triboulet JP. Therapeutic strategies in oesophageal carcinoma: role of surgery and other modalities. Lancet Oncol. 2007;8:545–53.
6. Hulscher JB, Tijssen JG, Obertop H, van Lanschot JJ. Transthoracic versus transhiatal resection for carcinoma of the esophagus: a meta-analysis. Ann Thorac Surg. 2001;72:306–13.
7. Orringer MB, Marshall B, Chang AC, Lee J, Pickens A, Lau CL. Two thousand transhiatal esophagectomies: changing trends, lessons learned. Ann Surg. 2007;246:363–72.
8. Espat NJ, Jacobsen G, Horgan S, Donahue P. Minimally invasive treatment of esophageal cancer: laparoscopic staging to robotic esophagectomy. Cancer J. 2005;11:10–7.
9. Boone J, Schipper ME, Moojen WA, Borel Rinkes IH, Cromheecke GJ, van Hillegersberg R. Robot-assisted thoracoscopic oesophagectomy for cancer. Br J Surg. 2009;96:878–86.
10. Omloo JM, Lagarde SM, Hulscher JB, Reitsma JB, Fockens P, van Dekken H, ten Kate FJ, Obertop H, Tilanus HW, van Lanschot JJ. Extended transthoracic resection compared with limited transhiatal resection for adenocarcinoma of the mid/distal esophagus: five-year survival of a randomized clinical trial. Ann Surg. 2007;246:992–1000.
11. Rizzetto C, DeMeester SR, Hagen JA, Peyre CG, Lipham JC, DeMeester TR. En bloc esophagectomy reduces local recurrence and improves survival compared with transhiatal resection after neoadjuvant therapy for esophageal adenocarcinoma. J Thorac Cardiovasc Surg. 2008;135:1228–36.
12. Stark SP, Romberg MS, Pierce GE, Hermreck AS, Jewell WR, Moran JF, Cherian G, Delcore R, Thomas JH. Transhiatal versus transthoracic esophagectomy for adenocarcinoma of the distal esophagus and cardia. Am J Surg. 1996;172:478–81.
13. Rentz J, Bull D, Harpole D, Bailey S, Neumayer L, Pappas T, Krasnicka B, Henderson W, Daley J, Khuri S. Transthoracic versus transhiatal esophagectomy: a prospective study of 945 patients. J Thorac Cardiovasc Surg. 2003;125:1114–20.
14. Colvin H, Dunning J, Khan OA. Transthoracic versus transhiatal esophagectomy for distal esophageal cancer: which is superior? Interact Cardiovasc Thorac Surg. 2011;12:265–9.
15. Luketich JD, velo-Rivera M, Buenaventura PO, Christie NA, McCaughan JS, Litle VR, Schauer PR, Close JM, Fernando HC. Minimally invasive esophagectomy: outcomes in 222 patients. Ann Surg. 2003;238:486–94.
16. Gemmill EH, McCulloch P. Systematic review of minimally invasive resection for gastro-oesophageal cancer. Br J Surg. 2007;94:1461–7.
17. Verhage RJ, Hazebroek EJ, Boone J, van Hillegersberg R. Minimally invasive surgery compared to open procedures in esophagectomy for cancer: a systematic review of the literature. Minerva Chir. 2009;64:135–46.
18. Ruurda JP, van Vroonhoven TJ, Broeders IA. Robot-assisted surgical systems: a new era in laparoscopic surgery. Ann R Coll Surg Engl. 2002;84:223–6.
19. Camarillo DB, Krummel TM, Salisbury JK. Robotic technology in surgery: past, present, and future. Am J Surg. 2004;188:2S–15S.
20. van Hillegersberg R, Boone J, Draaisma WA, Broeders IA, Giezeman MJ, Borel Rinkes IH. First experience with robot-assisted thoracoscopic esophagolymphadenectomy for esophageal cancer. Surg Endosc. 2006;20:1435–9.
21. Kernstine KH, DeArmond DT, Karimi M, Van Natta TL, Campos JH, Yoder MR, Everett JE. The robotic, 2-stage, 3-field esophagolymphadenectomy. J Thorac Cardiovasc Surg. 2004;127:1847–9.
22. Wittekind C, Greene FL, Hutter RVP, Klimpfinger M, Sobin LH. TNM atlas. Illustrated guide to the TNM/pTNM classification of malignant tumors. 2004.
23. Cense HA, Lagarde SM, de JK, Omloo JM, Busch OR, Henny C, van Lanschot JJ. Association of no epidural analgesia with postoperative morbidity and mortality after transthoracic esophageal cancer resection. J Am Coll Surg. 2006;202:395–400.
24. Block BM, Liu SS, Rowlingson AJ, Cowan AR, Cowan JA, Wu CL. Efficacy of postoperative epidural analgesia: a meta-analysis. JAMA. 2003;290:2455–63.
25. Michelet P, Roch A, D'Journo XB, Blayac D, Barrau K, Papazian L, Thomas P, Auffray JP. Effect of thoracic epidural analgesia on gastric blood flow after oesophagectomy. Acta Anaesthesiol Scand. 2007;51:587–94.
26. American Society of Anesthesiologists. Standards for basic anesthetic monitoring. http://www.asahq.org/For-Healthcare-Professionals/Standards-Guidelines-and-Statements.aspx. Accessed July 2011.

27. Sato N, Koeda K, Ikeda K, Kimura Y, Aoki K, Iwaya T, Akiyama Y, Ishida K, Saito K, Endo S. Randomized study of the benefits of preoperative corticosteroid administration on the postoperative morbidity and cytokine response in patients undergoing surgery for esophageal cancer. Ann Surg. 2002;236:184–90.
28. Pennefather SH, Russell GN. Placement of double lumen tubes: time to shed light on an old problem. Br J Anaesth. 2000;84:308–10.
29. Patane PS, Sell BA, Mahla ME. Awake fiberoptic endobronchial intubation. J Cardiothorac Anesth. 1990;4:229–31.
30. Gothard J. Lung injury after thoracic surgery and one-lung ventilation. Curr Opin Anaesthesiol. 2006;19:5–10.
31. Renner J, Gruenewald M, Quaden R, Hanss R, Meybohm P, Steinfath M, Scholz J, Bein B. Influence of increased intra-abdominal pressure on fluid responsiveness predicted by pulse pressure variation and stroke volume variation in a porcine model. Crit Care Med. 2009;37:650–8.
32. Chandrashekar MV, Irving M, Wayman J, Raimes SA, Linsley A. Immediate extubation and epidural analgesia allow safe management in a high-dependency unit after two-stage oesophagectomy. Results of eight years of experience in a specialized upper gastrointestinal unit in a district general hospital. Br J Anaesth. 2003;90:474–9.
33. Boone J, Borel Rinkes IH, van Hillegersberg R. Gastric conduit staple line after esophagectomy: to oversew or not? J Thorac Cardiovasc Surg. 2006;132:1491–2.
34. Ajani J, Bekaii-Saab T, D'Amico TA, Fuchs C, Gibson MK, Goldberg M, Hayman JA, Ilson DH, Javle M, Kelley S, Kurtz RC, Locker GY, Meropol NJ, Minsky BD, Orringer MB, Osarogiagbon RU, Posey JA, Roth J, Sasson AR, Swisher SG, Wood DE, Yen Y. Esophageal cancer clinical practice guidelines. J Natl Compr Canc Netw. 2006;4:328–47.

Robot-Assisted Thoracoscopic Esophagectomy in the Semi-Prone Position

13

Dae Joon Kim and Seong Yong Park

Abstract

Recent developments in robotic technology have enabled the introduction of robotic surgery in patients with esophageal cancer. Robotic esophagectomy enables the meticulous dissection in the restricted anatomic spaces and complex procedures with three-dimensional view, articulation of the instruments and tremor filtering. In several papers, robotic esophagectomy has been proven as technically feasible and safe procedures in terms of short-term operative outcomes. In this chapter, we described the detailed procedures of robotic esophagectomy for esophageal squamous cell carcinoma.

Keywords

Robot esophagectomy • Esophageal squamous cell carcinoma • Total lymphadenectomy • Bilateral recurrent laryngeal nerve nodes

13.1 Introduction

In Asia, squamous cell carcinoma remains the predominant type of esophageal cancer and primarily arises from the intrathoracic esophagus [1]. Early and widespread lymph node metastasis in squamous cell carcinoma has made a transthoracic esophagectomy with extensive mediastinal lymph node dissection (MLND) the standard procedure for a locally advanced lesion [2]. Especially total mediastinal lymphadenectomy (ML), including the bilateral dissection of recurrent laryngeal nerve (RLN) chains, is considered mandatory to achieve acceptable long-term survival [2]. However, this invasive procedure usually results in high morbidity and operative mortality [3]. The minimally invasive esophagectomy (MIE) has been introduced to reduce the high morbidity and operative mortality of esophageal cancer surgery. So far, the thoracoscopic esophagectomy is most popular form among MIE.

D. J. Kim, M.D., Ph.D. (✉) • S. Y. Park, M.D., Ph.D.
Department of Thoracic and Cardiovascular Surgery, College of Medicine, Yonsei University, Severance Hospital,
50 Yonsei-ro, Seodaemun-gu, Seoul 120–752, Republic of Korea
e-mail: kdjcool@yuhs.ac

Despite the favorable results in postoperative morbidity and mortality over the open esophagectomy, thoracoscopic esophaegctomy has not been widely performed, because it necessitates a substantial amount of learning [4, 5]. In addition, the thoracoscopic esophagectomy has many limitations. Circumferential dissection of the esophagus with a rigid, straight thoracoscopic instrument is difficult because the esophagus is a tubular structure which lies in the deepest area in lateral decubitus position. Especially the complete dissection of left recurrent laryngeal area where the metastasis occurs frequently is very difficult with long and rigid thoracoscopic instruments (Fig. 13.1a). Also, MLND is cumbersome especially at the subcarinal, infra-aortic, and bilateral recurrent laryngeal nerve area because the depth perception is lost in a 2-dimensional monitor system. In contrast to thoracoscopic system, the robotic system has several advantages over conventional thoracoscopic esophagectomy; the 3-dimensional view gives realistic images around the esophagus and surrounding structures, intrapleural articulation of instruments allows for better reach which is particularly useful in the dissection of left side of the esophagus with mediastinal nodes en bloc, and it provides better ergonomics (Fig. 13.1b).

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_13

We have utilized a *da Vinci* system (Intuitive Surgical, Mountain View, CA, US) for esophagectomy since July 2006 [6]. Initially we used prone position because it facilitates mediastinal dissection and minimizes lung manipulation, but we changed from the prone position to semi-prone position for better dissection of left recurrent laryngeal nerve nodes. Our main indication is curative intent surgery for resectable stage I-III tumors in the middle or lower thoracic esophagus, but salvage esophagectomy is also performed in selected patients who presented a good response from definitive chemoradiation. Regardless of the aim of surgery, the same surgical principle is applied: *en bloc* esophagectomy with extended mediastinal lymphadenectomy including bilateral recurrent laryngeal nerve nodes, followed by gastric mobilization with upper abdominal lymph node dissection and cervical esophagogastrostomy. When a primary lesion is located at the upper thoracic esophagus or if the upper mediastinal lymph node is involved in middle or lower thoracic esophageal cancer, bilateral cervical lymphadenectomy is added.

13.2 Operative Technique

13.2.1 Set-Up of Operation Room and Anesthetic Management

We use the Univent bronchial blocker tube (Fuji Systems Corp., Tokyo, Japan) to achieve one-lung ventilation (Fig. 13.2a). It has several advantages over the double lumen endotracheal tube in the semi-prone position: it can be more securely fixed, manipulation is easier, and there is no need for a change to a single lumen endotracheal tube after the thoracic phase. The central line catheterization and nasogastric tube placement are also mandatory. After intubation and placement of Univent bronchial bloacker, the position is changed into semi-prone position. The left arm should be placed parallel to the body, and the right arm is abducted and beside the head. It is important to secure working space to prevent a collision between the robotic cart, the patient's arms, and an anesthetic machine (Fig. 13.2b). Beanbags are

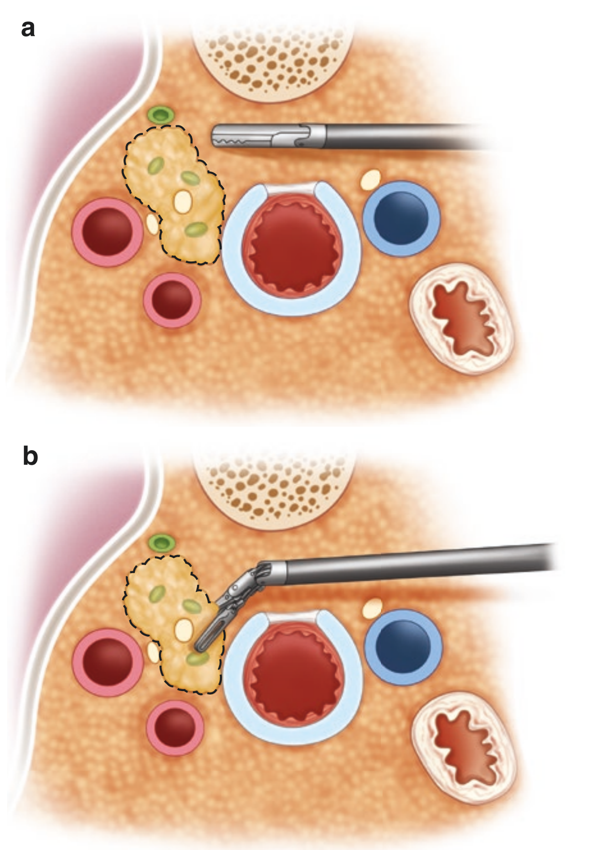


Fig. 13.1 (**a**) Thoracoscopic dissection of left recurrent laryngeal area. (**b**) Robotic dissection of left recurrent laryngeal area. The articulated robotic wrist enables the meticulous dissection in narrow and deep spaces without injurying the organs such as trachea. Adapted from Kim DJ, Park SY, Lee S, Kim HI, Hyung WJ. Feasibility of a robot-assisted thoracoscopic lymphadenectomy along the recurrent laryngeal nerves in radical esophagectomy for esophageal squamous carcinoma. Surg Endosc. 2014 Jun;28(6):1866–73. doi: https://doi.org/10.1007/s00464-013-3406-5. Epub 2014 Jan 24; used with permission

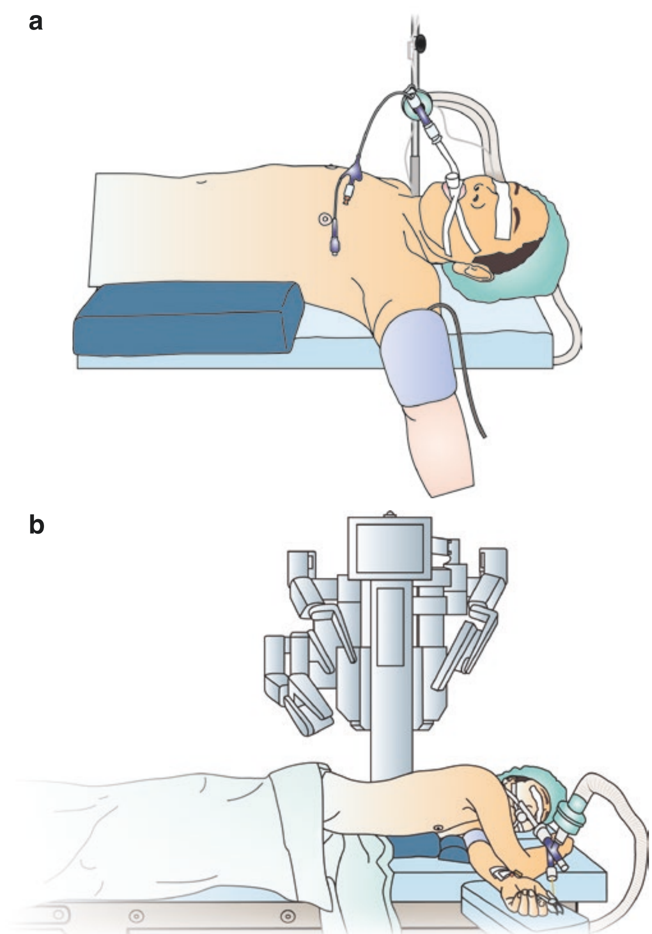


Fig. 13.2 (**a**) Patients are intubated with a Univent bronchial blocker tube (Fuji Systems Corp, Tokyo, Japan). (**b**) The position is changed into semi-prone position. Beanbags or roll bars are placed under the chest and pelvis to leave the abdomen free. A robotic cart is introduced from the left cranial side of the patient

applied under the chest and pelvis to leave the abdomen free, and an adjustable head support is placed. Continuous monitoring of airway pressure and expiratory CO_2 is recommended during the thoracic phase. Good communication with an anesthesiologist is crucial. If airway pressure is high enough to cause CO_2 retention, continuous positive airway pressure (CPAP) to the right lung or temporary two-lung ventilation should be considered in order to prevent irreversible lung damage. The bronchial blocker is deflated when thoracic phase is over and 2-lung ventilation is applied until the end of the operation.

After the one-lung ventilation is started, four trocars were placed as follows: a 12-mm trocar at the eighth intercostal space for a 30° angled thoracoscope; an 8-mm trocar at the sixth intercostal space medial to the scapula at the posterior axillary line for a right robotic arm; an 8-mm trocar at the tenth intercostal space for a left robotic arm; and a 12-mm trocar at the seventh intercostal space along the mid-axillary line for an accessory port (Fig. 13.3a). A *da Vinci* robotic cart was introduced from the left cranial side of the patient (Fig. 13.3b). The axis is from the thoracoscopic port to the imaginary line between the azygous vein and apex, for targeting the upper mediastinum. Then, the robotic cart is brought from the left cranial side of the patients by that axis, and the docking is completed. An assistant surgeon sit by the accessory port to retract the esophagus, retrieve the lymph nodes and suction any blood. By using the dual console system of *da Vinci*, the trainee can observe the operation with same view of operator.

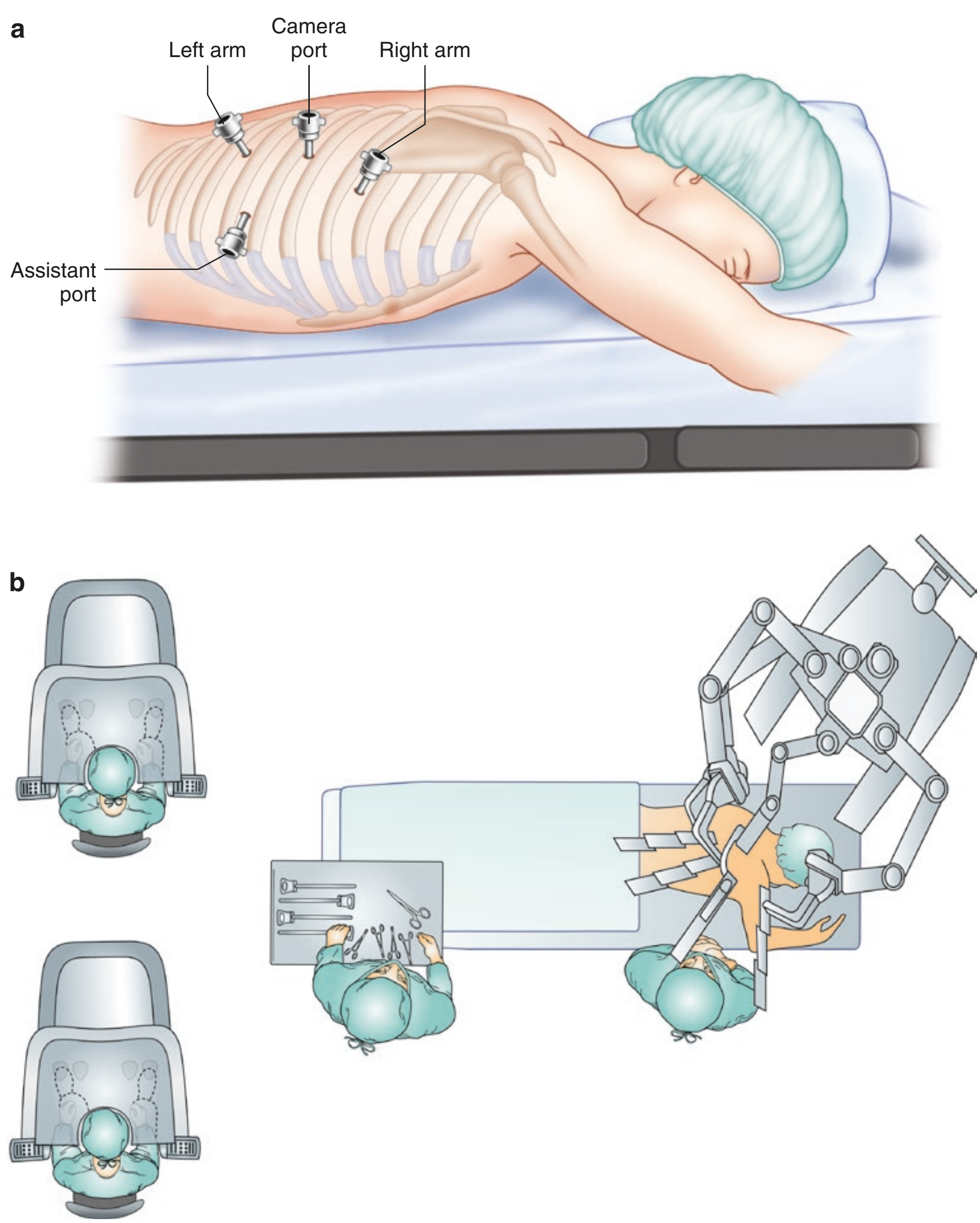


Fig. 13.3 (**a**) Robotic ports placements. (*C* camera port, *A* accessory port, *R* right arm, *L* left arm). (**b**) Operating room setup. *OS* operating surgeon, *AS* assistant surgeon, *T* trainee. Adapted from Kim DJ, Park SY, Lee S, Kim HI, Hyung WJ. Feasibility of a robot-assisted thoracoscopic lymphadenectomy along the recurrent laryngeal nerves in radical esophagectomy for esophageal squamous carcinoma. Surg Endosc. 2014 Jun;28(6):1866–73. doi: https://doi.org/10.1007/s00464-013-3406-5. Epub 2014 Jan 24; used with permission

13.2.2 Thoracoscopic Esophagectomy and Mediastinal Lymph Node Dissection

We usually use curved bipolar dissector for left arm (first arm) and Hot shear™ (monopolar scissors) and harmonic ACE shear for right arm (second arm) during the procedure. Even though the sequence of dissection could be changed according to patient's condition, we generally perform the operation like these sequence. First we first divide an azygos vein, dissect the right recurrent laryngeal nerve nodes, mobilize the upper thoracic esophagus, dissect the lower thoracic esophagus and paraesophageal tissues en bloc, and then finally dissect the infra-aortic and left recurrent laryngeal nerve nodes systematically (Fig. 13.4).

The arch of the azygos vein is isolated and cut after applying Weck Hemolock clips using large and medium-large clip applier (Fig. 13.5). Then dissection of mediastinal pleura over right vagus nerve starts, and continues to the right subclavian artery. The right RLN could be identified at the lower margin of the right subclavian artery. Small branches of vagus nerve to the trachea and upper esophagus is dissected. Lymph nodes at the medial part of the right RLN is usually dissected completely remaining the right recurrent laryngeal nerve and right subclavian artery (Fig. 13.6). In this procedure, we can dissect the lymph nodes just below the thyroid gland.

Then, the mediastinal pleura overlying the esophagus are incised, esophagus is dissected from the mediastinum. We usually dissect the esophagus en bloc with the adjacent fat and lymph nodes, so called the meso-esophageal dissection (Fig. 13.7). When dissecting the upper esophagus from the trachea, the cautions not to make the injury to the membranous portion of trachea are needed (Fig. 13.8). When we dissect the left side of the esophagus, use of the electrocautery should be minimized to avoid the injury of the left recurrent laryngeal nerve. When dissecting this level, one should pay attention to the movement of the membranous portion, to prevent the laceration of left main bronchus. While an assistant surgeon retracts or elevates the esophagus, subcarinal and left peribronchial nodes can be dissected. Sometimes we need to magnify the camera view at this region because one or two aorto-esophageal arteries cross this area. Small endoscopic clips are applied to the arteries, and gauzes pads are packed to control minor bleeding.

Dissection continued down to the left side of the middle thoracic esophagus (Fig. 13.9), and the left vagus nerve was cut below the level of its pulmonary branch. The tho-

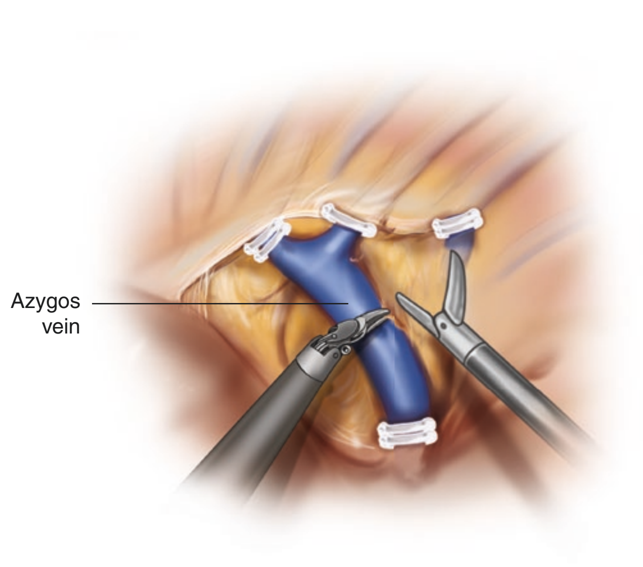


Fig. 13.5 Ligation of azygous vein with Weck Hemolock clip

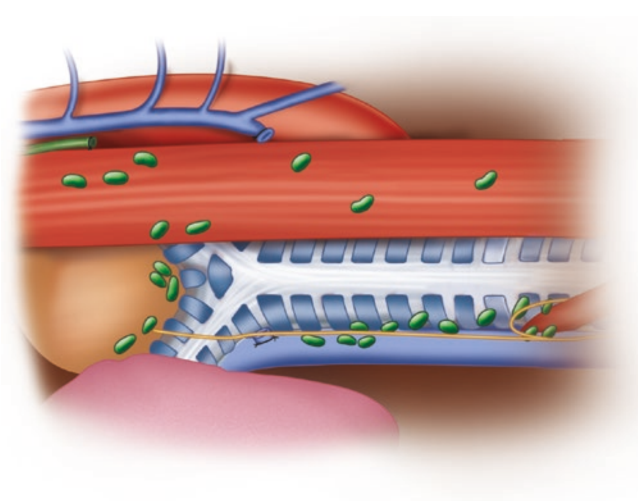


Fig. 13.4 The sequence of esophageal dissection

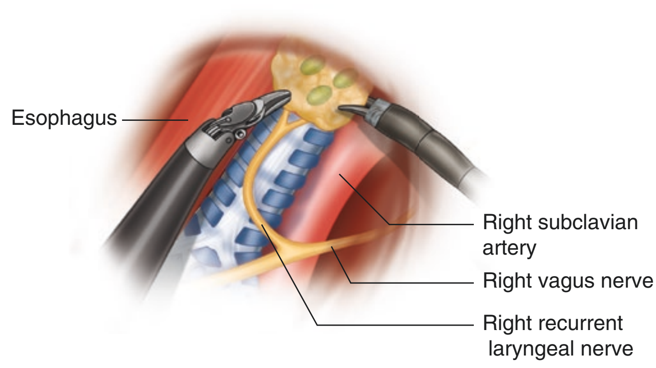


Fig. 13.6 Dissection of right recurrent laryngeal nerve nodes (*E*, esophagus, *Tr* trachea, *RCA* right subclavian artery, *arrow* left recurrent laryngeal nerve)

racic duct was clipped at the level of the diaphragm to prevent the postoperative chylothorax (Fig. 13.10). After dissecting to the hiatus, the right side of the esophagus was dissected with periesophageal tissues. After cutting the right vagus nerve below its pulmonary branch, subcarinal lymph nodes were dissected (Fig. 13.11). Sometimes small bronchial arteries run from the precarinal area, these bronchial arteries have to be ligated dur to bleeding. The thoracic duct, mediastinal pleura, and lymph nodes at paraesophageal, subcarinal, and peribronchial stations were dissected with attachment to the esophagus with en bloc manner.

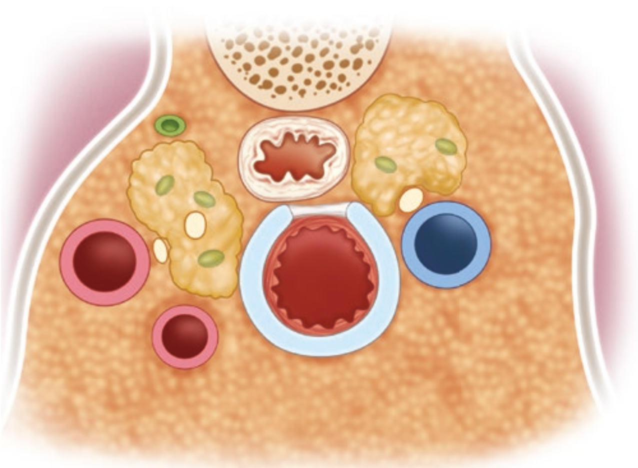


Fig. 13.7 (**a**) Cross sectional image of upper mediastinum. (*E* esophagus, *Tr* trachea, *LCA* right subclavian artery, *LCCA* left common carotid artery, *arrow* left recurrent laryngeal nerve). (**b**) The meso-esophageal dissection meant dissection of all soft tissues including lymph nodes just remaining the trachea, artery and recurrent laryngeal nerve. Adapted from Kim DJ, Park SY, Lee S, Kim HI, Hyung WJ. Feasibility of a robot-assisted thoracoscopic lymphadenectomy along the recurrent laryngeal nerves in radical esophagectomy for esophageal squamous carcinoma. Surg Endosc. 2014 Jun;28(6):1866–73. doi: https://doi.org/10.1007/s00464-013-3406-5. Epub 2014 Jan 24; used with permission

The trachea was retracted with a grasper by an assistant surgeon, and the left RLN was identified below the aortic arch. After dissection of infra-aortic and left tracheobronchial nodes, lymph nodes along the left RLN were dissected up to the thoracic inlet (Fig. 13.12). Small blood vessels run from the trachea to the posterior mediastinum, the fat pads along the left side of trachea are dissected first with cautery. The cross sectional structure of left recurrent laryngeal nerve nodes is illustrated in Fig. 13.13. To prevent the traction injury of recurrence laryngeal nerve, we routinely dissect the fat pads over the left recurrent laryngeal nerve including the adjacent lymph nodes, then dissect the fat pad below the left recurrent laryngeal nerve (Figs. 13.14 and 13.15). Another technique can be applied to dissect these areas; by lifting the esophagus upward by third robotic arm, then dissect the left recurrent laryngeal nerve nodes with attachment of the esophagus. We routinely skeletonize the left recurrent laryngeal nerve and the lymph nodes with their associated fat pads can be completely dissected along the recurrent laryngeal nerve. After completion of the total mediastinal lymphadenectomy, a 28Fr chest tube was placed, and the collapsed right lung was inflated. The patient was then turned to the supine position.

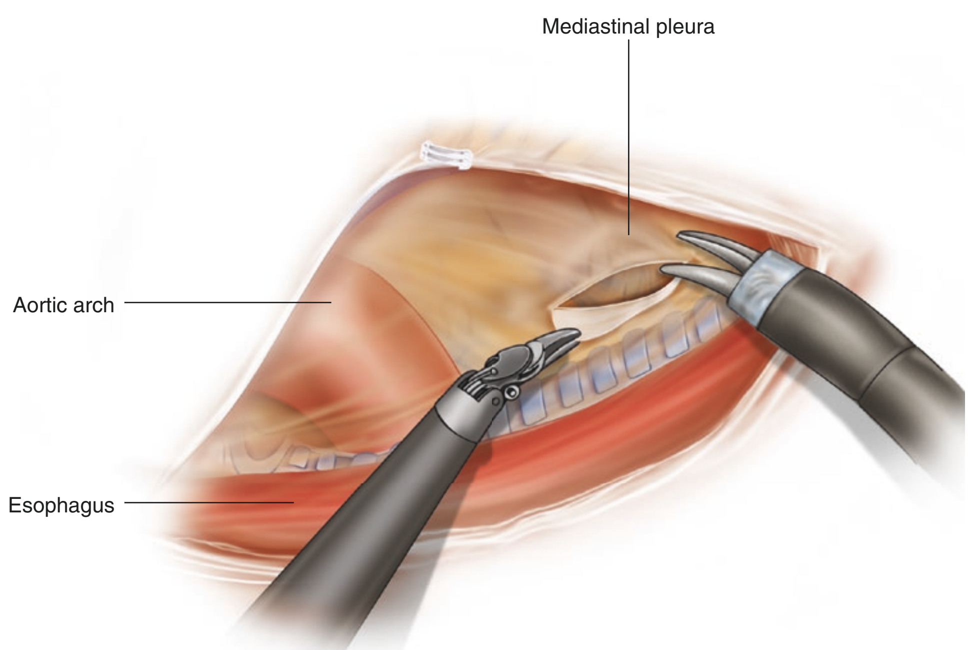


Fig. 13.8 Mobilization of the upper thoracic esophagus (*E* esophagus, *Tr* trachea, *AA* aortic arch)

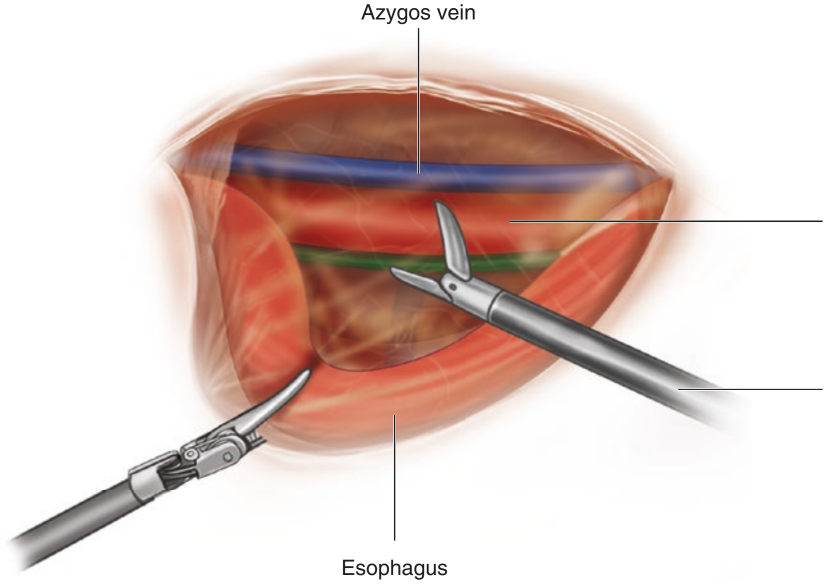


Fig. 13.9 En bloc resection of the lower thoracic esophagus (*E* esophagus, *A* azygous vein, *Pl* mediastinal pleura, *Lt* left lung, *DA* descending thoracic aorta)

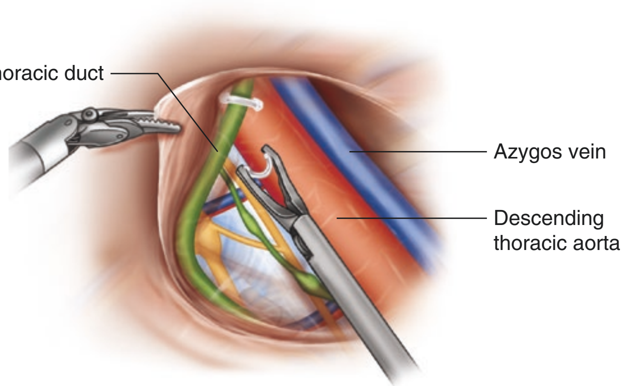


Fig. 13.10 Ligation of thoracic duct at diaphragm level (*T* thoracic duct, *A* azygous vein, *DA* descending thoracic aorta)

13.2.3 Laparoscopic Gastric Mobilization and Upper Abdominal Lymph Node Dissection

In the abdominal phase, we prefer to use conventional laparoscopy because it allows simultaneous neck dissection while a bulky robotic cart interferes with access to the neck area. The patient is placed in the reverse Trendelenburg position with the legs elevated about 30°. The first trocar is placed below the umbilicus by the open technique. Four other trocars are then placed (Rt. abdomen at umbilicus level, 12 mm; Lt. abdomen at umbilicus level, 5 mm; Rt. subcostal, 5 mm; midline in the upper epigastrium, 5 mm). The surgeon operates on the patient's right side, a camera operator is also on the patient's right side just beside the right side of the operator, and an assistant surgeon is on the patient's left side.

After pneumoperitoneum is established, the greater omentum is first divided by an ultrasonic shear. Division of the gastro-colic ligament is continued distally toward the pylorus and the stomach is further mobilized by dividing the short gastric vessels. The left gastric vessels are divided at the upper margin of the common hepatic artery. The lymph nodes bearing soft tissues around the common hepatic artery are dissected by lifting the anterior side of the stomach. Retroperitoneal attachment of the stomach is detached up to the diaphragmatic cruses and the abdominal esophagus is mobilized by dividing the parietal peritoneum. A gastric tube is then created by dividing the stomach at the lesser curvature using endoscopic linear staplers. We construct a 3- to 4-cm wide, narrow gastric tube without pyloroplasty. The phrenoesophageal membrane is dissected as the last step to avoid loss of the pneumoperitoneum.

13.2.4 Gastric Pull-Up and Cervical Esophagogastrostomy

Left cervicotomy is done and the cervical esophagus is mobilized after division of the omohyoid muscle. Horizontal collar incision is chosen when bilateral neck node dissection is indicated. The esophagogastric specimen is pulled out through a neck incision under laparoscopic control. The cervical esophagus is divided 2–3 cm below the cricopharyngeal muscle and then the specimen is removed. Esophagogastrostomy is done by the side-to-side stapled technique (Collard or Orringer's technique) or using 25 mm EEA, and the procedure is finished with the placement of a drainage catheter within the neck.

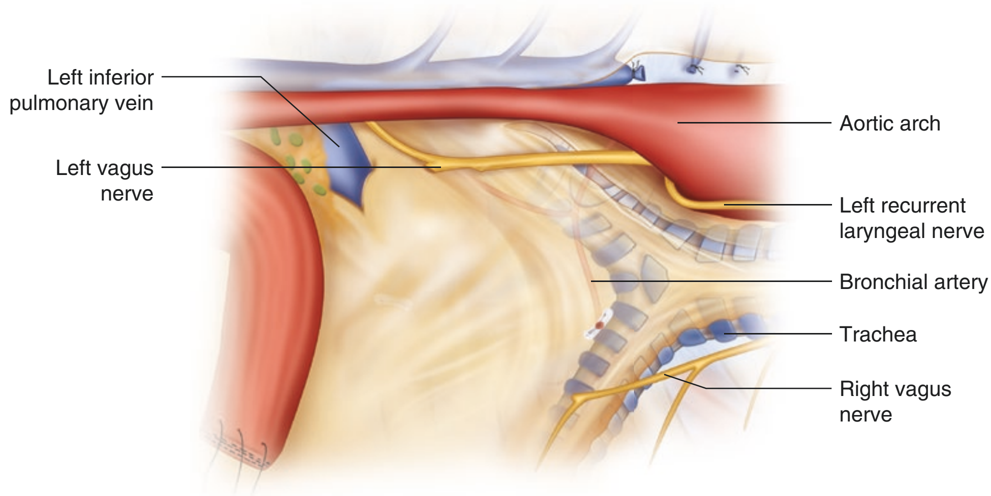


Fig. 13.11 Dissection of subcarinal lymph nodes and hilar area (*E* esophagus, *RBr* right bronchus, *LBr* left bronchus, *arrow* peribronchial nodes, *asterisk* subcarinal nodes). The vagus nerves have to be cut after branching the bilateral pulmonary branches. The hilum around the left inferior pulmonary vein has to be dissected carefully

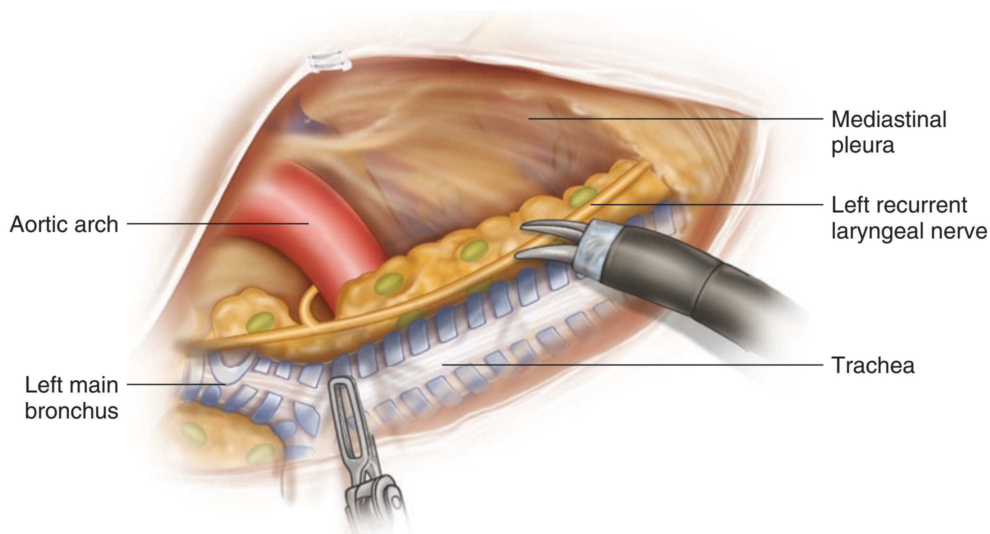


Fig. 13.12 Operative view of left recurrent laryngeal nerve

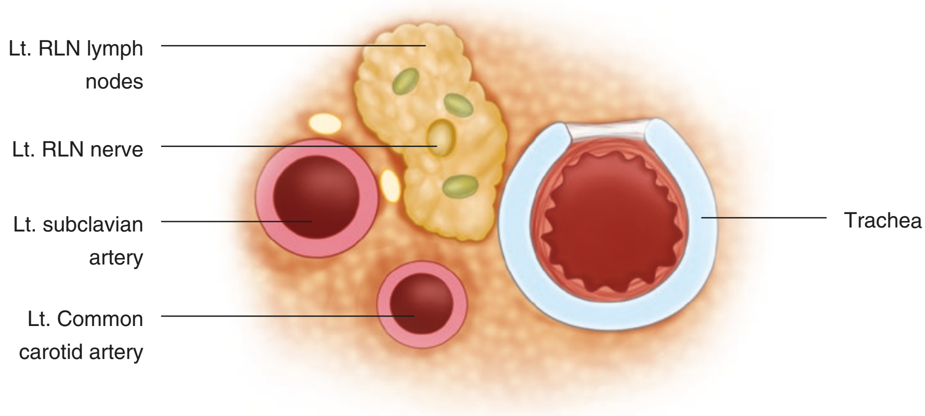


Fig. 13.13 Cross sectional image of left recurrent laryngeal area. Adapted from Kim DJ, Park SY, Lee S, Kim HI, Hyung WJ. Feasibility of a robot-assisted thoracoscopic lymphadenectomy along the recurrent laryngeal nerves in radical esophagectomy for esophageal squamous carcinoma. Surg Endosc. 2014 Jun;28(6):1866–73. doi: https://doi.org/10.1007/s00464-013-3406-5. Epub 2014 Jan 24; used with permission

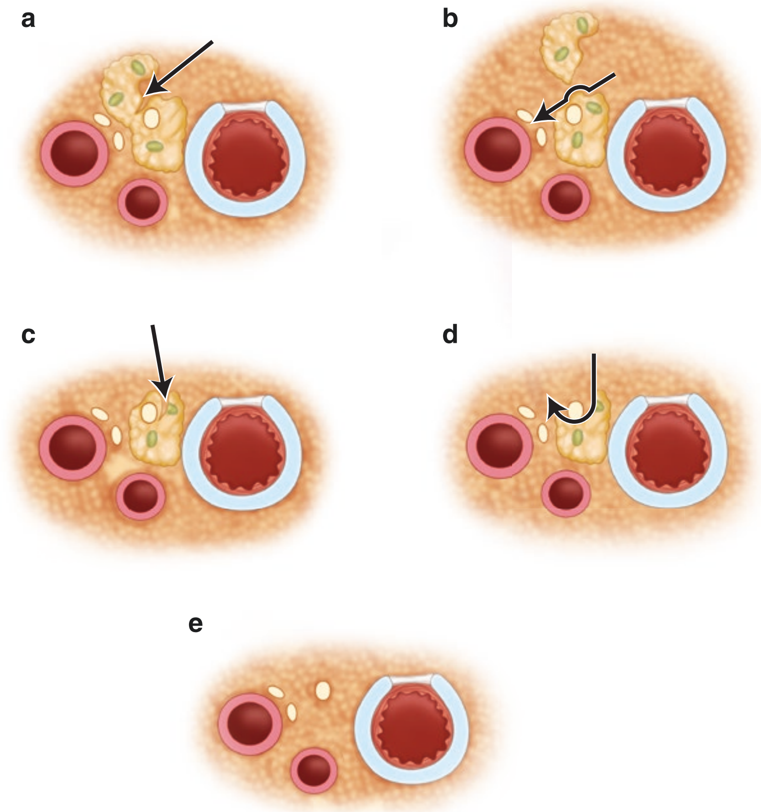


Fig. 13.14 Dissection of left recurrent laryngeal nerve nodes. (**a** and **b**) The dissection of the fat pads over the left recurrent laryngeal nerve including the adjacent lymph nodes. (**c** and **d**) The dissection of the fat pad below the left recurrent laryngeal nerve. (**e**) Completion of dissection of left recurrent laryngeal area. Adapted from Kim DJ, Park SY, Lee S, Kim HI, Hyung WJ. Feasibility of a robot-assisted thoracoscopic lymphadenectomy along the recurrent laryngeal nerves in radical esophagectomy for esophageal squamous carcinoma. Surg Endosc. 2014 Jun;28(6):1866–73. doi: https://doi.org/10.1007/s00464-013-3406-5. Epub 2014 Jan 24; used with permission

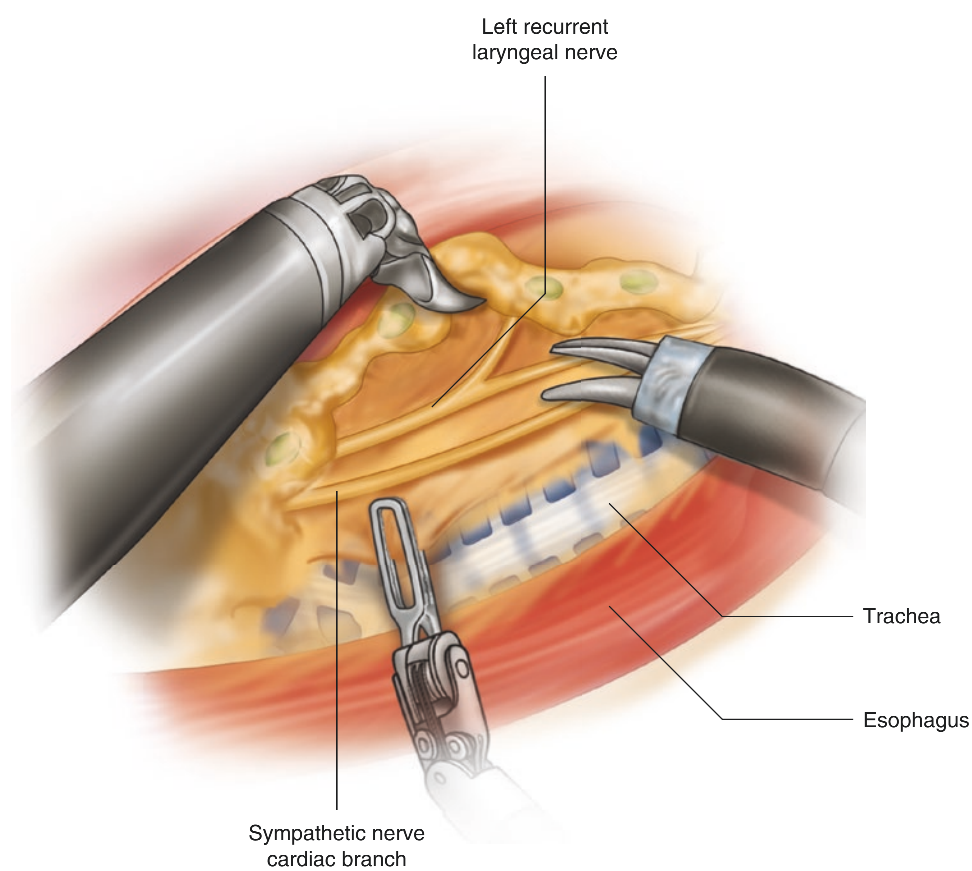


Fig. 13.15 Completion of dissection of left recurrent laryngeal area

13.3 Postoperative Care

The patient is usually transferred to the intensive care unit for monitoring. The nasogastric tube is removed on the second postoperative day and esophagography is done on the seventh postoperative day. Analgesia is achieved by intravenous patient-controlled analgesia for 2 days and then by fentanyl skin patch for 4–6 days.

13.4 Outcome

We have described operative outcome of the initial series of 114 consecutive patients [7]. Complete robotic esophagectomy was performed in all patients except for one, who required thoracotomy conversion because of bleeding from a superior segmental branch of the left inferior pulmonary vein. The total operation time was 419.6 ± 7.9 min, and robot console time was 206.6 ± 5.2 min. The mean numbers of dissected lymph nodes were 43.5 ± 1.4, and R0 resection was achieved in 111 patients (97.4%). Vocal cord palsy was the most common complication (30 patients, 26.3%), followed by anastomotic leakage (17 patients, 14.9%). The pulmonary complications were developed in 11 (9.6%) patients and the operative mortalities were developed in 3 (2.6%) patients.

Regarding the long-term outcome, 3-year overall survival (OS) after robot esophagectomy for esophageal squamous cell carcinoma was 85.0% in our data [8]. The 3-year OS in stage I, II and III were 94.4%, 86.2% and 77.8%, respectively. During the follow-up periods (mean follow-up time, 32.4 ± 2.2 months), only 6.3% patients suffered from loco-regional recurrences. We think that the acceptable oncologic outcomes of RATE might be related to the meticulous dissection of upper mediastinum especially including the bilateral RLN chains using the advantages of robotic system. A prospective randomized trial with longer follow-up times is necessary to validate the true efficacy of robotic esophagectomy for esophageal squamous cell carcinoma.

13.5 Tips and Pitfalls

- Proper selection of the patients is important in applying the semi-prone position. If a patient has a high body mass index or central obesity, or if a patient has a high risk of pulmonary morbidity, the semi-prone position may not be a good option.
- In case of pleural adhesion, it is better to do the adhesiolysis before the docking of robotic system.
- The robotic cart should be brought from the cranial side (not from the lateral side) of the patient. The angle between the long axis of the esophagus and the camera axis ranges from 45° to 60°. The distance between a camera port and a right arm port should be enough (more than 8 cm) to prevent a collision.
- During the dissection of hilum, especially be careful not to make the injury of left main bronchus and left inferior pulmonary vein. In our series, we have one case of thoracotomy conversion due to bleeding of left inferior pulmonary vein. Also we have two cases of left main bronchus injury, but it could be repaired by suture.
- Left pleura is incised from the inferior border of left main bronchus to the esophageal hiatus. When the exposure is not good at this area, we changed the camera angle to 30° in an upward direction.

References

1. Law S, Wong J. Current status of esophageal cancer treatment in Asia. Esophagus. 2004;1(4):169–76.
2. Akiyama H, et al. Radical lymph node dissection for cancer of the thoracic esophagus. Ann Surg. 1994;220(3):364.
3. Tachibana M, et al. Extended esophagectomy with 3-field lymph node dissection for esophageal cancer. Arch Surg. 2003;138(12):1383–9.
4. Boone J, et al. International survey on esophageal cancer: part I surgical techniques. Dis Esophagus. 2009;22(3):195–202.
5. Osugi H, et al. Learning curve of video-assisted thoracoscopic esophagectomy and extensive lymphadenectomy for squamous cell cancer of the thoracic esophagus and results. Surg Endosc. 2003;17(3):515–9.
6. Kim DJ, et al. Thoracoscopic esophagectomy for esophageal cancer: feasibility and safety of robotic assistance in the prone position. J Thorac Cardiovasc Surg. 2010;139(1):53–9.e1.
7. Park S, et al. Robot-assisted thoracoscopic esophagectomy with extensive mediastinal lymphadenectomy: experience with 114 consecutive patients with intrathoracic esophageal cancer. Dis Esophagus. 2016;29(4):326–32.
8. Park S, et al. The oncologic outcome of esophageal squamous cell carcinoma patients after robot-assisted thoracoscopic esophagectomy with total mediastinal lymphadenectomy. Ann Thorac Surg. 2017;103(4):1151–7.

Additional Readings

Kim DJ, Hyung WJ, Lee CY, Lee JG, Haam SJ, Park IK, et al. Thoracoscopic esophagectomy for esophageal cancer: feasibility and safety of robotic assistance in the prone position. J Thorac Cardiovasc Surg. 2010;139(1):53–9.e1. https://doi.org/10.1016/j.jtcvs.2009.05.030. PubMed PMID: 19660280.

Kim DJ, Park SY, Lee S, Kim HI, Hyung WJ. Feasibility of a robot-assisted thoracoscopic lymphadenectomy along the recurrent laryngeal nerves in radical esophagectomy for esophageal squamous carcinoma. Surg Endosc. 2014;28(6):1866–73. https://doi.org/10.1007/s00464–013–3406–5. PubMed PMID: 24464384.

Park SY, Kim DJ, Jung HS, Yun MJ, Lee JW, Park CK. Relationship between the size of metastatic lymph nodes and positron emission tomographic/computer tomographic findings in patients with esophageal squamous cell carcinoma. World J Surg. 2015;39(12):2948–54. https://doi.org/10.1007/s00268–015–3221–3. PubMed PMID: 26324159.

Park SY, Kim DJ, Yu WS, Jung HS. Robot-assisted thoracoscopic esophagectomy with extensive mediastinal lymphadenectomy: experience with 114 consecutive patients with intrathoracic esophageal cancer. Dis Esophagus. 2016;29(4):326–32. https://doi.org/10.1111/dote.12335. PubMed PMID: 25716873.

Park SY, Kim DJ, Do YW, Suh J, Lee S. The oncologic outcome of esophageal squamous cell carcinoma patients after robot-assisted thoracoscopic esophagectomy with total mediastinal lymphadenectomy. Ann Thorac Surg. 2017;103(4):1151–7.

Robotic Esophagectomy

14

Kemp Kernstine Sr.

Abstract

Robotic technology can be used to perform a careful and precise esophagectomy. Three approaches are described: the transhiatal approach, the transthoracic approach with the anastomosis in the chest, and the transthoracic approach with the anastomosis in the neck. The details of each technique are reviewed.

Keywords

Esophagectomy • Esophageal cancer • Esophageal neoplasm • Esophageal stricture • End stage achalasia • Recurrent gastroesophageal reflux disease • Gastroesophageal junction cancer • Robotic • Salvage esophagectomy • Minimally invasive

14.1 Background

Esophageal cancer is the most common indication for an esophagectomy. Others include:

- Stricture and/or dysfunction from caustic injury
- Large benign tumors or lesions requiring wide resection of the esophagus
- Refractory peptic stricture
- Refractory motility disorder with pain and dysphagia
- Failed antireflux surgery, typically after 2–3 prior antireflux procedures
- Idiopathic inflammatory disorders
- End-stage achalasia

For esophageal cancer, the role of esophagectomy for esophageal and gastroesophageal cancer is not clearly defined, whether it provides a potential cure or provides prognostic information. There are two points of view. Nihilists believe it provides a new conduit for swallowing and staging information; chemotherapy and/or radiation are the critical component of multimodal esophageal cancer therapy for long-term survival. Others believe that esophagectomy, if carefully performed to remove all adjacent lymphatic and potentially involved peri-esophageal tissue, not only provides palliation, it reduces the likelihood for loco-regional recurrence and will improve survival. Consensus guideline efforts have recommended that the depth of esophageal wall penetration and location of tumor are important for the extent that lymphadenectomy should be performed [1].

In the United States and in men, esophageal cancer is the seventh most common cause of cancer death, it occurs at a rate of 3–5 per 100,000 per year. Twenty-one percent present with localized disease and have a 5-year relative survival rate of 40%. Thirty percent have regional disease with a 5-year survival rate of 21% and 37% are found to have distant disease with a 4% 5 year survival rate [2]. For patients that undergo an esophagectomy, the in-hospital mortality is 6–8% nationally with a serious morbidity rate of 44–49% with an anastomotic leak rate of 10% and an average length of stay a 16–19 days [3]. The cost-of-care is $119–$138,000. The number of esophagectomies are rising at a rate of 4% per year and a greater percentage of patients are being sent to

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, Department of Cardiovascular and Thoracic Surgery, University of Texas Southwestern Medical Center,
5959 Harry Hines Blvd, POB1-10th Floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_14

high-volume centers; in 2010, nearly 60% were referred to a high volume center.

The first minimally invasive esophagectomies were performed in the early 1990s. The first robotic esophagectomies were performed in 2002, the RATE and the RALE; shortly after federal approval for the use of the robot to perform surgery in humans. Thus far, the benefit of using robotic technology over the performance of the video-assisted technique to perform an esophagectomy has not been demonstrated. Evidence does not yet support the claims of a better surgical resection, less pain, and reduced debility. The non-robotic minimally invasive or video-assisted approach can be challenging to perform a precise dissection, certain aspects of the procedure may be compromised, such as the performance of a wide resection may not be consistently achieved, because of the lack of visibility and/or the lack of articulations necessary to perform a thorough lymphadenectomy and the significant torque at the chest wall to obtain the best visibility increases the likelihood for postoperative discomfort. Robotics provides surgeon-directed 3-D high definition visibility and if the arms are set correctly, no motion at the chest wall. The robot functions very well in tight spaces, less tissue manipulation is required to perform the same function than with a video-assisted approach. The robotic technology and the techniques utilizing it will continue to evolve likely making this the preferred approach for esophagectomy.

Surgical preparation begins with the initial clinical evaluation. The issues of dysphagia, possible aspiration, performance status and weight loss and symptoms that might indicate the presence of metastatic disease must be identified and addressed. A thorough history and physical examination is performed to identify comorbidities; their severity and attempts made to optimize their care. An upper gastrointestinal endoscopy, endoscopic ultrasound, computed tomogram (CT) of the chest with 1 mm collimation and a positron emission tomography (PET)-CT are all potential tests to provide prognostic information and appropriateness of esophagectomy. Endoscopic assessment of the degree and location of esophageal involvement along with biopsy provide further prognostic information. Any non-bone or brain metastatic lesion must be confirmed with biopsy. Patients with T2 or greater stage are provided induction therapy, either chemotherapy alone or chemoradiotherapy. For those that undergo induction therapy, post-treatment restaging is performed at approximately 4 weeks after the last dose of radiation therapy repeating the imaging, endoscopy and endoscopic ultrasound. Most patients have been entered into routine physical therapy 3× per week during their induction therapy. For those without worsening performance status and no evidence of disease advancement or metastatic disease, surgical resection is performed at approximately 6–8 weeks after the last dose of radiation therapy. For those without disease advancement, but poor performance status, we continue to observe and support them and then if they have recovered without evidence of metastatic disease at 6 or more months after completion of induction therapy, we perform esophagectomy.

An esophagectomy is one of the most major operative procedures performed and patients should be carefully prepared and managed accordingly. Not uncommonly, we admit the patient preoperatively for intravenous hydration. Mechanical bowel preparation is performed in those patients with prior laparoscopic and open abdominal surgical procedures. The morning of surgery the patients thoroughly brush their teeth, tongue, buccal mucosa and gums; gargle and swallow 1000 mg of *amoxicillin-clavulanate* and 30 mL of nystatin. Two grams of cefuroxime is given on induction and then every 4 h during the case.

14.2 Operative Setup

The robot is positioned in the operating room with a plan for the different robotic surgical approaches necessary for the different procedures to be performed. The operating table is often much easier to reposition when moving from the abdomen position to the chest position. The surgical team should be ready to convert to the standard open procedure should the need arise; commitment to a minimally invasive approach should not overwhelm performing a careful operative procedure.

14.3 Anesthetic Management

The anesthesiologist should be experienced in thoracic anesthesia, specifically and especially, in esophagectomy. These are complex cases and maintaining the hemodynamics and acid-base balance can be challenging with the CO_2 insufflation required to perform the case, while attempting to minimize the likelihood of acute lung injury and compromising the perfusion to the gastric conduit. Many of these patients have numerous and severe co-morbidities, so management is even more complex. Most of the procedures are performed using single lung ventilation, either by bronchial blocker or double lumen endotracheal tube. Hypoperfusion to the stomach is manifested by the development thinning of the gastric wall and when incised, bleeds little. We avoid the use of central lines, if at all possible. An arterial line and 2–3 peripheral IVs are used.

14.4 Stepwise, Conduct of the Operation

In general, three different techniques are used to perform an esophagectomy:

Robot-Assisted Trans-hiatal Esophagectomy (RATE). This procedure is likely best for patients who have or are suspicious of early-stage esophageal cancer and benign disease. The procedure allows for extensive celiac axis lymph node dissection and fairly aggressive lower mediastinal lymph node removal, but the mid- and upper peri-esophageal lymphatic tissue are minimally addressed; if at all. The anastomosis is performed in the neck by a variety of techniques that will be discussed.

Robot-assisted Ivor Lewis Esophagectomy (RILE). This two-stage procedure is likely best for patients with gastroesophageal junction and lower-third esophageal cancer lesions. As with the RATE, it allows for a wide lymph node dissection in the abdomen, but provides better access of the mediastinum by the transthoracic route. The anastomosis is performed above the level of the azygous vein; usually at the level of the apex of the chest.

Robot-Assisted extended LymphadenoEsophagectomy (RALE). This procedure is like the open thoracotomy modified-McKeown technique. The mediastinal dissection is performed through a transthoracic route first and then in the second stage, the abdominal dissection and the creation of the gastric conduit are performed with the anastomosis performed through a left neck incision. Three lymph node fields are addressed, extensive lymphadenectomy is performed in the abdomen and the mediastinum with only the deep cervical lymph nodes are resected.

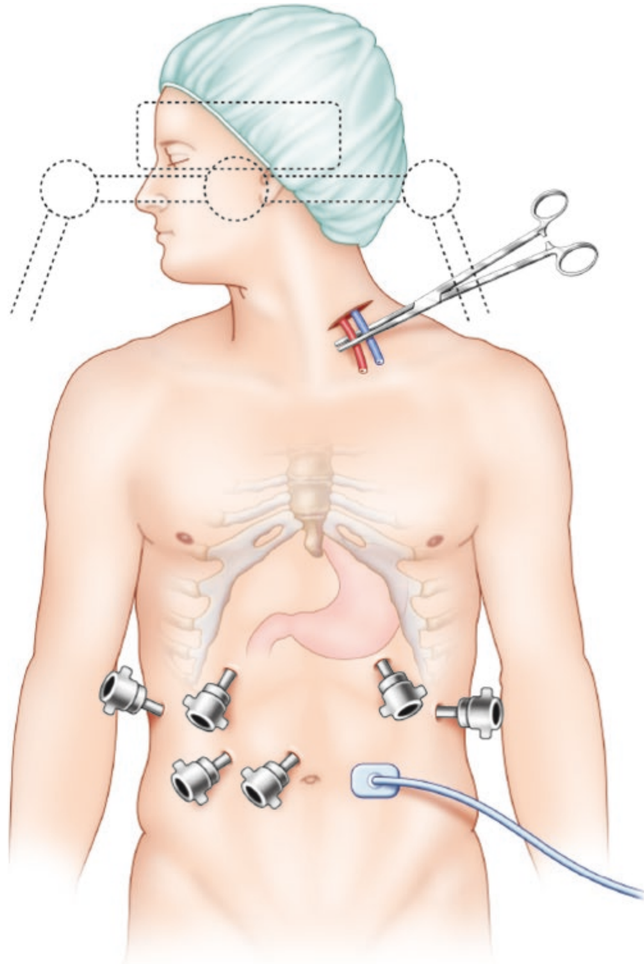


Fig. 14.1 Patient is placed supinely. A left neck incision is made and the dissection is performed along the anterior aspect of the sternocleidomastoid muscle. The omohyoid is transected and the esophagus identified, then encircled with a 1 in. Penrose drain and the wound packed with an antibiotic soaked laparotomy pad. Dependent upon the size of the patient, if they are larger, we place a Veress needle supraumbilically, inflate the abdomen to 15 mmHg of CO_2; then extend the incision and place a 12 mm port. Five other ports are placed as described and a laparaoscopic jejunostomy feeding tube is then placed. The robot is then brought in over the head, the abdominal lymphadenectomy is performed as necessary, dependent on the presence of malignant disease. A 4–5 cm stapled gastric tube is created after Botox is injected into the pylorus. A second 1 in. Penrose is placed around the GE junction of the intended specimen to pull the esophagus down, then the dissection is continued up into the mediastinum as far as possible

14.4.1 Robot-Assisted Trans-Hiatal Esophagectomy (RATE)

The RATE is performed in patients with benign disease or early stage esophageal cancer. After the patient has been thoroughly evaluated and the presence of esophageal cancer confirmed, the RATE is performed with the patient in the supine position. After the patient is surgically prepared, an oblique incision is made in the left neck along the anterior border of the sternocleidomastoid muscle. After the omohyoid muscle is divided, the leftward aspect of the esophagus is identified away from the tracheoesophageal groove where the recurrent laryngeal nerve is located, by finger dissecting in just beneath the omohyoid by pushing through the areolar tissue to the anterior longitudinal ligament of the cervical spine the leftward plane of dissection is cleared. This maneuver helps to avoid the major vascular and neural structures in the neck and initiates the medial direction of the dissection. A previously placed naso-gastric tube assists in the palpation and the careful digital manipulation of the most distal aspect that the esophagus can be palpated to avoid injury to the recurrent laryngeal nerves and the posterior aspect of the trachea and encircled with a 1 in. Penrose drain is placed around the esophagus and wound packed with an antibiotic soaked laparotomy pad.

Typically, six abdominal port sites are used, three of which are for the robotic arms (Fig. 14.1). A supraumbilical transverse small stab wound is made through which a Veress needle is passed and the abdomen/peritoneal cavity is inflated with carbon dioxide and then a 12 mm port is placed and the abdomen inflated to 15 mmHg of pressure. If there is no evidence of metastatic disease, we first place a laparoscopically-performed jejunostomy feeding tube. The initial steps are to identify a segment of small bowel approximately 20–30 cm from the Ligament of Treitz. We then place a jejunostomy feeding tube into the antimesenteric aspect of the chosen section of small bowel. Two 5 mm ports are placed, one on the right and one on the left at the mid- to anterior-axillary line just inferior to the costal margin. Then, the two robotic arms ports should be placed 10–12 cm to the right and left of the midline approximate 10–12 cm anterior to the transverse plane of the supra-umbilically placed videoscope site. These two sites can be adjusted so that the ports do not injure either of the costal arches. The final port, 12 mm in size, is placed laterally towards the right side approximately 10 cm and slightly anterior to the transverse plane of the videoscope site.

The bedside cart or robot is brought from the head of the bed over the patient's head with the patient in fairly steep reverse Trendelenburg. Through the rightward subcostal 5 mm port, we place a diamond-flex table mounted self-retaining retractor to hold the left lobe of the liver up and away from the hiatus. A Pro-Grasp is placed in the left robotic arm, patient's right side; and a harmonic scalpel is placed in the left. With a 30° down robotic videoscope view, we then enter the lesser sac through the transverse mesocolon, approximately 2 cm away from the right gastroepiploic arcade. The assistant or bedside surgeon uses a bowel grasper to assist in exposure and retraction. We continue this dissection along the greater curvature and divide the short gastric arcade maintaining the same distance away from the greater curve of the stomach. This exposes the structures in the lesser sac and retroperitoneum. Through the left accessory port, the assistant uses an atraumatic grasper or a 5 mm 3-prong fan retractor and without grasping lifts the stomach up and away from the retroperitoneum. We then dissect the lymphatic tissue away from the splenic hilum, along the splenic artery and around the celiac axis. After thoroughly dissecting the lymphatic tissue with the specimen, we ligate the left gastric artery with either a vascular endostapler or a robotic Hem-o-lok clip. We then perform a retrogastric dissection along the antrum to the gastric duodenal artery very carefully exposing it. Caution is exerted in this location to avoid tearing any prominent tributaries from either the duodenum or the artery; if it occurs, use Surgicel (Johnson & Johnson, Inc.). No Kocher maneuver is necessary, but we do divide any restrictive adhesions to the duodenum and pylorus that may be present. We then inject 100 U of Botulinum Toxin A diluted into 4 mL of saline for injection and through a mediastinoscopy aspiration needle into four quadrants of the muscular part of the pylorus, raising an intramuscular wheal in each location. After pulling back the previously placed NG tube to 25 cm from the nares, we then perform a stapled gastric tube that is approximately 4–5 cm wide and starting approximately 5–6 cm from the pylorus, providing about a 300 mL residual stomach (Fig. 14.2). Then, with 0 Ethibond on an SH needle, we secure the tip the gastric tube to the lesser curvature side of the specimen in two locations with figure-of-eight sutures. The lesser omentum is divided

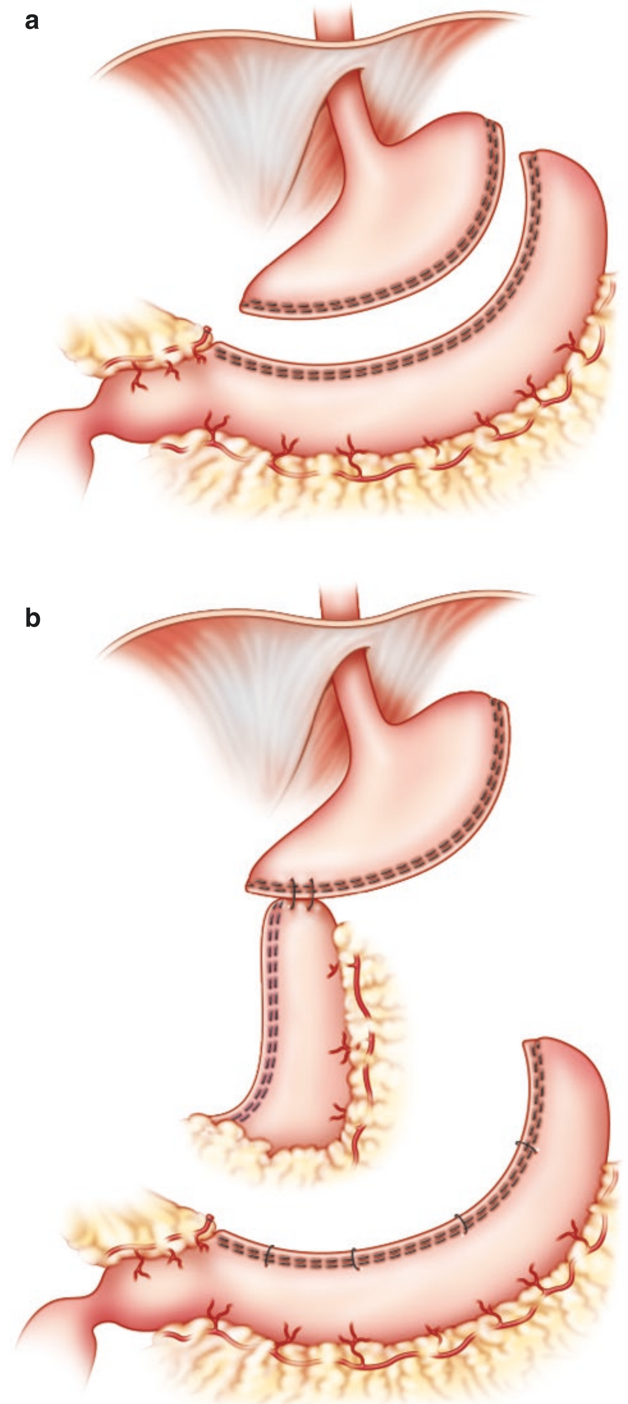


Fig. 14.2 A 4–5 cm wide gastric conduit is made maintaining the orientation of the staple line to the greater curve of the stomach. The tip of the conduit is sewn to the specimen with 2× figure-of-8 0 Ethibond sutures. For the RILE procedure, 4 fairly equally spaced 6 cm lengths of 0 Ethibond is sutured along the staple line to help estimate the length of tube remaining in the abdomen, this maneuver helps prevent leaving redundant gastric tube in the abdominal cavity after the conduit is pulled into the chest

widely to expose the right crus. All of the diaphragmatic attachments around the circumference of the esophagus are divided, exposing the right and left crus. In patients who do not have a sufficiently wide hiatus, we can make a small incision in the esophageal hiatus anteriorly. A 1 in. Penrose drain is placed around the distal aspect of the esophagus/gastroesophageal junction. This allows for grasping and retraction of the GE junction without tearing it and provides the ability to exert significant downward retraction on the esophagus. We then begin the mediastinal dissection widely and immediately adjacent to the diaphragm and the mediastinal pleura, leaving the mediastinal pleura, if possible, intact. We continue the dissection cephalad avoiding injury to the descending aorta posteriorly, mediastinal pleura laterally and the pericardium and airways anteriorly. To assist in the mediastinal dissection we often decrease the peritoneal CO_2 pressure to approximately 5 mmHg and use a 0° scope; the reduced pressure allows the tip of the endoscope to reach further into the mediastinum and to change the angle of approach. The 0° scope gives a wider view of the mediastinal dissection in all directions. We are able to reach as high as the mid to upper mediastinum. The two Penrose drains, the one on the left neck and the other around the GE junction are pulled back and forth to identify restricting areolar tissue that must be divided. Once the mediastinal dissection is completed, we undock the robot and move it away from the patient to again expose the left neck incision. Using digital exploration and a mediastinoscope through the left neck incision, the remainder of the mediastinal attachments are divided, again using both Penrose drains and a laparoscopic view to assist in the remaining dissection.

For patients with tumors greater than 3 cm greatest transverse diameter on the axial CT scan passage through the esophageal hiatus and the thoracic inlet may be difficult, potentially tearing the tumor and spilling tumor in the wound. In these cases, we make a upper abdominal midline laparotomy with a wound protector to remove the tumor transabdominally. Once all of the abdominal and mediastinal dissection has been completed the robot is undocked and moved away from the head of the operating table, an 8–9 cm upper midline laparotomy is performed as directed by the laparoscopic view to avoid the left lobe of the liver. An Alexis laparoscopic wound protector(Alexis Medical) is placed into the wound. Through the previously performed neck incision, the laparotomy pad that had been previously placed is removed and the Penrose drain is pulled up into the wound. Then using a tissue linear stapler to divide the upper esophagus, a #2 36″ silk is tied to the distal portion of the stapled esophagus. Esophageal specimen is then grasped through the hand port wound protector covered incision and brought out of the abdomen with the heavy silk attached. The silk is cut and the specimen sent to pathology to be examined for margins. The conduit is then brought out of the abdominal incision and examined. Any areas that might be bleeding are carefully and loosely oversewn in a Lemberted fashion to avoid ischemia. Using an adult Foley catheter and an arthroscopy bag cut to the length of the intended length necessary for the intrathoracic portion of the conduit. The endoscopy aperture of the arthroscopy bag is then placed around the distal end of the Foley catheter and firmly tied with an umbilical tape so that it is airtight. Once this is completed the abdominal wound portion heavy silk suture and sutured around the balloon in fusion portion of the proximal end of the Foley catheter. The neck incision portion of the heavy silk is then pulled up into the neck and saline is infused into the Foley balloon to approximately 30 mL. The arthroscopy bag is in bunched in a sock-like fashion the conduit tip is placed immediately adjacent to the inflated Foley balloon within the arthroscopy bag in an orientation that it will sit within the mediastinum. The bag is then unraveled to cover the conduit. Suction is placed in the open portion of the Fogarty catheter so that suction is exerted into the arthroscopy bag and it firmly collapses around the gastric neo-esophagus conduit. The suction is maintained while the Foley catheter is pulled, slowly advancing the conduit up into the neck (Fig. 14.3). Once sufficient length of the conduit has been achieved, without any redundancy in the abdomen, the suction is taken off and the bag is slowly removed. We then replace the Alexis laparoscopy cover over the wound protector and the conduit within the esophageal hiatus is laparoscopically examined. If the esophageal hiatus is too large around the conduit, 0 Ethibond sutures are carefully placed to reduce the size of the hiatus and to attach the conduit to the hiatus without injuring the blood supply to the conduit.

We have found that the robotic transhiatal approach does not allow for complete esophageal mobilization to the neck, as mentioned earlier, the dissection of the upper esophagus must be performed through the cervical incision site. The robot is undocked and moved away from the patient. Then, a mediastinoscope is used to perform the remainder of the upper periesophageal dissection through the left neck wound. Once this is completed, we replace the videoscope back into the abdomen and watch the conduit as it is passed through the esophageal hiatus up into the patient's cervical incision, removing the specimen from the neck incision. The previously placed nasogastric tube is pulled back just far enough so that the esophagus can be divided at an appropriate location and the cephalad aspect of the gastric tube is transected with a thick tissue stapler. The end of the gastric tube is embricated with interrupted 3–0 Vicryl sutures. Through an incision on the mesenteric side of the gastric tube, a side-to-side functional end-to-end anastomosis is performed (Fig. 14.4). We then pass a premeasured length of nasogastric tube and it is positioned within the conduit at the lower aspect of the mediastinum, the remaining portion of the anastomosis to be closed is approximated with interrupted 3–0 Vicryl. We instill air to check for any leak and reinforce the anastomosis as necessary. To protect the staple line to avoid the staple line

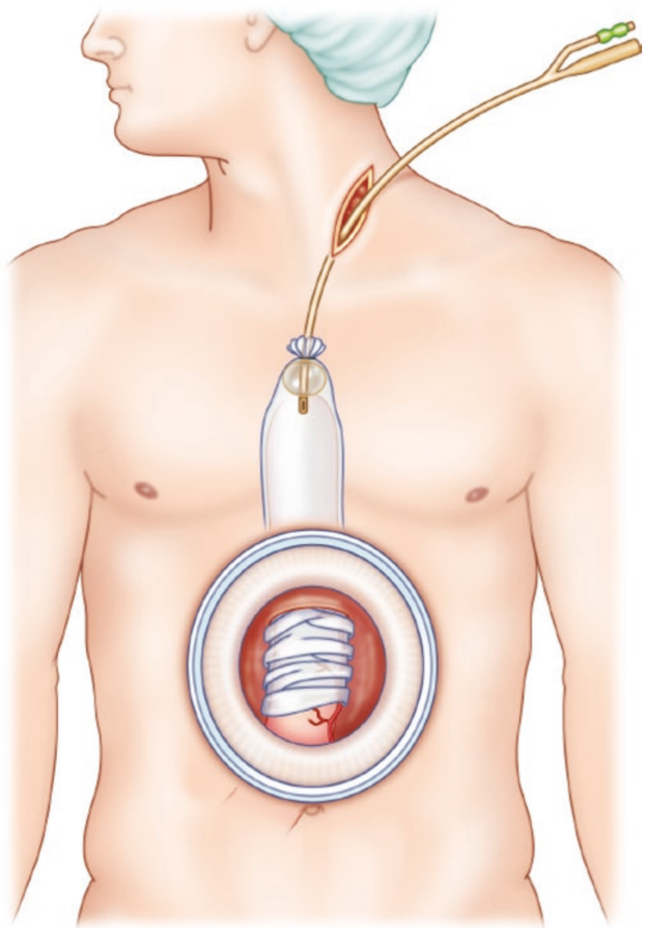


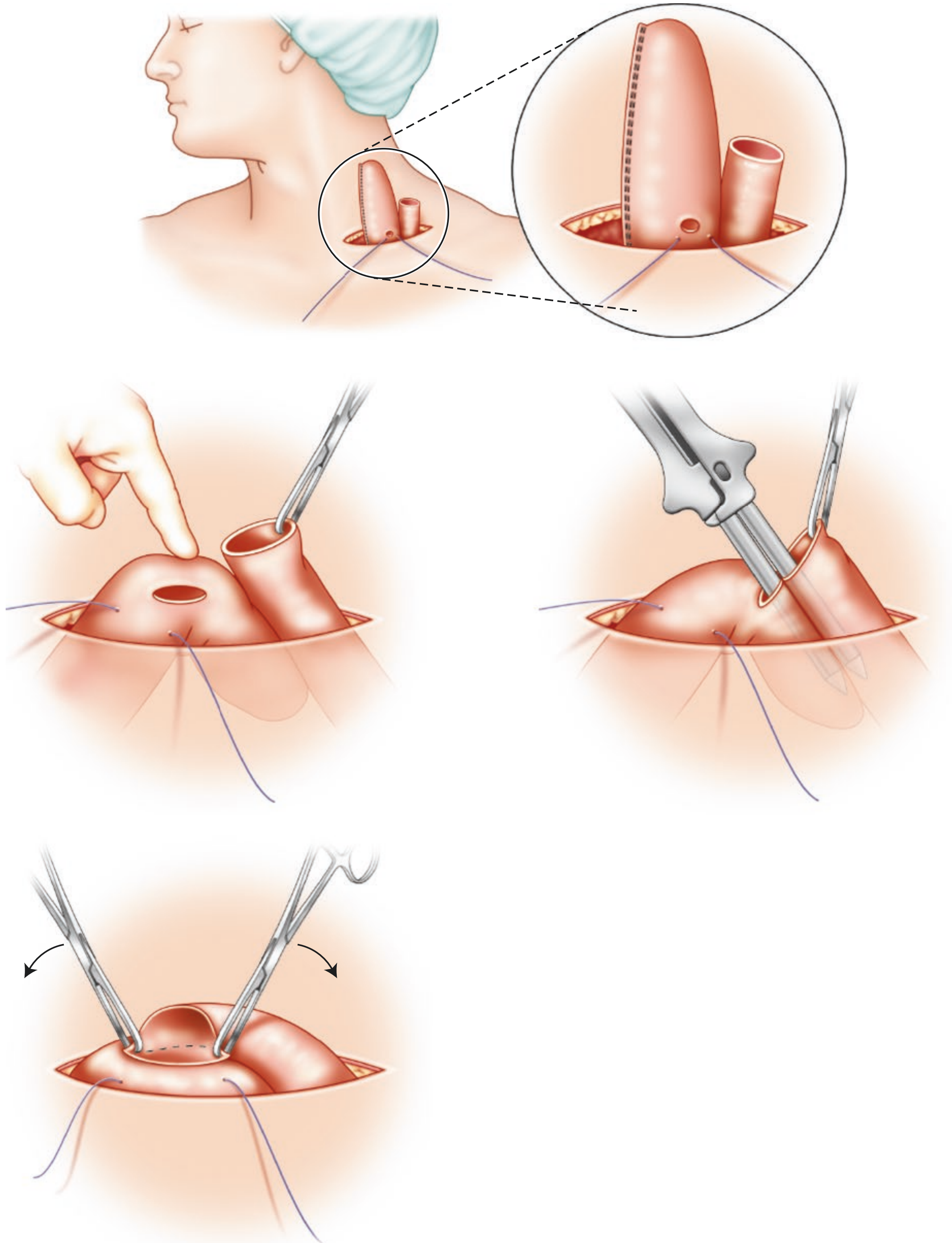
Fig. 14.3 An arthroscopy bag is fashioned to an adult Foley catheter with umbilical tape guided into its mediastinal location and into the left neck wound; then, placed onto the newly created gastric tube. Suction into the bag creates a suction pressure into the bag and onto the conduit to allow the Foley to balloon to serve as the lead point to bring the conduit up to the neck for the eventual anastomosis

injury to the trachea and bronchi, we embricate the upper third of the conduit with interrupted Lemberted Vicryl sutures. The neck is closed with a #10 flat Jackson Pratt drain brought through an inferior and separate stab wound. After the wound is irrigated, it is loosely closed in layers with interrupted Vicryl sutures and then skin staples. We often redock the bedside cart or robot and loosely re-approximate the hiatus and place some interrupted sutures from the hiatus to the gastric conduit, avoiding injury to the gastroepiploic blood supply. Any adjacent omentum is positioned around the lower aspect of the dissection and occasionally sutured into place. The 12 mm port sites are closed with 0 Vicryl. The abdominal skin incisions are closed with Vicryl as well.

14.4.2 Robot-Assisted Ivor Lewis Esophagectomy (RILE)

A double-lumen endotracheal tube is placed for single lung ventilation. No neck incision is required as the anastomosis will be performed in the chest. First, the abdominal procedure is performed as with the RATE with the upper extent of the periesophageal dissection goes to the lower third of the esophagus. No Penrose drain is necessary to retract the esophagus. Furthermore, we place 4× 0-Ethibond Lemberted sutures (on an SH needle) along the staple line marking the point 5 cm from the very distal portion of the staple line and then every 6–8 cm (Fig. 14.3). These are used as a guide to verify the amount of gastric conduit in the chest. Furthermore, at the end of the creation of the conduit, we push the specimen up into the lower mediastinum through the hiatus and the remaining conduit up to the upper abdomen in the correct orientation. Remaining intraabdominal omentum that is unattached to the conduit is pushed up into the upper abdo-

Fig. 14.4 The gastric tube is brought up to the neck, either using the specimen as a lead or the Foley arthroscopy bag technique. Any excess tube is transected with a tissue stapler for thicker tissue and the tip of the staple line embricated with Lemberted interrupted 3-0 Vicryl sutures leaving the needles on the suture and attaching each to a hemostat. The visible gastric staple line is then embricated with a running 0-vicryl on an SH needle so that the staple line cannot touch the trachea. Then two stay sutures of 3-0 Vicryl are sewn with a single throw into the gastric tube approximately 5–6 cm from the tip of the gastric tube on the lateral surface leaving a 1 cm space between the two sutures. Then using a low current cautery and hemostat the conduit is entered between the two previously placed Vicryl stay sutures. The end of the conduit is then pushed deep behind the proximal cut end of the esophageal remnant held with two Allis clamps, this is done in a fashion to maintain the Vicryl sutures. Once this is completed, the gastrostomy that was made between the two Vicryl stay sutures is dilated to allow passage of the 60 mm endoGIA linear stapler, the soft end should be inserted into the gastric tube to avoid potential trauma and tearing by the anvil portion of the stapler. Using the Vicryl stay sutures, the Allis clamps on the esophageal remnant and manual palpation of the gastric conduit and the proximal esophagus a 4–5 cm oblique anastomosis is made. Once this is completed, the NG tube is pushed down into the anastomosis and the gastric conduit to sit 40 from the nares. Then using 3-0 Vicryl, a running mucosal closure is performed. Then, 3-0 Vicryl Lemberted sutures are used to embricate the remaining closure and several interrupted sutures to reduce the tension at the staple line and help to orient the anastomosis. A tongue of omentum is then placed around the anastomosis and along the back of the airway to help protect the anastomosis and the airway. A #10 flat Jackson Pratt drain is then brought through a separate stab wound and placed into the wound and the wound is irrigated thoroughly with antibiotic irrigation and closed with interrupted Vicryl and skin staples to close the skin. These staples are typically removed in 5–7 days



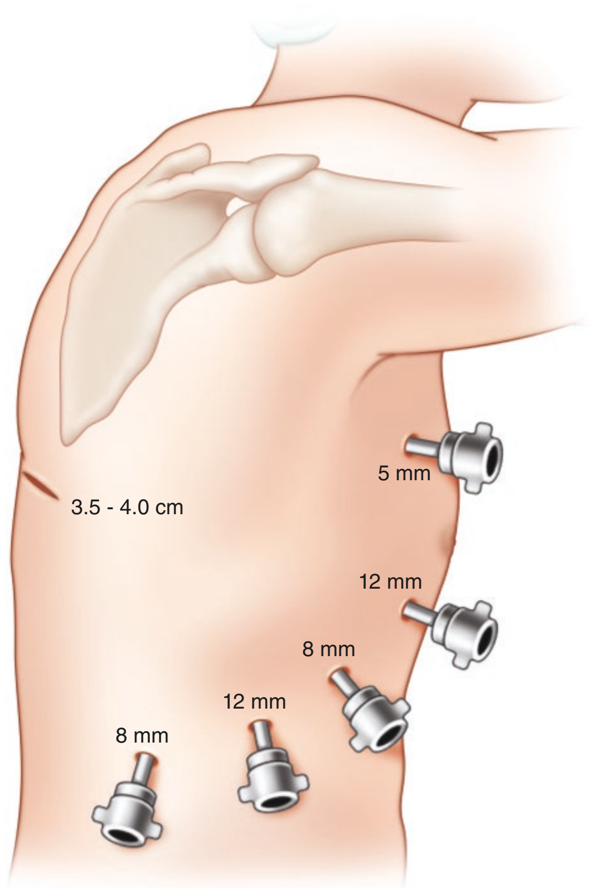


Fig. 14.5 The patient is positioned in the left lateral decubitus position, 15°–30° anterior and in reverse Trendelenburg. At the sixth to seventh ribs just posterior to the scapula a 3.5–4 cm transverse incision is made (larger dependent upon the size of the primary lesion to be removed) and a 6 cm segment of rib is resected avoiding injury of any sort to the intercostal bundle. An Alexis wound protector is then placed. Inferiorly at the level of the diaphragm a 12 mm port is placed in the posterior axillary line in the eighth intercostal space. Two 8 mm robotic ports are then placed 10–12 cm away from the 12 mm port, the one to the left or the most posterior is placed a the ninth to tenth intercostal space. Another is placed to the right of the 12 mm video port in the seventh intercostal space in the midaxillary line. Another 12 mm port is placed in the fifth intercostal space in the lateral to mid-clavicular line. A 5 mm port is placed in the third intercostal space in the anterior axillary line. The robot or bedside cart is brought obliquely over the shoulder

men, a maneuver that is intended to reduce the likelihood of postoperative delayed periconduit esophageal hiatus hernia.

Once the abdominal portion is completed, the bedside cart is undocked and the bedside cart moved away from the patient. The patient is then placed in the left lateral decubitus position (Fig. 14.5). Five port sites are marked on the patient's right chest. At the level of the sixth to seventh rib posteriorly, we make a 3.5–4 cm transverse incision along the rib (larger incision may be necessary dependent upon the size of the mass to be removed). We carefully remove a 6 cm segment of rib avoiding injury of the intercostal bundle and then make a wide parietal pleura incision on the cephalad aspect of the adjacent rib. Through this wound, midway between the spine and tip of the scapula, a laparoscopic wound protector is placed (Alexis Laparoscopic Wound Protector System, Alexis Medical, Rancho Santa Margarita, CA). The video 12 mm port site is placed in the posterior axillary line just at the level of the diaphragm and the right and left arms are placed 10–12 cm on either side of a line between the videoscope to the tip of the scapula. A 12 mm port is placed at the fourth to fifth intercostal space in the lateral- to mid-clavicular line and another 12 mm port at the eighth intercostal space posterior axillary line. The patient is positioned approximately 15°–30° anterior and in reverse Trendelenburg. The bedside cart is brought in from the patient's head. In the left arm a Pro-grasp is placed and in the right arm, a Harmonic scalpel. The dissection is started at the lower portion of the esophagus and continued cephalad. The lung is retracted out of the way, anteriorly, with a Fan Retractor (Endo Retract™ II Covidien/Medtronic, Dublin). It is best to widely resect all of the periesophageal tissue, cleanly from the aorta, diaphragm, taking the left mediastinal pleural as necessary, as well as the subcarinal and bilateral hilar lymph nodes including the upper chest periesophageal tissue. Use of the Harmonic is recommended along the aorta taking care to identify any large esophageal branches, some require endoclips and in some cases a robotic Hem-o-lok. When using clipping technology, it is important that the vessel end is sealed with a Harmonic should the clips fall off. The area clipped should healthy vessel, not damaged by either cautery or the Harmonic, for it to maintain the grasp and avoid it being dislodged later. Caution is exerted in the area of the main airways and trachea, we attempt to avoid any heat next to the airway, especially the membranous and attempt to maintain the vast network of perimembranous blood supply and tissue planes. The azygous vein is ligated with a vascular endostapler. We attempt to preserve the mediastinal pleura above the azygous vein while performing the periesophageal dissection at that location. We then clear a portion of the esophagus at that upper location for the anastomosis and divide it with an endostapler. We take a large segment as a specimen and send it to the surgical pathologist as a frozen section to determine completeness of resection, we attempt to achieve a 10 cm proximal margin as determined by the preoperative endoscopy, endoscopic ultrasound and PET-CT scan findings; usually at the upper thoracic esophagus close to the apex of the chest. Once the appropriate level of dissection is determined, while grasping the staple line with the Pro-Grasp, endoshears are used to transversely incise the esophagus immediately adjacent to the staple line cutting away about 60–70% of the staple line. The staple line will be used as a handle to allow insertion of the anvil of the EEA stapler. Any bleeding that occurs is controlled with pressure and/or very precise low current cautery. Carbon dioxide insufflation is discontinued at this point and the Alexis cover is removed from the wound protector. An adult Foley urinary catheter is passed through the posterior upper port where the Alexis is located into the proximal lumen of the open esophagus for approximately 5–10 cm and the balloon inflated with saline to 10–20 mL and slowly withdraw the Foley, carefully dilating, not tearing the esophagus (Fig. 14.6). This maneuver easily allows sufficient dilation to place a 29 mm anvil. It may be repeated as necessary. Then the anvil is placed through the posterior port and with a ProGrasp, the anvil is passed deeply into the proximal esophagus, just the very tip of the anvil is visible (Figs. 14.7 and 14.8). Once placed, it will remain in place. The robotic endoshears are then used to cut through the rest of the staple line, completely removing it. Two concentric baseball-type sutures are then placed with 0-Prolene on an SH needle, the first layer includes the mucosa in each bite and approximates the esophageal end around the anvil stem when tied down. The second layer is placed about 2–3 mm away and provides further security of the esophageal end closure around the anvil (Fig. 14.9). Once the baseball stitches are complete and they are firmly tied, the Prolene monofilament slides through the numerous

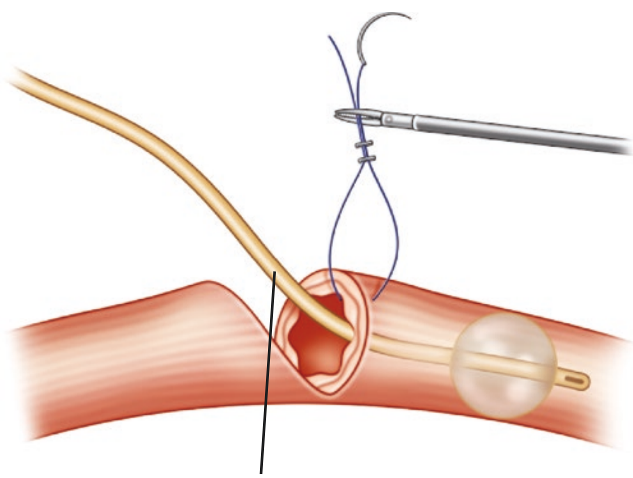


Fig. 14.6 Two ProGrasps are used to guide the Foley catheter from the most posterior Alexis port into the nearly completely cut esophagus after a 0-Prolene on an SH needle is placed at the 12 o'clock position and two 5 mm endoclips are placed to maintain the stitch orientation. A minimally invasive grasper is used to hold the suture

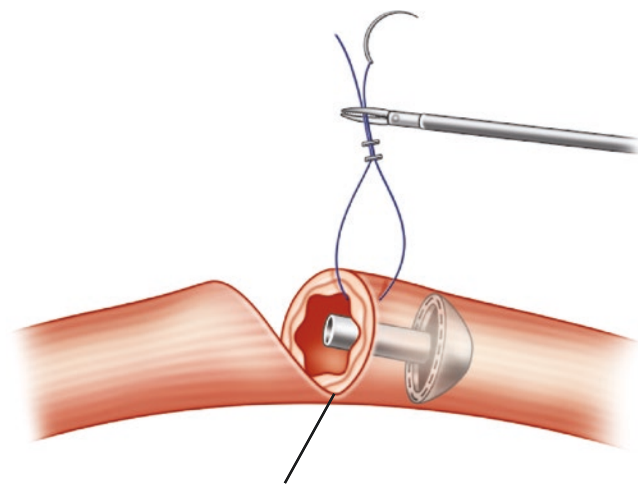


Fig. 14.8 Using the robotic ProGrasp in the left hand and robotic EndoShears in the right, the residual esophagus is incised, severing it from the proximal esophagus and allowing the specimen to be removed from the area for sewing of the proximal esophageal stump

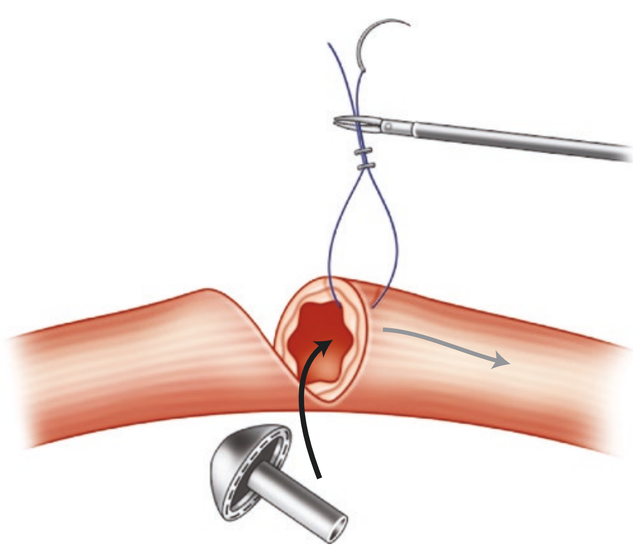


Fig. 14.7 After the esophagus is dilated, the EEA anvil is placed into the esophageal remnant using the ProGrasps to push it well down into the esophagus

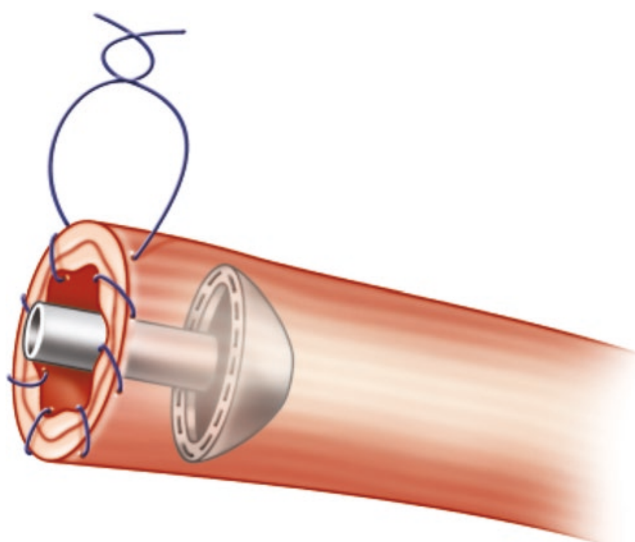


Fig. 14.9 Using two needle holders, the 0 Prolene is then sewn in a baseball stitch fashion 5 mm deep to the end of the esophagus. After the stitch is tied down, the EEA anvil end is pulled back using 2 ProGrasps, so that it can be grasped by the anvil grasper

bites in the esophageal end to firmly hold all layers of the esophagus to the anvil (Fig. 14.10). Then, the anvil is partially grasped and pulled back to expose the grasping rivets on the side of the anvil making it ready for the eventual anastomosis. Through the back port using a Forrester or other broad tissue grasping instrument the esophageal specimen is grasped and serves to provide all of the slow continuous force to draw the specimen and the attached esophageal conduit into the right chest, through the esophageal hiatus. The orientation is carefully preserved to avoid twisting, the staple line is arranged to the patient's right side of the chest, the temptation to grasp the conduit should be avoided pushing with the flat surface of the Pro-Grasp can be used instead. The previously placed 0-Ethibond sutures are then followed to make sure that the conduit has been pulled sufficiently into the pleural space without kinking or leaving redundancy in the peritoneal cavity. The assistant surgeon cuts the specimen away from the esophageal conduit and then places 1–2 Allis clamps on the tip of the conduit. Then, approximately 5–8 cm away a transverse incision is made, the conduit is dilated with a clamp as necessary and the base portion of the endostapler is passed, then the base unit and the Allis clamps are inserted into the upper posterior port through the Alexis wound protector (Fig. 14.11). We then watch the conduit to identify a location on the lesser curvature side that avoids any excessive tension in the conduit and avoids any retained omentum that could be included in the anastomosis, it is important that the serosa only is included in the eventual anastomosis. Once the correct location on the greater curve is chosen, the base unit hand twist unit is twisted to push the post out of the base unit. Through the anterior 12 mm port, the anvil grasper is grasped and firmly held. The base unit post and the anvil are then con-

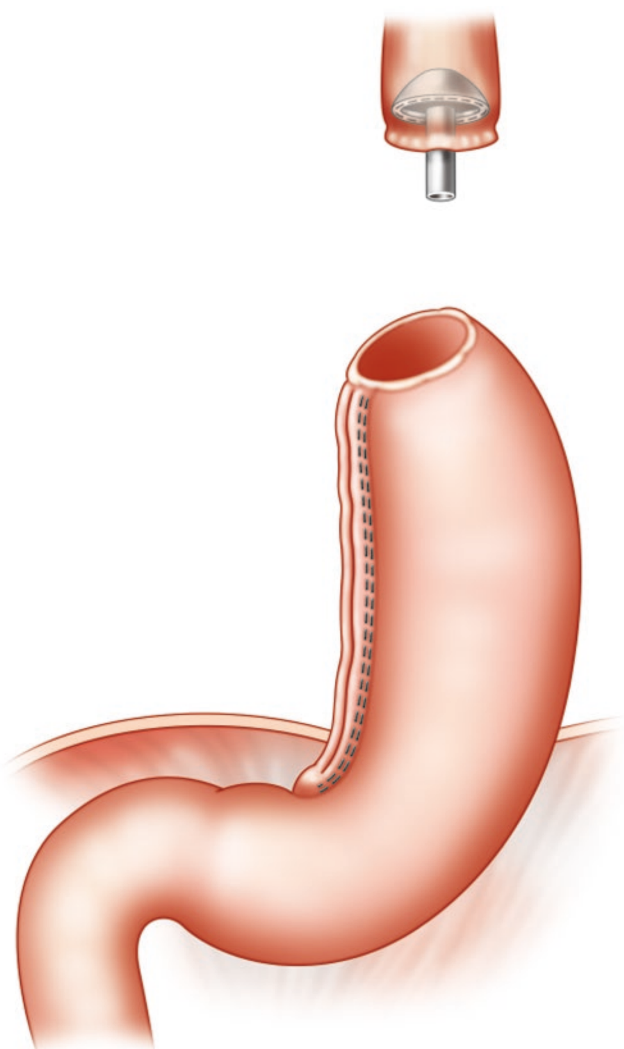


Fig. 14.10 Once the baseball stitches are completed and firmly tied, the Prolene monofilament slides through the numerous bites in the esophageal end to firmly hold all layers of the esophagus to the anvil

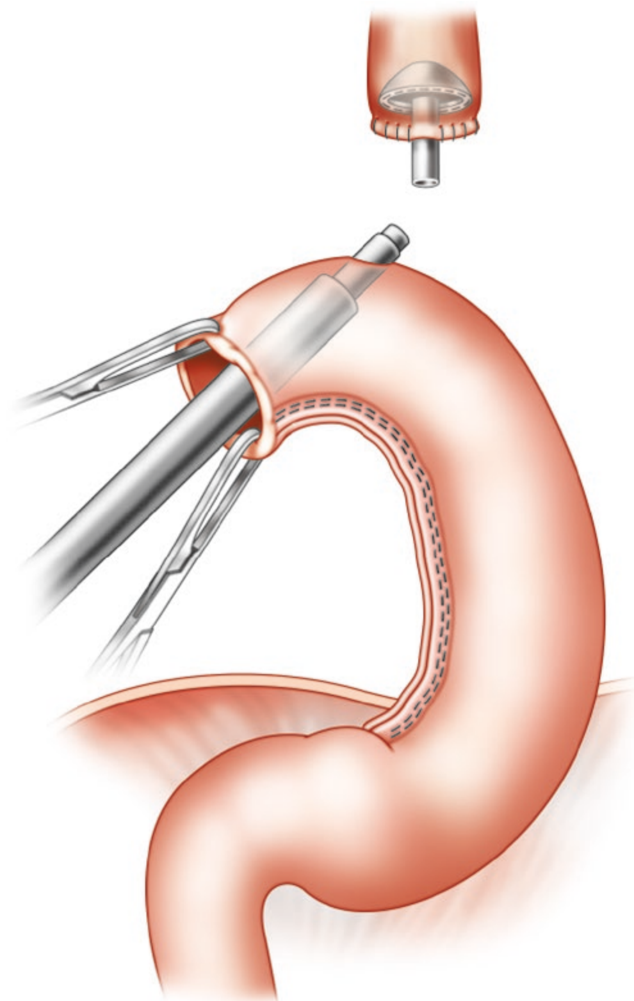


Fig. 14.11 After cutting away the specimen from the esophageal conduit and 1–2 Allis clamps are placed on the tip of the conduit. Then, approximately 5–8 cm away a transverse incision is made, the conduit is dilated with a clamp and the base portion of the EEA endostapler is passed into the conduit, then the base unit and the Allis clamps are inserted into the upper posterior port through the Alexis wound protector to perform the end-to-end anastomosis

nected and the two pushed together until the "click" is achieved performing an end-to-side esophago-gastrostomy. The base unit is twisted to marry the base unit to the anvil as designated by the green color in the view. The EEA is then fired, stapling the anastomosis; the base unit is untwisted to allow the EEA to be removed from the conduit. The EEA specimen doughnuts are removed and sent to pathology. Then, the Harmonic scalpel is then used to resect the omentum away from the redundant conduit, but is maintained so that it can be later used to wrap around the anastomosis. Then, through the anterior 12 mm port, a tissue stapler is used to transect the residual conduit in a fashion to continue the staple line (Fig. 14.12). With two needle holders, the anastomosis is intermittently reinforced with 3–0 Vicryl Lemberted sutures, especially in the potential areas were staples can be visualized. The tongue of omentum is then placed between the anastomosis and the trachea. Vicryl is then used to hold it in place. The mediastinal pleura is then pulled over the anastomosis and sutured to the small rim of remaining redundancy of the conduit, holding it in a nondependent fashion. Once this is completed, the NG tube is then pushed down to the 40 cm mark at the nares and fixed to the nares with tape.

During the resection of the esophagus, endoclips were placed on any large lymphatic vessels and at the end of the case, the thoracic duct can be ligated with 10–12 cm 0-Ethibond on a CT-1 needle to perform a figure-of-8 mass ligation of the tissue between the aorta and the azygous vein at the level of the diaphragm. Then, 0-Ethibond sutures are used to attach the esophageal hiatus to the gastric conduit that will hold the conduit in place and help to prevent peri-conduit herniation. Two #19 Blake drains are strategically placed both anterior and posterior to the conduit and brought out through the port sites. An additional #28 French Argyle is placed through the anterior 12 mm port just lateral to the anastomosis. We inject Marcaine 0.125% with epinephrine intercostally from the second to the tenth intercostal nerves and then further around each of the port sites. All the wounds were closed with Vicryl. These patients are managed in a similar fashion as with the RATE.

14.4.3 Robot-Assisted Extended Lymphadenoesophagectomy (RALE)

These patients are intubated with a double lumen endotracheal tube and positioned in a semi-prone reverse Trendelenburg fashion. Five port sites are placed in the right chest (Figs. 14.13, 14.14, and 14.15). Along a longitudinal

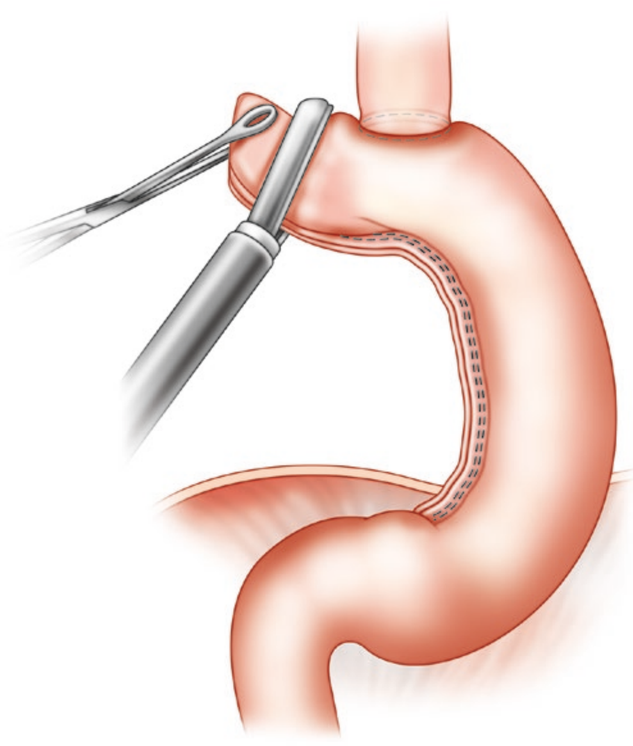


Fig. 14.12 A tissue stapler is used to transect the residual conduit in a fashion to continue the staple line the gastric conduit staple line

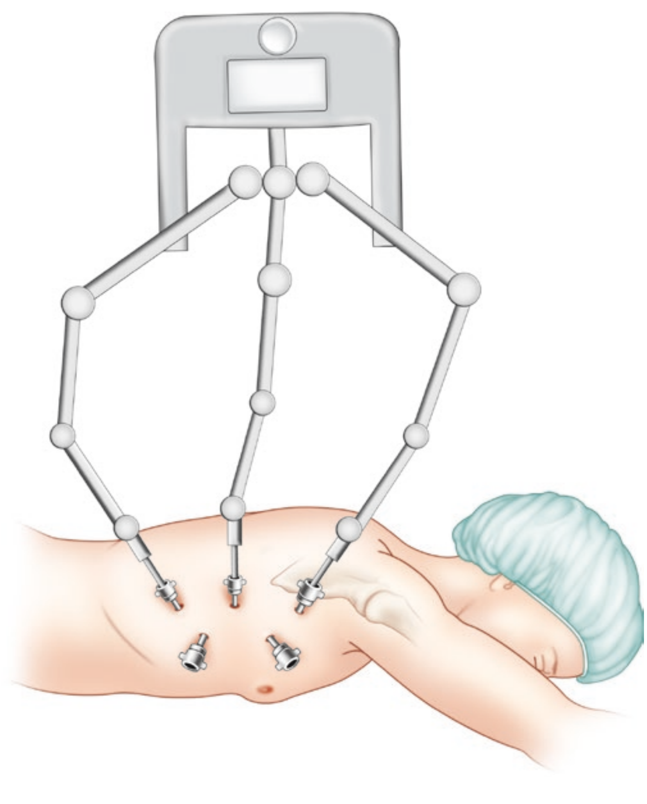


Fig. 14.13 The patient is placed in the left lateral decubitus position to nearly prone and in reverse Trendelenberg. Five ports are placed. Three ports are place along a line just anterior to the tip of the scapula. The central port, a 12 mm video port, is placed just over the level of the seventh rib at the very posterior axillary line. Robotic 8 mm ports are placed 10 cm to the right and left of the video port. Between the two right ward ports and anterior about 10 cm anteriorly another 12 mm port is placed and then along the same line a 5 mm port is placed between the leftward space

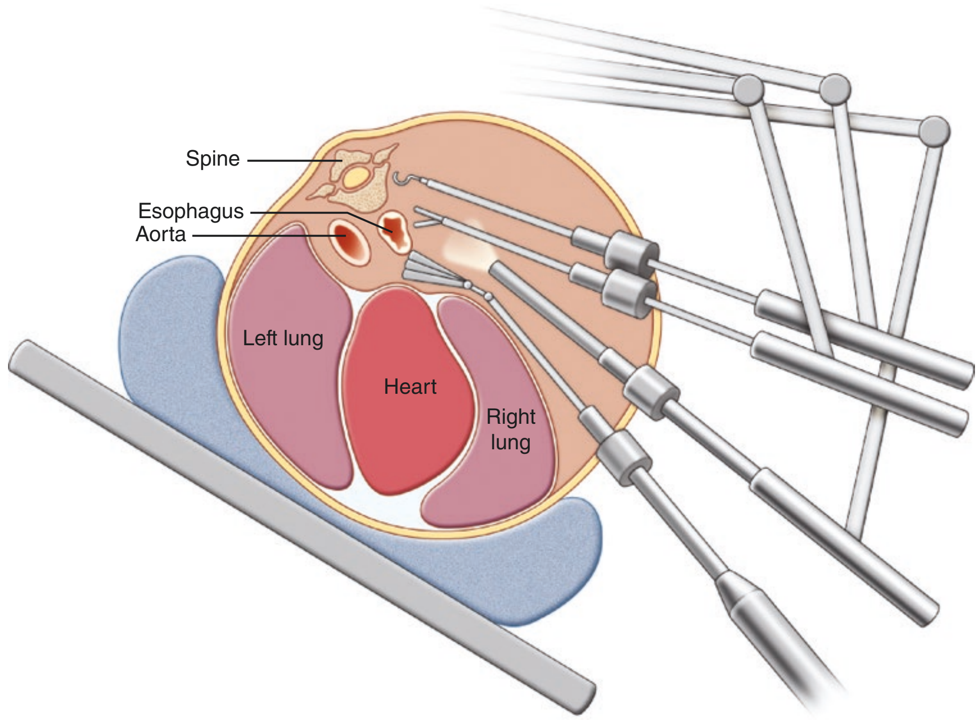


Fig. 14.14 Demonstration of the prone position allowing for the positioning of the mediastinal structures for careful dissection. The mediastinum falls toward gravity, exposing the mediastinum for dissection and provides counter-traction

line approximately 1–2 cm anterior to the tip of the scapula three ports are placed. The central port is at the level of the seventh rib, a 12 mm port, and is for the videoscope. Then approximately 10 cm cephalad and caudad, the right and left robotic arm ports are placed. Then approximately 10 cm along an anterior longitudinal line two more ports are placed. On that line a second 12 mm port is placed between the leftward arm and the mid-12 mm videoscope port and then a 5 mm port is placed along the same anterior line approximately 20 cm cephalad. A Pro-Grasp is placed in the left arm and a hook cautery and later Harmonic scalpel are placed in the left at right angle to the table. The robot is brought in from the posterior or back of the patient. After the arms are placed the dissection is begun at the anterior aspect of the esophagus just at the level of the inferior pulmonary vein. The pericardium is completely cleaned in both a cephalad and caudad direction. We continue this dissection up to the level of the right mean stem bronchus and stop when we have taken the mid-level aortic branch or branches. We then continue to dissect both deeply along the leftward pleura and caudally to the diaphragm completely cleaning all periesophageal tissue from the diaphragm, pericardium, aorta, the left pleura, both mainstem airways and trachea resecting adjacent tissues as necessary. The dissection is then continued along the anterior aspect of the aorta and continues to the level of the bronchial artery branches. For large ones, the robotic endoclips and Hem-o-lok may be necessary for ligation. Once ligated we thoroughly coagulate the transected end of the vessel without injuring the area where the vessel was clipped. We ligate the azygous vein with a vascular stapler and any encountered thoracic duct branches are ligated with endo-clips. We then continue the dissection cephalad and use the Harmonic scalpel in this location to divide the Vagus avoiding injury to the recurrent laryngeal nerve. The dissection is then continued up into the posterior aspect of the neck taking all the deep periesophageal lymph nodes. Once this is completed we place our chest drains, 1–2 #19 Round Blake drain and a single #28 French Argyle chest tube placed through port sites and perform a 0.125% Marcaine with epinephrine intercostal block from the second to the tenth intercostal nerves and then further around each of the port sites.

After the bedside cart is removed the patient is then positioned supinely. The previously placed double lumen endotracheal tube is removed and a single lumen endotracheal tube is placed. After positioning, the abdomen and neck are surgically prepared and draped. We then perform neck incision and esophageal dissection as described with the RATE (Figs. 14.16 and 14.17). Once this is completed the bedside cart is brought in over the patient's head and the abdominal phase is performed as described in the RATE procedure. Once completed, the anastomosis is performed as described.

14.4.4 Perioperative Management

Typically, patients are extubated in the operating room. Patients are aggressively managed with postoperative crystalloid and colloid used dependent upon the blood loss and chest tube drainage. We start D10W at 30 mL/h immediately after

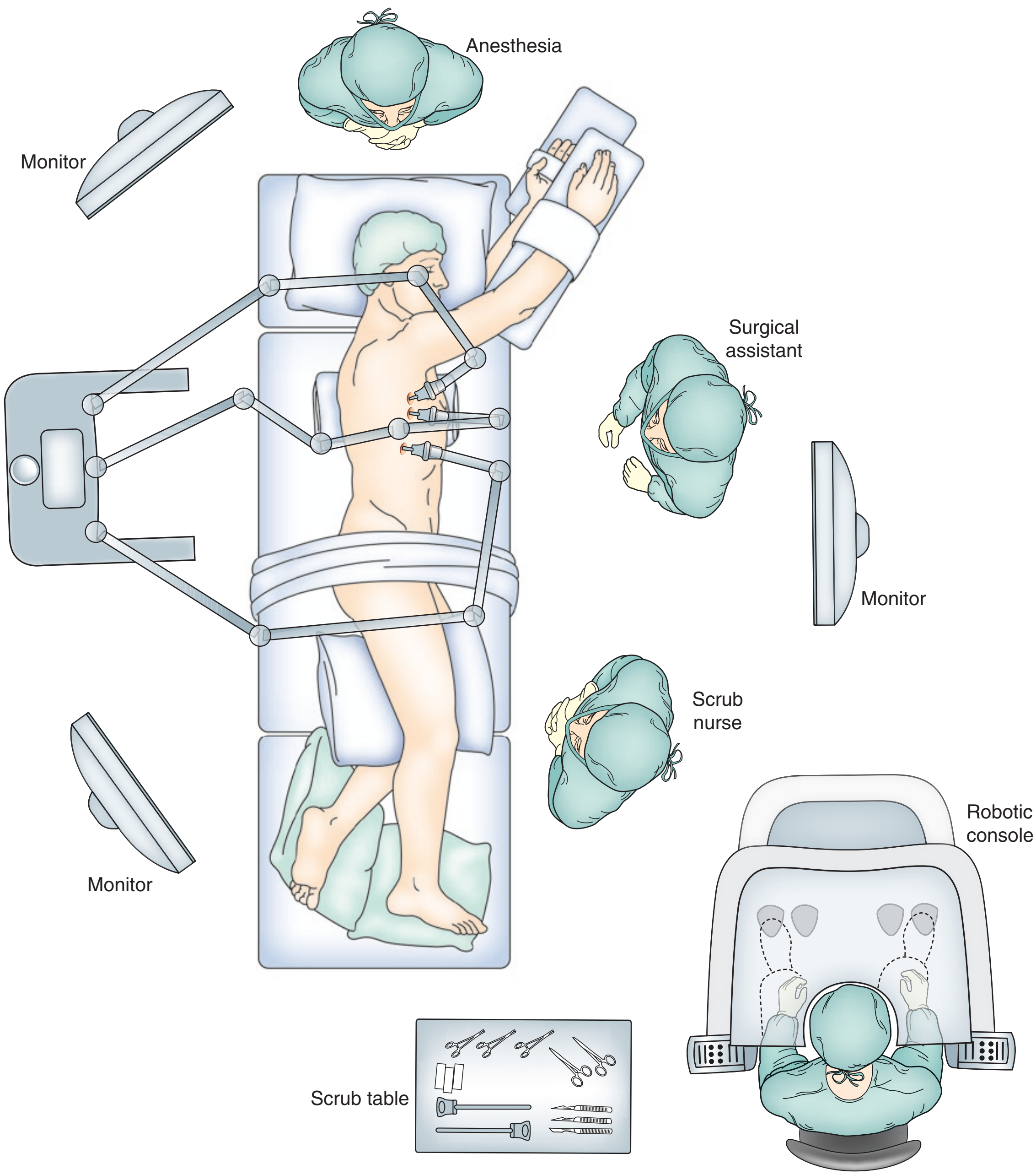


Fig. 14.15 Demonstrates the position of the robot or bedside cart during the first portion of the robotic modified McKeown or RALE esophagectomy

the surgery is completed and increase it to 60 mL/h by the second postoperative day. We do not start enteric tube feeding until after the fifth to the seventh postoperative day to allow the lymphatics to seal and allows for bowel function to return as demonstrated by bowel sounds, a nondistended abdomen and in most patients they are passing flatus and a possible bowel movement by this time. We follow the fluid status closely, reviewing urine and drain output, daily weight, and the peripheral perfusion by observing the capillary reperfusion and warmth in the knees and feet, as well as the quality of the dorsalis pedis pulse. Most patients are receiving a total of 200 mL/h after their surgery to maintain adequate perfusion. This can be a delicate balance in patients with lung or heart failure. We attempt to keep the hematocrit at or above 30% to sufficiently support the conduit. Once the output from the drain does not appear bloody, almost always by the next morning, we start subcutaneous heparin in addition to the already instituted lower extremity compression devices used throughout the operating and in postoperative period. We attempt to wean our patients off of their narcotics as soon as possible, choosing non-steroidals and acetaminophen instead. Patients are walked either the day of surgery or at least by the

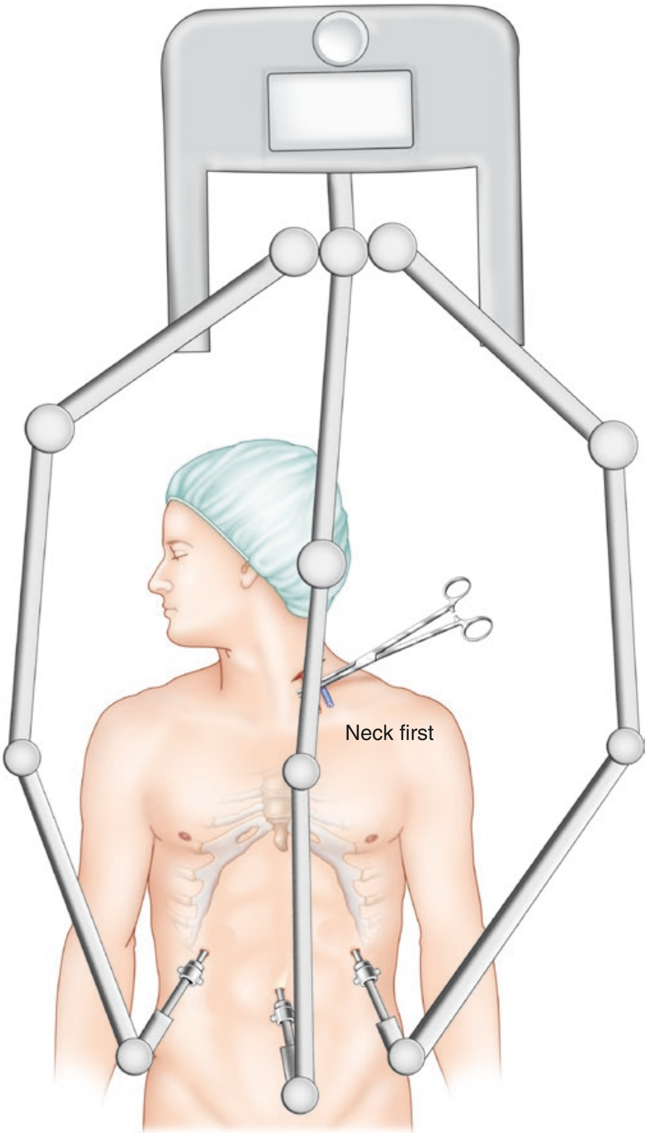


Fig. 14.16 After the neck dissection and encircling the esophagus with a Penrose drain and the packing of the neck wound with an antibiotic soaked laparotomy pad, the robot is brought over the patient's head

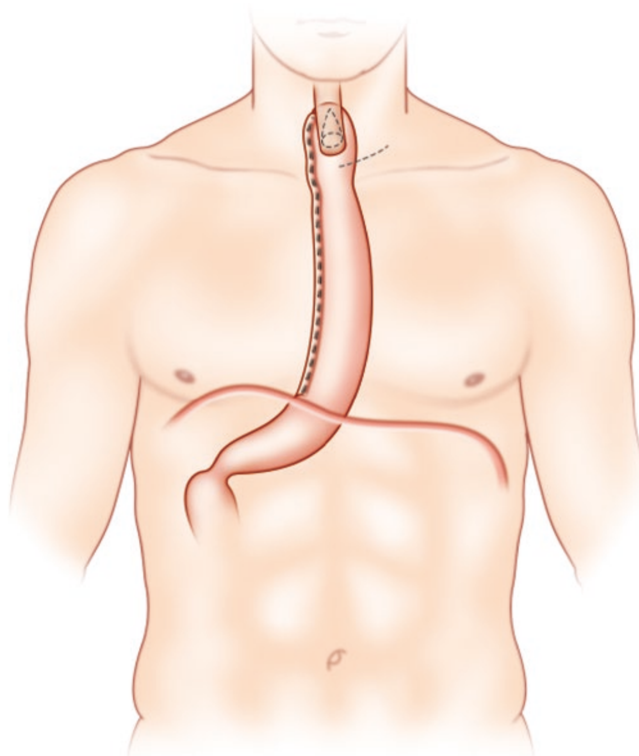


Fig. 14.17 For all of the esophagectomies, this is the orientation and location of the gastric conduit. We do not perform a Kocker maneuver and do not perform a pyloroplasty or pyloromyotomy. We attempt to leave a 300 mL residual stomach below the level of the diaphragm. We attempt to loosely close the hiatus around the conduit with a few interrupted sutures being careful not to disturb the blood supply to the conduit

first postoperative day. In the recovery room we start D10W at 30 mL/h through the feeding tube and do not initiate tube feeding until the patient has bowel sounds and is nondistended. A barium swallowing study is performed on the fifth to ninth postoperative day, first through the nasogastric tube gastrografin is infused at varying pressures and at various levels to fluoroscopically observe the conduit anatomy, potential leak and flow; and then followed by a normal thin barium swallowing study. Drain amylase levels are checked on the day of the swallow and then on the next day after the NG tube has been pulled. A daily chest x-ray PA and lateral is performed to assess for any evidence of conduit emptying problems, as demonstrated by a fluid column seen just anterior to the thoracic spine, and any evidence of aspiration. Patients are typically discharged on the sixth to tenth postoperative day. Oral liquids are initiated at approximately 3–4 weeks and slowly advanced, neck drains are removed after the initiation of liquids. We see the patients in the clinic within the week after discharge and perform a routine chest x-ray PA and lateral, routine labs, serum prealbumin and drain amylases. The patient's diet is usually advanced at approximately 3–4 weeks after surgery. For at least 6 months, all patients should receive a GI propulsive agent, metoclopramide 10 mg QID (erythromycin 250–500 mg TID or domperidone 10 mg may be used instead, as necessary), as well as proton pump inhibition. When sleeping, the patients must sleep with the head of the bed up at 30°–45° to reduce the likelihood of aspiration, wedges and pillows underneath the back and head are not sufficient. With the assistance of the speech pathologist, the diet is advanced from clear liquids to 5 × 1 cup per meal small feedings over the course of approximately 2 weeks. Once the soft diet is achieved and the drain amylase is consistently low (less than 120 U/L) and the output remains low, the remaining Blake drains are removed in the clinic.

14.5 Tips and Pitfalls

- Avoid grasping major structures, such as the stomach, especially the gastric conduit and the blood supply. The lack of tactile feedback makes it difficult to assess the amount of trauma to the tissues and may result in severe injury. Instead, use pushing with the end of the robotic instrument and sometimes the robotic arm.
- Before ligating a vessel, especially in the area of the celiac axis and on the distal greater curve of the stomach, make certain that key vasculature is not damaged. Approximately 2% of patients will have an accessory left hepatic artery that comes off the left gastric and will be present in the upper gastrohepatic ligament. It can be preserved by taking the left gastric artery distal to it.
- In creating the gastric conduit, take care to maintain the orientation of the gastric staple line to the greater curve of the stomach. Furthermore, match the staple lines, so that there is no gap between staple lines along the length of the gastric tube.
- When injecting the Botox, make certain that you can see the indention of the pylorus from the duodenum and other visual clues such as the location of the anterior indention and the anterior location of the Vein of Mayo. The injection should be performed well into the muscular portion of the pylorus.
- Dissection within 10 cm distal to the carina can be a challenge. Slow the dissection here. In 10% of males, there is a prominent middle esophageal artery and large bronchial arteries that if injured can be difficult to control. Take them slightly distal to their origin with either a robotic endoclip or robotic Hem-o-lok. These can fall off, so we combine the use of a Harmonic to seal the tip of the vessel. Taking the blood supply her first will reduce the blood loss for the subcarinal dissection, especially at the very distal medial right main stem bronchus.
- Avoid the use of cautery when dividing the Vagus nerve. Either a Harmonic scalpel or clipping and cutting it is preferred. The right recurrent laryngeal nerve is sometimes closer than predicted and the cautery energy can transmit up the nerve to the recurrent laryngeal.

14.6 Outcomes

The outcomes are dependent on numerous factors that include the surgeon's and surgical team's experience and skill, patient co-morbidities and degree of primary disease and the volume of cases of which the management team are exposed. In general, the in-hospital mortality is 1% and the morbidity is 40–60% with a leak rate of 10–20% and 20% of patients developing some pulmonary compromise with 5% requiring reintubation and/or bronchoscopy. Length-of-stay is 7–12 days. Anastomotic stenosis occurs in less than 5% and closely correlates with the patients who had a prior leak. The average number of nodes resected is 15–40, dependent on the pathology team and their experience and aggressive assessment of the specimen, and whether the patient has had induction therapy. Chronic pain is rare.

References

1. Rizk NP, Ishwaran H, Rice TW, et al. Optimum lymphadenectomy for esophageal cancer. Ann Surg. 2010;251:46–50.
2. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2015. CA Cancer J Clin. 2015;65:5–29.
3. Jafari MD, Halabi WJ, Smith BR, et al. A decade analysis of trends and outcomes of partial versus total esophagectomy in the United States. Ann Surg. 2013;258:450–8.

Part V

Diaphragm Procedures

Laparoscopic Robotic Diaphragmatic Plication

15

Jennifer A. Cameron and Rafael S. Andrade

Abstract

Laparoscopic and robotic-assisted laparoscopic diaphragm plication is a safe, effective, and minimally invasive surgical alternative to transthoracic approaches. Theoretic advantages of the laparoscopic approach are operative space and potentially less pain, but access to the posterior diaphragm in obese patients is more challenging than via a transthoracic approach. Midterm results with standardized quality of life questionnaires and imaging have shown excellent symptomatic improvement and radiologic confirmation of a persistent diaphragm position. In summary, robotic-assisted laparoscopic diaphragm plication is a good therapeutic alternative to transthoracic approaches.

Keywords

Diaphragm paralysis • Diaphragm eventration • Diaphragm plication • Robotic plication • Laparoscopic plication

15.1 Background

Diaphragmatic plication is the surgical treatment of choice for symptomatic patients with unilateral diaphragmatic paralysis or eventration. The goal of diaphragm plication is symptom palliation; hence, the only indication for diaphragm plication is dyspnea in the presence of unilateral hemidiaphragm elevation.

Dyspnea on exertion and orthopnea are the main clinical manifestations of an elevated hemidiaphragm secondary to paralysis or eventration; a precipitationg factor (e.g., cardiac surgery, mediastinal tumor) may be evident, but commonly no etiology can be identified. Potential causes of symptomatic hemidiaphragmatic paralysis must thoroughly assessed and the patient medically optimized prior to entertaining a surgical plication. The clinical evaluation must include a standardized symptom questionnaire to have appropriate preoperative assessment of dyspnea, careful physical examination, a postero-anterior (PA) and lateral chest x-ray, and pulmonary function tests (PFT). If clinically indicated, a computerized tomography (CT) scan should be obtained to search for pathologic causes of phrenic nerve paralysis (e.g., mediastinal or cervical mass) and to assess for a supra- or infra-diaphragmatic process, for example, atelectasis, infra-diaphragmatic fluid collection. A sniff test, in our experience, adds very little to the decision-making process; a distinction between paralysis and eventration may be impossible and is generally irrelevant. Additionally, patients with a positive sniff test, but no diaphragm elevation, will probably not benefit from plication. Relative contraindications for diaphragm plication include morbid obesity and neuromuscular disorders.

Traditionally, unilateral diaphragm plication was performed via thoracotomy with excellent long-term improvement of dyspnea [1]; thoracoscopic and, more recently, laparoscopic diaphragm plication have emerged as safe and effective alternatives to thoracotomy with excellent long and mid-term results [2–6]. Laparoscopic diaphragm plication is

J. A. Cameron, M.D., M.P.H.
Department of Plastic Surgery, Aspirus Health System, St. Paul, MN, USA
e-mail: Jennifer.cameron@allina.com

R. S. Andrade, M.D. (✉)
Section of Thoracic and Foregut Surgery, Department of Surgery, University of Minnesota Medical Center, Minneapolis, MN, USA
e-mail: andr0119@umn.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_15

ideally suited for robotic assistance, since the abdomen offers a large, pliable cavity.

15.2 Operative Set-Up

- Position: supine, steep reverse Trendelenburg (foot board), arms adducted
- Robotic tower: positioned over ipsilateral shoulder, close to midline
- Prepare and drape the entire abdomen and lower chest on the side of the plication

15.3 Anesthetic Management

General anesthesia with a single lumen tube is sufficient for laparoscopic robotic diaphragm plication.

15.4 Stepwise Conduct of the Operation

- Ports (Fig. 15.1):
  - Camera: 12 mm port; midclavicular line, 10–12 cm from the costal margin; CO_2 insufflation to 15 mmHg
  - Right and left robotic arm ports, 8 mm each, placed 10 cm on either side of the camera port along the same transverse plane
  - Assistant: 12 mm port; triangulated inferiorly between camera and ipsilateral instrument port; this port must allow the assistant to reach the diaphragm and work without colliding with robotic arm and camera
- Transect falciform ligament for right-sided plication to allow the liver to drop slightly and facilitate contralateral instrument access
- Perforate hemidiaphragm: the hemidiaphragm is taut and displaced cephalad from CO_2 insufflation, cauterize a small opening into the hemidiaphragm to help equilibrate intra-abdominal and intra-thoracic pressures; the hemidiaphragm will then fall caudally and will become a tension-free, easy-to-manipulate structure. The resulting pneumothorax is often well-tolerated; however, in the event hemodynamic instability or ventilatory difficulties a small chest drain can be inserted and left open. Eventually, the perforation will be included in the plication.
- Stitch technique:
  - Suture: 10 cm to 12 cm in length, braided, non-absorbable, #2 Ticron
  - Needle: half-circle, about 30 mm (SH)
  - Stitch: pledgeted, U-shaped, gathering large amounts of tissue, intracorporeal knot tying
- Plication sequence (Figs. 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, and 15.9):
  - Assistant: places the suture into the abdominal cavity (the 12 mm port is needed to allow passage of the SH needle), and then retracts the diaphragm for the surgeon; this is repeated with each stitch

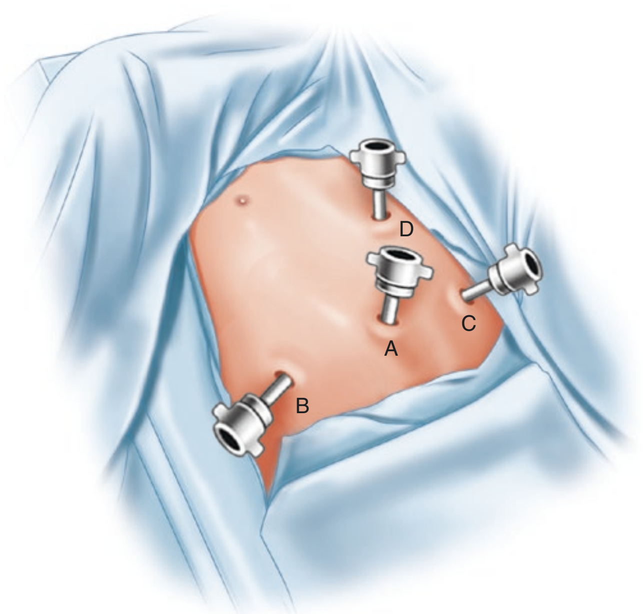


Fig. 15.1 Patient port and bed position for the right hemidiaphragm. Patients are placed supinely, the side to be plicated is raised up about 20°–30°. Four ports are placed. Port A is placed in the midclavicular line 10–12 cm below the costal margin. Ports B and C are placed to the right and left of port A approximately 10 cm along the same transverse plane. Port D is a 12 mm port and is placed in the subxiphoid location. It is used to pass sutures, suctioning, and retraction

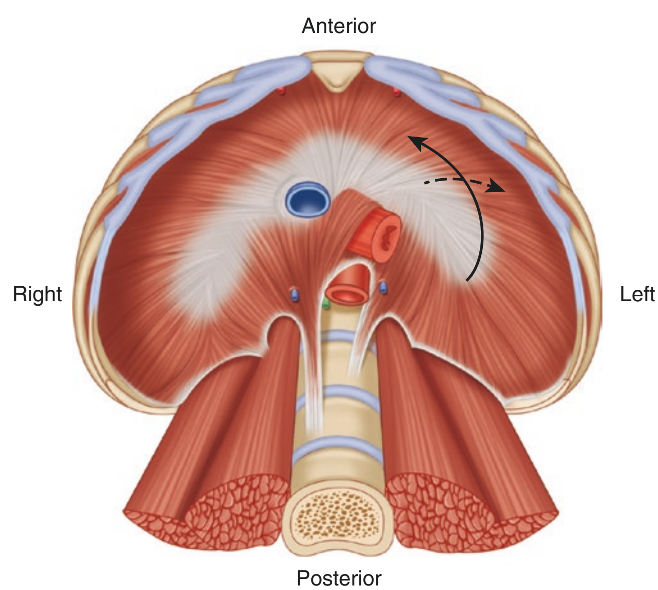


Fig. 15.2 Plication orientation of each hemidiaphragm. This is a cephalad view of both hemidiaphragms that one would have been performing a laparoscopic approach for a robotic repair of the paralyzed hemidiaphragm. A *solid curved arrow* is the direction of the plicated suture placement starting posteriorly to anteriorly. Each plicating suture is reinforced with a Teflon pledget. The second suture line, the guided arrow, those from medial to lateral

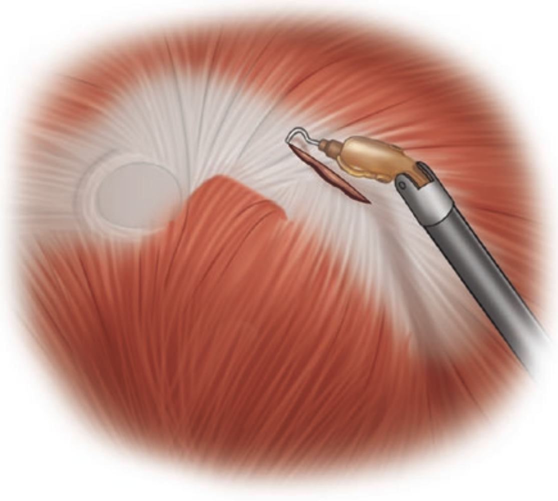


Fig. 15.3 Cautery incision of the hemidiaphragm to be plicated. A hook cautery is used through the assistant port to make a small puncture wound in the hemidiaphragm and to allow carbon dioxide to enter the pleural space freeing the diaphragm from the adjacent lung

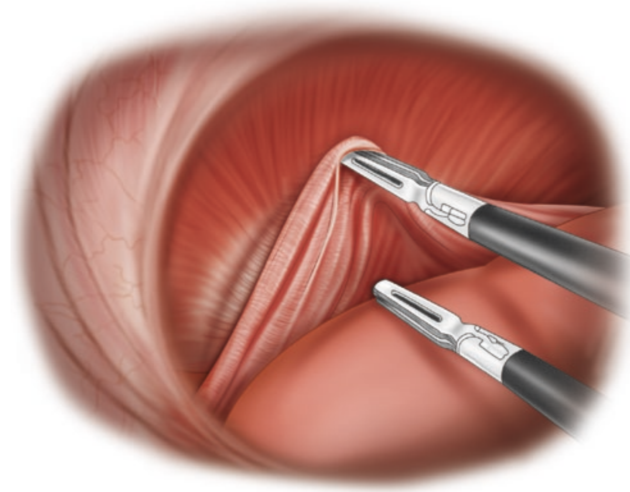


Fig. 15.4 Grasping of the hemidiaphragm for plication

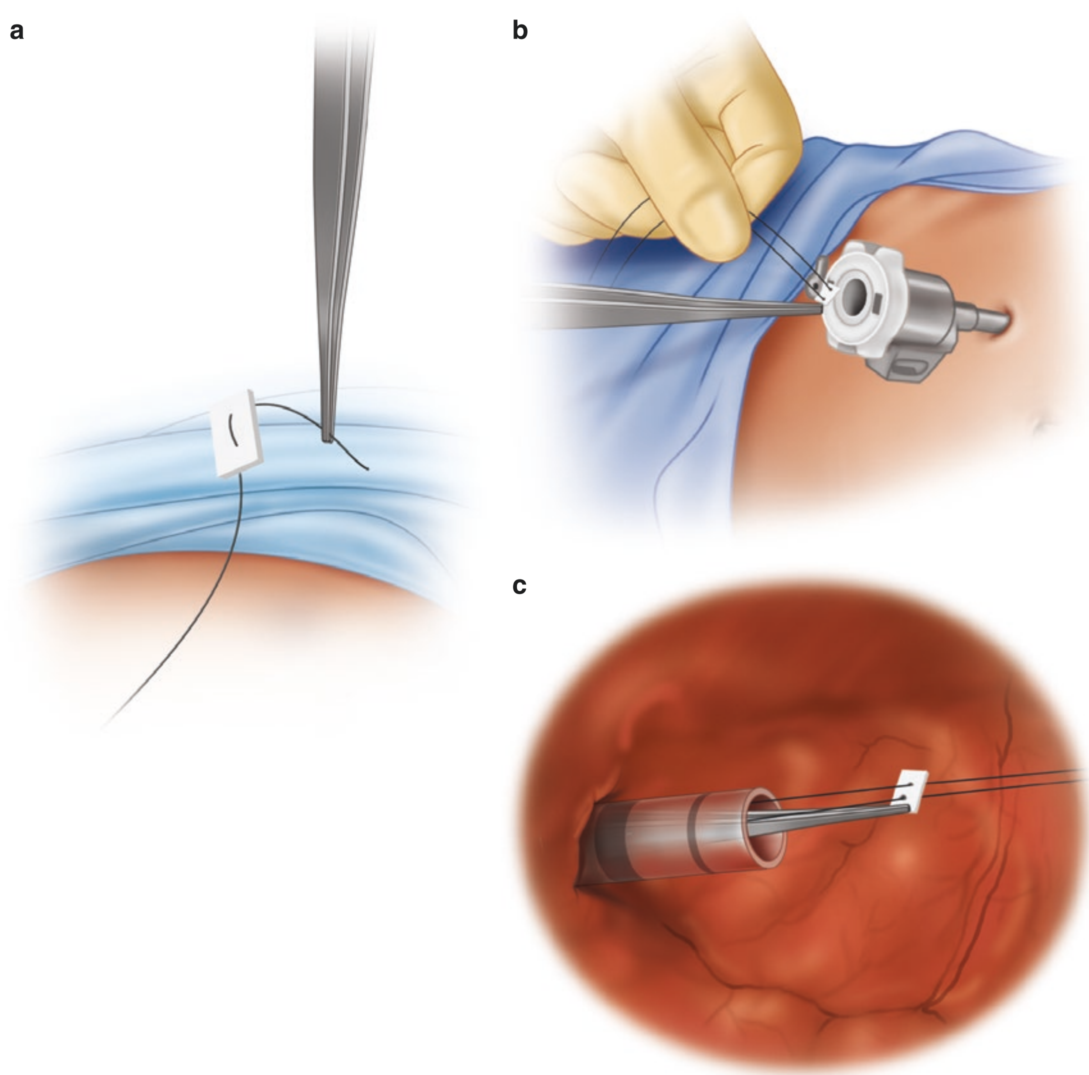


Fig. 15.5 Pledgeted suture placement. #2 Tycron sutures on SH needles that are reinforced with Teflon pledgets are individually passed and sewed each imbricating a wide area of the diaphragm and the orientation as described in Fig. 15.2. (**a**) Pledgeted tycron positioned for placement, (**b**) passage of pledgeted Tycron into port, and (**c**) passage of opposing pledget through port for tying

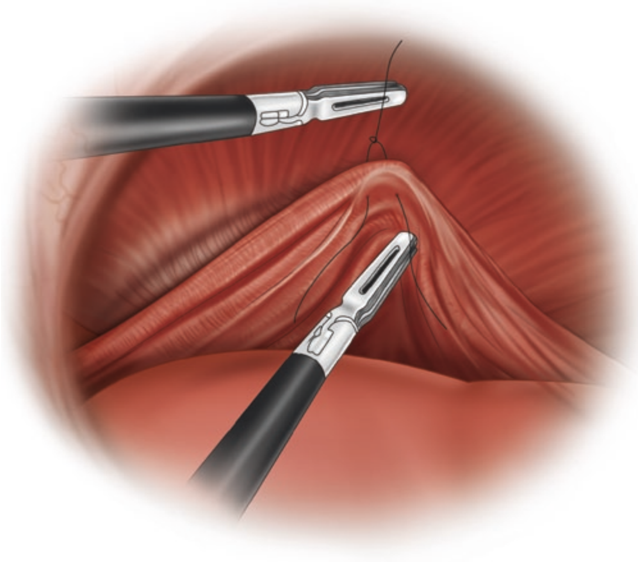


Fig. 15.6 Placement of the retraction suture. The first stitch that is placed is either a simple stitch or partially plicated stitch is used to retract the diaphragm and help to identify the portions of the diaphragm it must be imbricated in the suture placement

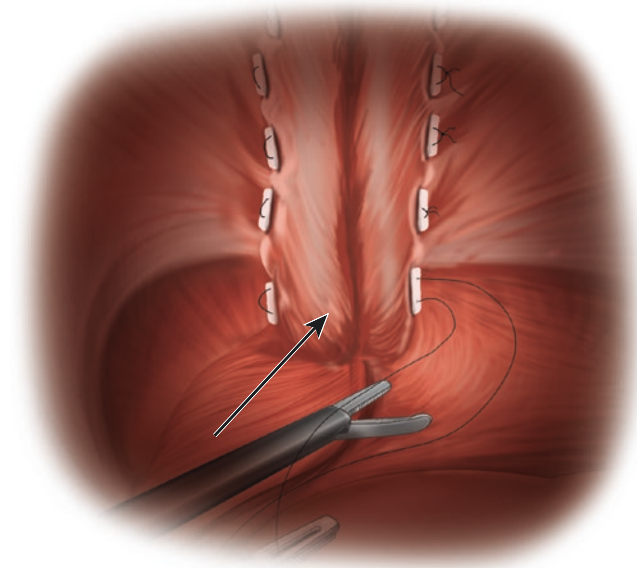


Fig. 15.7 First row of plicating sutures. The first row of plicating sutures those from posterior to anterior. The bedside surgeon holds tension on the most recently placed plicating stitch while the console surgeon ties the prior stitch down, taking the tension off of each stitch tied

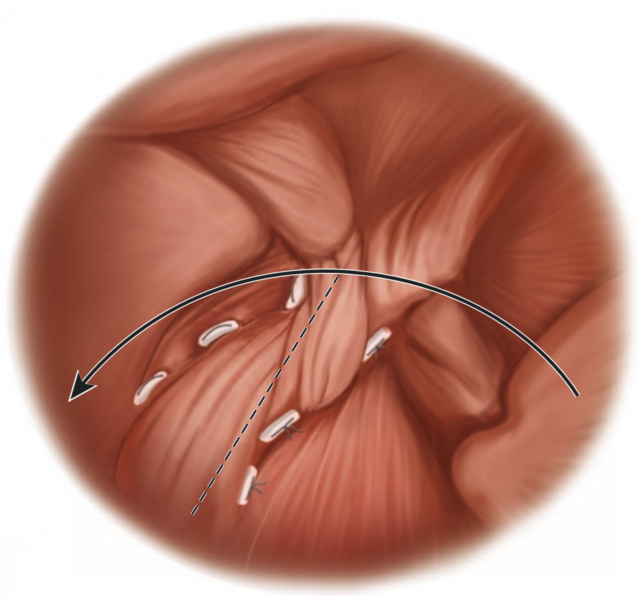


Fig. 15.8 Orientation of the second row of diaphragm plicating sutures, medial collateral

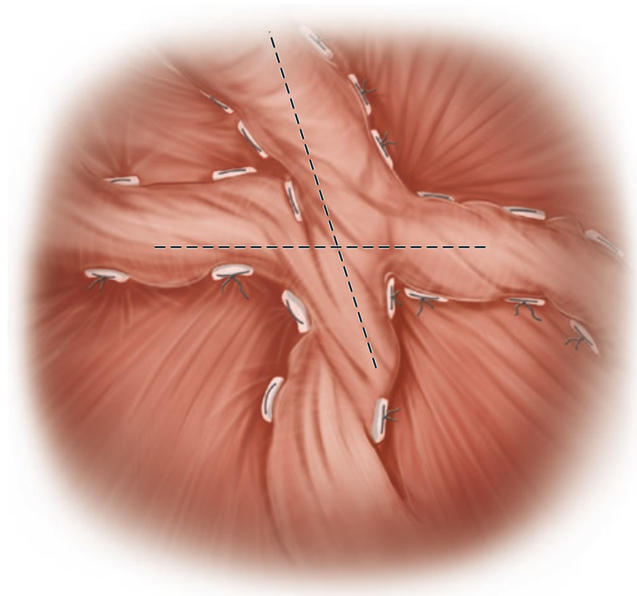


Fig. 15.9 Complete hemidiaphragm plication

- Surgeon:
  Anteroposterior (AP) plication: place first stitch in the middle of the hemidiaphragm, stitches are then sequentially placed in an anteroposterior direction to plicate the hemidiaphragm as far posteriorly as possible, then the plication is continued anteriorly to the costal margin
  Mediolateral (ML) plication: complete the plication in a cross or "T" pattern
- Number of stitches required: approximately 10 AP and 5 ML

- Ipsilateral tube thoracostomy: place at the end of the procedure if not done already.

15.5 Tips and Pitfalls

- Intraoperative:
  - Perforate hemidiaphragm before attempting to grasp it, it will be difficult to reach

  - Plicate posteriorly as far as possible, this is the most important part of the plication
  - The diaphragm will tend to tear laterally towards the costal margin, gauge tension appropriately
  - Intrathoracic adhesions will prevent the diaphragm from relaxing and dropping into the abdomen; extension of the initial perforation into a transverse 5–7 cm transverse incision allows for intrathoracic lysis of adhesions from the abdominal approach; an additional port in the chest can assist with dissection as well. The incision is then closed with the plication.
- Postoperative:
  - Immediate postoperative CXR should demonstrate that the plicated side is lower than the healthy side; at 1 month both hemidiaphragms should be at the same level
  - Premature removal of the chest tube can lead to a symptomatic pleural effusion; it is preferable to discharge the patient with a chest tube in place if the output is >200 ml/day
  - Intense pulmonary toilet is advisable to assist in re-expansion of the lower lobe
- Follow-up:
  - At 1 month after surgery with a validated questionnaire, such as Saint George's Respiratory Questionnaire (SGRQ), PA and lateral CXR, and PFT's; yearly thereafter.

15.6 Brief Outcomes

To date, we have performed 25 laparoscopic diaphragmatic plications. The results showed a significant reduction (20-point or greater) in the SGRQ scores at 1 month and 1 year with a median follow-up of 307 (1–1237) days. PFTs were also markedly improved on subsequent examination. Percent predicted forced vital capacity (FVC%), percent predicted forced expiratory volume in 1 s (FEV_1%), and percent predicted maximum forced inspiratory flow (FIFmax%) all reached statistically significant improvement ($p < 0.05$) at 1 and 12 months. Complications included one conversion to thoracotomy, two patients requiring delayed drainage of ipsilateral pleural effusions (please see "Tips and Pitfalls" section above), one respiratory failure requiring reintubation, one upper gastrointestinal bleed, one stroke, one urinary tract infection and one patient undergoing paroxysmal atrial fibrillation.

References

1. Versteegh MI, Braum J, Voigt PG, Bosman DB, Stolk J, Rabe KF, Dion RA. Diaphragm plication in adult patients with diaphragm paralysis leads to long-term improvement of pulmonary function and level of dyspnea. Eur J Cardiothoracic Surg. 2007;32(3):449–56.
2. Freeman RK, Van Woerkom J, Vyverberg A, Ascioti AJ. Long-term follow-up of the functional and physiologic results of diaphragm plication in adults with unilateral diaphragm paralysis. Ann Thorac Surg. 2009;88:1112–7.
3. Groth SS, Rueth NM, Kast T, D'Cunha J, Kelly RF, Maddaus MA, Andrade RS. Laparoscopic diaphragmatic plication for diaphragmatic paralysis and eventration: an objective evaluation of short-term and midterm results. J Thorac Cardiovasc Surg. 2010;139(6):1452–6.
4. Weiner DC, Jaklitsch MT. Surgery of the diaphragm: a deductive approach. In: Sellke FW, del Nido PJ, Swanson SJ, editors. Sabiston & Spencer surgery of the chest. 7th ed. Philadelphia, PA: Elsevier Saunders; 2005. p. 501–15.
5. Slater BJ, Meehan JJ. Robotic repair of congenital diaphragmatic anomalies. J Laparoendosc Adv Surg Tech. 2009;19(1):123–7.
6. Groth SS, Andrade RS. Diaphragmatic eventration. In: Darling G, Ferguson MK, editors. Surgical conditions of the diaphragm, an issue of thoracic surgery clinics; 2009;19(4). p. 511–9.

Robotic Diaphragmatic Mass Removal

16

Jennifer A. Cameron and Michael A. Maddaus

Abstract

Diaphragmatic masses can present a challenge to resect and reconstruct given the anatomical location of the pathology and proximity to the lower rib cage and costal arch and the presence of the upper abdominal structures such as the spleen and liver; especially if performed in a minimally invasive fashion. Using robotic technology, the minimally invasive approach can be enhanced. The set up and technique for an efficient robotic resection of a diaphragmatic mass and the reconstruction are described.

Keywords

Computer assisted surgery • Robotic surgery • Diaphragmatic tumor • Diaphragmatic mass • Diaphragmatic reconstruction • Laparoscopic

16.1 Background, Specific Indications

Isolated diaphragmatic masses requiring excision are rare. Case reports document examples of both solitary benign and malignant lesions, such as cysts, lipomas, endometriosis, fibrosarcomas, and rhabdomyosarcomas. However, more commonly, diaphragmatic masses result from metastatic disease, extension of primary tumors from the thoracic or abdominal cavity or peritoneal studding. Excision of such lesions usually requires multiple procedures during one operation. Therefore, a consensus must be reached with all participating surgeons regarding the approach and method of excision.

For robotic mass removal, we prefer an abdominal approach. Technical consideration should be given to the diaphragmatic anatomy, in the area of resection, and the size of the lesion. Fortunately, the redundancy of the diaphragmatic muscles lends itself to primary repair of defects. We contend that up to 1/3 of the diaphragm can be removed and repaired primarily. If a larger defect is encountered, a patch might be needed to maintain functionality. In addition, concurrent plication is often required for larger areas and for phrenic nerve paralysis.

J. A. Cameron, M.D., M.P.H.
Department of Plastic Surgery, Aspirus Health System, St. Paul, MN, USA
e-mail: Jennifer.cameron@allina.com

M. A. Maddaus, M.D. (✉)
University of Minnesota, Minneapolis, MN, USA
e-mail: michael@michaelmaddaus.com

16.2 Operative Set-Up

The Standard da Vinci surgical robot (Intuitive Surgical, Sunnyvale CA) is used for each case. We employ a three-port abdominal technique, with one 30° scope through a 12 mm port and two 8 mm ports for the instrument arms. (Fig. 16.1) The patient is placed supine on the operating room table, with arms outstretched. The abdomen and ipsilateral lower thorax are prepped to facilitate placement of a chest tube. A footboard is used to permit steep reverse-Trendelenburg.

16.3 Anesthetic Management

A single lumen endotracheal tube is appropriate for the abdominal approach, however, a double lumen tube is also an option for masses that extend into the thorax. No other special anesthetic considerations must be undertaken.

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_16

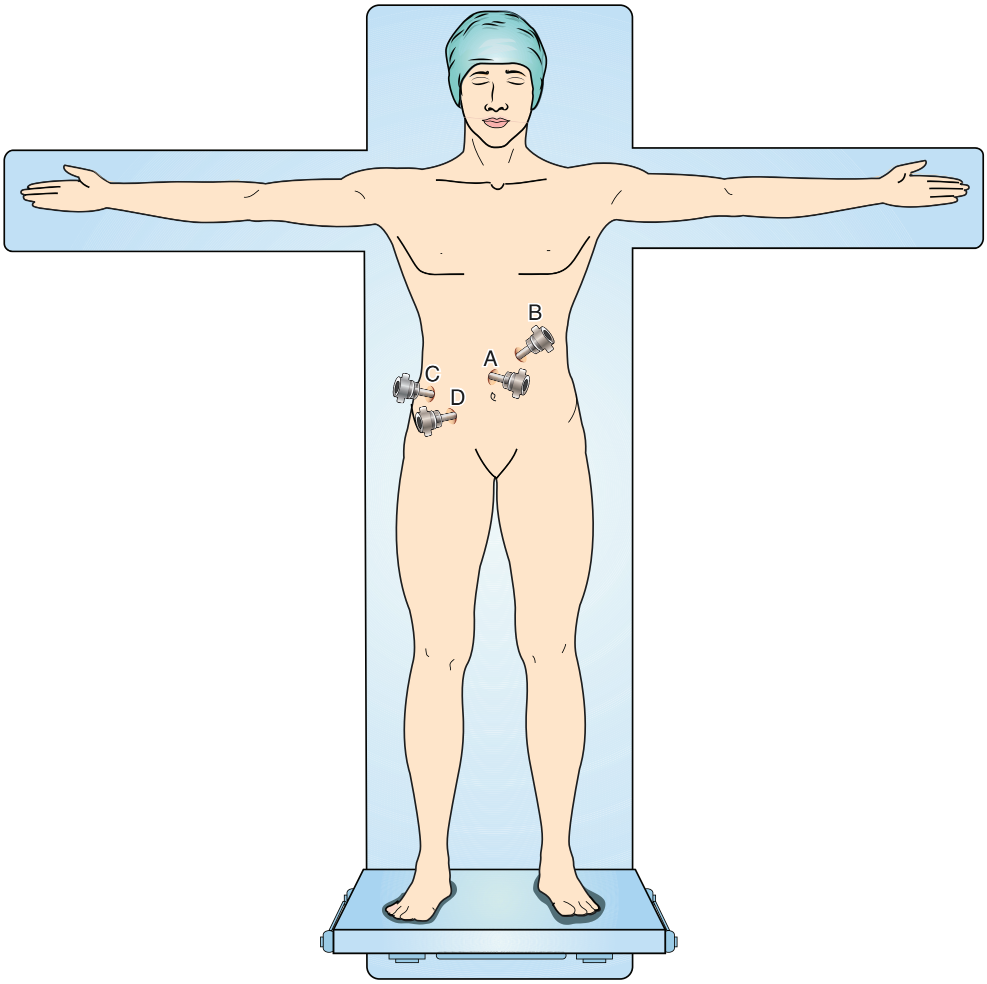


Fig. 16.1 The patient is placed supinely on the operating table with arms outstretched and a footboard at the base of the operating table. The body position is in steep reverse Trendelenburg. As described in the prose, there are three basic robotic ports and two additional ports may be necessary, one of them a 5 mm trocar into the ipsilateral chest and the second in the ipsilateral low midabdomen. At port site A approximately 2 cm above the umbilicus a 12 mm port is placed and through this a 30° up or down videoscope can be placed to optimize the visibility. Port B, an 8 mm robotic port, is placed 3 cm below the left costal arch for a right sided tumor in the left paramedian line. Port C, an 8 mm robotic port, is placed at the same transverse level as the video port at the right mid axillary line. An additional port D can be placed at the same transverse line as the umbilicus or slightly lower in the paramedian line on the ipsilateral side of the tumor to be removed, in this case the right side. The robot or bedside cart is brought in over the patient's head or slightly over the ipsilateral shoulder. The peritoneal cavity is inflated to 10–15 mmHg of pressure

16.4 Stepwise Conduct of the Operation

Once the patient is prepped and draped, the camera port is placed in the midline, two finger breadths above the umbilicus. A 30° camera is inserted and direct visualization is used to place the remaining ports. For a right sided mass removal, the left sided port is placed 3 cm below the costal margin, along the paramedian line. A second port is placed at the level of the camera port, along the right midaxillary line. (Fig. 16.1) Special consideration should be taken to place the ports so they can triangulate the diaphragm, without crossing one another. The abdomen is then insufflated with CO_2 to between 12 and 15 mmHg.

Hook cautery is used to perforate the diaphragm around the anterior margin of the mass (Fig. 16.2). If the mass is not visible from the abdomen, an additional 5 mm camera port can be inserted into the thorax. Please see the following section for management. Allow the abdominal CO_2 to cause a pneumothorax and equilibrate pressures. The diaphragm will loosen and move caudally. Closely monitor the patient for hypotension. Please see tips and pitfalls section for management of hemodynamic instability. Use a grasper to grab the edge of the perforation and continue to excise the mass.

Once completely excised, a retrieval bag can be inserted through the supraumbilical port and the lesion can be removed without risk of seeding. If the defect is less than 1/3 of the diaphragm, pledgeted horizontal mattress sutures are placed until the defect is closed and the diaphragm is taut. We recommend number 2 nonabsorbable sutures with

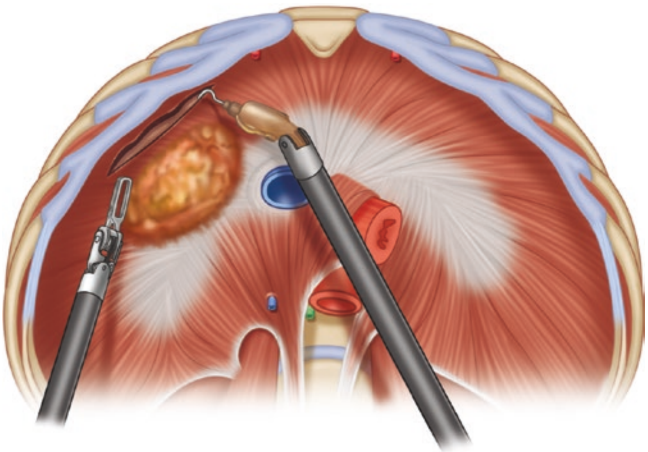


Fig. 16.2 A hook cautery is placed through the port B and a Pro-grasp is placed through the port C. The hook cautery is used to make an incision in the diaphragm a sufficient distance away from the mass to be excised to achieve an uninvolved margin and CO_2 is allowed to escape into the ipsilateral chest to push the diaphragm away from the lung. It may be necessary to place an additional port into the ipsilateral or in this case the right chest to provide greater visibility in the resection and potentially the reconstruction. Once the mass is completely resected is placed in an endobag and can be brought out through the umbilical port site

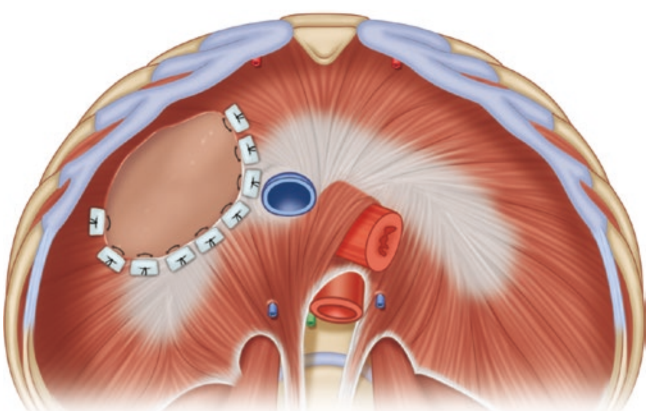


Fig. 16.3 Once the mass has been completely resected and if it is determined that the diaphragm cannot be reconstructed without a primary closure, a segment of thin cortex is cut to reconstruct the diaphragmatic defect. Is placed through one of the ports and a rolled fashion then after unrolling it and placing it into location defect is sutured into place with 1 cm^2 pledgets of Gore-Tex using two robotic needle holders to suture the Gore-Tex into place with interrupted vertical mattress sutures of 2-0 Ethibond on an SH needle each of the sutures cut to 8 cm length. The closure is completed an 18 French catheter is placed into the ipsilateral pleural space

intercorporeal knot tying. A synthetic patch may be used for closure of larger defects. (Fig. 16.3) Additionally, plication may be required if the phrenic nerve has been injured during the excision.

An 18 French thoracostomy tube should be inserted in the ipsilateral thorax. The authors recommend discontinuing the chest tube when output is less than 200 cm^3 in 24 h.

16.5 Tips and Pitfalls

The anatomic position of the mass is the first area for consideration. With lesions in the crural region, care must be taken to identify the phrenic vessels. The superior phrenic arteries are usually insignificant, and can be divided with cautery. On the other hand, the inferior phrenic arteries, which directly overlie the crura, are larger and therefore should be visualized and ligated. The right phrenic vein empties into the inferior vena cava and needs carefully dissection and division. The majority of the diaphragm is innervated by the phrenic nerve, composed of fibers from C3, 4, and 5. Before entering the abdomen the phrenic nerve divides into right and left branches. After passing through the diaphragm each side splits into anterior and posterior trunks, dividing the diaphragm into four motor quadrants. If the diaphragm remains floppy after closure, a plication is required.

Lesions originating in the thorax, can be difficult to localize with an abdominal approach. Therefore, we recommend placing a 5 mm scope in the chest. This can help insure the appropriate approach and complete excision. A thoracostomy tube should then be placed in this port incision site.

Another pitfall can occur when expanding the pneumoperitoneum. If the increased thoracic pressure leads to hemodynamic instability, we recommend placing a small chest tube before proceeding with the case. The tube can be used to vent CO_2 and relieve elevated pressures.

A larger defect may require diaphragmatic plication or patch closure to maintain thoracic function. Please see the chapter in this text on robotic diaphragmatic plication for further instruction on this procedure. A patch closure can be useful to prevent herniation of abdominal contents into the thorax. An impermeable Gore-Tex patch is recommended by these authors, attached with a 0 nonabsorbable running suture. This provides a watertight barrier while reducing permissiveness of the diaphragm.

Further Reading

Groth SS, Andrade RS. Diaphragmatic eventration. In: Darling G, Ferguson MK, editors. Surgical conditions of the diaphragm, an issue of thoracic surgery clinics; 2009;19(4). p. 511–9.

Groth SS, Rueth NM, Kast T, D'Cunha J, Kelly RF, Maddaus MA, Andrade RS. Laparoscopic diaphragmatic plication for diaphragmatic paralysis and eventration: an objective evaluation of short-term and midterm results. J Thorac Cardiovasc Surg. 2010;139(6):1452–6.

Kim MP, Hofstetter WL. Tumors of the diaphragm. In: Darling G, Ferguson MK, editors. Surgical conditions of the diaphragm, an issue of thoracic surgery clinics; 2009;19(4). p. 520–9.

Slater BJ, Meehan JJ. Robotic repair of congenital diaphragmatic anomalies. J Laparoendosc Adv Surg Tech. 2009;19(1):123–7.

Weiner DC, Jaklitsch MT. Surgery of the diaphragm: a deductive approach. In: Sellke FW, del Nido PJ, Swanson SJ, editors. Sabiston & Spencer surgery of the chest. 7th ed. Philadelphia, PA: Elsevier Saunders; 2005. p. 501–15.

Robotic Phrenic Nerve Pacemaker Implantation

17

Arielle Hodari Gupta and Jeffrey A. Morgan

Abstract

Diaphragmatic pacing is most commonly performed for patients with quadriplegia (usually at or above C3) and central alveolar hypoventilation. It has also been used in patients with amyotrophic lateral sclerosis (ALS). Phrenic nerve pacing can improve quality of life in quadriplegic patients and in patients with primary alveolar hypoventilation by eliminating the dependence on a ventilator. Insertion of a phrenic pacemaker through an endoscopic approach with robotic assistance minimizes surgical trauma. By avoiding multiple neck incisions, bilateral thoracotomies, or a sternotomy, an endoscopic approach is likely to yield a hastened postoperative recovery and improved quality of life. The phrenic nerve stimulator consists of an electrode placed on the phrenic nerve and connected to a subcutaneous receiver via lead wires. An external battery-operated transmitter sends radiofrequency energy to the receiver through an antenna, which is placed on the skin overlying the receiver. The receiver converts this energy into an electrical current that is directed to the phrenic nerve in order to stimulate the nerve, thereby causing contraction of the diaphragm. Pacing is usually not begun until 28 days after the operation, to allow edema and inflammation to subside. The patient is then studied under fluoroscopically to assess the function of the diaphragm. The pacemaker is tested and its settings are adjusted.

Keywords

Diaphragm • Pacing • Quadriplegia • Ventilator dependence • ALS

17.1 Background

Diaphragmatic pacing is most commonly performed for patients with quadriplegia (usually at or above C3) and central alveolar hypoventilation. It has also been used in patients with amyotrophic lateral sclerosis (ALS). It can eliminate the requirement for ventilator support [1, 2]. The procedure can be performed with an open technique through a cervical approach, a thoracic approach requiring thoracotomy, or a sternotomy [3]. A robotic approach minimizes the incisions to three 1 cm incisions.

Phrenic nerve pacing can improve quality of life in quadriplegic patients and in patients with primary alveolar hypoventilation by eliminating the dependence on a ventilator. Insertion of a phrenic pacemaker through an endoscopic approach with robotic assistance minimizes surgical trauma. By avoiding multiple neck incisions, bilateral thoracotomies, or a sternotomy, an endoscopic approach is likely to yield a hastened postoperative recovery and improved quality of life. Although a standard thoracoscopic approach may be used to perform this procedure, a specialized skill set is required. The use of robotic technology allows this relatively challenging thoracoscopic procedure to be performed easily by surgeons with little thoracoscopic experience.

A. H. Gupta, M.D. (✉)
Department of Surgery, Henry Ford Hospital, Detroit, MI, USA
e-mail: ahodari1@hfhs.org

J. A. Morgan, M.D., F.A.C.S.
Division of Cardiothoracic Transplant and Circulatory Support, Advanced Heart Failure Center, Baylor College of Medicine, Texas Heart Institute, CHI Baylor St. Luke's Medical Center, Houston, TX, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_17

17.2 Set Up and Operation

The phrenic nerve stimulator consists of an electrode placed on the phrenic nerve and connected to a subcutaneous receiver via lead wires. An external battery-operated transmitter sends radiofrequency energy to the receiver through an antenna, which is placed on the skin overlying the receiver. The receiver converts this energy into an electrical current that is directed to the phrenic nerve in order to stimulate the nerve, thereby causing contraction of the diaphragm [4].

The first 1-cm incision is made in the fourth intercostal space, 2 cm anterior to the anterior axillary line. The robotic endoscopic camera, which is attached to a fiberoptic cable, is inserted, and entry into the pleural space is confirmed. Two additional 1-cm incisions, through which the right and left arms of the robotic system are inserted sequentially under direct videoscopic guidance, are made in the second and sixth intercostal spaces about 10 cm away from the camera port (Figs. 17.1 and 17.2). Using a 0 videoscope, a EndoWrist Bipolar Maryland®, and a Cadiere® grasper; the surgeon dissects and carefully exposes a small segment of the left phrenic nerve free from the pericardium avoiding any cautery. Application of Surgicel® (Johnson & Johnson) material and pressure allows for hemostasis. The pacing lead is positioned around the nerve and affixed to the pericardium using two robotic needle holders and 3–0 Ethibond on a SH needle passed through a 12-mm thoracoport away from the robotic port sites (Figs. 17.3 and 17.4). On the left, the implantation site is best at the level of the left pulmonary artery, whereas on the right it is at the confluence of the superior vena cava and right atrium. The lead is passed through the robotic arm trocar site and attached to the receiver, which is implanted in a small subcutaneous pocket. The pacer is tested for proper function [5].

Pacing is usually not begun until 28 days after the operation, to allow edema and inflammation to subside. The patient is then studied under fluoroscopically to assess the function of the diaphragm. The pacemaker is tested and its settings are adjusted. The threshold necessary to generate the diaphragmatic excursion is recorded. Spirometric values are calculated, along with arterial blood gas values. Adjustments are made in current amplitude, pulse interval, and respiratory rate. The goal is to maximize respiration with the least amplitude required for diaphragmatic contraction.

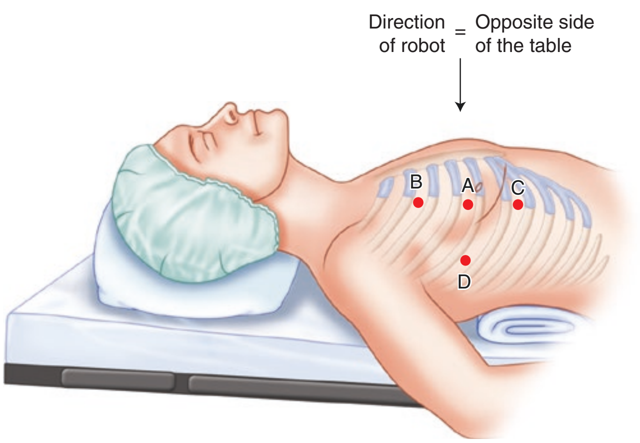


Fig. 17.1 After the patient is intubated the patient is positioned to the ipsilateral side of the operating room table the pad underneath the mid back the patient placed in slightly reverse Trendelenburg and the arm draped and padded down below the level of the table to expose the ipsilateral chest and axilla. The first incision (A) is in the fourth intercostal space approximately 2 cm anterior to the anterior axillary line. A 12 mm port is placed here and the pleural space examined. Then approximately along the same longitudinal line in the second intercostal space a robotic port is placed (B). And again along the same longitudinal line in the sixth intercostal space 1/3 port, a robotic port is placed (C). Then in the mid axillary line in the mid axilla and juxtaposed between any of the other ports to prevent collision an additional 12 mm port was placed (D). The same arrangement is performed on the left side for the left phrenic nerve pacer

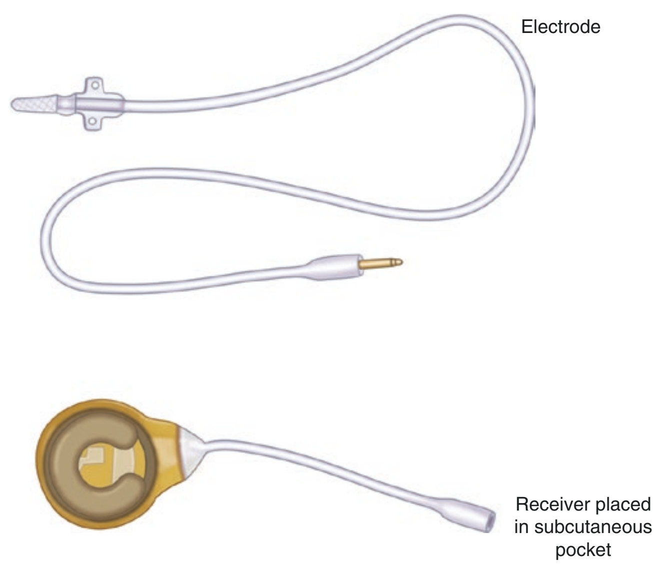


Fig. 17.2 There are two implantable components for the phrenic nerve pacer. The first is the electrode which has the electrode surface/clip that fits around the phrenic nerve and is sutured to the pericardium and its attachment to be placed to the subcutaneously placed receiver

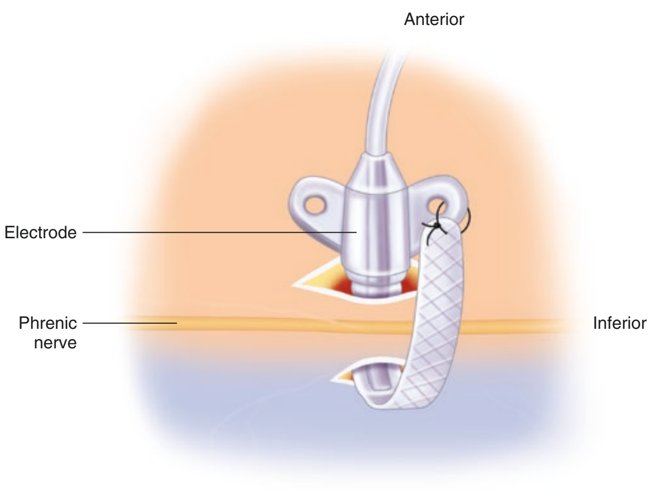


Fig. 17.3 In the conduct of the surgical procedure a 0° video scope is used and a bipolar Maryland and cardiac grasper were used to expose the phrenic nerve. The ideal locations for implantation on the right side is at the junction of the superior vena cava and right atrium, adjacent to the azygous vein (see Fig. 17.4). The phrenic nerve is identified and dissected up and away from the pericardium avoiding use of any coagulation system. Is certainly possible to use the bipolar aspects of the bipolar Maryland for any significant bleeding, but it is preferable to use pressure and hemostatic agents to control the blood loss and achieve complete hemostasis before placing the electrode. After the phrenic nerve is exposed and hemostasis achieved, the electrode lead can be put into the pleural space through the 12 mm Thoracoport (D). The lead is in draped over the mediastinal pleura and pericardium and the electrode portion is brought beneath the phrenic nerve. Once this is completed to robotic needle holders are placed and either a 3-0 Ethibond on an SH needle is used to suture the electrode in the place

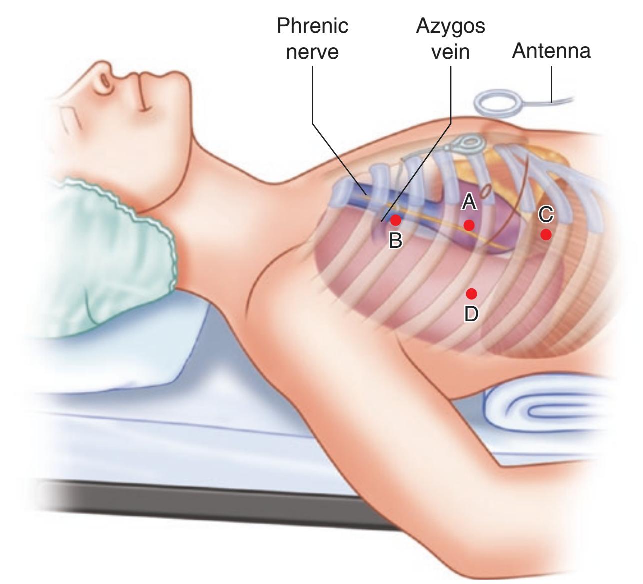


Fig. 17.4 The ideal location on the right side is at the confluence of the superior vena cava and right atrium and on the left side is at the level of the left pulmonary artery. Once the electrode has been fixed to the pericardium and done in a fashion to avoid any kinking of the phrenic nerve, the electrode lead is brought out through the uppermost robotic port (B) and a subcutaneous tunnel is made for the receiver. Once it is adequately placed in a subcutaneous location a temporary drain is placed through port C. Operative time for each side is typically about 30 min

17.3 Anesthetic Management

General anesthesia is used for the procedure. If the patient has ALS then succinylcholine is strictly contraindicated because of the upper motor neuron involvement leading to denervated muscles with increased acetylcholine receptors contributing to this succinylcholine-triggered hyperkalemia [6].

17.4 Tips and Pitfalls

- Post-operative aggressive pulmonary hygiene is required
- Major therapeutic objective of diaphragmatic pacing is oxygenation rather than the elimination of carbon dioxide. Expiratory flow must be adequate.
- Important to avoid handling of the nerve as injury would prevent accurate pacing
- Besides benefit of freedom from mechanical ventilation, pacing can also lead to: improved speech patterns, conversion from tracheostomy to stoma devices, and return of olfactory sensation

17.5 Results

There are multiple studies on outcomes after diaphragmatic pacemaker insertion; each with relatively small sample size and only one with robotic implantation. Weese-Mayer et al. [7] studied 35 children and 29 adults. They 94% of pediatric patients pacing successfully, 60% of these complication free, and 86% of adult patients pacing successfully, 52% of these complication free. Shaul et al. [8] successfully implanted phrenic nerve stimulators through a thoracoscopic approach. Nine patients, all children, were described. Over a mean follow-up period of 30 months, eight patients reached their long-term pacing goals. Four patients experienced post-operative complications (pneumonia, atelectasis, bradycardia and pneumothorax), with the recognition that aggressive post-operative pulmonary hygiene was required. Morgan et al. [5] published on robotic implantation in 6 patients. They had no post-operative complications or death. Mean follow up was 258.3 ± 176.3 days and they had no device malfunction or mechanical difficulties. Total operative time ranged from 80–120 min with no intraoperative complications.

References

1. Miller JI, Farmer JA, Stuart W, Apple D. Phrenic nerve pacing of the quadriplegic patient. J Thorac Cardiovasc Surg. 1990;99:35–40.
2. Glenn WL, Hogan JF, Loke JS, Ciesielski TE, Phelps ML, Rowedder R. Ventilatory support by pacing of the conditioned diaphragm I quadriplegia. N Engl J Med. 1984;310:1150–5.

3. Glenn WL, Hogan JF, Phelps ML. Ventilatory support of the quadriplegic patient with respiratory paralysis by diaphragmatic pacing. Surg Clin North Am. 1980;60:1055–78.
4. Khong P, Lazzaro A, Mobbs R. Phrenic nerve stimulation: the Australian experience. J Clin Neurosci. 2010;17:205–8.
5. Morgan JA, Morales DL, John R, Ginsburg ME, Kherani AR, Vigilance DW, Cheema FH, Smith CR Jr, Oz MC, Argenziano M. Endoscopic, robotically assisted implantation of phrenic pacemakers. J Thorac Cardiovasc Surg. 2003;126(2):582–3.
6. Brambrink AM, Kirsch JR. Perioperative care of patients with neuromuscular disease and dysfunction. Anesthesiol Clin. 2007;25: 483–509.
7. Weese-Mayer DE, Silvestri JM, Kenny AS, et al. Diaphragm pacing with a quadripolar phrenic nerve electrode; an international study. Pacing Clin Electrophysiol. 1996;19(9):1311.
8. Shaul DB, Danielson PD, McComb JG, et al. Thoracoscopic placement of phrenic nerve electrodes for diaphragmatic pacing in children. J Pedriatr Surg. 2002;37:974–8.

Robotic Pericardial Cyst/Mass Resection

18

Kemp Kernstine Sr.

Abstract

Pericardial lesions are particularly accessible for resection and biopsy by the video-assisted technique. However, with the numerous arcs of mobility and with limited motion at the chest wall and the surgeon-controlled 3-D view particularly provides assistance in the evaluation of diagnosed and undiagnosed pericardial lesions. This chapter provides the indications and a detailed approach to the pericardial cyst or mass.

Keywords

Pericardium • Parathyroid • Ectopic • Thymectomy • Thymus • Lymphoma • Thyroid • Seminoma • Metastasis • Goiter • Germ cell tumor • Teratoma • Lymphadenopathy

18.1 Background, Specific Indications

Pericardial cysts, referred to as "spring water cysts," are most commonly located at the lateral and inferior border of the pericardium [1]. They are the second most common mediastinal cyst behind bronchogenic cysts. Although it may result from trauma or surgery, it is most commonly from congenital origin. It accounts for 7% of all mediastinal tumors and can occur in 1 in 100,000 admissions. The cysts are found on routine chest radiological examinations, two thirds of them found to be symptomatic. The most common symptoms are chest pain, dyspnea, fever, and cough. Malignancy is suspected within hoarseness, Horner's syndrome, diaphragmatic paralysis, superior vena caval syndrome and chylothorax are present. The differential includes solid tumors, prominent pericardial fat, left ventricular aneurysm, prominent left atrial appendage, aortic aneurysm and Foramen of Morgagni hernia. Computed tomogram (CT) is the most useful diagnostic test. A cyst CT density of less than 20 Hounsfield units most likely represents fluid, where 30–120 Hounsfield units represents mucus. The size is typically 2–3 cm a can be nearly 30 cm. They are spherical or can be teardrop shaped located adjacent to the heart, diaphragm and the anterior chest wall. They are usually unilocular and filled with clear transudate fluid, but can have proteinaceous fluid instead. A color spectral Doppler may be used to differentiate a pericardial cyst from vascular structures. Magnetic resonance imaging (MRI) and MRI angiogram (cine) may be used instead. The use of a positron admission tomography-computed tomogram scan (PET-CT) is of limited value. In comparison to a bronchogenic cyst that is lined with respiratory tract ciliated columnar epithelium or cuboidal epithelium, pericardial cysts are lined with a single layer of mesothelial cells. They may present as intra-or extrapericardial in their relationship to the pericardial sac. The natural history of the pericardial cyst is unclear; some may resolve with time. Severe life-threatening complications have occurred in pericardial cysts that includes spontaneous hemorrhage, spontaneous infection and cyst calcification; each of which is felt to be rare [2]. In good surgical candidates, symptoms are an acceptable indication for resection of pericardial cysts. Other indications include: suspicion of malignancy, cystic enlargement during observation, and in those patients who present with a pericardial cyst receiving

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, Department of Cardiovascular and Thoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th Floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_18

chronic anti-coagulation. These are only recommendations as there is not sufficient data to provide evidence supported recommendations. Other potential procedures to evaluate and treat pericardial cysts include partial resection, simple aspiration, or aspiration with drain placement and possible infusion of sclerosant.

Pericardial nodules and masses are more likely to represent concerning pathology. As with the pericardial cyst, a computed tomogram with or without contrast is the initial diagnostic test. MRI and MRI angiogram may provide further diagnostic information. In the case of a solid density, PET CT to be beneficial to assess the metabolic activity as well as a screening tool for possible metastatic lesions. These lesions can vary in size, but are typically less than 3 cm in greatest dimension. The differential diagnosis includes pericardial fat, an inflamed or infected pericardial cyst, prominent left atrial appendage, benign or malignant lymphadenopathy that includes Mycobacterium tuberculosis, amycobacterial infected node as well as fungal infections including histoplasmosis; Sarcoidosis, Castleman's disease, primary malignancy such as primary pericardial, thymic origin, germ cell tumor, primary sarcoma, esophageal cancer, lymphoma, and possible mesothelioma; metastatic tumors include lung cancer, gastrointestinal origin, renal cell cancer, melanoma and sarcomas; paraesophageal hiatal hernia; Foramen of Morgagni Hernia; Foramen of Bochdalek Hernia; parathyroid adenoma; left ventricular aneurysm; aortic aneurysm and contained esophageal perforation. Once the imaging has been completed, there should be sufficient information to exclude vascular anomalies. For lesions less than 3 cm in greatest dimension, complete excision could be entertained for diagnostic purposes; these include: open thoracotomy, median sternotomy, thoracoscopic or robotic resection. For larger lesions or in those patients who appear to be a significant surgical risk, a CT-guided needle biopsy could be performed. Potential resection may be necessary in those cases where CT-guided needle biopsy is equivocal or unable to achieve the diagnosis.

18.2 Operative Setup

For lesions that are located in the anterior half of the pericardium/heart; the patients are place supine. After intubation, they are brought to the edge of the operating table with a soft jelly roll placed beneath the midportion of the ipsilateral chest. The ports are then placed in the ipsilateral chest that is raised up 45° from the level. Dependent upon the angles necessary, a 0° or 30° up into scope is used; placing the thoracoport into the ipsilateral chest directly opposite the midportion of the lesion in question. The robot bedside cart is then brought in directly opposite of the scope placement. The robotic arms are placed 10–14 cm on either side of the endoscope. An additional 5 mm thoracoport can be placed for suctioning and retraction purposes.

For lesions in the posterior half the pericardium, the patient is positioned in the lateral decubitus position. The first thoracoport, a 12 mm, is placed in the midportion of the axillary hairline and the third or fourth intercostal spaces. The thoracoport for the videoscope is placed at the lowest portion of the chest in the midline with the robotic arms 10–14 cm on either side of the thoracoport for the scope. The robot is brought in over the patient's head. Before docking the robot, the patient is placed in the reverse Trendelenburg position.

Warmed carbon dioxide is insufflated at 5–10 mmHg of pressure.

We use a large grasping clamp in the leftward arm and either a harmonic scalpel or hooked cautery (setting of 15–45). We used a grasping clamp to push the cyst or lesion, rather than grasping it. It creates edges for resection.

18.3 Specific Anesthetic Management

Typically, we use single lung ventilation, but in cases where the lesions are small and the placement of a double-lumen tube or a bronchial blocker are difficult, a single-lumen endotracheal tube is used. Carbon dioxide is used to create an operative field, compressing the lung and shifting the mediastinum away from the videoscope.

18.4 Stepwise Conduct of the Operation

18.4.1 Mid- to Anterior Pericardial Cyst or Mass

After the induction of general anesthesia and intubation to achieve single lung ventilation, the patient is positioned to the ipsilateral side of the operating room table with the ipsilateral arm down below the level of the table in the mid chest bumped with a soft jelly roll. Once the hips are taped to the table, the ipsilateral chest is prepped and draped so as to allow for an as necessary ipsilateral thoracotomy or a median sternotomy. Four thoracoports are placed as demonstrated in Fig. 18.1 and the bedside cart is brought into position (Fig. 18.2). The grasping tool in the leftward arm is used like a spatula to identify the areas of attachment and the vascular supply and to expose for the harmonic scalpel to divide these attachments. Division of the attachment is performed around the circumference rather than focusing on any one particular area, it reduces the likelihood of causing any damage to any unexpected structures that may be involved in the attachment, such as the phrenic nerve (Fig. 18.3). Unless the cyst was particularly large, we avoid injuring the cyst so that its bulk

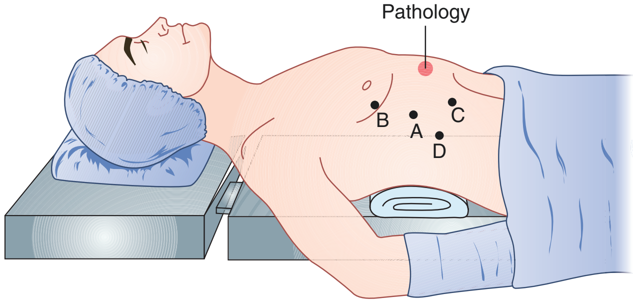


Fig. 18.1 The patient is brought to the edge of the table and a soft bump placed under the midportion of the chest and the arm padded below the table to allow the ipsilateral shoulder to fall down, avoiding potential obstruction of the adjacent robotic arm. After the ipsilateral chest is prepped and draped, four thoracoports are placed. Port A, a 12 mm port, is placed directly opposite the pathology along the marked the chest wall to achieve at least a 10 cm distance from the port to the pathology (marked). Once the video port is placed ports B and C, the leftward and rightward robotic arms are placed, both 8 mm ports. Port D is a 5 mm port was placed between and inferior to ports A and C, posteriorly displaced by approximately 5–8 cm. Once the ports are placed the table is rotated with the ipsilateral side up by approximately 30°–45°. The robot bedside cart was brought into place on the contralateral side, directly opposite port A, putting the pathology between port A and the base of the bedside cart. Prior to docking the robot, the bed is positioned into a reverse Trendelenburg position. The robot is then docked

can be used to assist in the retraction exposing the attachment. Once excised, it is placed in an endobag for extraction. If the cyst is particularly large, and assist is incised with in the endobag, avoiding spillage into the pleural space. The aspirated material is sent for cytology and/or culture as necessary. The endobag is typically passed through port B, removing the robotic arm to do so. An intercostal block is then performed with bupivacaine with epinephrine from approximately two rib spaces above the most cephalad port and two rib spaces below the most caudad port. We usually place a single #19 round fluted drain through one of the port sites and the remaining port sites are closed with dissolving suture.

18.4.2 Posterior Pericardial Cyst or Mass

For patients with a mid to posterior pericardial mass, they are positioned in the contralateral side down decubitus position with the ipsilateral arm up in a well-padded close to the face. The ipsilateral chest is then prepped and draped in the usual fashion. Four thoracoports are placed as outlined in Fig. 18.4. Through port A Forrester clamp is passed and the most inferior medial portion of the lower lobe is gently grasped to

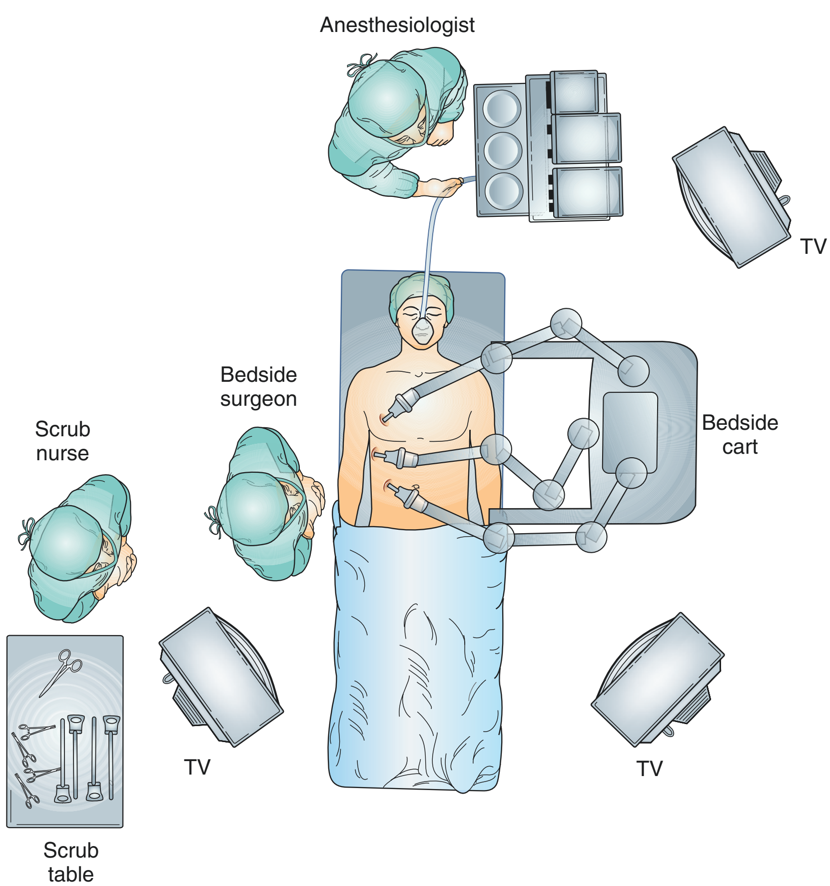


Fig. 18.2 Robotic Room Position for Resection of a Right Sided Pericardial Cyst or Mass

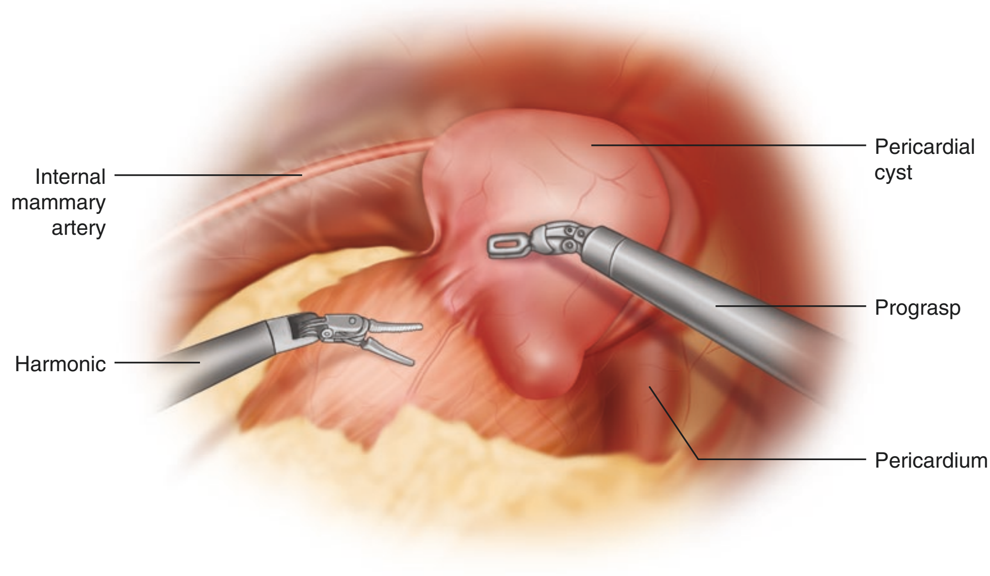


Fig. 18.3 The grasping device in the leftward arm is used like a spatula pushing the cyst or mass away from the resection area, that point of attachment to the pericardium, and so that the harmonic scalpel coming in from the rightward port can be used to coagulate and resect an effort to remove the lesion from the pericardium

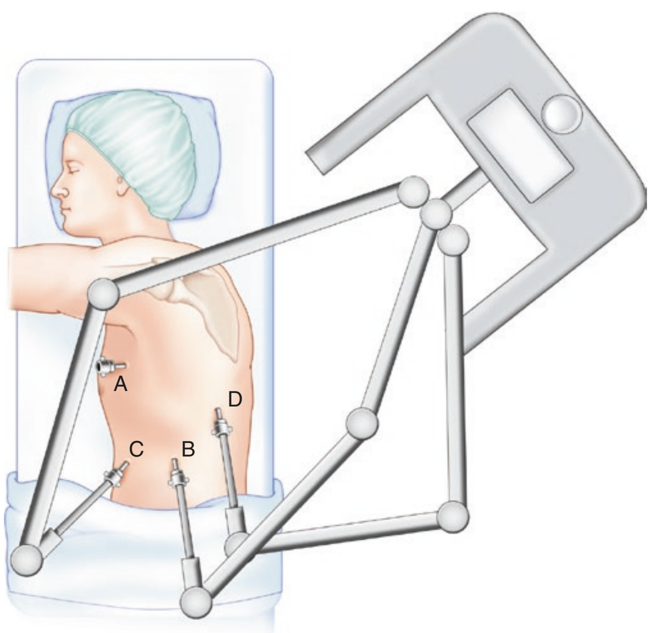


Fig. 18.4 For pericardial cyst or masses that are in the mid to posterior aspect of the pericardium, they are best approached in a lateral position with the robot or bedside cart brought in over the patient's head. Four thoracoports are placed. Port A is a 12 mm port is placed in the midaxillary line just at the hairline into the third or the fourth intercostal space. This port is used for extraction. Port B is also a 12 mm port in his the video port for the robot and is placed at near to the most inferior recess of the chest along a longitudinal line along the tip of the scapula. Ports C and D are placed 10–14 cm away from the video port and are both 8 mm robotic ports. In the leftward arm, port C, a grasping tool is placed. In the rightward arm, port D, the harmonic scalpel or hooked cautery are placed. Prior to docking the robot, the patient is positioned in the reverse Trendelenburg fashion so that the abdominal contents fall away from the operative field allowing for better exposure

expose the inferior pulmonary ligament. The ligament is then divided as necessary with the harmonic scalpel to expose the cyst or mass to be resected. Then without grasping the cyst or mass, using the leftward arm grasping tool as a spatula to push and expose the area of intended resection. The attachments should be taken down in a near circular fashion, gradually releasing the cyst or mass from its attachment to the pericardium and providing sufficient exposure to avoid injury to any potential critical structure. Once the lesion had been completely excised from the pericardium is placed into an endobag and brought out through port A which can be enlarged as necessary with a hook cautery before bringing the endobag in that location. A multilevel bupivacaine with epinephrine intercostal block is performed in the same fashion as noted above. A single drain is placed as well through one of the anterior ports, usually port B. The remaining wounds are closed with dissolving suture.

18.5 Tips and Pitfalls

Avoid using any cautery next to cysts and if used placed the cautery on very low setting.

Maintain the cyst contents unless it is absolutely necessary to achieve visibility. A gallbladder needle can be used to aspirate cyst contents as necessary.

Avoid grasping cysts or masses to minimize the likelihood for cyst rupture or tumor bleeding.

Cannot concentrate the dissection in one particular area; even when left with a fairly small area to be resected, continue to come at the line of resection in multiple planes. This reduces the likelihood of local injury.

18.6 Outcomes

Early experiences of robotic resection of a pericardial cyst or mass was reported in 2002 [3] and 2003 [4]. The time of surgical resection was quick, taking approximately 1 h in the first case and 15 min in the second. The drains were removed the next day and patients were discharged within 24 h returning to their normal preoperative status within approximately a week. Since then, Augustin et al. described their approach to mediastinal tumors, including the pericardial tumors and cysts [5]. They provided on outcomes data, but a review of the literature and a description of their approach. In 2012 Melfi et al. described their 10-year experience with mediastinal mass resection at the University of Pisa in their series of 69 patients there were nine pericardial cysts, four lymph node removals and one enterogenic cysts excised; nearly all of the remaining were thymectomy is, mostly for myasthenia gravis [6]. As a group they reported postoperative complications of 7.2% and mean postoperative stay of 4.3 days. The largest report to date is by Cerfolio et al. at the University of Alabama in their 30 month experience in 153 patient's 11 of which had an esophageal or bronchogenic cyst and 41 with a posterior mediastinal mass or lymph node [7]. The median tumor size was 4.4 cm. They are medium length of stay was 1 day. One patient was converted to an open thoracotomy. The morbidity was 12%. The mean operative time was less than 1.5 h and the median blood loss was 50 mL.

Our experience performing a robotic resection of pericardial pathology, cyst or mass is note similar results. The time of resection is typically less than 1 h. Bleeding is minimal, less than 50 mL. The hospital stay is typically 1 day and patients are back to their functional status within approximately 1 week. We have found that the use of this technology to be beneficial in the performance of a pericardial cyst or mass resection.

References

1. Kernstine KH, Eneh P. Bronchogenic and pericardial cysts: resect or observe. In: Difficult decisions in thoracic surgery (second edition): an evidence-based approach; 2011. p. 461–9.
2. Korst RJ. Asymptomatic pericardial cyst: observe or resect? In: Difficult decisions in thoracic surgery: an evidence-based approach; 2007. p. 488–92.
3. Yoshino I, Hashizume M, Shimada M, Tomikawa M, Sugimachi K. Video-assisted thoracoscopic extirpation of a posterior mediastinal mass using the da Vinci computer enhanced surgical system. Ann Thorac Surg. 2002;74(4):1235–7.
4. Bacchetta MD, Korst RJ, Altorki NK, Port JL, Isom OW, Mack CA. Resection of a symptomatic pericardial cyst using the computer-enhanced da Vinci (TM) surgical system. Ann Thorac Surg. 2003;75(6):1953–5.
5. Augustin F, Schmid T, Bodner J. Robotic surgery for mediastinal tumors. Eur Surg Acta Chirurgica Austriaca. 2011;43(4):218–23.
6. Melfi F, Fanucchi O, Davini F, et al. Ten-year experience of mediastinal robotic surgery in a single referral centre. Eur J Cardiothorac Surg. 2012;41(4):847–51.
7. Cerfolio RJ, Bryant AS, Minnich DJ. Operative techniques in robotic thoracic surgery for inferior or posterior mediastinal pathology. J Thorac Cardiovasc Surg. 2012;143(5):1138–43.

The Surgical Treatment of Pericardial Disease: The Robotic Approach

19

Ramzi K. Deeik

Abstract

Surgery on the pericardium has been relegated to a median sternotomy, open thoracotomy and subxiphoid laparotomy approach. Video-assisted or thoracoscopic techniques may present some limitations in some patients. The robotic approach described in this chapter provides sufficient information to perform a safe and efficient procedure. The anesthetic management, the progress of the procedure and the placement of 3–4 puncture wounds and their position on the chest wall are described.

Keywords

Mediastinum • Pericardium • Pericardiectomy • Tamponade • Pericarditis • Pericardial effusion • Pericardial window • Heart failure

19.1 Background

Robotic da Vinci pericardiectomy offers a much improved minimally invasive approach for the diagnosis and management of pericardial disease than video-assisted thoracic surgery (VATS). VATS has been proven to be effective and safe in combining the advantages of subxiphoid pericardiotomy and pericardiectomy performed via thoracotomy or median sternotomy [1–3]. However, there are some limitations with the VATS approach. With the availability of the da Vinci® robot at our institution since 2002, we have been able to overcome the technical limitations of VATS.

The combination of 3-D video imaging and the da Vinci Endo-Wrist® features of instruments with multiple degrees of freedom, has allowed us to perform routine partial pericardiectomy as well as technically difficult pericardiectomy with safe and precise dissection. Practically the entire pericardium between the phrenic nerves can be excised either through the left or right chest.

The robotic da Vinci approach, also, provides a diagnostic advantage due to the excellent view obtained of the pleural cavity and the pericardium. All suspicious sites, whether pericardial, pleural, lung, or mediastinal, could be precisely localized for biopsy. It, also, allows for concurrent performance of additional procedures, such as management of a concomitant pleural effusion by talc pleurodesis.

For pericardial effusions, drainage is achieved by pericardial resection to create a true pleuropericardial connection/window. Although the subxiphoid drainage procedure is a simple technique for the treatment of cardiac tamponade, it allows for only limited pericardial resection and does not create such connection. Even posteriorly located loculated effusions, that cannot normally be reached without open thoracotomy, are easily drained.

In patients with purulent or subacute constrictive pericarditis., every attempt should be made to remove the pericardium from phrenic to phrenic to prevent recurrence. The incidence of pericardial effusion recurrence may be lower for VATS than the subxiphoid route because a larger window of pericardium can be excised [4]. Piehler and associates [4] suggested a direct relationship between the extent of pericardium resected and the incidence of recurrence or development of constriction. Therefore, the removal of a generous

R. K. Deeik, M.D. (✉)
Department of Cardiothoracic Surgery, Santa Rosa Memorial Hospital, Santa Rosa, CA, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_19

amount of the pericardium is prudent when dealing with purulent or constrictive pericarditis.

19.2 Operative Technique

19.2.1 Patient Position

Align either the right or left chest of patient with the edge of operating room table. Patients are positioned supine with the chest elevated 30° using either a positioning roll or pillows. The side chosen depends on the preoperative imaging. Allow the arm of the desired side to hang down alongside the patient below table level and pad appropriately. Roll the operating table 10°–15° to raise the patient operating side. External defibrillation pads are placed, as a precaution, to be used in the event of ventricular arrhythmia occurring during dissection (Fig. 19.1).

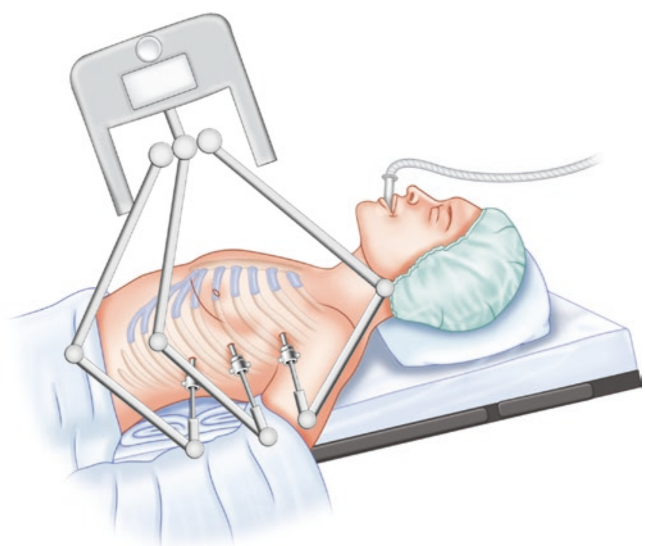


Fig. 19.1 The patient is positioned to the side of the operating room table of the side of the patient being surgically treated. A roll is placed under the mid to upper portion of the back that allows the ipsilateral shoulder to fall down toward the operating table. This roll provides approximately 30° of ipsilateral chest elevation. The ipsilateral arm is allowed to fall below the level of the table and is well-padded to avoid any pressure injury. Once the patient is positioned, the operating room table can be rotated with the ipsilateral side up approximately 15° and the operating table position can be elevated approximately 30° in reverse Trendelenburg. The chest is prepped to include the lower neck and upper abdomen as well as the full sternum for possible median sternotomy, the drapes are placed. Three ports are then placed. The first port or the video port is placed in the fifth intercostal space approximately 3 cm lateral to the midclavicular line. Once this is placed a second trocar is placed along the same line in the third intercostal space and then the third port is placed again along the same line in the seventh intercostal space. Once the ports are placed, the robot is brought in from the opposite side of the table and attached to the ports

19.2.2 Anesthetic Management

Double-lumen endotracheal intubation and single lung ventilation provides facile mediastinal exposure. For patients with constrictive pericarditis, a trans-esophageal echocardiographic probe is placed to define cardiac function.

19.2.3 Port Placement

First trocar is placed in the fifth intercostal space about 3 cm lateral to the midclavicular line. Via this trocar, CO_2 is insufflated to a maximal intrathoracic pressure of 8–10 mmHg. Under three-dimensional (3D) view, two additional instrument-carrying trocars are placed. The left instrument port is about four finger breadths from the camera port (approximately in the seventh intercostal space) at about the same elevation. The right instrument port is about four finger breadths from the camera port (approximately in the third intercostal space) at about the same elevation.

19.2.4 Pericardial Effusion

The pleural cavity and lung are examined first, and any pleural effusion is evacuated and sent for cytology. Thirty degrees down scope is preferred. A partial pericardial lipectomy is required to expose the pericardium. After the phrenic nerve is identified, an incision is made in the distended pericardium using the cautery spatula under direct vision. The fluid is collected for cytologic and microbiologic analysis. The pericardium is then grasped with the EndoWrist® DeBakey forceps and a piece of pericardium approximately 4 cm in diameter is resected. A large pericardial window is created. A chest drain is inserted into the cavity, through one of the port sites with no attempt to drain the pericardium (Figs. 19.2 and 19.3).

19.2.5 Subacute or Effusive Pericarditis

A right thoracic approach is preferred. Pleural adhesions are divided with scissors and cautery spatula. Cautery energy is reduced to a minimum to prevent ventricular fibrillation. Pericardium is then grasped and carefully opened at the diaphragmatic edge. With cautious dissection, the pericardial space is entered. The pericardial effusion is drained into the right pleural cavity. The pericardium is resected along the sternal edge from the superior vena cava above the level of phrenic nerve to the diaphragm with the cautery spatula.

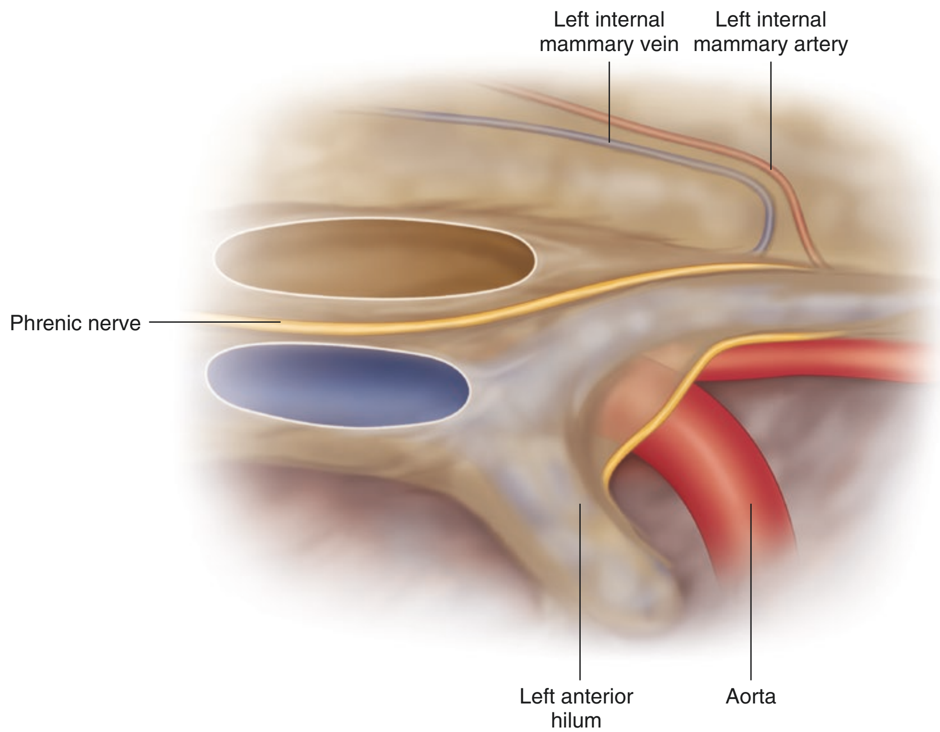


Fig. 19.2 Once the ports are placed into the left chest, this is a view of the chest. Noted is the location of the phrenic nerve and in the diagram are drawings of potential resection sites for pericardial windows both anterior and posterior to the phrenic nerve. 8–10 mmHg of carbon dioxide pressure can assist in providing sufficient space and assisting in removing any cautery smoke or harmonic scalpel vapor

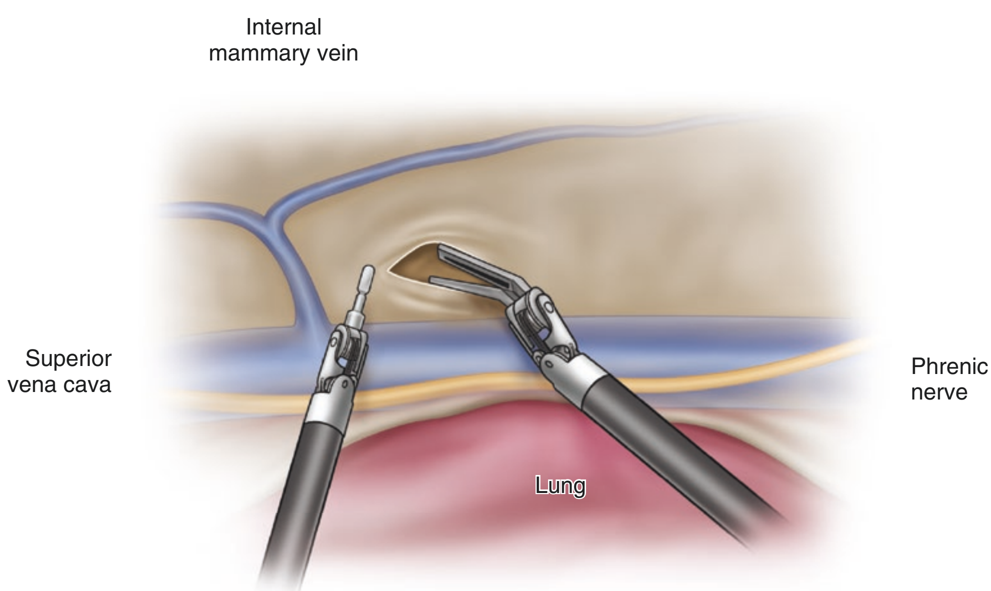


Fig. 19.3 This is a view of the right pericardium demonstrating the spatula cautery in the leftward arm and the Cadiere grasper or Prograsp in the rightward arm performing a pericardial window just anterior to the phrenic nerve

Pericardium is then removed. As a next step, further pericardium is resected beyond the left anterior descending artery and removed, thus allowing resection of a 20 cm^2 piece of pericardium. The cardiac cavity is washed with normal saline. At the end of the procedure, complete hemostasis is ensured followed by placement of chest tubes via trocar incisions. The pericardial specimen and fluid are sent for pathological and microbiologic examination.

19.3 Pitfalls and Pearls

There are some potentially major complications associated with this operation. Specific pearls and pitfalls for robotic pericardiectomy include:

- Upon opening the pericardium, the phrenic nerve should be visualized at all times to avoid injury. Staying 2–3 cm above the phrenic nerve during resection is imperative.
- Meticulous dissection is mandatory to avoid damage of the myocardium or the coronary vessels.
- The only reliable technique to prevent recurrence of pericardial effusion is the resection of a large part of pericardium.
- Robotic da Vinci pericardiectomy is contraindicated in patients who are clinically unstable from tamponade or have altered respiratory function as single-lung ventilation is necessary. In these circumstances, subxiphoid drainage remains the method of choice.
- Subxiphoid pericardial drainage should be the preferred approach in patients with a short expected life span due to major comorbidities or extensive metastatic disease. The subxiphoid procedure can be performed with local anesthesia.
- In the event of a combined malignant pericardial and pleural effusion, talc can be applied under direct vision on the pleural dome, chest wall, and diaphragm, but not on the mediastinal part.
- The operative times are much longer when performing pericardiectomy for sub-acute or purulent pericarditis than for effusion drainage with partial pericardiectomy.
- For purulent pericarditis, the dissection is more difficult when patients had symptoms lasting longer than 2 weeks. Pericardiectomy size should be as large as possible to completely free the anterior part of the heart from the cardiac apex to the origin of the great vessels and from above the left phrenic to the area lateral to the Left anterior descending artery. Residual thick and adherent epicardial peels can lead to treatment failure.
- A third instrument port can be placed in difficult cases to utilize the da Vinci's fourth arm if needed. This can be helpful in holding the edges of the pericardium for dissection or for counter-traction.
- The presence of pericardial calcifications on the preoperative images should be considered a contraindication to the Robotic approach. In the late stage, with pericardial constriction, detaching the calcified peel stuck to the epicardium is the most difficult step to perform and can prove to be un-safe.
- Conversion to an open approach is recommended if there is excessive bleeding, a dissection plane cannot be found or in the presence of adherent epicardial peel that is difficult to dissect off of the epicardium.

References

1. Flores RM, Jaklitsch MT, DeCamp MM Jr, Sugarbaker DJ. Video-assisted thoracic surgery pericardial resection for effusive disease. Chest Surg Clin North Am. 1998;8:835–51. [Medline].
2. Hazelrigg SR, Mack MJ, Landreneau RJ, Acuff TE, Seifert PE, Auer JE. Thoracoscopic pericardiectomy for effusive pericardial disease. Ann Thorac Surg. 1993;56:792–5. [Abstract].
3. Ohtsuka T, Wolf RK, Wurnig P, Park SE. Thoracoscopic limited pericardial resection with an ultrasonic scalpel. Ann Thorac Surg. 1998;65:855–6. [Abstract/Free Full Text].
4. Piehler JM, Pluth JR, Schaff HV, Danielson GK, Orszulak TA, Puga FJ. Surgical management of effusive pericardial disease. Influence of extent of pericardial resection on clinical course. J Thorac Cardiovasc Surg. 1985;90:506–6.

Robotic Transthoracic Thoracic Duct Ligation

20

Kemp Kernstine Sr. and John K. Waters

Abstract

Historically, thoracic duct ligation has been performed by thoracotomy. The video-assisted technique has offered possibilities, but because of the thoracic duct location deep in the mediastinum and the challenges related to patient's anatomy, the robotic approach offers the consistent opportunity of performing a very precise procedure in often a confined space despite the anatomical variability. The most common location chosen for thoracic duct ligation is just as it enters the mediastinum from the retroperitoneum and just deep to the rightward and vertebral area behind the descending aorta. Medial retraction of the aorta provides the best exposure for a complete ligation. Many advocate a mass ligation; although some recommend dissection to identify the duct for accurate and precise ligation.

Keywords

Chylothorax • Pleural effusion • Esophagectomy • Chyloma • Chylomicrons • Octreotide • Somatostatin • Lymphangiogram • Pleurodesis • Povidone-iodine

20.1 Background, Specific Indications

Chylothorax is a relatively uncommon postoperative complication, occurring in nearly 0.5% of all thoracotomies and as many as 4–9% of esophagectomies. Patients at greatest risk are those who have had extensive mediastinal dissection as part of an intrathoracic operation. Traumatic chylothorax can also occur after coronary artery bypass grafting during preparation of the left internal mammary artery conduit, head and neck surgery, heart transplantation, high spinal surgery, blunt chest trauma, extreme hyperextension of the spine, external cardiac massage, weight lifting and yawning.

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, Department of Cardiovascular and Thoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th Floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

J. K. Waters, M.D.
Cardiothoracic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

In patients who have never had surgery, there is an association between chylothorax and mediastinal lymphoma. More than 50% of de novo chylothoraxes are caused by malignancy and greater than 75% are from lymphoma followed by chronic lymphocytic leukemia, lung cancer, and metastatic disease to the mediastinum.

Less common conditions associated with chylothorax include superior vena cava and subclavian vein thromboses, cirrhosis, heart failure and illnesses where there is disruption in the mediastinal lymphatic drainage (lymphangioleiomyomatosis, tuberous sclerosis, lymphangiomyomatosis, Castleman's disease, mycobacterial disease, radiation-induced mediastinal fibrosis, sarcoidosis, yellow nail syndrome, amyloidosis, filariasis, Gorham's syndrome, and Kaposi's sarcoma). Identifying the etiology of the chylothorax is necessary in order to develop a treatment plan for patients and to assist with prognostic planning.

Patients with chylothorax usually present with dyspnea and a sensation of fullness in the lower aspect of the chest of the affected side. Chest radiography can reveal an effusion. Some thoracic duct leaks may present as contained collections, referred to as a chyloma, rather than free pleural

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_20

effusion. These typically occur 2–10 days after chest trauma and present as a posterior mediastinal mass. Most commonly this is in the right chest at the level of the tenth thoracic vertebra. Thoracentesis of the pleural effusion or contained collection should be performed and the fluid suspected of chyle should be sent for triglyceride, lipoprotein analysis for chylomicrons, cholesterol, and lymphocyte count. Nearly 90% of chylothorax cases are exudates. A triglyceride of greater than 110 mg/dL is 99% likely to be chyle. If the triglyceride is less than 50 mg/dL, there is a 5% likelihood that it is chyle. The cholesterol to triglyceride ratio of less than 1% raises the suspicion that the fluid is chyle. The cell count of chyle is predominately lymphocytes, greater than 80% with a range of 400–6800 cells/μ[mu]L. Lipoprotein analysis demonstrating chylomicrons is diagnostic. The caveat to this test is that it is not widely available at many hospitals. Pseudochylothorax occurs when the triglyceride is elevated, the cholesterol level is greater than 200 mg/dL and no chylomicrons are present; this may be present in cases of tuberculous empyema and effusions associated with rheumatoid arthritis.

The normal adult produces 4 L of chyle per day. Fatty acids with more than ten carbon atoms are absorbed directly into the portal system; the majority (60–70%) drain directly into the cysterna chyli. Branches of the cysterna chyli coalesce to form the thoracic duct, which typically enters the mediastinum adjacent to the aorta and the azygous vein. The duct or ducts ascend and cross at the level of the fifth thoracic vertebra to the left side of the mediastinum and enter the venous circulation lateral to the convergence of the left internal jugular vein with the subclavian vein. Injury may occur anywhere along the course of the duct.

There are many treatment options for chylothorax:

1. Placement of an intrapleural drain or drains to palliate symptoms;
2. Initiation of a low fat diet to reduce thoracic duct flow. For outputs greater than 200 mL/day, this may be of limited value, requiring the placement of a feeding tube to administer a medium chain triglyceride diet, which is not palatable. Total parental nutrition can also be used with discontinuation of oral intake in order to further reduce thoracic duct flow;
3. Initiation of treatment with octreotide, a long acting somatostatin analog, at a dose of 50–200 μ[mu]g subcutaneously three times per day for 2–3 weeks in adults. In children octreotide dosing is started at 0.5 μ[mu]g/kg/h and increased to 10 μg/kg/h intravenously until effect is observed. Octreotide typically reduces the thoracic duct flow within 1–2 days through agonism of the somatostatin receptors in the gut mesentery by direct reduction of lymphatic fluid excretion and the increase in splanchnic arteriolar resistance. This reduces gut blood flow and thus lymphatic flow. Side effects of Octreotide include headache, nausea, vomiting, abdominal cramping, fluid retention, hyponatremia, and epistaxis;
4. Lymphangiography and lymphangiographic coiling;
5. Surgical ligation of the breach and/or mass ligation at the origin of the thoracic duct, where the thoracic duct enters the chest;
6. Pleurodesis with talc or povidone-iodine,
7. Pleuroperitoneal shunting, and
8. Radiation therapy.

In our experience, intrapleural drain placement is an efficient and rapid way of palliating symptoms caused by chylothorax. Drains assist with apposition of the visceral and parietal pleura and provides a means to measure the volume of thoracic duct leakage. Usually a single small bore drain—10 Fr. or larger—is sufficient and may be attached to a low continuous suction or can be intermittently drained. In patients with chronic effusions, such as tuberous sclerosis, we place a long term cuffed-pleural catheter and have patients drain their chests intermittently for symptoms. In post-esophagectomy patients, drains are almost always left in place after surgery. In these patients management of chylothorax is driven by daily drain output. Greater than 1 L of drainage per day must be managed aggressively and rapidly as the mortality with conservative management is nearly 50%. Continued loss of fatty acids, electrolytes, volume, and protein through a high output thoracic duct leak results in malnutrition, electrolyte imbalances, acidosis, and immunodeficiency. Chyle outputs of less than 500 mL per day have a good prognosis for resolution with surgery or lymphangiographic embolization. A computed tomogram may be helpful in determining the location of the leaking thoracic duct, represented by a small pleural fluid collection in or adjacent to the mediastinum. At out institution, patients returning to surgery are placed on a continuous enteric infusion of cream 4–6 h prior to arriving to the operating room. This assists with localizing the leak, expediting ligation and evaluating the effectiveness of the intervention.

In the post esophagectomy patient we do not routinely administer octreotide. Since somatostatin reduces mesenteric blood and lymphatic flow and gut motility and we view this intervention as a risk of for conduit necrosis and pressurization.

20.2 Operative Setup

For patients without a small bowel feeding tube, a nasoduodenal tube is placed intraoperatively to infuse cream. Alternatively patients may ingest a single dose 60 mL of olive oil 2 h prior to surgery.

Patients are positioned in lateral decubitus with the operative side up, rotated slightly anterior to prone. The upper arm is raised up over the face and placed under no tension. The bedside cart or robot is brought over the patient's back, directly at a right angle to the operating room table. It is best for the anesthesia team to have the head positioned toward the ventilator for easy access. We use five ports for robot assisted thoracic duct ligation—three robotic arm ports and two accessory ports. The port position is demonstrated in Fig. 20.1. Once the robot is in place, the patient is positioned in steep reverse Trendelenburg and 45° to near prone to allow the liver (on the right hand side) or spleen (left side) to fall away from the operative area and expose the lower posterior mediastinum. Equipment used includes: ProGrasp robotic grasper, robotic Harmonic dissector, and two robotic needle holders. Accessories used are two laparoscopic needle holders, 2 × 12 mm thoracoports and 2 × 8 mm robotic ports, and a laparoscopic 5-mm suction irrigator, 5-mm laparoscopic endoshears, 5-mm laparoscopic needle holders, a package of Endo Peanuts (Covidien/Medtronic, http://products.covidien.com/pages.aspx?page=ProductDetail&id=13468&cat=Devices&cat2=Model), 10-mm Endo Clip Applier (Covidien/Medtronic) and a 10-mm Endo Retract II (Covidien/Medtronic, http://www.medtronic.com/covidien/products/hand-instruments-ligation/retractors) or 12-mm Endo Paddle Retractor (Covidien/Medtronic, http://www.medtronic.com/covidien/products/hand-instruments-ligation/retractors). Although we have not experienced any major bleeding events, we are prepared with Surgicel® (Absorbable Hemostat by Ethicon, http://www.ethicon.com/healthcare-professionals/products/biosurgery/surgicel-family-of-absorbable-hemostats/surgicel-original-absorbable-hemostat) rolled up into a tight 2 cm long roll and tied with 3–0 Vicryl sutures in two locations, and 5–0 Prolene on an RB-1 needle and 0-Ethibond Sutures on SH or CT-1 needles and cut to 10–12 cm in length. We may also use 3–0 Ethibond on an SH needle cut to 6–8 cm to ligate smaller thoracic duct branches. 3–0 Chromic sutures on an SH needle cut to 6–8 cm is sometime used to suture drains in place. We often use fibrin glue (Ethicon, http://www.ethicon.com/healthcare-professionals/products/biosurgery/evicel-fibrin-sealant-human) on a long applicator to help seal suture holes and 200–300 mL of 10% povidone-iodine solution for pleurodesis, usually only 50 mL is necessary for the direct application after the fibrin glue has sealed.

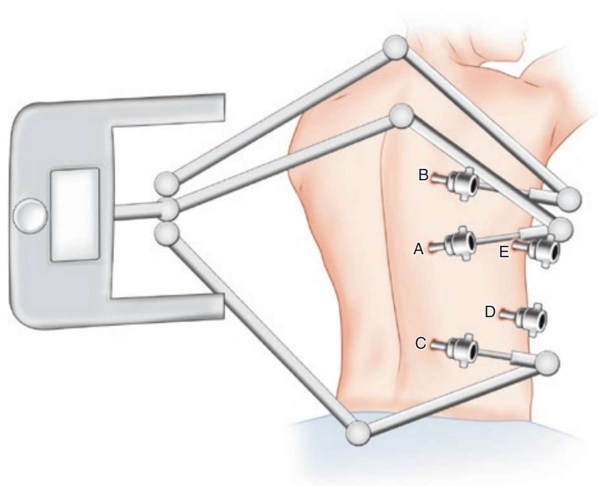


Fig. 20.1 Robotic port position for the thoracic duct ligation. The first port (Port A), a 12 mm port, is placed 2 cm inferior to and in the same longitudinal line as the tip of the scapula in the seventh or eighth intercostal space. The second port (Port B), an 8 mm robotic port, is placed cephalad a hand breadth away and slightly posterior and immediately adjacent to the anterior edge of the scapula. The third port (Port C), another 8 mm robotic port, is placed a hand breadth away and caudad at the same parallel line as Port B. Port D, a 12 mm port, is placed midway and anterior to the parallel line anterior Port A and C

20.3 Anesthetic Management

We prefer single lung ventilation for thoracic duct ligation, but this is not always necessary. Close attention must be paid to patient hemodynamics as patients may be dehydrated due to electrolyte and fluid depletion from high output leaks.

20.4 Stepwise Conduct of the Operation

For patients without chyloptysis, 60 mL of olive oil can be given orally to patients 2 h prior to anesthetic induction. After being brought into the operating room, patients are first placed supine, induced, and intubated. Patients without an enteric feeding tube undergo upper esophagogastric duodenoscopy and a nasoduodenal feeding tube is placed under direct visualization. The tube is secured and the patient is placed on a bean bag in the lateral decubitus position, rotated to nearly prone position. The ipsilateral arm is positioned close to the head, exposing the axilla and anterior chest. The patient is fixed to the operating table with 3″ wide cloth tape wrapped around the table and the patient's hips at the greater trochanter. (Fig. 20.1) The upper shoulder is also fixed in placed so that when operating room table is moved, the patient stays in one position. No portion of the bean bag should be over the anterior chest to avoid any potential compression of the anterior chest/sternum. This can compromise intrathoracic exposure when the patient is rotated anteriorly. The lateral chest is prepped and draped. Five ports are inserted into the chest. The bed is then rotated anteriorly so that the patient is semiprone. The pleural space is first examined to clear any effusion, dissect adhesions, and identify thoracic duct leak. Endoclips or sutures are used to mark any leaking tributaries or the leaking duct.

The robot or bedside cart is then brought toward the operating room table, perpendicular to the patient's back and the patient is then placed in steep reverse Trendelenburg position. The robot is docked and a ProGrasp device is placed in the left robotic arm and a Harmonic in the right (Figs. 20.2, 20.3, 20.4, and 20.5). A 0° videoscope is used. To improve-exposure, suction is used and a fan retractor may be needed to hold the lung out of the way. It is often not necessary to transect the inferior pulmonary ligament. The Harmonic scalpel is used to incise the inferior posterior parietal pleural longitudinally in the inferior posterior sulcus of the chest to expose the most lateral posterior bulge of the aorta. This is done with great care to avoid injuring intercostal branching vessels. An area of about 2–3 cm long is cleared along the aorta and the adjacent vertebral body is palpated, but not incised. Once this is completed, a similar and parallel incision is made along the medial border of the most inferior aspect of the azygous vein; it is between these two areas that the thoracic duct is located. In adults, the duct is typically 2–3 mm wide in this location and may have numerous branches. We believe this dissection provides a more accurate and less traumatic intervention with ligation. It also allows the quality of the ligation to be judged by evaluating for any leaks that may have been present at the beginning of the procedure.

Ligating the thoracic duct requires uses of two robotic needle holders. It is key to identify the pulsation of the aorta and to visualize the aorta and lower azygous vein. A fan retractor is placed through **Port D** to expose the posterior mediastinum, holding the lung out of the operative field. In most cases, the fan retractor may only be needed for a few minutes. In patients with a double lumen endotracheal tube, the lung can be decompressed and carbon dioxide insufflated into the ipsilateral hemithorax. Carbon dioxide pushes the lung, diaphragm, and mediastinum away from the port through which it is infused and can improve exposure of the duct leak. We have found that attempting to dissect inflamed tissues around a leaking thoracic duct is counterproductive and inefficient. Instead, we place a figure-of-eight suture at the area of the leak using surrounding tissue to close the breach. The suture is tied carefully, just enough to stop the leak, but not enough to tear the surrounding tissues. A 0-Ethibond suture with either a SH or CT-1 needle 10–12 cm long is then used to ligate the duct proximal to the leak in a figure-of-eight fashion. The suture and needle are passed through the accessory 12-mm port, Port D. We often place 2–4 of these sutures to assure complete control of the leak. If there is no injury to the lung, we place 1–2 fluted 19–24 French drains placed through 1–2 port sites and in some cases can be sutured into place with 3–0 Chromic Sutures. In cases where there is no breach found or multiple areas of leak exist, the duct can be ligated in a mass fashion using the CT-1 needle and 0-Ethibond in a figure-of-eight fashion at the diaphragm and aortic hiatus. Two to three sutures at this location are often sufficient to control the leak. We then place 10% povidone-iodine solution into the posterior mediastinum, allowing it to dwell for 30 min.

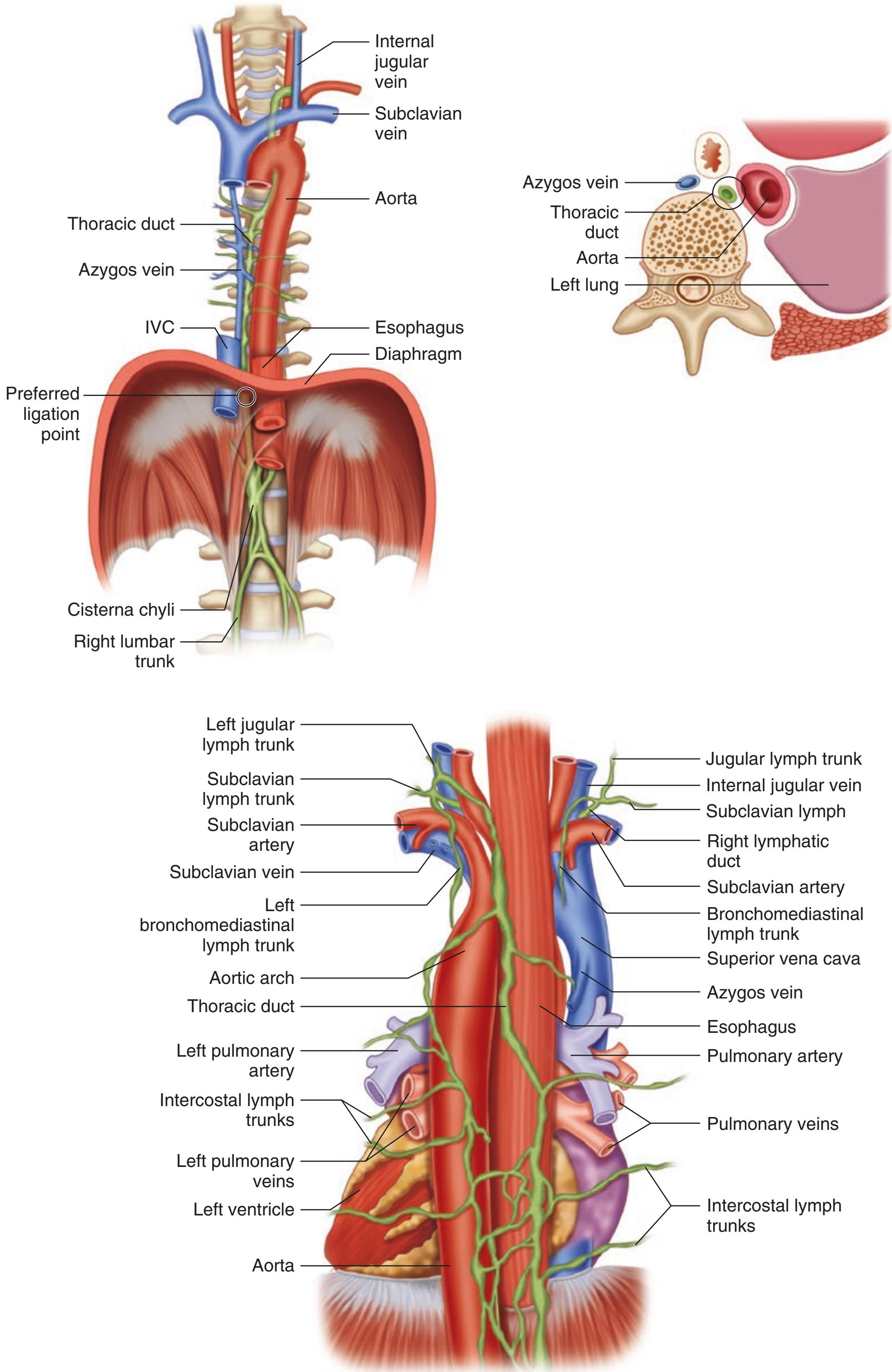
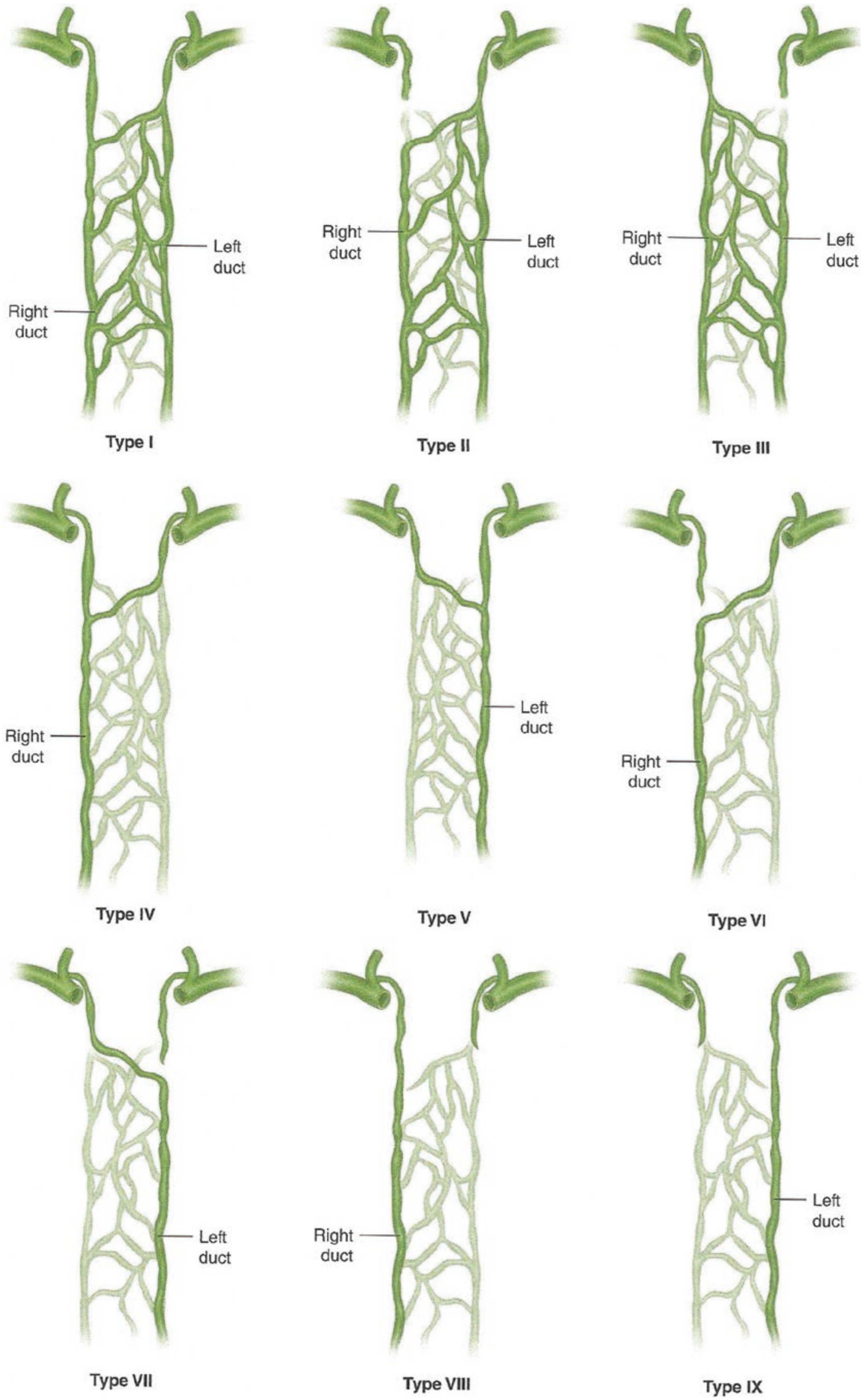


Fig. 20.2 Thoracic duct anatomy and anomalies. The abdominal lymphatics coalesce in a fusiform fashion to form the cisterna chyli just to the right of L2, but can occur from L3 to T10. The thoracic duct starts just posterior to the right crus of the diaphragm and deep to the rightward edge of the aorta adjacent to the spine and between the aorta and the azygous vein (see *inset* above). Variations of the thoracic duct anatomy were presented by Davis in 1915, the most common variation of anatomy is a Type VI below with 63% and Type II being 27%. Understanding of the location of the thoracic duct and the variations in the anatomy will greatly assist in a successful ligation. Furthermore, these numerous tributaries and variations of the anatomy are likely the reason that ligation of thoracic duct flow is temporary, wherever the duct is surgically ligated the cessation or decreased flow is likely to be temporary, crossover branches and natural tributaries will eventually take over the normal flow (Adapted with permission from Hematti H, Mehran RJ. Anatomy of the thoracic duct. Thorac Surg Clin. 2011;21: 229–38. https://doi.org/10.1016/j.thorsurg.2011.01.002)

Fig. 20.2 (continued)



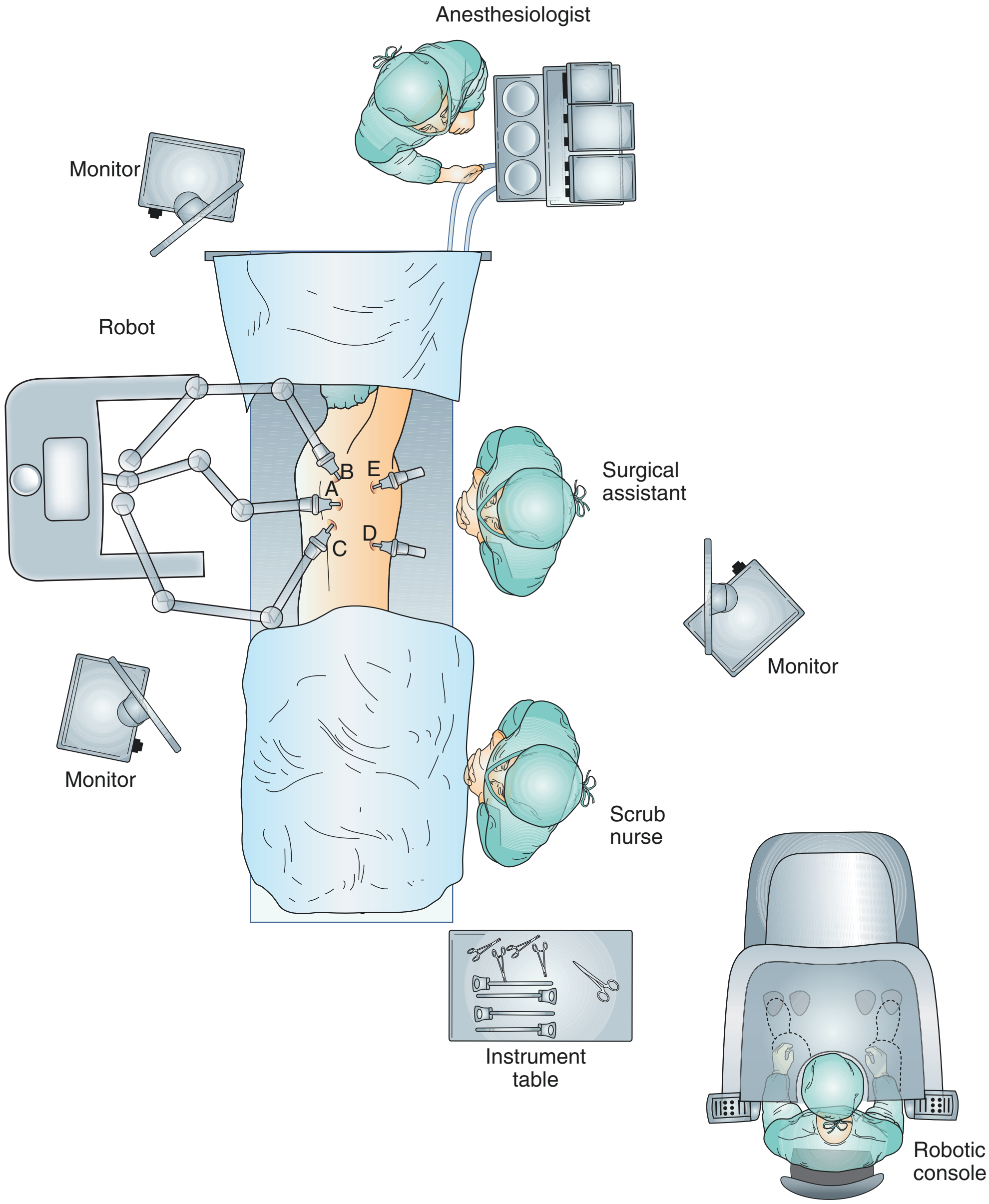


Fig. 20.3 Patient positioning and port placement. Five thoracoports are placed. We mark the chest with an indelible marker after the patient has been positioned and prior to preparing the chest for surgery. Once the drapes have been placed, each potential port site is liberally injected with 0.125% bupivacaine with epinephrine. **Port A**, the videoport, is 12-mm port that is placed along the same longitudinal line and 3–5 cm below the tip of the scapula. **Port B** is an 8-mm robotic port and placed 10 cm cephalad nearly along the same longitudinal line, immediately anterior to the scapula. **Port C** is another 8-mm robotic port and is placed along the same longitudinal like as Port A and Port B and is 10 cm caudad to Port A. **Port D** is another 12-mm port and is placed 10–14 cm anterior to the longitudinal line of the first three ports, midway between Ports A and C. **Port E** is a 5-mm port and is placed along the same longitudinal line as Port D, midway between Ports A and B. Port C is for a ProGrasp initially and a robotic needle holder. Port B is for a Harmonic scalpel and needle holder. Port D is to use the Endo Paddle or Endo Fan Retractor, pass and retract sutures, suctioning, Endo Peanuts, and to insert Surgicel® pads. Port E is for the Endo Peanuts and suctioning

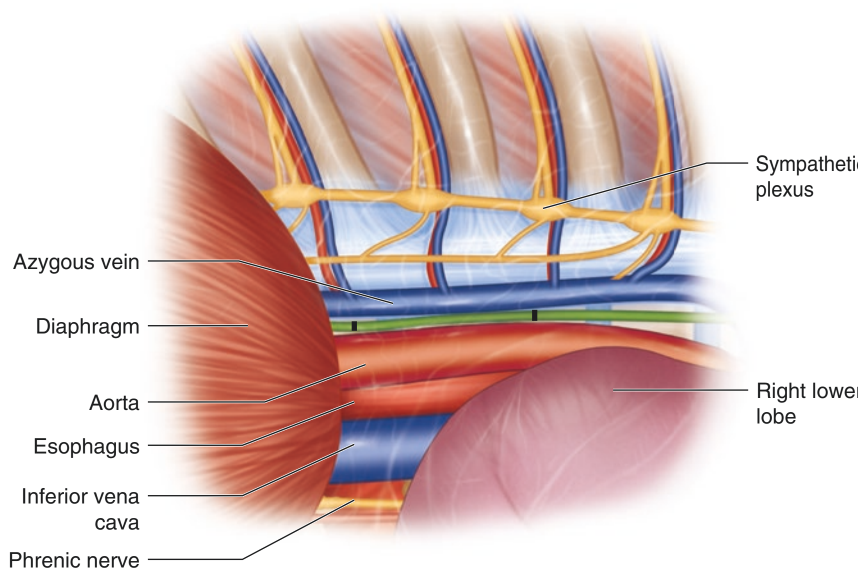


Fig. 20.4 Operative view of the inferior pleural space. The thoracic duct enters the pleural space from the retroperitoneum and the cisterna chyli just deep to along the rightward edge of the aorta and in the tissue between the aorta and the azygous vein. The ideal location for mass ligation of the duct is just above the level of the diaphragm; this location has fewer draining tributaries and network lymphatic branches to be injured during dissection and mass ligation and an area that is more likely to be effective in ceasing lymphatic flow

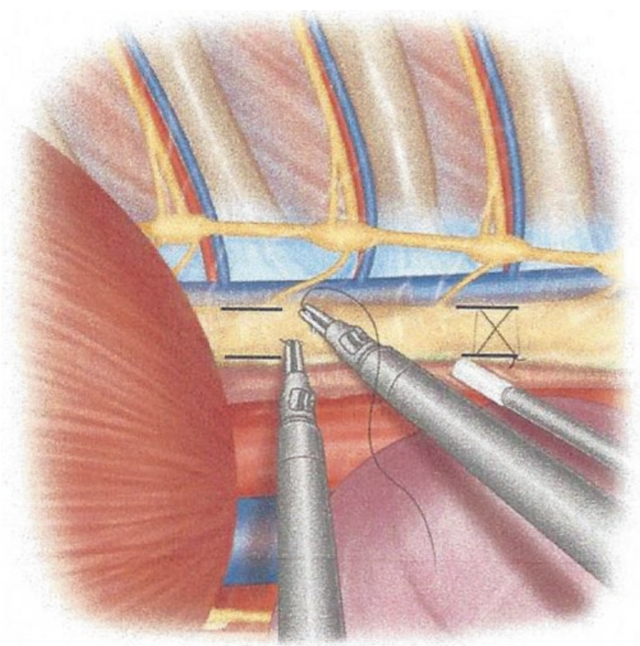


Fig. 20.5 Mass ligation of the thoracic duct and periductal tissue. After any effusion and scar has been cleared from the inferior posterior sulcus, a Harmonic scalpel is used to dissect two areas of adipose tissue between the azygous vein and the aorta down to near the vertebra shown in the diagram. Then, using a SH- or CT-1 needle on a 0-Ethibond 2 × 10 cm long figure-of-8 sutures were passed around the adipose tissue around the tissue around the thoracic duct. Success of the thoracic duct over-sewing is determined by complete discontinuation of chyle leak from any of the breaches marked with endoclips at the beginning of the procedure. Once chyle leakage has stopped, the breaches where the clips were previously placed is then over-sewn with 1–2 × 3–0 Ethibond on a SH needle. Fibrin glue is then infused around the tissues where the sutures had been placed and allowed to dry. Once completed, povidone-iodine is used to flood the area for 30 min then removed after which drains are placed. A 0.125% bupivacaine with epinephrine multi-level intercostal nerve block is then performed to provide postoperative analgesia

20.5 Tips and Pitfalls

(a) For mass ligation of the thoracic duct use the needle size which correlates most to the estimated depth of the tissue. SH for narrower bites of tissue and CT-1 for thicker and deeper tissue.
(b) For mass ligation, the needle should be passed directly toward the spine taking the tissue adjacent to the aorta and azygous vein.
(c) Ligation of the duct is best performed by including surrounding tissue, not the friable duct directly.
(d) Fibrin glue may be used to create a dry operative field.
(e) Combining povidone-iodine pleurodesis may be helpful to further provide assurance of a seal.

20.6 Brief Outcomes Section

We have been performing thoracic duct ligations for the past 14 years, largely after esophagectomy. In over 150 cases, of which half underwent mass ligation after esophagectomy, we have had three cases that we would consider failures. One patient was post-esophagectomy, one had tuberous sclerosis, and the last had chyloptysis. In the tuberous sclerosis patient, his output was treated by repeat thoracentesis at an outside facility over a 1 year period was reduced with thoracic duct ligation. Unfortunately his chylothorax required daily intrapleural drainage following ligation via a cuffed pleural catheter and pleurodesis with povidone-iodine on five occasions over a 2 month period. The esophagectomy and chyloptysis patients both experienced refractory chylothorax and underwent accessory thoracic duct ligation by median sternotomy.

Thoracic duct ligation after esophagectomy by either direct thoracic duct ligation or mass ligation is controversial. At the 2015 American Association of Thoracic Surgeons meeting, Zheng et al. presented their results of prophylactic mass ligation of the thoracic duct and surrounding tissue. The results of their retrospective review of their 11-year experience in 827 esophagectomies at the Brigham and Women's Hospital in Boston found a potentially higher rate of chylothorax in patients who underwent a prophylactic mass ligation. There was a 5.2% (33/635) rate of postoperative chylothorax in those patients without thoracic duct ligation and a 7.1% (4/56) rate with precise ligation of the thoracic duct, and a 19.9% (27/136) rate of chylothorax with mass ligation ($p = 0.0314$). This group surmised that ligating the potential leak and surrounding lymphatic tributaries resulted in a pressurize lymphatic system which was prone to leak.

Thoracic duct ligation to treat postoperative chylothorax appears to be dictated by the volume of output. High volume leaks (>1000 mL/day) appear to have higher rates of complication and death. Brinkmann et al. reviewed their experience of prophylactic thoracic duct ligation in 906 patients who underwent Ivor Lewis Esophagectomy between 2005 and 2015. All patients underwent routine thoracic duct ligation at the time of esophagectomy; this group observed a 1.9% rate of chylothorax. Repeat ligation was performed in 15 patients. Early ligation was associated with a lower mortality. Thoracic duct ligation was recommended in patients with greater than 10 mL/kg/day of chylous chest tube output.

Bender et al. provides an algorithm for treatment of chylothorax. Dietary changes, octreotide, pleuroperitoneal shunts, lymphangiogram and embolization, and pleurodesis are feasible options to manage thoracic duct leaks, but surgical ligation appears to be the most common intervention. Management of patients with chylous effusions can be quite complicated and require a vigilant and persistent approach.

Selected References

Artemiou O, Marta G-M, Klepetko W, Wolner E, Muller M-R. Pleurovenous shunting in the treatment of nonmalignant pleural effusion. Ann Thorac Surg. 2003;76:231–3.

Bender B, Murthy V, Chamberlain RS. The changing management of chylothorax in the modern era. Eur J Cardiothorac Surg. 2016;49:18–24.

Brinkmann S, Schroeder W, Junggeburth K, Gutschow CA, Bludau M, Hoelscher AH, Leers JM. Incidence and management of chylothorax after Ivor Lewis esophagectomy for cancer of the esophagus. J Thorac Cardiovasc Surg. 2016;151:1398–404.

Crucitti P, Mangiameli G, Petitti T, Condoluci A, Rocco R, Gallo IF, Longo F, Rocco G. Does prophylactic ligation of the thoracic duct reduce chylothorax rates in patients undergoing oesophagectomy? A systematic review and meta-analysis. Eur J Cardiothorac Surg. 2016;50(6):1019–24. https://doi.org/10.1093/ejcts/ezw125.

Davis HK. A statistical study of the thoracic duct in man. Am J Anat. 1915;17:211–44.

Davis KK, Berry GJ, Raffin TA, Faul JL. Thoracic lymphatic disorders. Lymphat Res Biol. 2004;2:131–7.

Doerr CH, Allen MS, Nichols FC, Ryu JH. Etiology of chylothorax in 203 patients. Mayo Clin Proc. 2005;80:867–70.

Hematti H, Mehran RJ. Anatomy of the thoracic duct. Thorac Surg Clin. 2011;21:229–38.

Kalomenidis I. Octreotide and chylothorax. Curr Opin Pulm Med. 2006;12:264–7.

Langert J, Trachiotis G. Chylothorax. Curr Respir Med Rev. 2012;8:322–6.

Martucci N, Tracey M, Rocco G. Postoperative chylothorax. Thorac Surg Clin. 2015;25:523–8.

McGrath EE, Blades Z, Anderson PB. Chylothorax: aetiology, diagnosis and therapeutic options. Respir Med. 2010;104:1–8.

Nadolski G, Itkin M. Thoracic duct embolization for the management of chylothoraces. Curr Opin Pulm Med. 2013;19:380–6.

Nair SK, Petko M, Hayward MP. Aetiology and management of chylothorax in adults. Eur J Cardiothorac Surg. 2007;32:362–9.

Riquet M, Le Pimpec Barthes F, Souilamas R, Hidden G. Thoracic duct tributaries from intrathoracic organs. Ann Thorac Surg. 2002;73:892–8. Discussion 8–9.

Shah RD, Luketich JD, Schuchert MJ, Christie NA, Pennathur A, Landreneau RJ, Nason KS. Postesophagectomy chylothorax: incidence, risk factors, and outcomes. Ann Thorac Surg. 2012;93:897–903. Discussion –4.

Smoke A, Delegge MH. Chyle leaks: consensus on management? Nutr Clin Pract. 2008;23:529–32.

Squitieri RP, DiMeo AC. Left-sided robotic thoracic duct clipping for chylothorax. J Thorac Cardiovasc Surg. 2013;145:299–300.

Soto-Martinez M, Massie J. Chylothorax: diagnosis and management in children. Paediatr Respir Rev. 2009;10:199–207.

Sriram K, Meguid RA, Meguid MM. Nutritional support in adults with chyle leaks. Nutrition. 2016;32:281–6.

Steven BR, Carey S. Nutritional management in patients with chyle leakage: a systematic review. Eur J Clin Nutr. 2015;69:776–80.

Thompson KJ, Kernstine KH, Grannis FW Jr, Mojica P, Falabella A. Treatment of chylothorax by robotic thoracic duct ligation. Ann Thorac Surg. 2008;85:334–6.

Tutor JD. Chylothorax in infants and children. Pediatrics. 2014;133:722–33.

Robotic Transthoracic Diaphragm Plication

21

Kemp Kernstine Sr. and Raghav Alampalli Murthy

Abstract

Patients with unilateral diaphragm paralysis may present with dyspnea. For those patients unable to improve with physical and respiratory therapy, diaphragm plication may provide significant respiratory improvement. Patient and bedside cart position and port placement are described to provide an efficient procedure to remove the laxity from the ipsilateral diaphragm.

Keywords

Diaphragm • Plication • Phrenic nerve • Diaphragm paralysis • Diaphragm eventration

21.1 Background, Specific Indications

Diaphragm paralysis and eventration represent two reasons for diaphragm elevation on a radiological examination that warrant potential surgical consideration. Each can result in dyspnea at rest and on exertion, orthopnea, and can have gastrointestinal symptoms that include bloating, abdominal pain, heartburn, constipation, nausea, and vomiting. Eventration of the diaphragm is congenital and is a very rare phenomenon with intact pleura and peritoneum, but a paucity of the muscular portion of the diaphragm. It is usually recognized in infancy or childhood. In contrast, diaphragm paralysis is acquired and may be the result of phrenic nerve injury from trauma such as chiropractic neck manipulation, sudden neck injury, and weight lifting; iatrogenic injury from thoracic, head and neck, and spine surgery, direct invasion by tumor, neuropathic, infectious from diphtheria, typhoid, measles, influenza, herpes zoster, West Nile virus, polio and from adjacent infections of the lung (pneumonia), neck, and mediastinum; cervical spine degenerative and disk disease, aortic aneurysm or traumatic disc or bony abnormalities, endocrine disorders such as diabetes, thyroid disease and Cushing's syndrome, severe protein malnutrition, and electrolyte abnormalities from hypophosphatemia, hypomagnesemia, hypokalemia, and metabolic alkalosis; most being idiopathic, most likely from a subclinical viral illness. Parsonage-Turner syndrome is a brachial plexopathy that is manifested by an insidious onset of pain and weakness of one or both upper extremities and can be associated with phrenic nerve paresis (Fig. 21.1a). In adults, most patients with hemidiaphragm paralysis are asymptomatic; diaphragm elevation and possible paralysis are often discovered on a radiograph for other indications. While the etiology of these two processes may differ, the pathophysiology is similar and both problems are corrected with diaphragm plication to prevent paradoxical movement during inspiration to resolve dyspnea. Patients with asymptomatic diaphragmatic elevation do not need surgical correction. Relative contraindications to diaphragm plication include patients who have an elevated diaphragm but no evidence of paralysis or eventration, patients with a life expectancy that is less than 6 months, primary or secondary pulmonary disease that is unlikely to improve function if diaphragm plication is performed, lung infection, congestive

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Department of Cardiovascular and Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

R. A. Murthy, M.B.B.S.
Department of Cardiovascular Surgery, Rady Children's Hospital, University of California San Diego, San Diego, CA, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_21

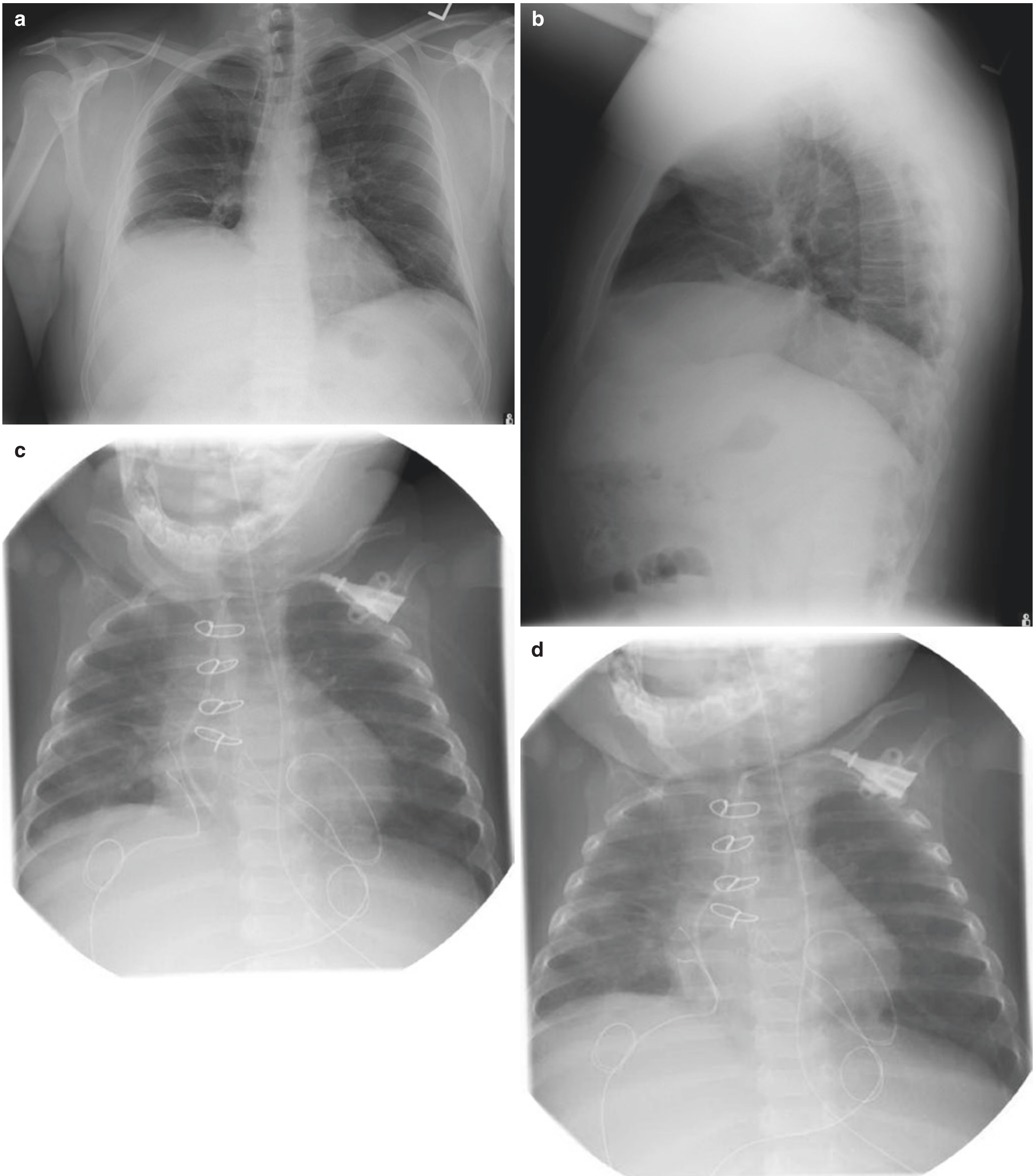


Fig. 21.1 (**a** and **b**) **Pathology, the problem.** Chest radiograph of a patient with idiopathic right sided hemidiaphragm paralysis. He noted worsening of his dyspnea at rest and with reclining. His FVC was 41% sitting and 32% supine. He participated in physical therapy for 6 months without any improvement. Fluoroscopic sniff test was positive. (**c** and **d**) **Diaphragm paralysis, post-cardiac surgery.** Fluoroscopic evaluation shows mildly elevated right diaphragm (**c**) with paradoxical movement on inspiration (**d**)

heart failure, morbid obesity, calcified or severely scared diaphragm, and neuromuscular disorders. Bilateral diaphragm paralysis also remains a contraindication as bilateral plication do not help recruit lung function.

Patients that are suspected of diaphragm paralysis should be thoroughly evaluated for the progression and potential etiologies of their dyspnea or other symptoms. It is very helpful to obtain any prior chest radiographs including routine radiographs and previously performed computed tomograms that might provide more information as to the etiology and progression of diaphragmatic dysfunction. Pulmonary function studies in the upright and supine position provide objective information prior to any intervention. The supine forced vital capacity (FVC) of affected patients decreases by 20–50% compared with the upright FVC. This is a sensitive test and when there is no reduction in the FVC from upright to supine, diaphragmatic paralysis is unlikely the cause of dyspnea. Furthermore, PFTs will serve as a reference study along with radiographic studies to objectively assess response to surgical treatment. An anterior-posterior and lateral chest radiograph are helpful prior to surgery and a chest and abdominal computed tomogram may help to assess the course of the phrenic nerve, the lung parenchyma, assess for diaphragmatic hernia, and to evaluate for thoracic or abdominal disease. A chest X-ray is 90% sensitive for unilateral paralysis and is 44% specific. A fluoroscopic sniff test is performed to assess the diaphragmatic excursion while asking the patient to sniff. Normally, both diaphragms move downward or caudally upon sniffing, but in diaphragmatic paralysis the affected diaphragm moves upward or cranial; 2 cm or more of cranial movement on the affected side is necessary for a test to be considered positive (Fig. 21.1b). In patients undergoing analysis of bilateral diaphragm paralysis, 6% of the normal population will have a falsely positive test. The sensitivity of the test may be insufficient for all patients suspicious of having diaphragmatic paralysis and other testing may be warranted, such as two-dimensional B-mode ultrasound and/or dynamic magnetic resonance dynamic imaging. Electromyography and nerve conduction studies may be used to assess nerve dysfunction in patients suspected of neuromuscular disorders and phrenic nerve injury, but is not usually necessary in the routine evaluation of diaphragmatic paralysis. It may help to differentiate between neuropathy and myopathy and prognosis for recovery of function.

Most cases of diaphragm paralysis or dysfunction are managed with nonsurgical conservative measures. For the acute cases, supportive care is provided in the form of supplemental oxygen as necessary to keep the saturation greater than 92%, maintaining the head of the bed at 30° or greater, and if aspiration is a concern, nasoenteric feeding. For adults with more chronic symptomatic and life-style compromising diaphragmatic paralysis, physical therapy to strengthen the auxiliary musculature, weight reduction, and continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BiPAP). Diaphragm pacing has been used in cases of bilateral diaphragmatic paralysis either direct phrenic nerve stimulation when the phrenic nerve is intact or direct diaphragmatic pacing. Before embarking on a diaphragmatic plication, a search for a reversible or temporary source of dysfunction is indicated. As an example, in the case of open-heart surgery, diaphragmatic paralysis may occur in approximate 10–15% of patients in which ice/slush topical hypothermia has been employed. The majority of these cases of diaphragm dysfunction will resolve within 1–2 years. Unilateral or bilateral diaphragm involvement can occur in Guillain-Barre syndrome that may recover completely. Diaphragm weakness from viral neuropathies is also usually reversible. In the case of Parsonage-Turner syndrome there is potential recovery of function within 2 years, plication is not recommended until after that time. If malnutrition is the etiology of the dysfunction, then diaphragm function is likely to return to normal after correction of the nutritional deficiency. Diaphragm dysfunction due to hypo- and hyperthyroidism usually recovers when the disease is treated. In the case of limb-girdle muscular dystrophy, acid maltase deficiency, systemic lupus erythematosus diaphragm paralysis may be irreversible. Alternative therapies to plication include reinnervation of the phrenic nerve reported by Kaufman and colleagues in 2011 and in 2014 and direct diaphragmatic pacing reported by Onders et al. in 2014. These early and the subsequent reports have not demonstrated the degree and sustainable improvement achieved by diaphragm plication.

Plication is performed by placing layers of sutures with or without Teflon pledgets in rows along the diaphragm, typically at the center of the diaphragm. The operation can be performed either by thoracotomy or laparotomy, thoracoscopy or laparoscopy or robotic approach through the chest or the abdomen. Groth and Andrade in 2010 found that the minimally invasive techniques appear to be as effective as the open surgical methods. To reduce pain and debility associated with larger incisions, the trend has been towards smaller incisions to accomplish the same goals. The pleating of the redundant diaphragm should be performed in a manner to avoid under- and over-correction. The goal of surgical plication is to provide tension to the diaphragm in order to prevent paradoxical diaphragmatic motion. Following plication, the diaphragm will be displaced inferiorly by one to two intercostal levels. The plicated paralyzed diaphragm does not move into the ipsilateral chest on inspiration. As a result the contralateral diaphragm creates sufficient negative intrathoracic pressure to adequately inflate both lungs. This reduces the work of ventilation by preventing the abdominal contents from displacing the lungs and increases lung volumes. Atelectasis and its resultant shunting are corrected leading to improvements in exercise performance and pulmonary function.

Robotic technology did not appear in the literature until 2012 when Kwak, Lazzaro, and their team at Methodist Hospital in Brooklyn reported a single case of a 26-year-old with left hemidiaphragm elevation and progressively worsening dyspnea on exertion that underwent a 4 h robotic diaphragm plication using CO_2 insufflation. The patient was discharged on the 3rd postoperative day and readmitted on the 14th postoperative day for a pleural effusion that required catheter drainage. The authors report a sustained benefit of the approach. Then, in 2016 Zwischenberger and colleagues at the University of Kentucky described their robotic laparoscopic technique in three patients, one left hemidiaphragm and two right. Illustrated were their four port method sewing two strips of felt with a chest tube being placed after the procedure. All patients were discharged in postoperative day 2. To date there has been no large reports of using robotic technology and no evidence that it is superior to any other minimally invasive approach.

21.2 Operative Setup

The patient will be placed in a lateral decubitus position and the robot is directed from a caudal position in an oblique fashion toward the front and cranial aspect of the patient. Steep reverse Trendlenberg is used to allow the abdominal contents to fall away from the operative area. Either the 0° or 30° down robotic videoscope is used. This provides a downward view of the diaphragm and an overview of the areas of laxity. Two 12-mm thoracoports, 2 × 8-mm robotic ports, and a 5-mm thoracoport are used. Additional equipment includes:

- 2× robotic needle holders
- Laparoscopic scissors
- 2× laparoscopic graspers
- 0-Ethibond sutures on an SH Needle
- Teflon pledgets—5 mm squares
- Laparoscopic suctioning system
- Robotic Hook Cautery

Have in the room available:

- 12-mm Fan Retractor (Covidien)
- 5-mm Fan Retractor (Covidien)
- Additional 5 and 12-mm ports

21.3 Anesthetic Management

Anesthesia during surgical plication is critical and requires an anesthetist with experience in single lung ventilation. Prior to the induction of anesthesia, a single dose of prophylactic antibiotics is given and anti-embolic stockings or sequential compression devices are placed to reduce the risk of thromboembolism. A dual lumen endotracheal tube is placed and the endotracheal tube position is verified with direct fiberoptic bronchoscopy. Invasive hemodynamic monitoring lines are placed and include an arterial line and central venous pressure monitors. A nasogastric tube is placed to decompress the stomach to reduce the risk of visceral injury during the repair and reduce the risk of aspiration.

21.4 Stepwise Conduct of the Operation

The patient is placed in the lateral decubitus position and supported with the aid of a vacuum beanbag. The ipsilateral chest is prepped and draped. Five thoracoports are then placed (Fig. 21.2). A 12-mm port for the robotic videoscope is introduced into the 5th to 6th intercostal space in the posterior axillary line. Carbon dioxide is infused through the port at 10–15 mmHg of pressure. Along the same transverse line 10 cm anterior and 10 cm posteriorly 8-mm robotic arm ports are then placed. A 5 mm port is also placed in the 5th to 6th intercostal space over the anterior axillary line. Lysis of any adhesions is performed and a thorough examination of the diaphragm is completed to determine the extent of lax diaphragm. The ipsilateral lung is deflated and retracted superiorly. The weakened area of the diaphragm once identified is grasped with an endoscopic grasper and lifted to determine the best orientation of suture repair lines (Fig. 21.3). Three to four linear rows of pledgeted nonabsorbable horizontal mattress sutures are placed in a radial fashion. During this step of the procedure, it is imperative that great attention is paid to preventing injury to any of the abdominal organs. When a sufficient series of stitches is placed, the sutures are tightened and the weakened area of diaphragm is drawn up in a series of pleats (Figs. 21.4 and 21.5). The goal of the plication is a taunt diaphragm. If the diaphragm is not taunt following the tightening of the sutures additional stitches can be placed to draw more of the diaphragm tissue into the pleats. At the completion of the operation excess diaphragm tissue is reconfigured and the diaphragm is flattened at the base of the thorax. In cases where the abdominal cavity is too restrictive to allow the intraperitoneal return of the abdominal organs, a temporary ventral hernia may be created and then closed after allowing for the relaxation of the abdominal wall musculature. Chest tubes are placed to drain and fluid or air that accumulates. An alternative method to the transthoracic approach is to perform the plication transabdominally (Fig. 21.6). The plication is performed in a similar fashion to the transthoracic approach.

The accessory port is used to introduce an instrument to invaginate the diaphragm. An additional 5 mm port is then

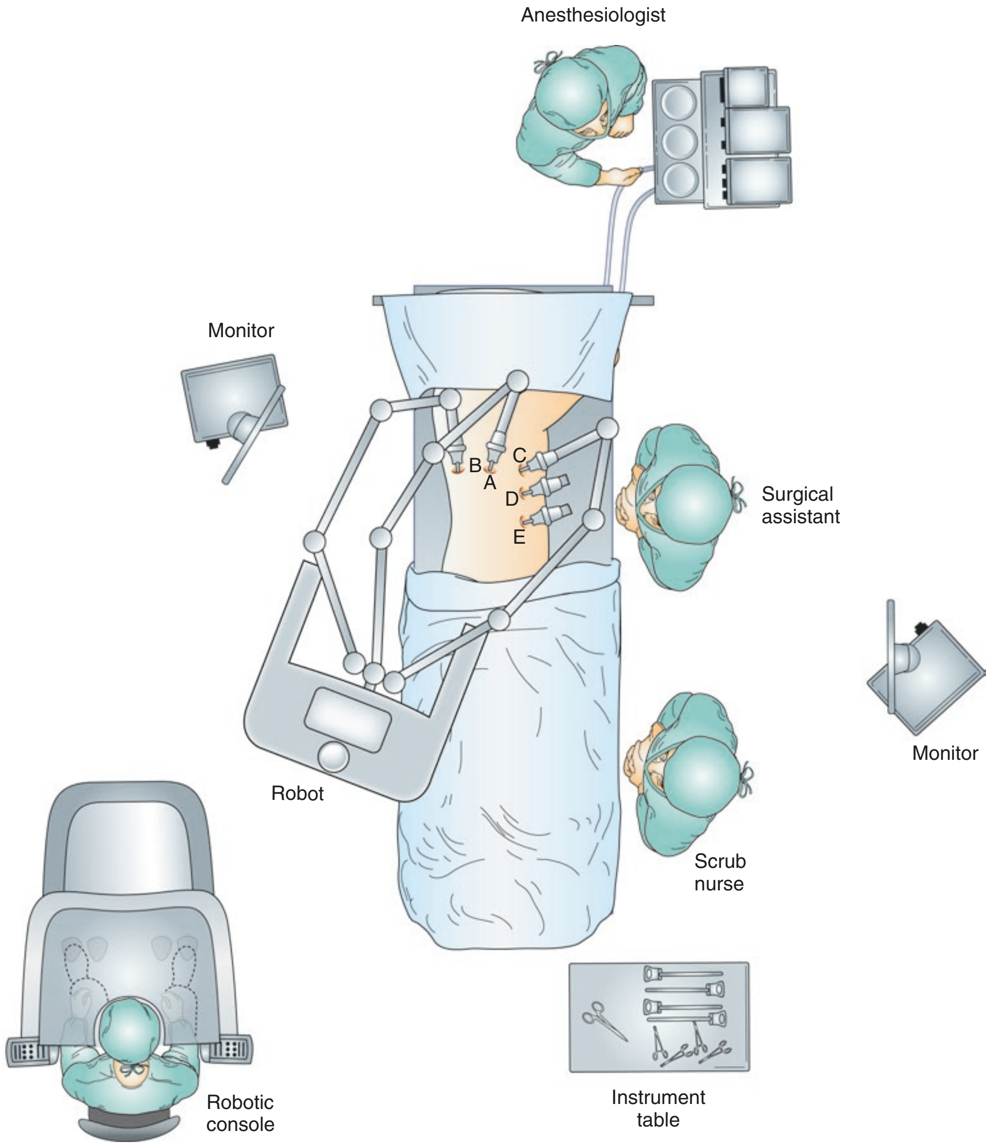


Fig. 21.2 **Body position, room set-up, and port location.** After intubation with a double lumen endotracheal tube and placement of a nasogastric tube, the patients are placed in the lateral decubitus position with the affected side up. Five thoracoports are then placed. Each is treated with 0.125% bupivacaine with epinephrine injected liberally, especially in the presumed area of the adjacent intercostal nerve. In the 5th to 6th intercostal space just anterior to the tip of the scapula, **Port A**, a 12-mm port for the 0° robotic videoscope, is placed at to avoid accidental injury to the paralyzed diaphragm. Once the pleural space is examined through this port, CO_2 is introduced at a pressure of 10–15 mmHg and the ipsilateral lung is no longer inflated. Then, at the same transverse level on the chest, the two robotic port arm ports are placed 10–12 cm away from Port A, both 8-mm, **Port B** and **Port C**. Then, two accessory ports are placed. **Port D**, a 12-mm port, is placed in the anterior axillary line in the 4th intercostal space. This port is used for passing and withdrawing suture needles, passing pledgets, and placing the large fan or paddle retractors. **Port E**, a 5-mm port, is placed in the anterior axillary line level at the 6th intercostal space and is used to place an endograsper to grasp the diaphragm for suturing, holding it up and away from the abdominal viscera. Both Ports D and E can be used for suctioning

placed in the 9th intercostal space. This port will be used to run a continuous heavy non-absorbable suture along the diaphragm. The diaphragm is inverted and bites are taken with the suture to create a fold in the diaphragm. Once the proper amount of tension has been achieved, the suture is tied and trimmed. Chest tubes are left in place to drain any blood or pleural fluid.

The postoperative course of a patient undergoing plication may vary depending upon the duration and severity of symptoms prior to surgical interventions. Prophylactic

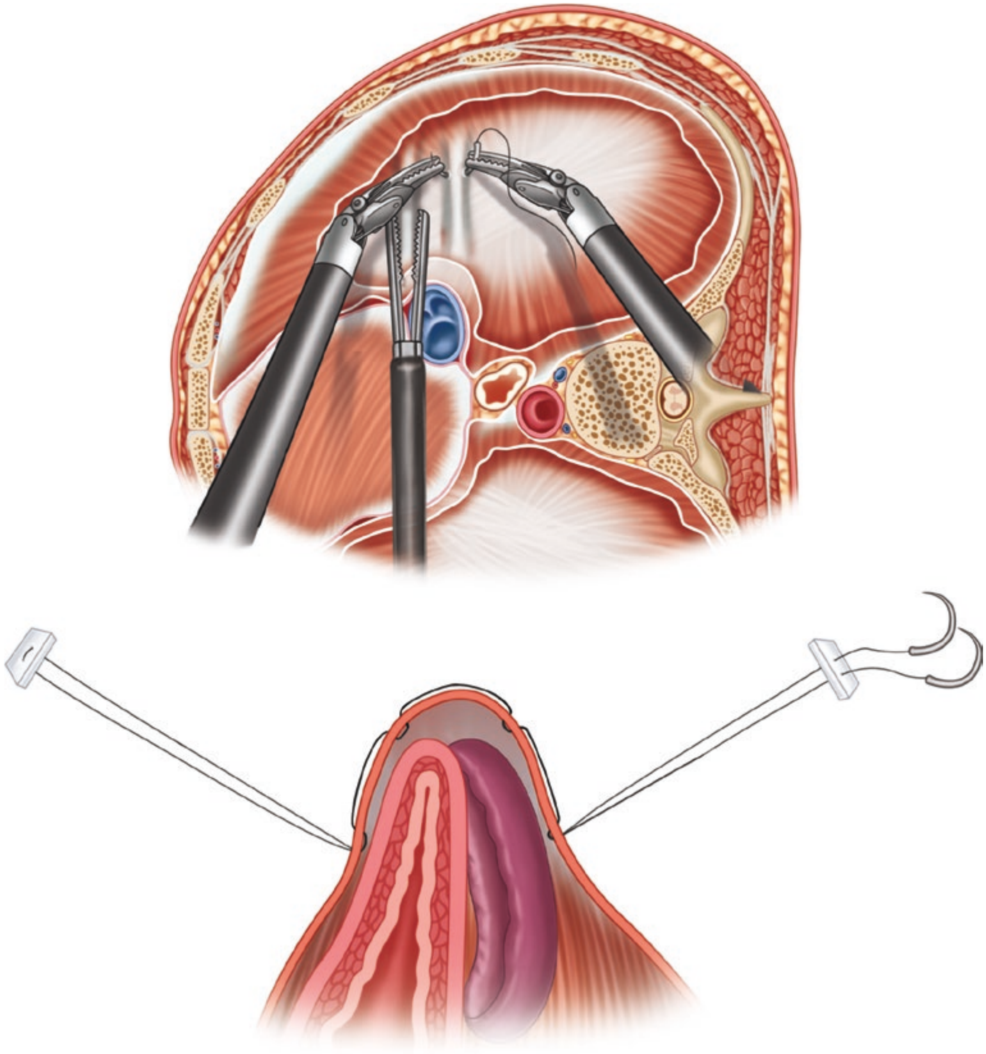


Fig. 21.3 **Initiation of plication, grasping of the diaphragm.** The procedure is initiated by examining the diaphragm to assess for any abnormalities of the diaphragm that might need to be addressed. A 5-mm grasper is used through the 5-mm port, **Port E**, to grasp the central portion of the diaphragm and left it up and away from the abdominal viscera. When there is concern that there is nearby viscera, a hook cautery can be used to incise the central portion of the diaphragm and allow the CO_2 to enter beneath the diaphragm. This will allow the CO_2 to lift the diaphragm away from the abdominal viscera. The 5-mm grasper is then used to help assess the placement of the sutures. We find a lateral portion of the planned series of 0-Ethibond Teflon pledgeted U stitches and start the placement of a simple stitch, single armed 0-Ethibond with an SH needle 14-cm length. Each jump of the needle into the diaphragm is 1.5 cm from the last and the stitch is occasionally tightened to assess the tension and the firmness of the diaphragm that results. Once completed, the suture is simply tied down to hold the newly pleated diaphragm in place. Once first stitch is placed, then a series of additional U stitches of the same suture are placed into the pleated diaphragm, this time with Teflon pledgets at each end of the U stitch and progressively tied down to take the tension off of a first single simple stitch

antibiotics should be discontinued within the first postoperative day. Patients who required ventilatory support prior to surgery may require additional support in the immediate post-operative period. The ventilator should be weaned as tolerated. Weaning of the ventilator should be assisted by the improved pulmonary mechanics. Patients who did not require support pre-operatively may be extubated immediately; however, they should be monitored carefully. Chest tubes can be removed as long as there is no evidence of air leak from the lungs and the pulmonary effluent is not likely to accumulate. In older children and adult patients, measures should be taken to ensure good pulmonary toilet including incentive spirometry and early ambulation.

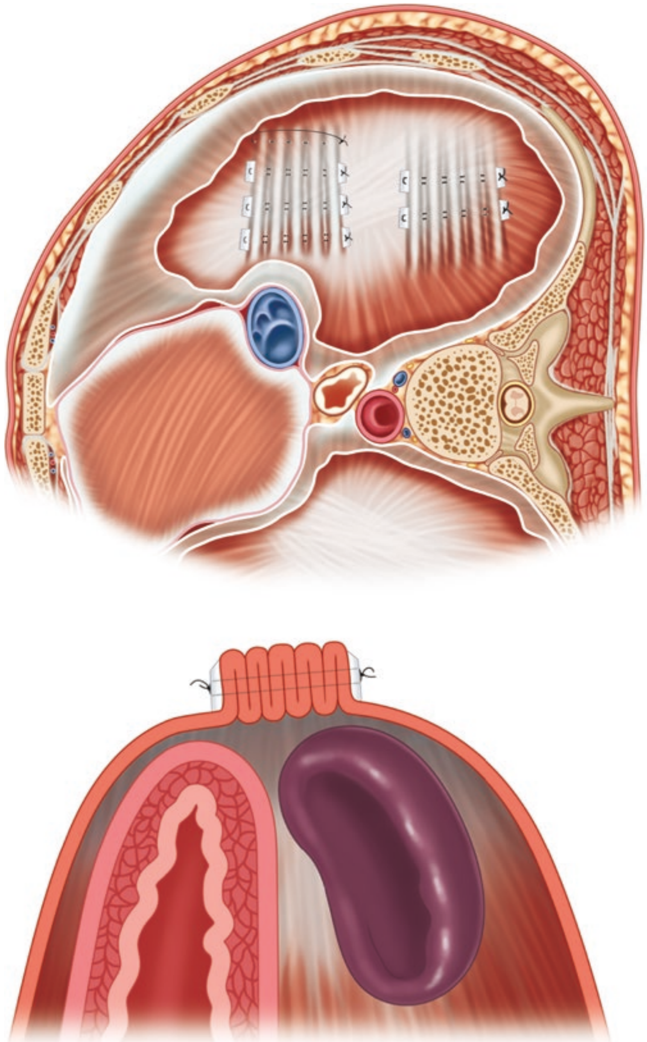


Fig. 21.4 **Completion of the plication.** The first imbricating suture is tied down (see *arrow*) and allows for the placement of additional sutures to secure the diaphragm imbrication securing each additional horizontal mattress with Teflon pledgets. Additional lax areas of the diaphragm are identified after this first series is tied down and the same process is performed at those locations to tighten the diaphragm. At the end of the procedure, we place a #19 round fluted drain through one of the port sites

21.5 Tips and Pitfalls

- Diaphragmatic plication is an elective surgical procedure. Patient selection and timing are critical to achieve optimal results. Dyspnea and GI symptoms can have multiple other causes and can be the result of multiple factors. Thoroughly explore the other possible causes.
- Many of these patients have one or more serious co-morbidities. Assessing for them and then controlling for them is paramount to a successful outcome.
- Patients with a body mass index of greater than 32–35 should be encouraged to lose weight prior to a repair.
- Entering patients into a good pulmonary/physical rehabilitation program will help to give patients the support to adequately prepare for surgery. Even 2 weeks is considered beneficial to optimize outcomes.
- Resection of the diaphragm has been attempted and felt to be less helpful in the long term. The imbrication of the diaphragm, the pleated muscle, is believed to create a fairly rigid form that is less likely to recur over the long term. Resection not only raises the likelihood for herniation by tearing through the resection line, but it does not thicken the area of the diaphragm once extraordinarily pliable. Bleeding is also more likely with resection.

21.6 Brief Outcomes Section

Complications of the procedure are related to surgical technique. Under-tensioning of the diaphragm may allow for continued paradoxical muscle motion and no improvement in symptoms. Too much plication and tension may result in disruption of the suture lines and failure of the repair. Stitches placed too deep through the diaphragm may result in injury to any of the abdominal viscera and lead to the potential of intra-abdominal bleeding, hollow viscus perforation and intra-abdominal sepsis.

In 2009, Freeman and colleagues at St. Vincent Hospital in Indianapolis reported their long term outcomes in a series

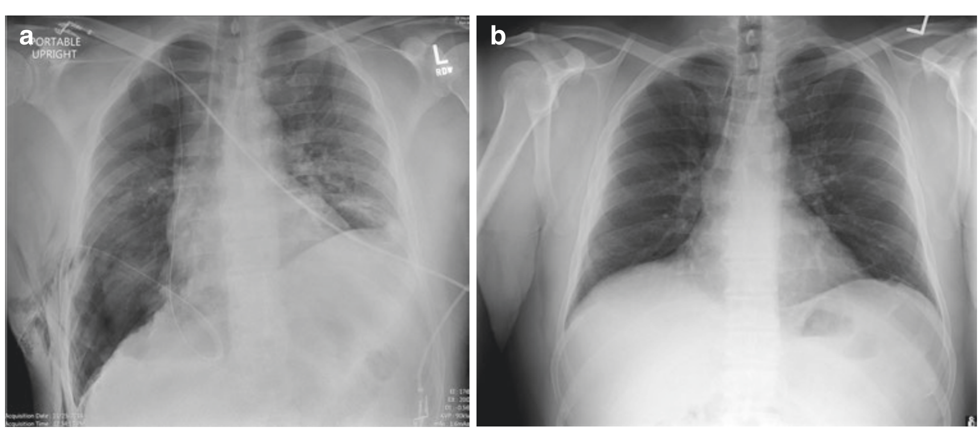


Fig. 21.5 **Chest radiograph after completed diaphragm plication.** The chest radiograph to the left is the immediately after surgery and the one to the right is 7 months after surgery. The patient had immediate recovery from dyspnea and was able to return to fully functional status

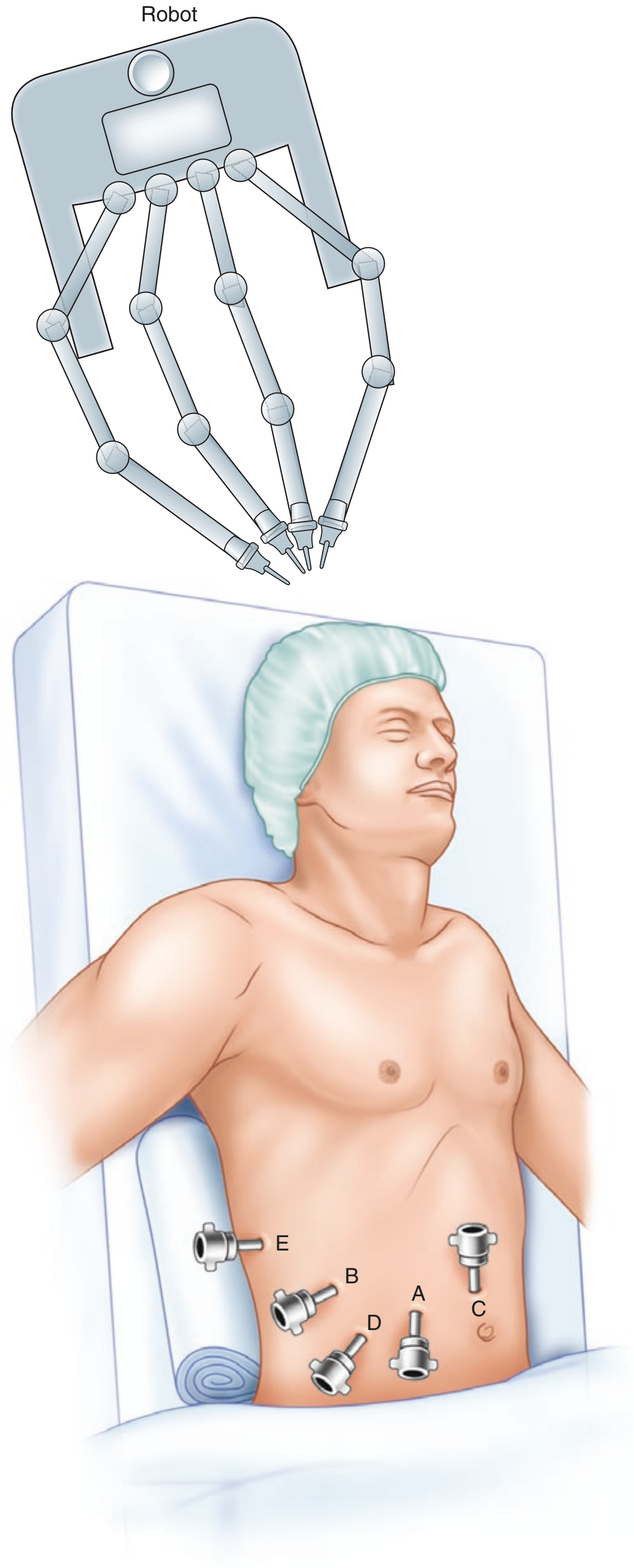


Fig. 21.6 **Transabdominal approach, port placement for a right hemidiaphragm plication.** Our preference is to perform the diaphragm plication through a chest approach. However, there are some situations where that approach is less advantageous; for example, patients that have had a prior ipsilateral thoracic procedure that might make it difficult to gain access to the diaphragm. This diagram shows the port placement for a right sided approach (the left hemidiaphragm plication is the same approach directed to the left costal arch). The patient has a bump beneath the ipsilateral side and the side is raised about 15° ipsilateral side up and in steep reverse Trendlenberg to allow the viscera to fall away from the diaphragm. The table positioning is done once the ports are placed and the robot has been brought into postion for docking (see the direction of the arrow for the robot postion). Five ports are used. **Port A**, the robotic videoport for the 0° scope, is a 12-mm port and placed in the midclavicular line approximately 15 cm from the costal margin. **Ports B** and **C** are placed along a parallel line just 2 cm anterior to Port A and 10 cm on either side of Port A, these are 8-mm robotic ports. They are for the robotic arms. **Port D** is another 12-mm port and is placed 5 cm caudad to Port A and midway between Ports A and B. It is used to pass sutures, pledgets, suctioning, grasp, and retracting the liver, as necessary. **Port E** is a 5-mm port and is placed in the mid axillary line just at the costal margin. It is used for grasping, cutting suture, and suctioning. On the right the Falciform ligament is taken down to provide sufficient exposure to the right hemidiaphragm. The plication process is performed in the same manner as it is for the thoracic approach. A #19 round fluted drain is placed into the ipsilateral chest at the end of the procedure

of unilateral diaphragm paralysis patients that underwent diaphragm plication patients, 30 by video-assisted 3-port Endostitch (Ethicon) technique and 11 by thoracotomy with a mean follow-up of 57 months and found a significantly sustained improvement of their forced vital capacity by 19% at 6 months and 17% at 48 months. There were no deaths with two pneumonias, two atrial fibrillation, a prolonged ileus, and a deep venous thrombosis. The mean length of stay was 3 days (range 2–10 days). The physiological improvement correlated with the dyspnea score, respiratory quality, and work status. The four patients that did not achieve the desired results included two patients that had a body mass index of more than 35 and three patients who had a diaphragm paralysis for at least 4 years (see Fig. 21.5). This demonstrated that the minimally invasive technique, in the majority of these cases, is sustainable and that patients with an elevated body mass index and a prolonged diaphragm paralysis are less likely to achieve the desired results.

Selected References

Aguirre VJ, Sinha P, Zimmet A, Lee GA, Kwa L, Rosenfeldt F. Phrenic nerve injury during cardiac surgery: mechanisms, management and prevention. Heart Lung Circ. 2013;22:895–902.

Allen KS, Mehta I, Cavallazzi R. When does nutrition impact respiratory function? Curr Gastroenterol Rep. 2013;15:327.

Freeman RK, Van Woerkom J, Vyverberg A, Ascioti AJ. Long-term follow-up of the functional and physiologic results of diaphragm plication in adults with unilateral diaphragm paralysis. Ann Thorac Surg. 2009;88:1112–7.

Groth SS, Andrade RS. Diaphragm plication for eventration or paralysis: a review of the literature. Ann Thorac Surg. 2010;89:S2146–50.

Kaufman MR, Elkwood AI, Rose MI, Patel T, Ashinoff R, Saad A, Caccavale R, Bocage JP, Cole J, Soriano A, Fein E. Reinnervation of the paralyzed diaphragm: application of nerve surgery techniques following unilateral phrenic nerve injury. Chest. 2011;140:191–7.

Kaufman MR, Elkwood AI, Colicchio AR, CeCe J, Jarrahy R, Willekes LJ, Rose MI, Brown D. Functional restoration of diaphragmatic paralysis: an evaluation of phrenic nerve reconstruction. Ann Thorac Surg. 2014;97:260–6.

Kharma N. Dysfunction of the diaphragm: Imaging as a diagnostic tool. Curr Opin Pulm Med. 2013;19:394–8.

Kwak T, Lazzaro R, Pournik H, Ciaburri D, Tortolani A, Gulkarov I. Robotic thoracoscopic plication for symptomatic diaphragm paralysis. J Robot Surg. 2012;6:345–8.

Onders RP, Elmo M, Kaplan C, Katirji B, Schilz R. Extended use of diaphragm pacing in patients with unilateral or bilateral diaphragm dysfunction: A new therapeutic option. Surgery. 2014;156:776–86.

McCool FD, Tzelepis GE. Dysfunction of the diaphragm. N Engl J Med. 2012;366:932–42.

Odell JA, Kennelly K, Stauffer J. Phrenic nerve palsy and Parsonage-Turner syndrome. Ann Thorac Surg. 2011;92:349–51.

Prezant DJ, Richner B, Aldrich TK, Valentine DE, Gentry EI, Cahill J. Effect of long-term undernutrition on male and female rat diaphragm contractility, fatigue, and fiber types. J Appl Physiol (1985). 1994;76:1540–7.

Tsakiridis K, Visouli AN, Zarogoulidis P, Machairiotis N, Christofis C, Stylianaki A, Katsikogiannis N, Mpakas A, Courcoutsakis N, Zarogoulidis K. Early hemi-diaphragmatic plication through a video assisted mini-thoracotomy in postcardiotomy phrenic nerve paresis. J Thorac Dis. 2012;4(Suppl 1):56–68.

Part VI

Hiatal Hernia Repair

Robotic Laparoscopic Modified Belsey Procedure (Gastroesophageal Valvuloplasty) for Gastroesophageal Reflux Disease

22

Farid Gharagozloo, Marc Margolis, Eric Strother, and Barbara Tempesta

Abstract

Gastroesophageal reflux is a common disease affecting one in five Americans. Medical therapy is the primary treatment modality. Surgical therapy attempts to create a physiological barrier to gastrointestinal reflux; yet, allow normal swallowing. This historical review provides the support for the development of a unique approach to reflux. The steps of the robotic laparoscopic modified Belsey Procedure (gastroesophageal valvuloplasty) (RLGV) are described in detail. The outcomes of this unique approach are described as well.

Keywords

Gastroesophageal reflux disease • GERD • Stomach fundoplication • Nissen fundoplication • Dor fundoplication • Toupet fundoplication • Belsey fundoplication • Esophagoscopy • Robotics • Laparoscopy • Minimally invasive surgery • Gastroparesis • Acid suppressive therapy • Esophageal pH monitoring • Anterior fundoplication

Gastroesophageal reflux disease (GERD) affects approximately 20% of Americans [1]. Normal individuals experience some GERD on a regular basis [2] Pathologic reflux results in injury to the esophagus and the upper aero-digestive tract. GERD has been shown to be a strong risk factor for esophageal carcinoma [3]. Curiously, esophageal adenocarcinoma has nearly quadrupled in frequency in the United States since the 1980s, when oral and acid medications have had their greatest use [4, 5]. GERD classically presents as heartburn and regurgitation. In addition to the classic presentation, GERD can present with a number of atypical symptoms which stem from exposure of the upper aerodigestive tract to gastric contents [6]. The history of antireflux surgery sheds light on the present surgical approach to the treatment of gastroesophageal reflux disease.

F. Gharagozloo, M.D. (✉)
Center for Advanced Thoracic Surgery, Global Robotics Institute, Florida Hospital Celebration, Celebration, FL, USA

M. Margolis, M.D.
MedStar Georgetown University Hospital, Washington, DC, USA

E. Strother, L.S.
Washington Institute of Thoracic and Cardiovascular Surgery, The George Washington University Medical Center, Washington, DC, USA

B. Tempesta, B.S.N., C.R.N.P.
Center for Advanced Thoracic Surgery, Florida Hospital Celebration, Celebration, FL, USA

22.1 Background

During the first half of the twentieth century, surgeons treated hiatal hernias like any other hernia. The major operative procedures concentrated on closing the defect and repositioning the hernia contents into their normal anatomic configuration. The debate in surgical circles concentrated on how large the hiatal hernia had to be to warrant repair and whether the repair should be performed through the chest or the abdomen [7]. During this period, the subject of hiatal hernia was covered in chapters which dealt with other hernias and coelomic ruptures in the textbooks of surgery. In fact, the present classification of hiatal hernias into sliding and paraesophageal hernias with grading from I to IV stems from this era in the surgical knowledge of hiatal hernias. One of the terms of this era which has been carried over to the present time and resulted in significant degree of misunderstanding is a

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_22

"sliding" hiatal hernia. A "sliding" hiatal hernia, or type I, is invariably and erroneously interpreted as a "hernia where the GE junction slides up and down." Unfortunately, line drawings in textbooks of surgery encourage this misconception. In fact, the sliding hiatal hernia was originally classified in a manner similar to a sliding inguinal hernia. A sliding hernia is defined as a hernia with a partial peritoneal sac and the remaining portion of the hernia is comprised of a viscous. In the case of a sliding hiatal hernia, esophagus compromises the posterior aspect of the hernia.

The early part of the twentieth century was characterized by the "anatomic" approach to hiatal hernias. In 1951, Philip Allison published his classic article where he argued that the symptoms of sliding hiatal hernias derived from exposure of the esophagus to the gastric contents as opposed to the anatomic defect in the esophageal hiatus [8]. He subsequently reported a group of patients with a columnar line segment of the distal esophagus. He and Johnstone correctly speculated that this condition might be the result of the replacement of the denuded squamous cell epithelium with adjacent columnar epithelium. In fact, it was Allison who coined the term "Barrett's esophagus." Interestingly, in 1950, Barrett had described changes in the esophagus seen at the time of postmortem examination of some patients with hiatal hernias and had concluded erroneously that this phenomenon was due to a congenitally short esophagus [9]. Allison and Johnstone emphasized that the change in the esophageal mucosa might be acquired rather than congenital.

For the next 20 years, it was felt that hiatal hernia was the primary cause of gastroesophageal reflux disease which occurred as the result of the loss of competence of the "valve-like mechanism" at the gastroesophageal junction [10].

The approach to GERD and hiatal hernias changed in 1971 when Cohen and Harris asserted that hiatal hernias had little to do with the control of reflux. They attributed the control of reflux to the lower esophageal sphincter. Their work was the culmination of an era which started in 1956 with Fyke's identification of a high-pressure zone at the gastroesophageal junction during manometry [11, 12]. The high-pressure zone was referred to as the lower esophageal sphincter. The concept of the lower esophageal sphincter was embraced by gastroenterologists [13, 14]. Since the 1980s, with the understanding that the LES is not a sphincter but that it represents a functional high-pressure zone at the gastroesophageal junction, there has been a slow return to the understanding of the association between hiatal hernias and gastroesophageal reflux disease. Over the years, one of the problems with the identification of hiatal hernia has been the type of diagnostic modality which has been used. Radiographic studies used in the early years were hampered by very high false negative rates. This fact was especially true with small hernias. Increasing use of endoscopies, CT scanning, and intraoperative observation during laparoscopic surgery has shown that 90–100% of patients with gastroesophageal reflux disease have an associated hiatal hernia [15–18].

Although Allison is responsible for the era where the functional sequelae of hiatal hernias were better understood, ironically, he designed an operation to restore the normal anatomy of the esophagogastric junction. Using a left transthoracic, transdiaphragmatic approach, he reapproximated the right and left aspects of the right crus of the diaphragm and reattached the phrenoesophageal ligament to the underside of the diaphragm. This procedure which amounted to an anterior closure of the crural arch did not correct gastroesophageal reflux disease. In a study which is a landmark in intellectual integrity in surgery, in 1973, Allison reported a 50% long-term recurrence rate following the "Allison" procedure [19].

In December 1955, Rudolf Nissen of Switzerland reported an operation on a 49-year-old woman with a long history of gastroesophageal reflux disease where he enveloped the lower esophagus with the gastric fundus by suture approximation of the anterior and posterior fundal folds anterior to the esophagus [20]. This technique had been born from a serendipitous observation of a technique which he had used 20 years earlier to manage postoperative reflux after resection of a peptic ulcer in the distal esophagus [21]. This procedure subsequently underwent modifications by Nissen and other investigators. Later, in an attempt to decrease the complications from a tight wrap and the resultant dysphagia, "gas bloat" syndrome, and wrap disruption, a number of modifications were made. These modifications have included the placement of intraesophageal stents varying from 46 Fr. to 60 Fr., division of short gastric vessels in order to obtain a floppy wrap, closing the esophageal hiatus posteriorly, anchoring the fundoplication to the preaortic fascia, decreasing the length of the wrap to 1–2 cm, concomitant highly selective vagotomy, and less than a 360 wrap [22–34]. Interestingly, the Dor procedure, which wraps the esophagus anteriorly as a partial fundoplication, and the Toupet procedure, which accomplishes partial fundoplication by wrapping the esophagus posteriorly, were both originally described for the relief of gastroesophageal reflux disease following Heller's myotomy for achalasia [35, 36]. These procedures which date back to the early 1960s have become more popular as partial wraps have become more widespread during the era of laparoscopic fundoplication.

By contrast to the serendipitous observations resulting in Nissen's fundoplication, Mr. Belsey's approach to the treatment of GERD was the culmination of years of careful observation and follow-up in the clinic. Importantly, although today we appreciate that the Belsey Mark IV procedure produces a gastroesophageal valve by intussuscepting the esophagus anteriorly into the stomach for the span of 270, Belsey's creation of the intussusception was designed to allow for the secure placement of sutures from the gastroesophageal junction to the underside of the diaphragm. Belsey studied the original group of 71 patients for 6 years before publishing the results of his procedure [37]. Belsey held that a good antireflux procedure met the following criteria:

1. It would achieve relief of reflux.
2. It would preserve swallowing, venting of gas, and the ability to regurgitate.
3. It would be easy to teach to other surgeons.

Between 1955 and 1962, 632 patients underwent the Belsey Mark IV procedure at his clinic. He reported an overall good to excellent result of 85% [38]. For the next 30 years, the open transabdominal Nissen fundoplication and the transthoracic Belsey repair were the mainstay of surgical therapy for gastroesophageal reflux disease. Although the Nissen fundoplication when performed by laparoscopy is associated with excellent relief of reflux symptoms and restoration of the esophageal acid exposure in 85–95% of patients, it is associated with obstructive symptoms of gas bloat and dysphagia in up to 20–40% of patients [38]. On the other hand although the Besley Mark IV operation is comparable to the Nissen fundoplication for the relief of reflux symptoms and restoration of esophageal acid exposure, it results in dysphagia and gas Bloat in less than 5% of patients [39].

During the 1980s with the advent of better medical therapy, surgery was less commonly advised. In 1991, Villemagne and associates reported the first minimally invasive laparoscopic antireflux procedure and initiated a renaissance in the surgical treatment of reflux disease [39]. Before the development of laparoscopic antireflux surgery, fewer than 10,000 antireflux procedures were performed annually in the United States. With the laparoscopic procedures, over 50,000 procedures are performed per year. This change has occurred for four reasons:

1. GERD is a very common disease and provides a demand for new medical and surgical procedures.
2. Antireflux surgery has been shown to be curative rather than palliative. It is the only form of therapy for GERD which changes the natural history of the disease. Even advances in medical therapy have not successfully addressed the anatomic alterations and the resultant related deterioration and physiologic function which are associated with gastroesophageal reflux disease.
3. Video-assisted minimally invasive techniques have made surgery more acceptable. Clinical studies of laparoscopic Nissen fundoplication have documented that the procedure can be performed with outcomes similar to the 90% rate which was achieved by open procedures but with significantly less morbidity. As a result, the laparoscopic procedure has become the standard surgical procedure for patients with complicated GERD.
4. A link between esophageal cancer and GERD has been established. Interestingly, the rates of esophageal adenocarcinoma have continued to rise in the face of H2 antagonists and protein pump inhibitors. There has been a greater desire to prevent rather than to manage esophageal cancers.

22.2 The Antireflux Barrier

The Nissen fundoplication dates back to the time when it was believed the antireflux barrier was made up of a sphincter at the gastroesophageal junction. Indeed, reflux control and the postoperative complications of the Nissen procedure are related to the formation of a fixed obstruction at the gastroesophageal junction.

Presently we understand the antireflux barrier to consist of a valve-like mechanism. Specifically, the valve consists of (1) the anterior intussusception of the esophagus into the stomach 270° of the circumference from the right limb to the left limb of the esophageal hiatus, (2) angulation at the esophagogastric junction created by the anterior arch of the crural sling, and (3) the positioning of the entire three-dimensional relationship under the esophageal hiatus. GERD would occur continuously without an antireflux barrier.

Considering these naturally occurring aspects, the ideal surgical procedure would attempt to recreate the antireflux barrier and should have the following aspects:

1. Reduce the hiatal hernia.
2. Close the crural arch.
3. Restore the angulation of the gastroesophageal junction.
4. Restore the intussusception of the esophagus into the stomach.

The robotic gastroesophageal valvuloplasty is designed to replicate the normal antireflux barrier by providing these four features.

22.3 Conventional Laparoscopy Compared to Robotics

One of the shortcomings of conventional laparoscopic techniques stems from the facts that the instruments introduced for ports or small incisions amount to holes in the abdominal wall. The instruments pivot at the entry hole and can be moved in four directions. The limited mobility of conventional endoscopic instruments has been referred to by some investigators as "chopstick surgery". The chopstick nature of the limited maneuverability of the effector instruments stems from the rigid shaft access fixed to the abdominal wall by the entry hole. This technical shortcoming limits the surgeon in performing fine dissection and complex three-dimensional maneuvers. Pivoting instruments on the abdominal wall results in a large radius of curvature for the tip of the instrument and makes fine dissection in deep spaces such as the esophageal hiatus very difficult and even dangerous. Indeed, it is this fact which has necessitated indirect means of accomplishing what can be performed through an open incision. With an open incision the surgeon is able to utilize conventional instruments and his own wrist in order to provide additional degrees of freedom for movement.

Another shortcoming of the laparoscopic technique is the lack of three-dimensional visualization. The surgeon has to use two-dimensional information from the video monitor in order to create a three-dimensional mental image. This fact requires significant experience and can prove to be a source of fatigue for the surgeon. Most importantly, using such indirect means of judging depth perception is rarely equivalent to binocular vision. In performing the complex maneuvers during an antireflux procedure binocular three-dimensional visualization of the structures is paramount for achieving a good repair. The use of robotic technology obviates these difficulties. In our view, the da Vinci robot represents an ideal tool for the accurate dissection of the esophageal hiatus.

22.4 Robotic Laparoscopic Gastroesophageal Valvuloplasty (Fundoplication)

This procedure takes advantage of the excellent visualization and maneuverability of the *da Vinci* robot for the dissection, identification of the hiatal structures, and fundoplication. The anesthetic management is similar to other laparoscopic procedures. The patient is placed in the lithotomy position. Preprocedure UGI endoscopy is performed and the gastroesophageal junction is examined by the retroflexed endoscope and the gastroesophageal valve is graded by the Hill Classification. The surgeon stands between the legs. Two laparoscopic CO2 insufflators are used. We prefer to use the Visiport Instrument (US Surgical Corp.) for initial port entry into the peritoneum. Port #1 (Camera Port) is placed inferior to the umbilicus. A small curvilinear incision is made under the umbilicus. A Kocher clamp is used to grasp the frenulum of the umbilicus and to elevate the anterior abdominal wall. Upward traction on the clamp provides the countertraction which is necessary for safe peritoneal entry under direction videoendoscopic guidance using the Visiport instrument (US Surgical, Inc.). Pneumoperitoneum is created using CO2 gas to a maximum pressure of 15 mmHg. The table is placed in a steep reverse Trendelenburg position. Under direct videoendoscopic guidance four other ports are placed. We prefer to

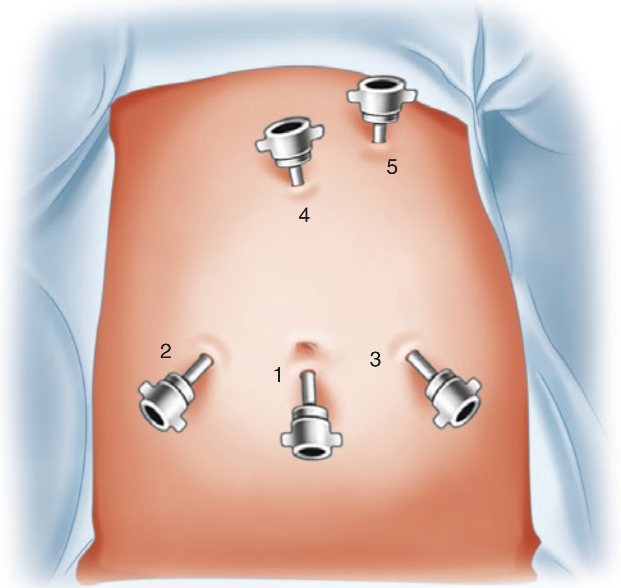


Fig. 22.1 Port placement

use the Step Bladeless Trocars (US Surgical) for all ports. These ports do not require closure. In addition, the capless design of these ports enables rapid instrument change without loss of pneumoperitoneum. A 0° Olympus Endoeye videoendoscope is introduced through Port #1. Port #2 is placed in the right paraumbilical region at the right mammary line. Port #3 is placed in the left paraumbilical region in the left mammary line. An Endo-Paddle paddle retractor (US Surgical) is introduced through Port #2 and used to place upward traction on the left lobe of the liver and to expose the phrenoesophageal ligament as well as the esophagogastric junction. Using the videoendoscope the left and right limbs of the right crus are identified. Port #4 is placed in the subcostal region halfway between the umbilicus and the xiphoid just to the left of the midline. This port is aligned with the right limb of the right crus of the diaphragm. Port #5 is placed in the subcostal region two finger-breaths to the left and caudad to Port #4. Port #5 is aligned with the left limb of the right crus of the diaphragm. The laparoscopic insufflator is disconnected from Port #1 and attached to port #4. A second insufflator is attached to Port #5. The use of two high flow insufflators preserves pneumoperitoneum and exposure of the esophageal hiatus during the robotic dissection (Fig. 22.1).

The head of the table is rotated 30° away from the anesthesia machine on its longitudinal axis in order to facilitate the docking of the robot. At this point the daVinci robot is positioned to the left of the table and a "Side docking" technique is used (Fig. 22.2). A 30° down-viewing robotic binocular camera is used and it is introduced through Port #1. The right robotic arm with a hook cautery instrument is introduced through Port # 3. The left robotic arm with a EndoWrist® DeBakey grasper instrument is introduced

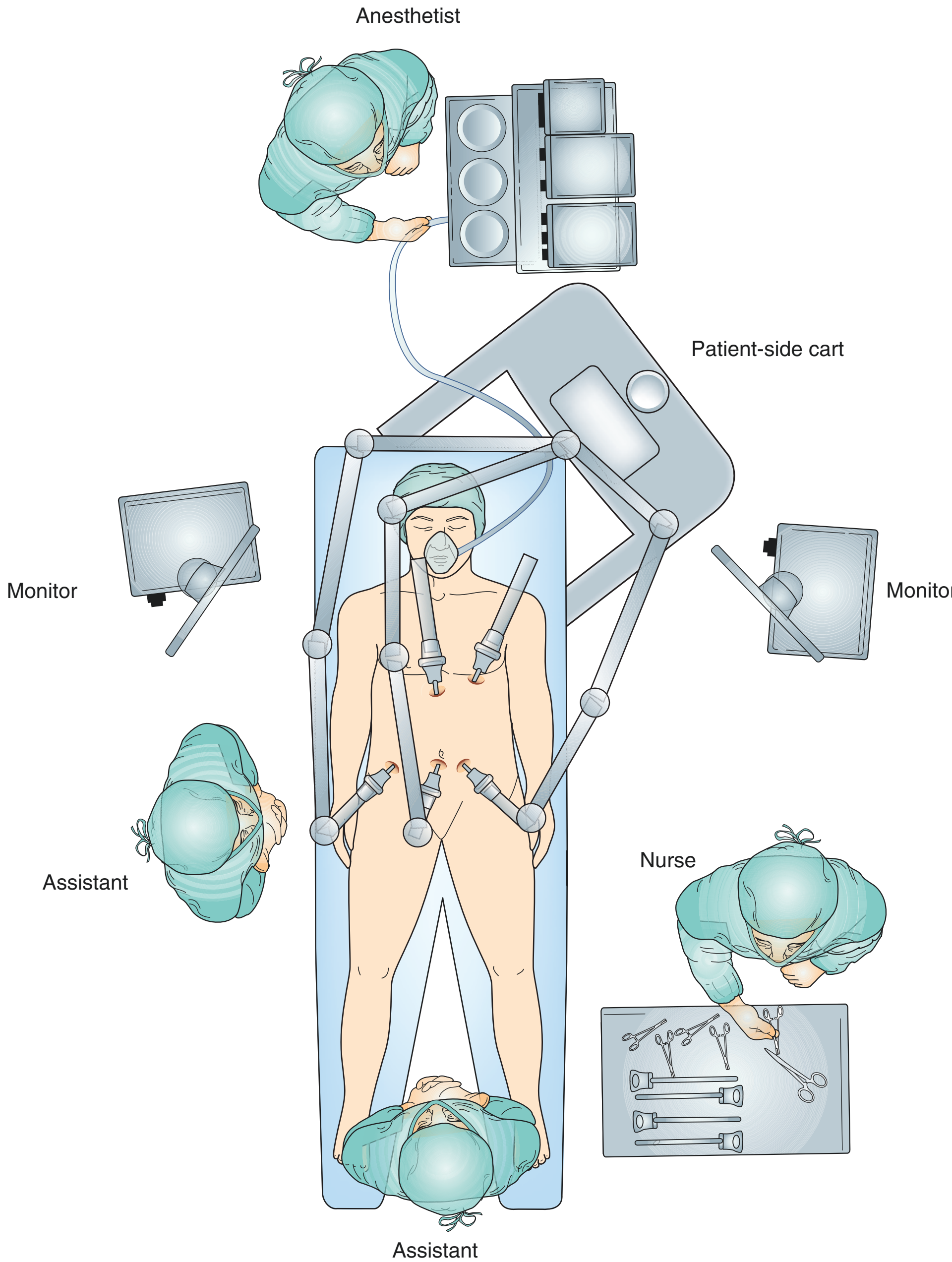


Fig. 22.2 Side-Docking technique for the robot

through Port #2. The entire dissection uses electrocuatery and meticulous hemostasis. Port #5 is used to vent smoke out of the peritoneal cavity. At other times, an endoscopic grasper or an endo-kitner is introduced through Port #5 by the assistant and is used to provide appropriate countertraction and exposure at the esophagogastric junction. The right crural arch is identified. The phrenoesophageal ligament is divided. The hepatogastric omentum is divided and the caudate lobe of the liver is identified. This maneuver necessitates division of the hepatic branch of the anterior Vagus nerve and a small arterial branch of the left gastric artery. This vessel is to be distinguished from a large aberrant left hepatic artery which arises from the left gastric artery in 25% of patients. In these patients the hepatic artery should be avoided and dissection should be confined to the superior aspect of the artery. At this point, the right limb (RL) of the right crus is visualized. The lateral and medial borders of the RL are identified. This maneuver facilitates the identification of the esophagus. Lateral traction is placed on the esophagus. The fatty tissue overlying the RL is excised and the RL is followed inferiorly to its junction with the left limb (LL) of the right crus. Next the dissection of the RL is carried superiorly onto the crural arch and around to the LL of the right crus. The LL is dissected inferiorly by taking down the angle of His and gastric fundal attachments. At this point following the curve of the LL, the left robotic hand is used to encircle the esophagus and a large vessel loop is passed underneath the esophagus, and secured by clips. The assistant places upward traction on the vessel loop and the dissection is continued in order to fully expose the entire esophageal hiatus.

22.4.1 Posterior Crural Closure

Posterior crural closure is accomplished by reapproximating the RL and LL with 3–0 Ethibond sutures. The assistant retracts the esophagus laterally and to the left. The maneuver exposes the "V" shaped posterior junction of the RL and LL of the right crus. A 1 cm^2 absorbable pledget cut from Vicryl mesh (Ethicon, Inc.) is passed through Port #4. Intracorporeally, the pledget is loaded onto the needle. The needle is passed through LL and RL respectively. Next intracorporeally the needle is passed through a second Vicryl pledget which is introduced through port #4 by the assistant. The suture is tied using intracorporeal technique. This technique is repeated for all the posterior crural sutures.

22.4.2 Anterior Crural Closure

At this point, the anesthesiologist passes a 60 French bougie into the esophagus. The esophageal hiatus is sized and one suture is placed anteriorly in a similar manner as the posterior sutures. The anterior crural closure allows for the formation of an acute angle at the Gastroesophageal junction and recreates one of the important features of the normal antireflux barrier. Following crural closure, the gastric fundoplication is performed.

22.4.3 Gastroesophageal Valvuloplasty (Fundoplication)

The gastroesophageal valve is formed by anterior intussusception of the esophagus into the stomach for the anterior 270° (from RL to LL of the right crus) of the 360° circumference of the esophagogastric junction. The esophagogastric fat pad is removed. The esophagus is marked 2 cm above the esophagogastric junction (EG) lateral to the left Vagus nerve (E1), lateral to the Right Vagus nerve (E3) and halfway in between (E2) (Fig. 22.3). The stomach is marked 2 cm below the GE junction at the greater curvature (G1), the lesser curvature (G3) and at a point halfway between G1 and G3 (G2). 0 Ethibond suture is used. The first valvuloplasty suture (E1 to G1, greater curve) passes in mattress fashion from G1 to E1 and to the left limb of the esophageal hiatus. This suture is tied a later time. Placing a tie on the "G1-E1" suture at this time will obscure the precise placement of the "E2-G2" and "E3-G3" sutures. A second valvuloplasty suture (E3 to G3, lesser curve) is passed in a similar manner from G3 to E3 and to the right limb of the esophageal hiatus. This suture will be

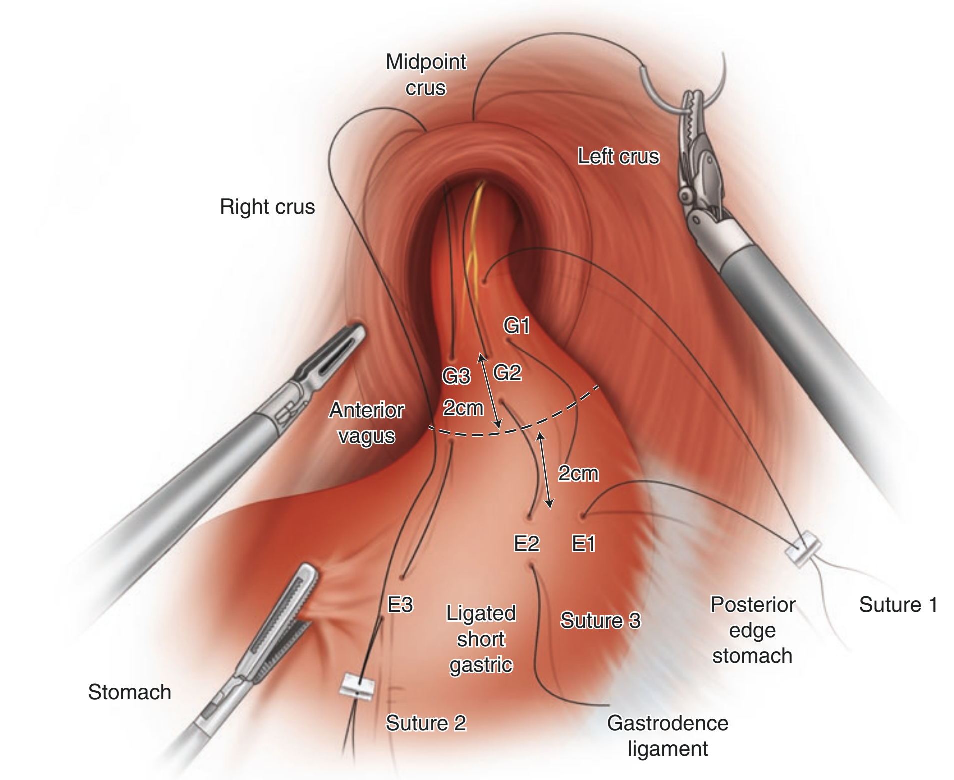


Fig. 22.3 Suture arrangement of the gastroesophageal valvuloplasty

tied a later time. The third valvuloplasty suture (E2 to G2, midpoint) is introduced in the same manner from G2 to E2 and to the midpoint of the crural arch of the esophageal hiatus. Next the sutures are tied using intracorporeal technique starting with the "E1 to G1" suture, then the "E2 to G2" suture and finally the"E3 to G3" suture (Fig. 22.3). Placement of the mattress valvuloplasty sutures results in the intussusception of the esophagus into the stomach by 2 cm for 270°. The liver retractor is withdrawn, and the abdomen is deflated of CO2. Only the infraumbilical trocar site needs to be closed. The Step Trocars are designed to be withdrawn without the need for fascial closure. Subcutaneous tissues are closed with 00 Vicryl and the skin is closed with staples (Fig. 22.4). Upper GI endoscopy is repeated and the gastroesophageal valve is inspected and graded based on the Hill Grading System (Fig. 22.5).

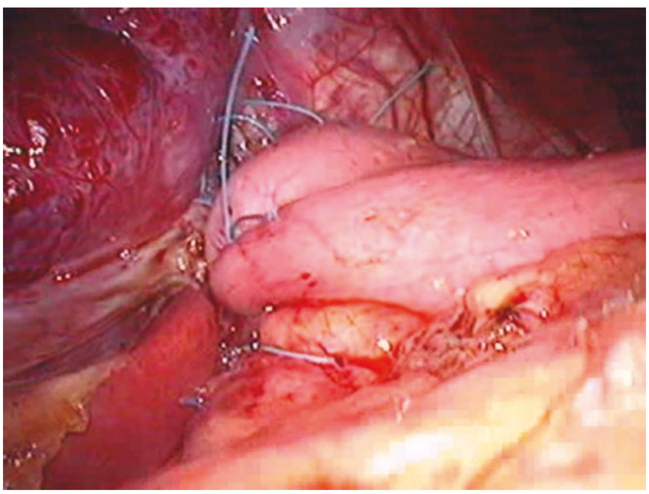


Fig. 22.4 Laparoscopic view of the completed gastroesophageal valvuloplasty

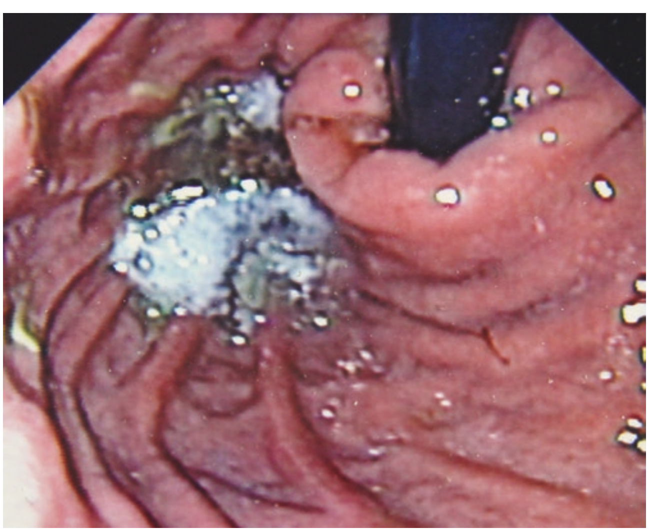


Fig. 22.5 Retroflexed endoscopic view of the gastroesophageal valvuloplasty

22.5 Outcomes

During a 71 month period, 302 patients underwent robotic GE valvuloplasty. Eleven patients (3.6%) were lost to follow up. In the remaining 291 patients, there were 156 men, and 135 women. The mean age was 51 ± 14 years. Indication for surgery was failure of medical therapy in 212/291 patients (73%) and upper respiratory symptoms (cough, hoarseness, bronchospasm) in 79/291 patients (27%). On Upper GI endoscopy 183/291 patients (63%) had a Hill Grade IV GE junction, 73/291 (25%) had a Hill Grade III GE junction and the reaming 35/291 (12%) patients were graded as Hill Grade II. On contrast esophagography 230/291 patients (79%) were diagnosed with a hiatal hernia. All patients had normal esophageal motility and increased acid exposure.

At the time of surgery, exploration of the esophageal hiatus revealed a hiatal hernia in all patients. The mean operative time was 130 ± 52 min. In 19/291 (6%) the intraoperative post fundoplication endoscopy revealed an incompetent gastroesophageal valve. In these patients the valve underwent further repair in order to obtain a satisfactory Hill Grade I score.

Complications were seen in 61 patients (21%). The pleura was entered in 55/291(19%) patients. This was treated with closure of the pleural opening and intraoperative evacuation of the pleural space. There was no conversion to an open procedure. A pneumothorax was diagnosed in 5/291 (1.7%) postoperatively. These patients underwent drainage with a 10 French radiographically placed pig tail catheter. One patient had atrial fibrillation (0.3%). There was no mortality.

Mean hospitalization was 2.8 ± 1.7 days. The majority of patients required 2 days in the hospital in order to meet discharge criteria.

22.5.1 Early (1–12 Weeks) Postoperative Results

Immediately after surgery 221/291 patients (76%) reported dysphagia to solids. Dysphagia had resolved in all patients by the third postoperative week. There was no incidence of gas bloat in the early postoperative period. By 12 weeks, acid suppression therapy was discontinued in all patients. 5/291 (2%) patients had transient gastroparesis which resolved by the third postoperative month.

22.5.2 Late Follow-Up

Mean follow up was 85 ± 7 months. At the time of follow up the mean score on the SSQ decreased from 8.3 ± 0.6 to 0.7 ± 0.2 ($p < 0.05$). 279/291 (96%) of patients scored 0 on the questionnaire and were completely asymptomatic. The remaining patients (4%) had some degree of heart burn and continued acid suppression therapy. Long term Gas Bloat was not reported by any patient.

Preoperatively 58/291 patients were objectively graded as Visick III, and 231/291 (80%) were Visick IV. At the time of follow up 276/291 (95%) were graded as Visick I and 5% as Visick II.

The hiatal hernia recurred in 8/291 patients (2%). Recurrence was documented on Upper GI endoscopy and contrast esophagography. In all instances the recurrence was in the anterior aspect of the esophageal hiatus. There was no posterior crural disruption.

References

1. Locke GR III, Talley NJ, Fett SL, Zinsmeister AR, Melton LJ III. Prevalence and clinical spectrum of gastroesophageal reflux: a population-based study in Olmsted County, Minnesota. Gastroenterology. 1997;112(5):1448–56.
2. Demeester TR, Wang CI, Wernly JA, Pellegrini CA, Little AG, Klementschitsch P, et al. Technique, indications, and clinical use of 24 hour esophageal Ph monitoring. J Thorac Cardiovasc Surg. 1980;79(5):656–70.
3. American Gastroenterological Association. American Gastroenterological Association medical position statement on the management of Barrett's esophagus. Gastroenterology. 2011;140(3):1084–91.
4. Richter JE. Chest pain and gastroesophageal reflux disease. J Clin Gastroenterol. 2000;30(3 Suppl):S39–41.
5. Devesa SS, Blot WJ, Fraumeni JF Jr. Changing patterns in the incidence of esophageal and gastric carcinoma in the United States. Cancer. 1998;83(10):2049–53.
6. Ormseth EJ, Wong RKH. Reflux laryngitis: pathophysiology, diagnosis, and management. Am J Gastroenterol. 1999;94(10):2812–7.
7. Hiebert CA. Surgical management of esophageal reflux and hiatal hernia, 1951. Ann Thorac Surg. 1991;52(1):159–60.
8. Allison PR. Reflux esophagitis, sliding hiatal hernia, and the anatomy of repair. Surg Gynecol Obstet. 1951;92(4):419–31.
9. Allison PR, Johnstone AS. The oesophagus lined with gastric mucous membrane. Thorax. 1953;8(2):87–101.
10. Pearson FG. Pathophysiology of hiatal hernia and gastroesophageal reflux. In: Pearson FG, et al., editors. Esophageal surgery. Philadelphia: Churchill Livingstone; 2002. p. 223–33.
11. Cohen S, Harris LD. Does hiatus hernia affect competence of the gastroesophageal sphincter? N Engl J Med. 1971;284(19):1053–6.
12. Code CF, Fyke FE Jr, Schlegel JF. The gastroesophageal sphincter in healthy human beings. Gastroenterologia. 1956;86(3):135–50.
13. Dent J, Dodds WJ, Friedman RH, Sekiguchi T, Hogan WJ, Arndorfer RC, Petrie DJ. Mechanism of gastroesophageal reflux in recumbent asymptomatic human subjects. J Clin Invest. 1980;65(2):256–67.
14. Stein HJ, Liebermann-Meffert D, DeMeester TR, Siewert JR. Three-dimensional pressure image and muscular structure of the human lower esophageal sphincter. Surgery. 1995;117(6):692–8.
15. Berstad A, Weberg R, Larsen IF, Hoel B, Hauer-Jensen M. Relationship of Hiatus Hernia to Reflux Oesophagitis A Prospective Study of Coincidence, Using Endoscopy. Scand J Gastroenterol. 1986;21(1):55–8.
16. Kaul B, Petersen H, Myrvold HE, Grette K, Roysland P, Halvorsen T. Hiatus hernia in gastroesophageal reflux disease. Scand J Gastroenterol. 1986;21(1):31–4.
17. Ott DJ, Gelfand DW, Chen YM, Wu WC, Munitz HA. Predictive relationship of hiatal hernia to reflux esophagitis. Gastrointest Radiol. 1985;10(1):317–20.
18. Sontag SJ, Schnell TG, Miller TQ, Nemchausky B, Serlovsky R, O'Connell S, et al. The importance of hiatal hernia in reflux esophagitis compared with lower esophageal sphincter pressure or smoking. J Clin Gastroenterol. 1991;13(6):628–43.
19. Allison PR. Hiatus hernia: (a 20-year retrospective survey). Ann Surg. 1973;178(3):273–6.
20. Nissen R. Eine einfache Operation zur Beeinflussung der Retluxoesophagilis [A simple operation for control of reflux esophagitis]. Schweiz Med Wochenschr. 1956;86(Suppl 20):590–2.
21. Nissen R. Die transpleurale Resektion der Kardia. Deutsche Zeitschrift für Chirurgie. 1937;249(3):311–6.
22. Nissen R. The treatment of hiatal hernia and esophageal reflux by fundoplication. In: Nyhus LM, Harkins HH, editors. Hernia, vol. 19W. Philadelphia: J.B. Lippincott; 1964. p. 488–96.
23. Nissen R, Rossetti M. La fundoplication et la gastropexie dans henie Hiatal [Fundoplication and gastropexy in the surgical treatment of cardial insufficiency and hiatal hernia. Indications, technic and results]. Ann Chir. 1962;16:825–36.
24. Nissen R, Rossetti M. Die Behandlung von Hiatushemien und Refluxoesophagitis mil Gastropexie und Fundoplication. Stuttgart: Thieme; 1959.
25. Nissen R, Rossetti M. Surgery of hiatal and other diaphragmatic hernias. J Int Coll Surg. 1965;43:663–74.
26. DeMeester TR, Stein HJ. Minimizing the side effects of antireflux surgery. World J Surg. 1992;16(2):335–6.
27. Donahue PE, Samelson S, Nyhus LM, Bombeck CT. The floppy Nissen fundoplication. Effective long-term control of pathologic reflux. Arch Surg. 1985;120(6):663–8. https://doi.org/10.1001/archsurg.1985.01390300013002.
28. Herrington JL Jr, Meacham PW, Hunter RM. Gastric ulceration after fundic wrapping. Vagal nerve entrapment, a possible causative factor. Ann Surg. 1982;195(5):574–81.
29. Siewert JR, Feussner H, Walker SJ. Fundoplication: how to do it? Peri-esophageal wrapping as a therapeutic principal in gastro-esophageal reflux prevention. World J Surg. 1992;16(2):326–34.
30. DeMeester TR, Bonavina L, Albertucci M. Nissen fundoplication for gastroesophageal reflux disease. Evaluation of primary repair in 100 consecutive patients. Ann Surg. 1986;204(1):9–20.
31. Ellis FH Jr. Nissen fundoplication. In: Braasch JW, et al., editors. Atlas of abdominal surgery. Philadelphia: Saunders; 1990. p. 10–6.
32. Cordiano C, Rovere GQ, Agugiaro S, Mazzilli G. Technical modification of the Nissen fundoplication procedure. Surg Gynecol Obstet. 1976;143(6):977–8.
33. Jordan PH Jr. Parietal cell vagotomy facilitates fundoplication in the treatment of reflux esophagitis. Surg Gynecol Obstet. 1978;147(4):593–5.
34. Guarner V, Martinez N, Gavino JF. Ten year evaluation of posterior fundoplasty in the treatment of gastroesophageal reflux: long-term and comparative study of 135 patients. Am J Surg. 1980;139(2):200–3.
35. Dor J, Humbert P, Dor V, Figarella J. L'intérêt de la technique de Nissen modifiée dans la prévention du reflux après cardio-myotomie extra-muqueuse de Heller. Mem Acad Chir (Paris). 1962;88:877–83.
36. Toupet A. Technique d'oesophago-gastroplastie avec phréno-gastropexie appliquée dans la cure radicale des hernies hiatales et comme complément de l'opération de Heller dans les cardio-spasmes. Mem Acad Chir. 1963;89(20):384–9.
37. Hiebert C, Belsey R. Incompetency of the gastric cardia without radiologic evidence of hiatal hernia. The diagnosis and management of 71 cases. J Thorac Cardiovasc Surg. 1961;42:352–62.
38. Skinner DB, Belsey RH. Surgical management of esophageal reflux and hiatus hernia. Long-term results with 1,030 patients. J Thorac Cardiovasc Surg. 1967;53(1):33–54.
39. Lerut T, Coosemans W, Christiaens R, Gruwez J. The Belsey Mark IV antireflux procedure: indications and long-term results. Acta Gastroenterol Belg. 1989;53(5–6):585–90.

Robotic Fundoplication: Nissen-Rossetti

23

PierCristoforo Giulianotti and Pietro Addeo

Abstract

Gastroesophageal reflux disease (GERD) affects between 10 and 40% of the population. Surgical treatment is reserved for selected cases and Nissen-Rossetti fundoplication is considered the gold standard. Minimally invasive surgery is gaining popularity for this benign, functional disease. The use of the robotic system allows the construction of a technically adequate, floppy fundoplication with a very limited dissection.

Surgical steps as well as tips and pitfalls are described in detail. The operation starts with a conventional laparoscopic exploration followed by the port placement and the cart docking. Dissection begins opening the gastro-hepatic ligament to expose the right pillar of the diaphragm and dissect the right side of the inferior mediastinal segment of the esophagus. Afterward, we move to the posterior part of the gastric fundus, creating a retroesophageal window and obtaining a mobilization of the abdominal portion of the esophagus. Once the crura is completely exposed, a cruroplasty can be achieved with few interrupted stitches. The next phase of the procedure is the confection of a floppy wrap, followed by the suturing of the two gastric hemi-valves, kept in position by the assistant. The calibration of the wrap is usually tested with a 32-French bougie.

Our experience counts 167 robot assisted Nissen-Rossetti fundoplications performed from October 2000 to April 2007. The robotic system enables precise and selective dissection with the potential to reduce complications related to injuries of the vagal fibers, routine take down of the short gastric vessels and extensive dissection of the greater curvature.

Keywords

Gastroesophageal reflux disease • Anti-reflux procedure • Nissen-Rossetti • Fundoplication • Robot assisted • Minimally invasive

23.1 Background and Specific Indications

Gastroesophaegal reflux disease (GERD) is a very common problem in the western world and affects between 10 and 40% of the population [1]. Medical therapy using a proton pump inhibitor is typically considered the first line of treatment, while surgery is generally reserved for cases that do respond adequately to medical therapy or for those who are medication-dependent and wish to cease further medication. Among the various anti-reflux procedures performed, the Nissen-Rossetti fundoplication is widely regarded to be the gold standard for the surgical treatment of GERD, as it provides good long-term functional results in approximately 90% of patients [2].

The laparoscopic approach to the Nissen-Rossetti procedure was first described by Dallemagne et al. [3] in 1991. While the functional outcomes [4] are comparable to the

P. Giulianotti, M.D., F.A.C.S (✉)
University of Illinois Hospital and Health Sciences System,
840 S. Wood St., Suite 435E (MC958), Chicago, IL 60612, USA
e-mail: piercg@uic.edu

P. Addeo
Department of Surgery, UIC, 840 S. Wood St, Chicago,
IL 60612, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_23

open Nissen-Rossetti fundoplication, it results in faster convalescence and less postoperative pain when compared with the open procedure [5]. This allows for anti-reflux surgery to be performed on an outpatient basis [6].

The procedure does, however, require advanced laparoscopic skills and, as a result, is characterized by a steep learning curve [7]. The fulcrum effect, rigid non-articulating instruments, and two-dimensional imaging are all issues impacting laparoscopic surgery, even for those surgeons with years of experience.

The robotic approach to Nissen-Rossetti fundoplication was first described in 2001 by Cadiere et al., [8] although reports of its use are rare today. In our opinion, the use of a robotic system in anti-reflux surgery allows for the construction of a technically correct floppy Nissen-Rossetti fundoplication with a very limited dissection, something that is almost impossible to achieve laparoscopically. In this chapter, we describe the surgical technique for the robotic Nissen-Rossetti operation. The technical points are highlighted, as are tips and pitfalls for both new and experienced robotic surgeons to take into consideration when performing this procedure.

23.2 Operative Set-Up

23.2.1 Positioning and Trocar Placement

The patient is placed supine in a 15–20° reverse Trendelenburg with legs parted. A slight rotation of the table toward the right side is generally helpful in order to displace the left lobe of the liver from the operative field.

A bedside assistant surgeon is required and is positioned in between the legs. In this position, the assistant can easily control the three operative arms, change instruments and, at the same time, use the assistant port for complementary maneuvers such as suction, introduction of needles, retraction, etc. The scrub nurse is positioned on the left side of the patient, able to work with the side assistant.

The operating surgeon is seated at the console which is positioned in a corner of the operating room. The robotic cart is positioned coming from the patient's head and docked to the robotic port after the initial laparoscopic phase is completed. A drawing of the operative set-up is shown in Fig. 23.1.

23.2.2 Anesthetic Management

General anesthesia is given with orotracheal intubation and a nasogastric tube is inserted to keep the stomach deflated during the entire procedure. Complete monitoring of the patient is achieved with EKG, venous line, and a Foley catheter.

At the beginning of the procedure, and throughout, the anesthesiologist must be sure that there is no contact between the robotic arms and the patient, so as to avoid any accidental injury. At the end of the procedure, the nasogastric tube is removed. Once the fundoplication is complete, the anesthesiologist will pass a 32-French bougie through the esophageal lumen, in order to rule out the presence of strictures of the gastro-esophageal (GE) junction. This can occur due to excessive tightening of the wrap or of the cruroplasty.

23.3 Operative Procedure

23.3.1 Laparoscopic Exploration and Port Placement

The operation begins with the conventional laparoscopic exploratory phase. This phase plays a fundamental role in: (1) detecting and treating adhesions from previous operations; (2) estimating the dimension of the left liver lobe; (3) finding the presence of a hiatal hernia and estimating it's size; and (4) planning the correct positioning of the trocar according to the patient's characteristics (i.e. obese, tall patients, pendulous abdomen, etc).

A Veress needle is placed in the left upper quadrant and the insufflation of carbon dioxide to a pressure of 14 mmHg is started. A 5-mm trocar (Visiport™, Covidien, Mansfield MA) is then placed in the left hypochondrium under direct vision. This is used for preliminary visual exploration of the abdominal cavity and will be replaced later with an 8-mm robotic trocar for the right robotic arm.

The Nissen-Rossetti operation is performed using all four arms of a da Vinci Robotic surgical system (Intuitive, Sunnyvale, CA). Once the preliminary exploration is completed and the trocar positioning is planned, a 12-mm trocar is placed for the 30° robotic camera just a few centimeters above and on the left side of the umbilicus. Four additional trocars are then placed. One 8-mm robotic port is introduced into the left upper quadrant (right operating arm), replacing the initial 5-mm port. Two 8-mm ports are placed in the right upper quadrant for the left operating arm and the fourth arm (very laterally on the right subcostal area). The fourth robotic arm instrument is used to lift the left lateral segment of the liver to expose the GE junction. An accessory 12-mm trocar is usually placed in between the optical and left upper quadrant trocar (right robotic arm), as shown in Fig. 23.1.

Depending on the patient characteristics, the positioning of the trocar in the abdomen can be modified in order to achieve the best triangulation and to easily reach the target anatomy. As previously described, the robotic cart is always docked coming from the patient's head.

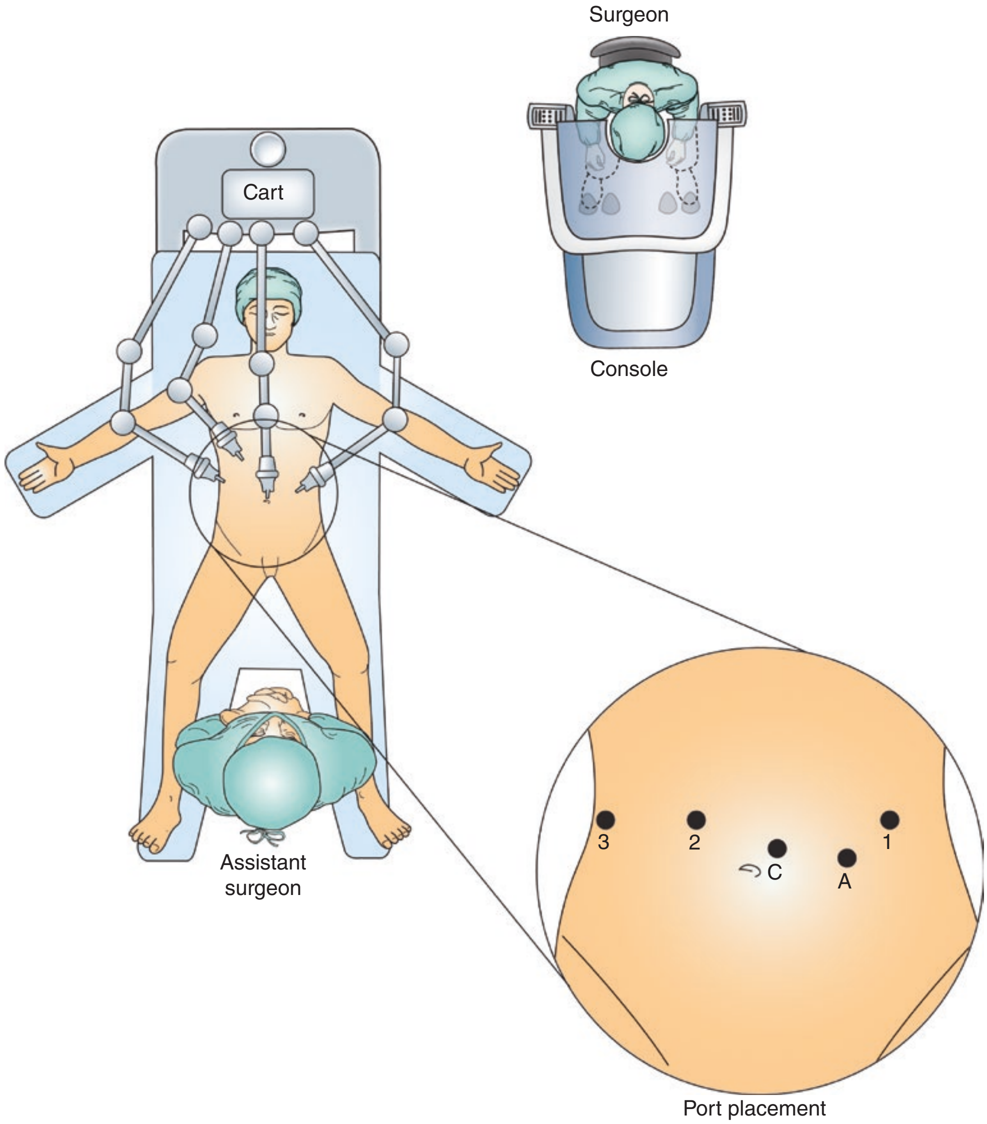


Fig. 23.1 Operating room set-up, patient and port positioning for robotic Nissen-Rossetti fundoplication. C = 12-mm trocar for a 12-mm robotic camera; 1 = 8-mm trocar for the right robotic arm; 2 = 8 mm trocar for the left robotic arm; 3 = 8 mm trocar for the fourth robotic arm; A = 12 mm trocar for the assistant surgeon

23.3.2 Exposure of the Operative Field

All instruments are inserted in the abdomen under direct camera control to avoid any accidental injuries. As a first step, a Cadiere Grasper® (Intuitive, Sunnyvale CA) is used as the instrument for the fourth robotic arm. This instrument will hold a sponge and can gently lift the left liver lobe in order to expose the GE Junction (Fig. 23.2). A robotic monopolar hook is used as the main tool for the right instrument and bipolar forceps are used for the left instrument to begin the dissection.

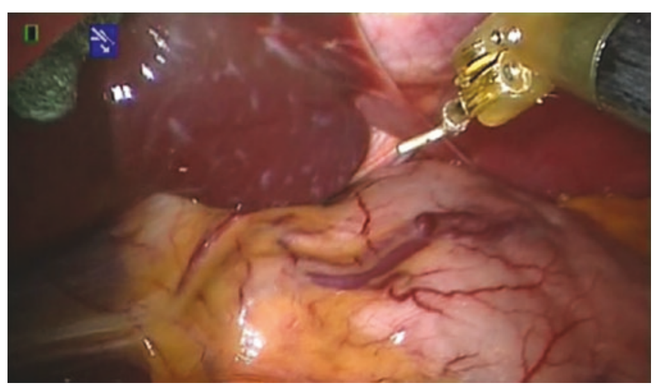


Fig. 23.2 Exposure of the operative field. Lifting of the left liver lobe by the fourth robotic arm instruments

23.3.3 Dissection of the Gastroesophageal Junction

The dissection begins by opening the pars condensa of the gastrohepatic ligament (Fig. 23.3). In this phase, the assistant uses a conventional laparoscopic grasper to retract downward the anterior gastric wall. Care should be taken in detecting the presence of the accessory left hepatic artery and ensuring that no damage is done to the vagal branches directed to the liver.

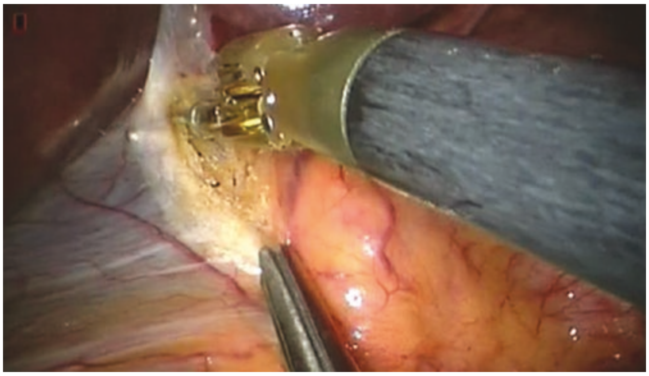


Fig. 23.3 Opening of the pars condensa of the gastrohepatic ligaments with monopolar hook

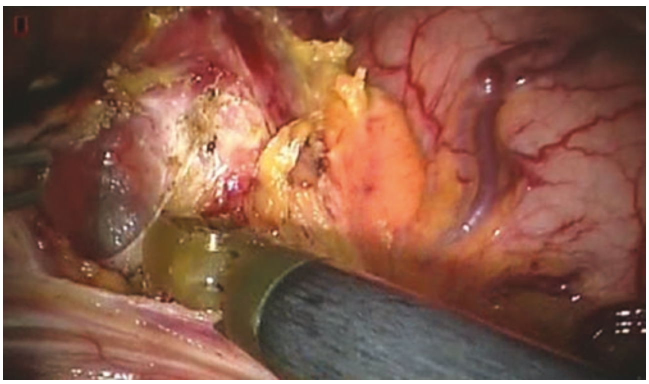


Fig. 23.4 Dissection of the right pillar

Fig. 23.5 Dissection of the phrenogastric ligament

A minimal dissection is generally required to expose the right pillar and dissect the right side of the inferior mediastinal segment of the esophagus (Fig. 23.4). After the anterior vagal nerve is identified, the anterior peritoneal reflection of the GE junction is dissected. The dissection moves toward the left pillar and the phrenogastric ligament is incised with a monopolar hook, where the angle of His is then opened (Fig. 23.5). Following this, the assistant retracts the anterior part of the stomach toward the right side and the operating

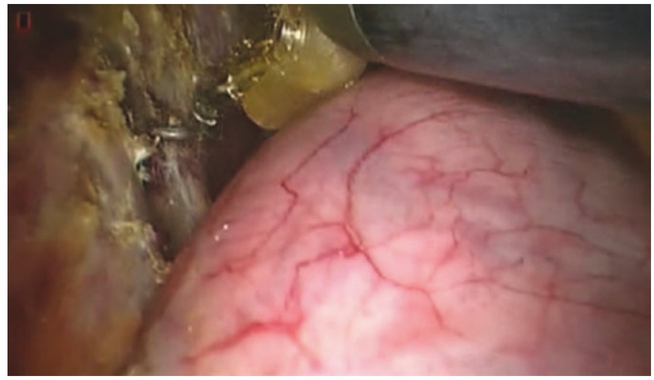


Fig. 23.6 Dissection of the left pillar

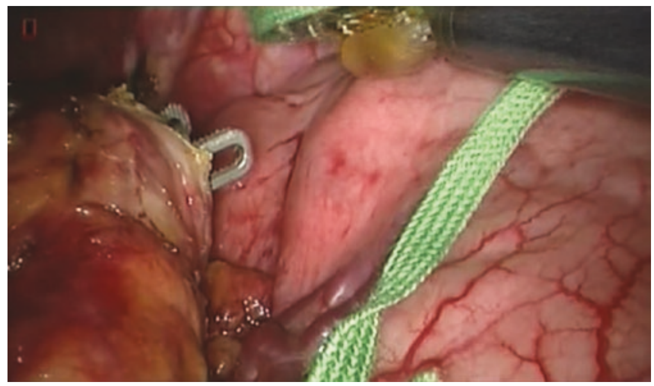


Fig. 23.7 Creation of the retroesophageal window and taping of the abdominal esophagus

surgeon continues the dissection to expose the left pillar (Fig. 23.6).

A wide, selective dissection of the posterior "extraperitoneal" part of the gastric fundus must now be carried out. During our experience, we found that this dissection provides the maximal availability of the stomach wall, which is essential to construct a floppy wrap. Additionally, by doing this, there is no longer a need to cut the short gastric vessels, which is often done as a matter of routine in laparoscopy.

Once the left pillar has been exposed, the dissection continues from right to left behind the esophagus, using a grasper forceps to create a retroesophageal window. Care must be taken to avoid injuries to the posterior vagus during this phase. Once the tip of the grasper forceps reaches the left part of the dissection, a Penrose drain or umbilical tape is passed posterior to surround the esophagus (Fig. 23.7). The traction made on the tape by the assistant surgeon allows for further dissection of a posterior retroesophageal window, which is large enough to accommodate the wrap. The dissection must be carried out completely in the lower mediastinum in order to have an increased length of the abdominal portion of the esophagus. Once this is done, the crura is

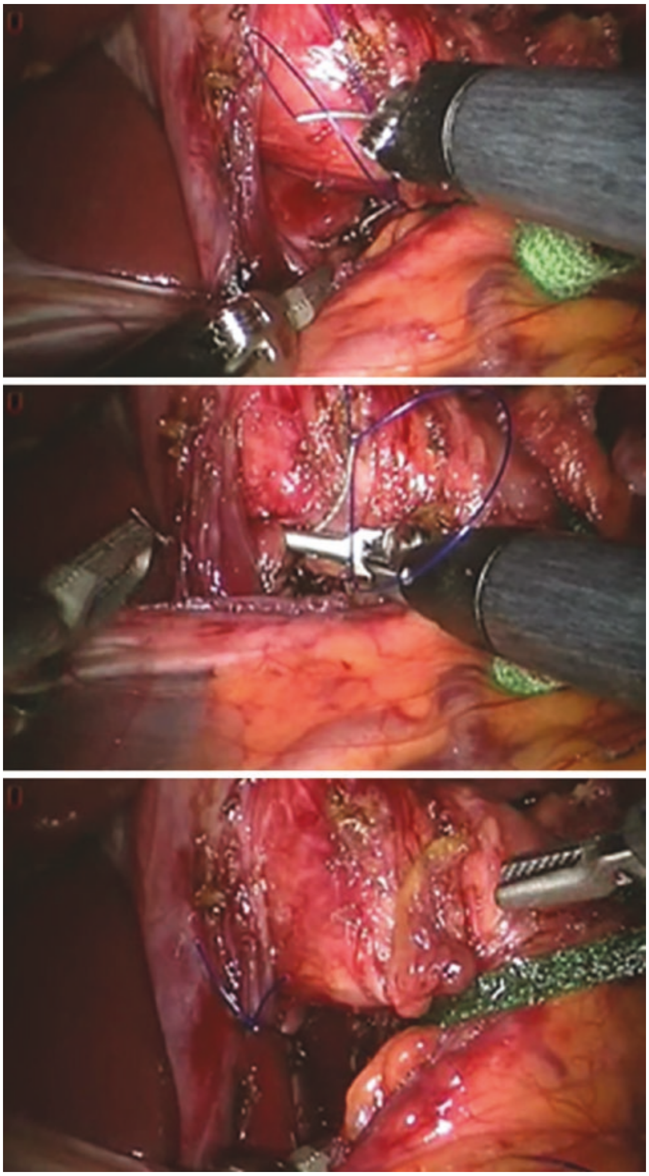


Fig. 23.8 Cruroplasty

completely exposed and a cruroplasty can be achieved using one to two stitches of polypropylene 3/0 (Fig. 23.8). In the case of a large hiatal defect (>4 cm), additional sutures and/or a mesh are required.

23.3.4 Fundoplication

Once the dissection is completed, the posterior wall of the gastric fundus is grasped using the right instruments and passed behind the esophagus (Fig. 23.9). In most cases, if the selective mobilization of the retroperitoneal portion of the gastric fundus is complete, the wrap is sufficient without needing to cut the short gastric vessels. In only 40–50% of cases we have seen the need to cut one or two short gastric

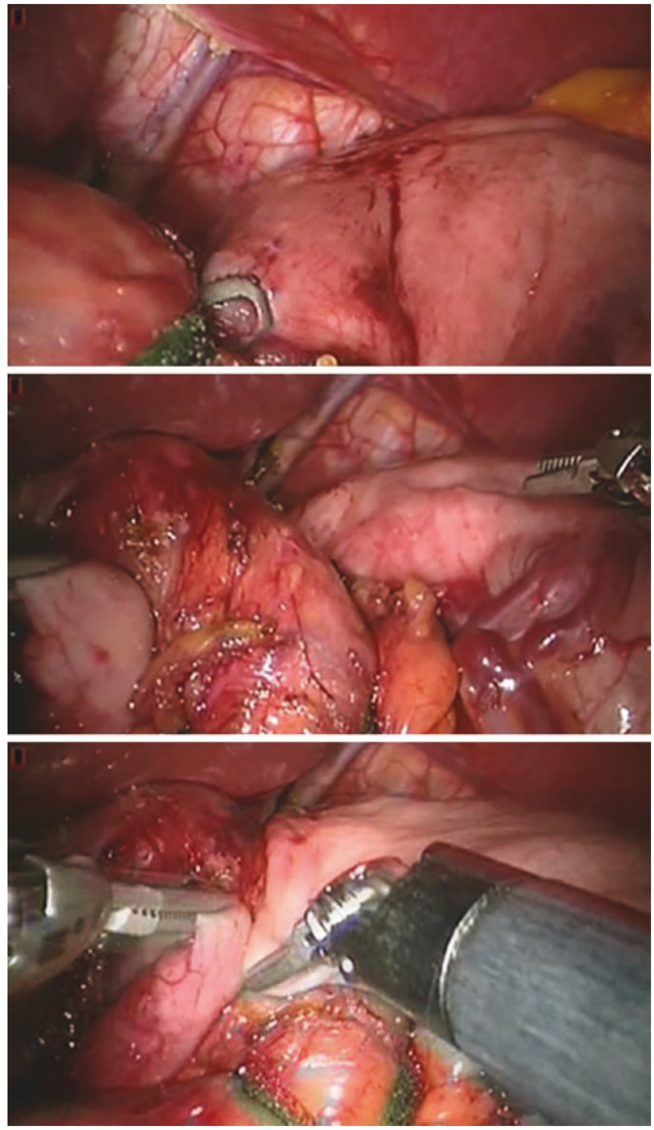


Fig. 23.9 Confection of a floppy wrap

vessels in order to create a wider wrap. These short gastric vessels are usually transected using the robotic harmonic shears (Ethicon Endo-Surgery, Cincinnati, OH).

The assistant surgeon keeps the two gastric hemi-valves in a stable position using a laparoscopic grasper (Fig. 23.10). They are then sutured with three stitches of polypropylene 3/0. Be sure that one of these, the intermediate, picks a small bite of the anterior muscular layer of the esophagus (Fig. 23.11). Care should be taken during this passage to avoid injury to the anterior vagus nerve and to not transfix the esophageal lumen.

At the end of the procedure, the anesthesiologist should check the calibration of the wrap by passing down a 32-French bougie to rule out the presence of stricture.

With the procedure now complete, the nasogastric tube can be removed and the patient extubated. Patients are

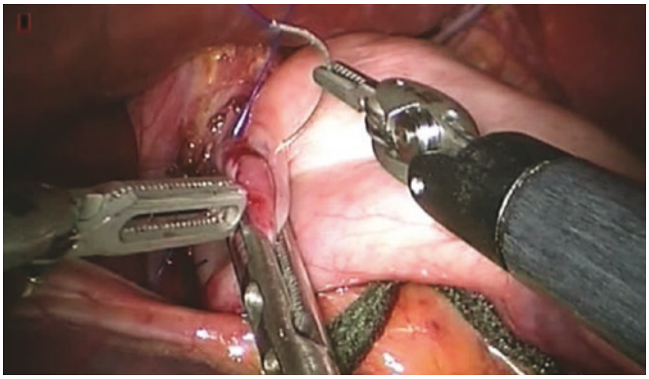


Fig. 23.10 Keeping in stable position of the two gastric hemi-valves by the assistant surgeon

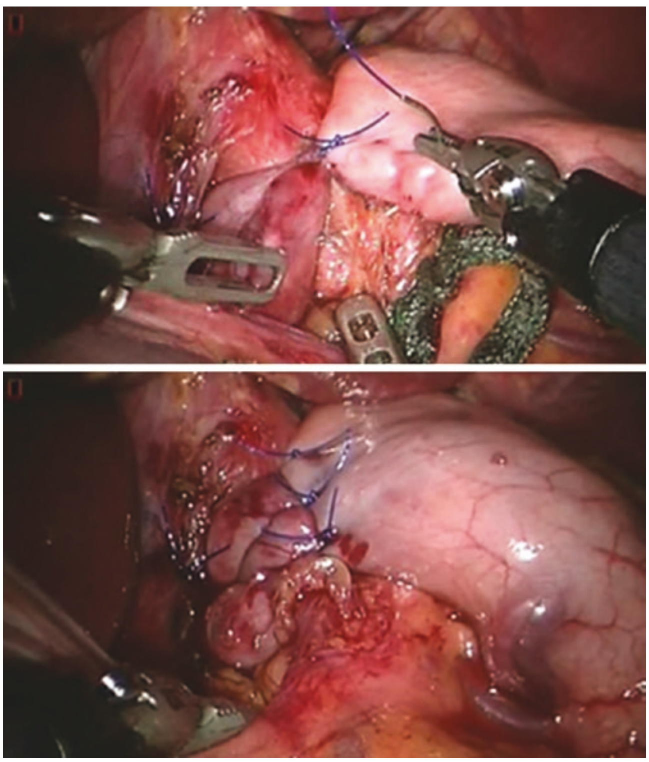


Fig. 23.11 Suturing of the anti-reflux wrap

allowed on a liquid diet the night of the operation and are instructed to avoid large amounts of meat or bread for 10 days. Approximately 90% of patients are discharged on the first operative day and most are able to resume their regular activity within 2 weeks.

23.4 Tips and Pitfalls

23.4.1 Exposure of the Operative Field

In order to achieve better exposure of the GE junction, particularly in the presence of a bulky left liver lobe (as seen in

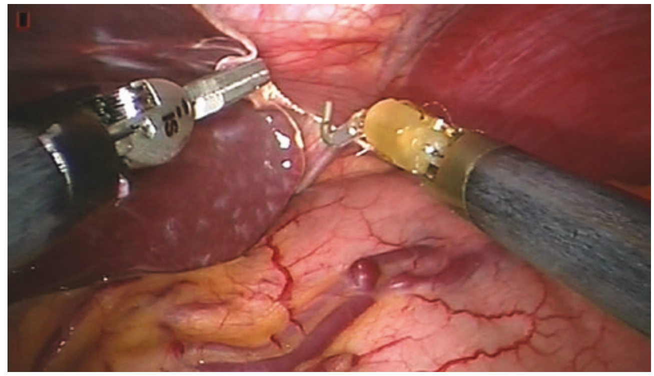


Fig. 23.12 Sectioning of the left triangular ligament with the robotic monopolar hook

obese patients), the left triangular ligament often may have to be completely taken down (Fig. 23.12). In such cases, further care must be taken to avoid injury to the fragile hepatic parenchyma by the fourth robotic arm. This is done by avoiding excessive pressure on the liver when using the sponge held by the instrument in the fourth arm.

The positioning of the fourth arm is also critical in achieving the right movements. If the trocar is too close to the costal ribs, the instrument may not be able to achieve the most effective retraction of the left lobe.

23.4.2 Dissection of the Gastroesophageal Junction

In order to avoid possible injuries in the presence of an accessory left hepatic artery, the dissection of the gastroesophageal junction must be started close to the diaphragm. The retro-esophageal window is created and the junction then taped. The assistant surgeon will provide traction on the tape downward, in order to move the left hepatic artery and the vagal branches. The dissection of the crura can be then safely completed.

23.4.3 Fundoplication

In constructing a 3-cm floppy wrap, the most important step is to maximize the mobilization of the posterior extraperitoneal part of the gastric fundus. By doing this, there is no longer a need to cut the short gastric vessels. In a selected cases (short esophagus, previous surgery, short gastric fundus), two of the short gastric vessels did have to be taken down. Here, the dissection should start downward using robotic harmonic shears and sectioning the next to the last short gastric vessel, which allows for better control of the last vessel which is usually very short.

A correct floppy wrap remains visible when the grasping is released. If the two hemi-valves are moving, care should be taken to find the causes for this. Typically, there are two main reasons for excessive tension on the GE junction: (1) a short posterior fundus; and (2) torsion because the wrap has been built with the anterior part of the fundus.

23.5 Outcomes

Cadiere et al. [8] reported the first application of robotic surgery for Nissen-Rossetti fundoplication in 2001. Since then, various authors have demonstrated the feasibility and safety of robot-assisted antireflux surgery both in adult patients [9, 10] and children [11]. Several studies [12–18], including four prospective randomized trials, [14–17] have compared robotic with standard laparoscopic fundoplication (Table 23.1) and no differences were found in terms of intraoperative and postoperative complications, length of hospital stay and symptomatic outcomes. Operative times were found to be longer than with standard laparoscopic procedures in five of the seven studies [12–16], and cost of the robotic procedures were significantly increased as well [14–17].

It is important to note, however, that the majority of these studies presented significant bias due to the small number of patients recruited and the fact that they represented the first cases of the learning curve (for both the surgeon and the team), while a larger experience with laparoscopic Nissen-Rossetti fundoplication had been already accumulated [14–16].

Recently, one prospective randomized study [17] and one retrospective comparative study [18] reported decreased operative times for robotic versus laparoscopic Nissen fundoplication. The author's personal experience (October 2000–April 2007) is reported in Fig. 23.13 and in Table 23.2. In our experience, the operative time significantly decreased after the first 20 procedures (92 ± 21 min vs. 132.8 ± 40 min) [9] and with the introduction of the fourth arm on the system

Table 23.1 Reported studies comparing Robotic versus laparoscopic fundoplication

Author	N (R/L)	Age ± SD (range)	Operating time ± SD (range)	Setup time ± SD (range)	Conversion	Costs	Morbidity	LOS ± SD (range)
Cadiere [12]	10 11	38 (18–52) 40 (29–62)	76 (59–130) 52 (45–62)	NA	NA	NA	1 1	1 (1–4) 1 (1–18)
Melvin [13]	20 20	49.6 42.9	140.9 (88–271) 97.1 (45–161)	NA	NA	NA	0 0	1 1
Morino [14] [a]	25 25	43 ± 13 46 ± 11	131 ± 3 91 ± 1	23 ± 65	1 2	3157 1527	0 0	3.0 2.9
Nakadi [15][a]	9 11	44 ± 4 48 ± 4	137 ± 4 96 ± 5	23 ± 4	1 0	6973 5167	1 0	4.1 ± 0.3 4.4 ± 0.2
Draaisma [16][a]	25 25	48 (20–74) 52 (27–71)	120 (80–180) 95 (60–210)	10 (3–15)	0 2	NA	0 8	3 (2–6) 3 (1–13)
Muller-Stich [17]a	20 20	49.6 ± 12 50.5 ± 12.4	88 ± 18 102 ± 19	23 ± 5 20 ± 3	NA	NA	0 0	2.9 ± 0.8 3.3 ± 0.8
Ceccarelli [18]	45 137	54 (26–76) 55 (29–76)	65 (40–105) 85 (45–130)	NA	2 0	NA	1 8	3.04 (2–4) 3.19 (2–6)

N: number of patients. R: Robotic approach. L: laparoscopic approach. Age in years. Operative time in minutes. Setup time in minutes. SD: standard deviation. Costs in Euros. LOS: length of stay (in days)
[a]Randomized studies

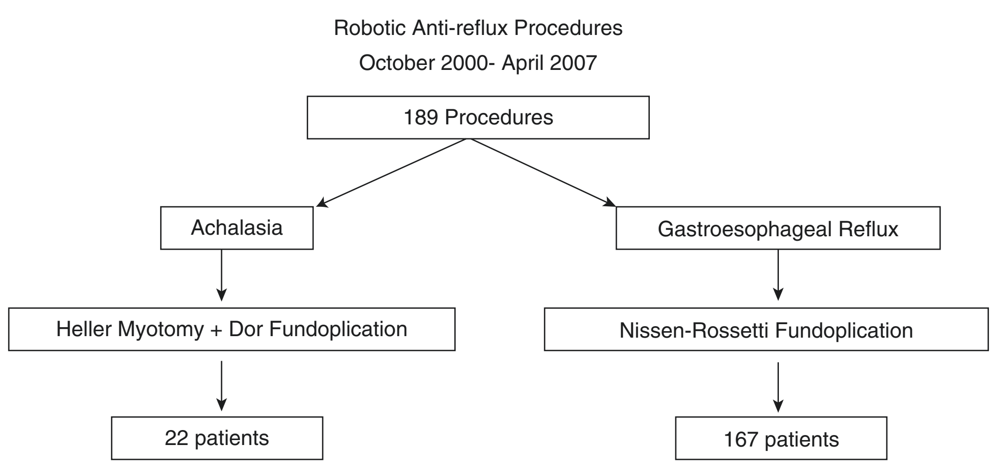


Fig. 23.13 Personal experience of robotic fundoplication

Table 23.2 Demographics and peri-operative results for 167 Robotic Nissen-Rossetti fundoplication

		p value
Gender (M/F)	83/84	–
Mean age (± SD)	53 ± 15 years	–
Conversion (%)[a]	3 (4.4%)	–
Associate procedures[b]	25 (14.9%)	–
Three arm version Four arm version	86 81	–
Overall mean operative time[c] (± SD)	84 ± 49 min	–
Mean operative time for the first 20 cases (± SD)	132.8 ± 40 min	
Mean operative time for the second 20 cases (± SD)	92 ± 21 min	**p < 0.05**
Mean operative time cases with the three arms version (±SD) after the learning curve	88 ± 47 min	
Mean operative time cases with the four arms version (±SD)	71 ± 34 min	**p < 0.05**
Mortality	0	–
Morbidity[d]	0.5%	–
Mean hospital stay (range)	1.6 days (1–5)	–

[a]One to open surgery for left liver lobe injury; two to conventional laparoscopy for adhesions
[b]24 cholecystectomies and one ventral hernia repair
[c]Excluding associate procedure
[d]One peri-operative hemorrhage treated conservatively

(71 ± 34 min vs. 88 ± 47 min). In fact, in our last 40 cases, the overall operative time, including operative set-up, was less than 1 h. Thus, in institutions where the robot is used on a daily basis, and the team is well trained, the operative time is comparable to conventional laparoscopy. In our experience, on long-term follow up, two patients (1.19%) required reoperation due to permanent dysphagia, as a result of peri-hiatal sclerosis.

At the beginning of the laparoscopic experience, it was suggested that dividing the short gastric vessels would improve the outcome following laparoscopic total fundoplication. Several studies, however, including four prospective randomized trials, [19–21] have investigated the role of the short gastric vessels during Nissen-Rossetti fundoplication, and have found division of the vessels to be associated with an increase in the length and complexity of the procedure. In fact, in two studies, it resulted in a poorer outcome due to an increase in wind-related sequelae [20, 22].

Huntington et al. [23], in a study that focused on the geometry involved in the construction of a laparoscopic Nissen fundoplication by measuring individual variations in fundic length, showed that tension on the antireflux wrap, rather than division of the short gastric vessels, was the crucial factor for achieving a satisfactory clinical outcome. Thus, the division of the short gastric vessels has to be tailored, according to the geometry of the gastric fundus.

We believe that the robotic system enables the performance of a technically correct floppy fundoplication, in large part to its wristed instruments and stable view, which allow the dissection to be targeted to the hiatal region only. As mentioned earlier, the dissection of the extraperitoneal posterior part of the gastric fundus represents the most important factor in achieving an optimal length of the wrap. The sparing of all vagal fibers in the gastrohepatic ligament and the avoidance of a routine take down of short gastric vessels allow for better preservation of the regional physiology. Some of the complications observed following laparoscopic Nissen-Rossetti fundoplication can be attributed to accidental injuries of vagal fibers and/or extensive dissection of the greater curvature and consequent denervation. The technique presented for the robotic Nissen-Rossetti fundoplication has the potential to reduce these types of complications.

References

1. Watson DI, Jamieson GG. Antireflux surgery in the laparoscopic era. Br J Surg. 1998;85:1173–84.
2. Nilsson G, Wenner J, Larsson S, Johnsson F. Randomized clinical of laparoscopic versus open fundoplication for gastro-esophageal reflux. Br J Surg. 2004;91:552–9.
3. Dallemagne B, Weerts JM, Jehaes C, Markiewicz S, Lombard R. Laparoscopic Nissen fundoplication: preliminary report. Surg Laparosc Endosc. 1991;1:138–43.
4. Stewart GD, Watson AJ, Lamb PJ, et al. Comparison of three different procedures for antireflux surgery. Br J Surg. 2004;91:724–9.
5. Richards KF, Fisher KS, Flores JH, Christensen BJ. Laparoscopic Nissen fundoplication: cost, morbidity, and outcome compared with open surgery. Surg Laparosc Endosc. 1996;6:140–3.
6. Bailey ME, Garrett WV, Nisar A, Boyle NH, Slater GH. Day-case laparoscopic Nissen fundoplication. Br J Surg. 2003;90:560–2.
7. Watson DI, Baigrie RJ, Jamieson GG. A learning curve for laparoscopic fundoplication. Definable, avoidable, or a waste of time? Ann Surg. 1996;224:198–203.
8. Cadiere GB, Himpens J, Germay O, et al. Feasibility of robotic laparoscopic surgery: 146 cases. World J Surg. 2001;25:1467–77.
9. Giulianotti PC, Coratti A, Angelini M, et al. Robotics in general surgery: personal experience in a large community hospital. Arch Surg. 2003;138:777–84.
10. Chitwood WR Jr, Nifong LW, Chapman WH, et al. Robotic surgical training in an academic institution. Ann Surg. 2001;234:475–84. discussion 484–6
11. Meehan JJ, Meehan TD, Sandler A. Robotic fundoplication in children: resident teaching and a single institutional review of our first 50 patients. J Pediatr Surg. 2007;42:2022–5.
12. Cadiere GB, Himpens J, Vertruyen M, et al. Evaluation of telesurgical (robotic) Nissen fundoplication. Surg Endosc. 2001;15:918–23.
13. Melvin WS, Needleman BJ, Krause KR, Schneider C, Ellison EC. Computer-enhanced vs. standard laparoscopic antireflux surgery. J Gastrointest Surg. 2002;6:11–5. discussion 15–6
14. Morino M, Pellegrino L, Giaccone C, Garrone C, Rebecchi F. Randomized clinical trial of robot-assisted versus laparoscopic Nissen fundoplication. Br J Surg. 2006;93:553–8.
15. Nakadi IE, Melot C, Closset J, et al. Evaluation of da Vinci Nissen fundoplication clinical results and cost minimization. World J Surg. 2006;30:1050–4.

16. Draaisma WA, Ruurda JP, Scheffer RC, et al. Randomized clinical trial of standard laparoscopic versus robot-assisted laparoscopic Nissen fundoplication for gastro-oesophageal reflux disease. Br J Surg. 2006;93:1351–9.
17. Muller-Stich BP, Reiter MA, Wente MN, et al. Robot-assisted versus conventional laparoscopic fundoplication: short-term outcome of a pilot randomized controlled trial. Surg Endosc. 2007;21:1800–5.
18. Ceccarelli G, Patriti A, Biancafarina A, et al. Intraoperative and postoperative outcome of robot-assisted and traditional laparoscopic Nissen fundoplication. Eur Surg Res. 2009;43: 198–203.
19. Watson DI, Pike GK, Baigrie RJ, et al. Prospective double-blind randomized trial of laparoscopic Nissen fundoplication with division and without division of short gastric vessels. Ann Surg. 1997;226:642–52.
20. O'Boyle CJ, Watson DI, Jamieson GG, Myers JC, Game PA, Devitt PG. Division of short gastric vessels at laparoscopic Nissen fundoplication: a prospective double-blind randomized trial with 5-year follow-up. Ann Surg. 2002;235:165–70.
21. Blomqvist A, Dalenback J, Hagedorn C, Lonroth H, Hyltander A, Lundell L. Impact of complete gastric fundus mobilization on outcome after laparoscopic total fundoplication. J Gastrointest Surg. 2000;4:493–500.
22. Chrysos E, Tzortzinis A, Tsiaoussis J, Athanasakis H, Vassilakis J, Xynos E. Prospective randomized trial comparing Nissen to Nissen-Rossetti technique for laparoscopic fundoplication. Am J Surg. 2001;182:215–21.
23. Huntington TR, Danielson L. Variation in fundic dimensions with respect to short gastric vessel division in laparoscopic fundoplication. Surg Endosc. 2001;15:76–9.

Robotic Paraesophageal "Giant" Hiatal Hernia Repair

24

Kemp Kernstine Sr. and John K. Waters

Abstract

Paraesophageal hiatal hernias are typically type III, the gastroesophageal junction and the viscera are herniated through the esophageal hiatus. Symptomatic patients should be surgically repaired. The asymptomatic patients should be managed on a case-by-case basis. The preoperative evaluation and the details of the operative techniques of performing a robotic paraesophageal hiatal hernia repair are described.

Keywords

Esophagitis/surgery • Female • Fundoplication • Gastroesophageal reflux/etiology/surgery • Hernia • Hiatal/complications • Paraesophageal hernia • Intrathoracic stomach • Giant hiatal hernia • Laparoscopy • Robotic • Sac excision • Esophagogastric junction/physiopathology • Hiatal hernia repair • paraesophageal hernia recurrence • Crural repair • Technique • Mesh cruroplasty

24.1 Background, Specific Indications

Hiatal hernia affects 5% of the Western population. Most are sliding hernias; 5 % are paraesophageal. Paraesophageal hernias result from localized defects in the phrenoesophageal ligament, leading to cephalad migration of abdominal viscera through the diaphragmatic hiatus. This most likely is an acquired defect, predominantly affecting the elderly. Additional associative factors include female gender, family history, obesity, chronic cough, repeated straining, and childbirth.

Hiatal hernias are classified into categories I—IV. Paraesophageal hernias represent Types II, III, and IV. Type II hernias are the rarest and contain a normally positioned gastroesophageal (GE) junction with a herniated stomach. Type III hernias are the most common and contain an intrathoracic GE junction and herniated stomach. Type IV hernias includes a hernia of other abdominal visceral beside the stomach.

GE junction migration occurs for a variety of reasons. These include distortion and thinning of the normal phrenoesophageal ligament attachments by a large abdominal hernia sac and esophageal and periesophageal inflammation from the trauma of the hernia and chronic reflux induced inflammation and submucosal scarring. Negative intrathoracic pressure creates a vacuum for abdominal viscera to enter the chest. Herniated abdominal viscera can twist and rotate, resulting in variable degrees of obstruction and/or strangulation.

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Department of Cardiovascular and Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

J. K. Waters, M.D.
Department of Cardiovascular and Thoracic Surgery, University of Texas Southwestern Medical Center,
5959 Harry Hines Blvd, POB1-10th floor, Suite HP10.110, Dallas, TX 75390-8879, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_24

Most paraesophageal hernias are symptomatic. Symptoms include: chest and abdominal pain, regurgitation, dysphagia, nausea and retching, iron deficiency anemia, and frank gastrointestinal bleeding. Ulcerative esophagitis occurs in 20% of patients; esophageal stricture in 15%. An uncommon presentation is Borchardt's Triad of chest pain, retching, and the inability to pass a nasogastric tube, due to gastric torsion and strangulation.

Management of paraesophageal hernias is controversial. Historically, surgeons advocated repairing all of these hernias. This stemmed from Skinner and Belsey's review of 1030 patients in 1967, which reported 30% mortality in patients with unrepaired hernias [1]. Hill et al. corroborated this data in 1973, reporting that 30% of patients with an intrathoracic stomach presented for emergency surgery [2]. In patients who underwent emergency operation in this series, 20% died. Pearson et al. found that 43 of 53 patients with an intrathoracic stomach (which was observed) developed acute symptoms of substernal or epigastric pain and dysphagia. Bleeding and gastritis occurred from gastric incarceration in 24 of 53 [3]. In 1984, Walther et al. reported a 30% incidence gastric volvulus, strangulation, and bleeding in patients with incarcerated paraesophageal hernias [4].

Recent data however is less convincing on the need for surgery in all patients with paraesophageal hernias. In 1993, Allen and colleagues reported that patients with an intrathoracic stomach could be safely observed; 0 of 23 patients in this Mayo Clinic series developed symptoms over a period of 6 years [5]. Two national database studies from the US and Finland verified this finding [6, 7]. Stylopoulos et al. [6] showed that the likelihood of developing acute symptoms with a paraesophageal hernia was 1.1%. Although the reported mortality of emergency surgery for a large paraesophageal hiatal hernia was high (17%), this group estimated that 83% of paraesophageal hernias were appropriately managed by watchful waiting. Seventeen percent were best managed by elective surgery. In 2009, Sihvo and colleagues presented a study of a Finnish population database noting that the emergency surgery rate for an intrathoracic stomach was 1.16% per year, operative mortality of emergent surgery was 2%, and that the mortality of symptomatic "watchful waiting" was 16% [7].

Current recommendations from the Society of American Gastrointestinal and Endoscopic Surgeons are that patients with a symptomatic paraesophageal hernia or with a prior episode of volvulus should undergo elective surgical repair. Asymptomatic patients should be selected for surgery on a case-by-case basis. Surgical decision-making should include analysis of patient age, physiologic status, disease severity, the presence and degree of co-morbidities, and the likelihood of hernia incarceration and strangulation.

The most helpful study in patients with a paraesophageal hernia is an upper gastrointestinal contrast examination (UGI). This provides information about the esophageal and gastric anatomy, the size of the hiatal defect, the type of hiatal hernia, the relationship of the hernia to other structures in the thorax and the upper abdomen, the location of the GE junction relative to the esophageal hiatus, esophageal and gastric motility, esophageal reflux, strictures, masses, ulcers, gastric or esophageal obstruction, and gastric volvulus. Scrutiny of the esophageal portion of the swallowing study may obviate the need for a motility study. The UGI series also serves as a baseline evaluation of which to compare future upper gastrointestinal series (Fig. 24.1).

An upper gastrointestinal endoscopy provides additional, important information. It can detail the amount of herniated stomach, the presence of volvulus and degree of venous engorgement, the health of the stomach and gastric mucosa, the presence of gastritis and/or ulcerations– specifically Cameron's ulcers, evidence of esophageal reflux, ulceration, and stricture, the presence of Barrett's esophagus and esophageal masses, and the location of the gastroesophageal junction.

Manometry and pH studies are not uniformly performed in patients with a paraesophageal hernia. Surgeons who do not perform these tests believe that regardless of the test results, an antireflux procedure will be performed at the time of hernia repair. Our experience is that between 30 and 60% of patients with a paraesophageal hernia are found to have disordered esophageal motility and 70–80% have abnormal esophageal acid exposure. This information can be helpful in tailoring a surgical repair, providing baseline data against which surgery can be compared, and giving patients a more realistic expectation of their likelihood for swallowing improvement after surgery.

The goals of paraesophageal hiatal hernia surgery are to alleviate symptoms, to minimize morbidity and mortality, to reduce the cost-of-care and to minimize recurrence.

Basic surgical principles of paraesophageal hernia repair include:

1. Restoration of intrathoracic viscera to the peritoneal cavity; resection of threatened or necrotic tissue.
2. Removal of the hernia sac

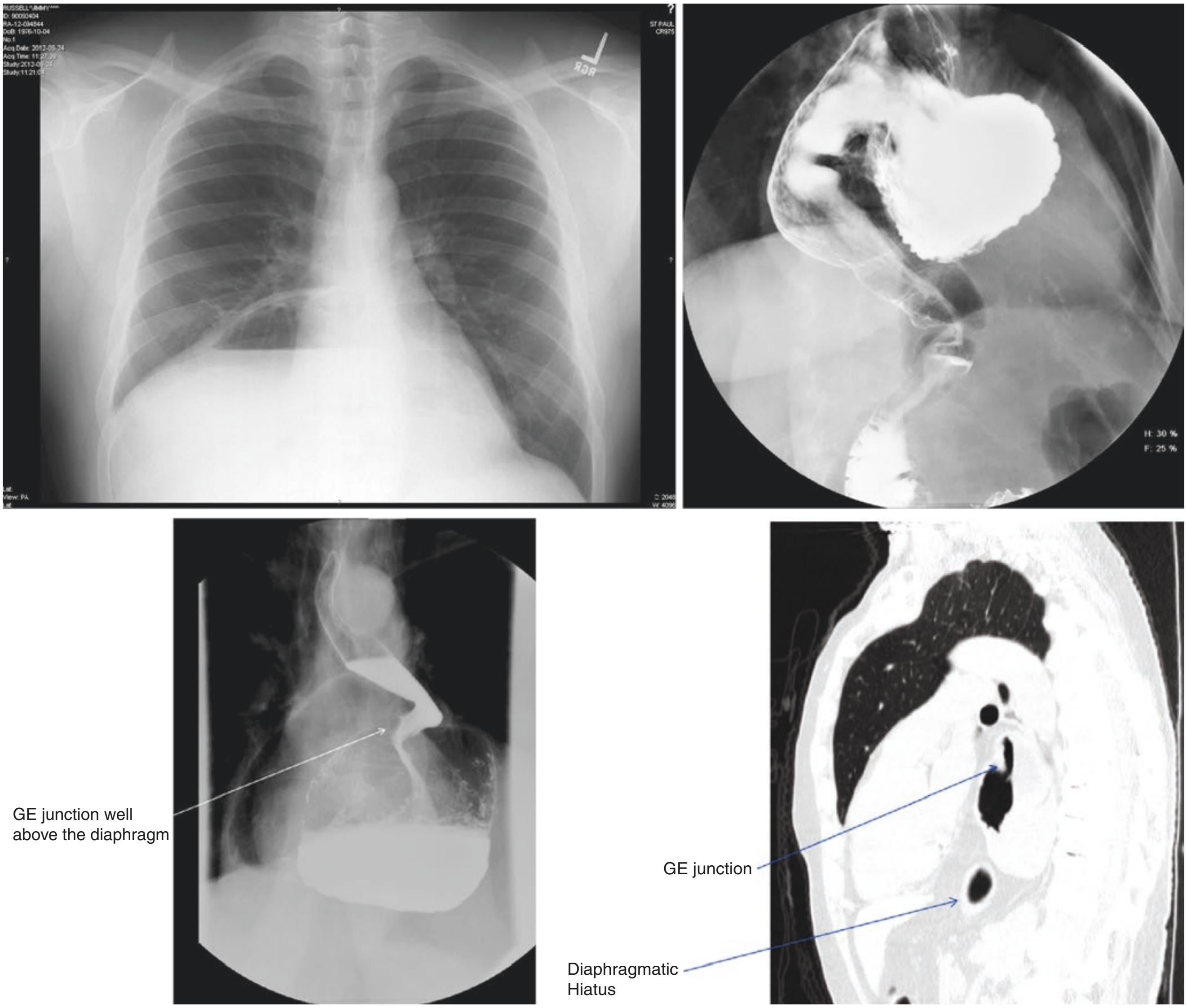


Fig. 24.1 **Representative radiographic images of a type III hiatal hernia.** A representative series of radiographic pictures from one of our patients showing a chest radiograph (**a**), an upper gastrointestinal contrast series (**b**, **c**) demonstrating the mediastinal position and rotation of the stomach into the thorax. At surgery, all of the stomach was found in the chest. (**d**) The lateral projection of the contrast study notes the aortic knob indentation into the patulous esophagus and the distorted and dysfunctional gastroesophageal junction (see *arrow*). In the bottom right is the sagittal view of a chest computed tomogram demonstrating the location of the gastroesophageal junction and the level of the diaphragmatic hiatus

3. Repair of the hiatal or diaphragmatic defect in a tension-free fashion
4. Creation of adequate intra-abdominal esophageal length
5. Fixation of the stomach in the abdomen and performing an antireflux procedure, if necessary

In most patients, the hernia contents can be reduced easily into the abdomen. Adhesions and the attenuated gastric wall can present challenges however. The intra-thoracic peritoneal lined hernia sac is surrounded by scar, which should be excised; persistence of the sac and the surrounding scar tissue results in chronic tension on the gastroesophageal junction and the sac contents, preventing the creation of sufficient intra-abdominal esophageal length. Failure to remove the sac also results in difficulty identifying the precise location of the gastroesophageal junction, increased likelihood for hernia recurrence, and increased risk of developing symptomatic mediastinal fluid collections that may require reoperation.

To reduce the likelihood of recurrence, there must be adequate intra-abdominal length of the distal esophagus; historically, this is approximated at 3–4 cm. To achieve this, circumferential dissection of the esophagus to the level of the aortic arch may be necessary. Occasionally, the middle esophageal artery and left inferior bronchial artery may need to be divided. Some surgical groups advocate the routine use of an esophageal lengthening procedure, such as a Collis gastroplasty. Placing acid secreting gastric mucosa at or above the hiatus repair can lead to post-operative esophagitis, dysphagia, or esophageal dysmotility.

Large defects in the diaphragm hiatus (greater than 5–6 cm) can be challenging to close. In these cases, the crura, surrounding diaphragm muscle, and supportive fascia are attenuated and do not hold sutures well. To stabilize repairs, both anterior and posterior cruroplasty have been described. Most authors advocate the posterior cruroplasty as the closure is more easily achieved without tension and esophageal length is more likely to be preserved. Preserved esophageal length is achieved in the posterior cruroplasty because the esophagus traverses the diaphragm at the apex of the diaphragmatic curvature rather than at the base. The hiatus closure is performed with a 60-French bougie inside of the esophagus. Simple, vertical or horizontal mattress sutures are placed in areas of visible tension along alternating muscle anatomical planes of the esophageal hiatus. This can have the effect of "rolling-up" the muscular defect. Pledgets of synthetic or biologic reinforcement are selectively used. Polypropylene and polytetrafluoroethylene mesh have the benefit of reducing hernia recurrence by 60%, but carry the risk of resulting in erosion, ulceration, and esophageal stricture. Biologic materials such as the ligamentum teres, AlloDerm®, Strattice®, and Surgisis® have been used in various ways to provide support. Biologic reinforcement does not appear to result in stricture or erosion. Randomized data does not show that biological mesh reduces the rate of recurrence, but it may reduce the likelihood of requiring reoperation.

Gastric fixation is the final component of paraesophageal hernia repair. This can be performed by gastropexy or fundoplication. The posterior gastropexy or Hill repair provides suture anchoring of the gastroesophageal junction to the median arcuate ligament. The anterior gastropexy can be accomplished with several suture ligatures to the anterior abdominal wall and can also be performed by placing a gastrostomy tube. Both anterior gastropexy techniques provide anterior fixation to the abdominal wall; the gastrostomy provides an option to decompress the stomach and ready access for postoperative feeding in malnourished patients. Gastropexy has been used as an adjunct to maintain the stomach in the abdomen, but has a rate of recurrence when used alone, because the pliability and redundancy of the stomach can result in reherniation through the diaphgram hiatus. If gastropexy is used in conjunction with an antireflux procedure, it may increase the rate of recurrence as it can place tension on the wrap.

Fundoplication alone has the advantage of fixing the stomach below the diaphragm and creating an antireflux mechanism. The vast majority of paraesophageal hiatal hernia patients have a defective lower esophageal sphincter and many complain of reflux-related symptoms. At the time of surgery, the extensive surgical dissection required to remove the sac and lengthen the esophagus destroys the normal phrenoesophageal attachments. These factors suggest that the performance of an anti-reflux procedure, such as Nissen fundoplication, is necessary. Performing a Nissen does not appear to impair esophageal body motility in these patients. In patients who have evidence of preoperative esophageal dysmotility, some surgeons advocate a partial fundoplication, such as a Toupet or Dor. There is evidence that partial fundoplication rather than full fundoplication worsens the likelihood for post-operative reflux in patients with impaired esophageal motility.

We have applied a robotic approach to the repair of the giant paraesophageal hiatal hernia. The robotic approach has several advantages: the three-dimensional surgeon-directed visibility allows for detailed characterization of the anatomical defect and complete removal of the hernia sac and the multiple arcs of rotation on the robotic arms allow for dissection high into the mediastinum and precise placement of sutures during the repair. With greater experience, the lack of tactile feedback can be visually overcome.

24.2 Operative Setup

Two hours prior to surgery, patients brush their teeth, buccal cheeks, floor and roof of the mouth, and tongue with 1000 mg of Augmentin and then 30 mL of nystatin, swallowing the remainder after completion. Within 30 min of incision, patients receive prophylactic intravenous antibiotics which is re-administered every 4 h. Patients are placed in supine or lithotomy position and all pressure points are padded. A padded footboard is placed on the OR table if the patient is placed supine. After induction of general anesthesia, a single-lumen endotracheal tube is placed. The robot or bedside cart is brought in over the patient’s head and the patient is placed in steep reverse-Trendelenburg position. The abdomen is marked with an indelible pen for the potential port locations. Lower extremity sequential anti-thrombotic compression devices are placed.

24.3 Anesthetic Management

After the endotracheal tube is placed, a nasogastric tube is inserted into the patient and placed on continuous low suction. Sufficient space is made at the head of the operating room table for the upper GI endoscopy equipment. The endoscope is advanced to the GE junction, the light is turned off and the operating end of the scope is fixed to the operating room table. The light may be turned back on periodically during surgery to view the dissection area and to help prevent injury to the esophagus and stomach during the dissection.

Fluid management can present a challenge. Patients are place in reverse-Trendelenburg position and CO_2 is infused at various pressures to provide adequate intraabdominal operating space. The CO_2 pressure and dissection around the heart may decrease venous return and cause hypotension. Patients with compromised baseline heart function may require reduction of the intraperitoneal CO_2 pressure, judicious fluid administration, and vasopressor and/or inotropic support.

Respiratory acidosis from the infused CO_2 can also occur. Increasing the minute ventilation will help to correct the acidosis. Partial pressures of CO_2 are fairly well tolerated in the range of 60–70 mmHg. It is rare that patients will require bicarbonate or lactate to correct a respiratory acidosis.

24.4 Stepwise Conduct of the Operation

Most patients are placed in the supine position. Pressure points are well padded and an antithrombotic lower extremity compression system is used. Following intubation, the abdomen and lower chest are marked for prospective laparoscopic ports placement and then prepped and draped. Prior to placing each port, a solution 0.125% bupivacaine with epinephrine (diluting the standard mixture of 0.25% bupivacaine with epinephrine with saline for injection to reduce the concentration by half) is infiltrated into the subcutaneous tissue, fascia, and preperitoneal space. A Veress needle is placed into the peritoneum at Port site D and insufflated to 15 mmHg with CO_2 (Fig. 24.2). The robot is brought over the patient’s head from the top of the operating table. The patient is then placed in steep reverse-Trendelenburg position and the robot is docked. The 30° down videoscope is inserted into the video port. A Prograsp is placed into the right robotic arm. A Harmonic scalpel is placed into the left robotic arm. The Bedside Surgeon assists with exposure, using atraumatic bowel graspers to retract viscera to expose the diaphragm hiatus. A liver retractor is placed in the abdomen to retract the left lateral segment of the liver. It is important to avoid grasping the viscera with the Robotic ProGrasp, as it will lead to bowel injury. Once there is sufficient space around the diaphragmatic hiatus, the Bedside Surgeon-and robotic surgeon grasp and evert the hernia sac into the peritoneal cavity (Figs. 24.3 and 24.4).

Large hernia sacs can be challenging to manage. In these cases, the hernia sac can be grasped cephalad to the most anterior and superior aspect of the left crus. The sac is then incised and this incision is continued circumferentially in both anterior and posterior directions. It is essential to resect the sac and to bluntly separate it from mediastinal structures. Too deep of a dissection can result in bleeding.

Once the hernia sac is excised, the GE junction is exposed by removing its overlying fat pad (Fig. 24.5). A ½ to 1 in. Penrose drain is passed around the distal esophagus and a vascular stapler is used to connect the two ends of the Penrose drain (Fig. 24.6). The Penrose—not the stomach, esophagus, or perigastric tissue –is then grasped to create tension along the esophagus, during the dissection in order to improve visualization. Slow, steady caudad retraction will expose fibrous bands adherent to the esophagus in the mediastinum, which can be divided to achieve adequate esophageal mobilization (Fig. 24.7). The shortened esophagus can be managed by performing circular myotomies, extensive mediastinal dissection, truncal vagotomy, small or large bowel intestinal interposition, and Collis gastroplasty. Of these, Collis wedge gastroplasty is most commonly performed.

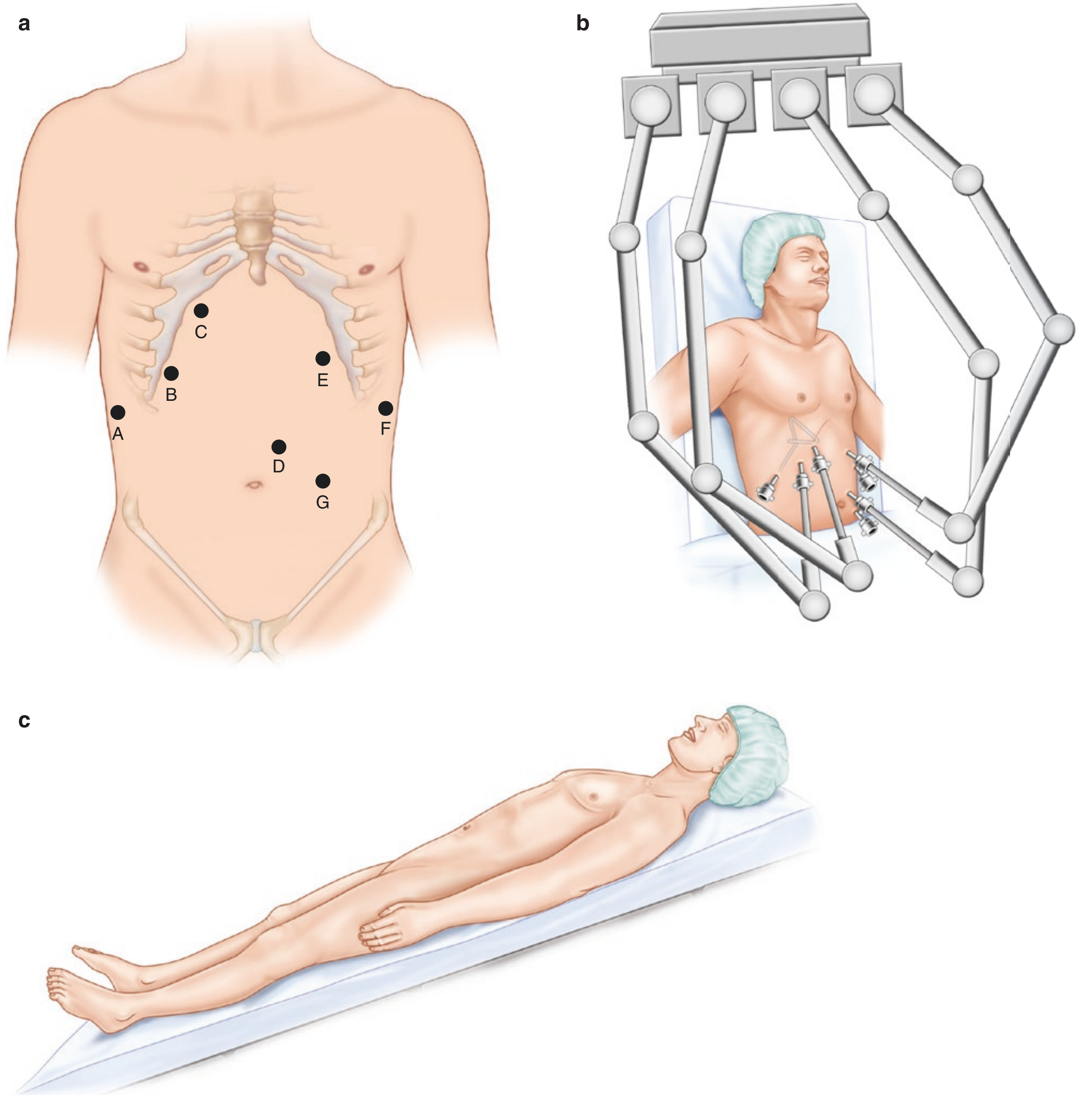


Fig. 24.2 **Potential laparoscopic/robotic port location.** The patient is positioned supine throughout the case. The bedside cart or robot is brought in over the patient's head and the patient is placed in steep reverse-Trendlenberg prior to attaching the robotic arms to the appropriate ports. **Port A**-5-mm port, mid to anterior axillary line just at the right costal arch-liver retractor, Diamond Flex, attached to a snake self-retaining retractor. CO2 infusion system attached here. **Port B**-8-mm robotic port, lateral-mid clavicular line, inferior to the costal arch, 8–10 cm lateral to Port C. Port is optional. Used for the 4th arm of the robot. Usually a ProGrasp. **Port C**-8-mm robotic port, just inferior to the costal arch about 2–4 cm caudad and near to a horizontal line as Port E, Ports C and E should be positioned 10 cm on either side of a lengthwise longitudinal line that includes Port D, used for ProGrasp, needle holder and Harmonic scalpel to provide angles. **Port D**-12-mm laparoscopic port, along a horizontal plane just anterior to the umbilicus and to the patient's left by 1–2 cm, used for the 30° down robotic videoscope (can be converted to a 0° scope for complex dissection in the mediastinal sac. **Port E**-8-mm robotic port, left mid clavicular line 1–4 cm just inferior to the costal arch dependent upon the abdominal protuberance of the patient, leftward robotic arm, Harmonic scalpel, ProGrasp, needle holder, and Bipolar Maryland dissector. **Port F**-5-mm port, mid to anterior axillary line just at the left costal arch, Bedside-surgeon auxiliary port. Increased to a 12-mm port for patients that require a Collis wedge gastroplasty. Used for a laparoscopic grasper, 5-mm fan retractor, laparoscopic suture scissors. **Port G**-12-mm port, along a horizontal plane 2 cm inferior to the umbilicus and to the patient's left by 4–5 cm—should be between the longitudinal lines of the videoport (**Port D**) and the leftward robotic arm (**Port E**) to avoid collision and maximal use, Bedside-surgeon auxiliary port. Used for grasping the hernia sac with caudad retraction, passage of sutures SH and CT-1 needles through the port without problems, passage of the mesh and Penrose drain, and passage of the vascular load stapler to attach the two ends of the Penrose around the distal esophagus

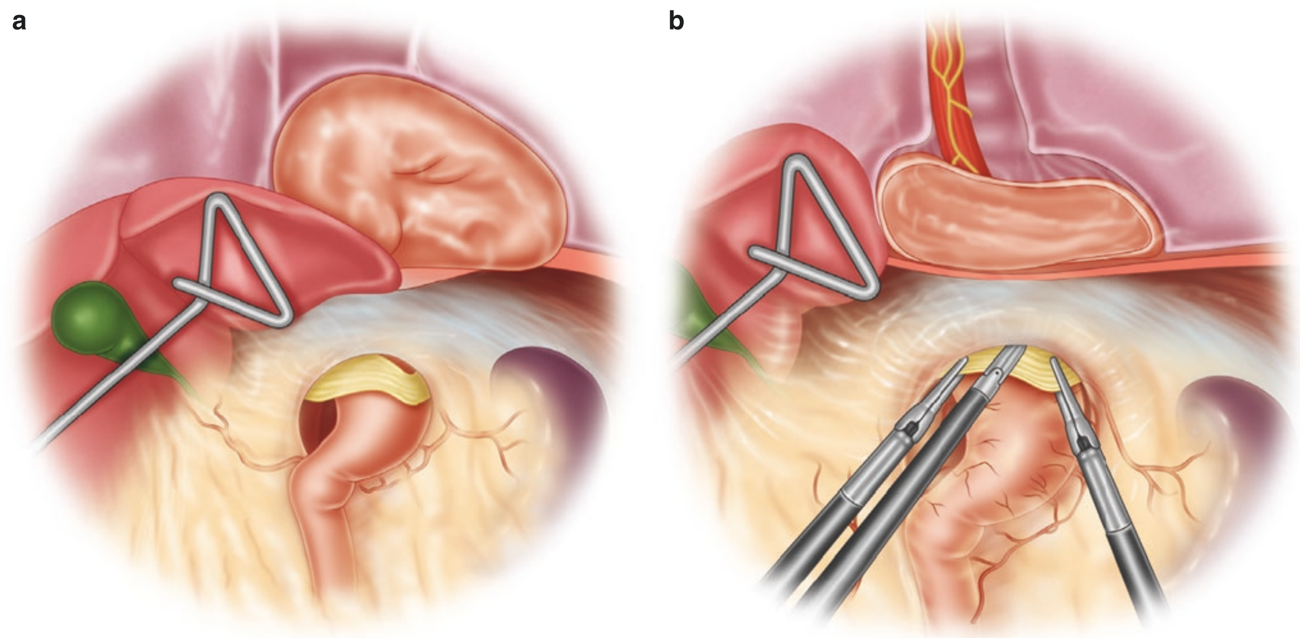


Fig. 24.3 Initial view of the operative area and reduction of the paraesophageal hernia. These two pictures are pictoral representations of the exposure at the beginning of the surgical procedure. The Diamond Flex liver retractor is positioned beneath the left lobe of the liver to expose the esophageal hiatus. For the majority of paraesophageal hernia patients, just placing the patient in reverse-Trendlenberg will allow most of the hernia contents to be reduced into the peritoneal cavity. Reducing the hernia contents is performed very carefully as they are often ischemic and edematous lending themselves to tearing, bleeding, and perforation. Grasping the contents with any of the robotic instruments poses risk and should be avoided. The Bedside surgeon-directed atraumatic graspers should be used instead

After sufficient esophageal length is created, the hiatus is closed. Unless the crura are healthy, completely covered with viable peritoneum, and appose under little tension, we use a posteriorly placed biological mesh to reapproximate the crura (Fig. 24.8). We used thick multi-ply Strattice® mesh (ACell [http://www.lifecell.com/health-care-professionals/lifecell-products/stratticetm-reconstructive-tissue-matrix/]). One-cm pledgets are cut from the Strattice and 4–5 horizontal and vertical mattress 0-Ethibond sutures (SH needle) are placed. A custom-made piece of Strattice® is then fashioned, which allows for sufficiently wide coverage of the base of the diaphragm (Fig. 24.9). Numerous 0-Ethibond sutures are placed to fix the edges of the mesh to the diaphragm and crura. Care is taken to prevent the mesh from touching the esophagus in order to reduce the risk of injury to the esophagus. We believe that this fixation technique provides a scaffold for tissue ingrowth, reduces tension, and strengthens the repair (Fig. 24.10).

In the majority of patients, we perform a fundoplication, either Nissen or Toupet. In patients who are elderly or have significant dysphagia, we perform an anterior gastropexy with a gastrostomy tube (Figs. 24.11 and 24.12). Once the operation is complete, we place a #19 round fluted silicone drain into the mediastinum through one of the lateral port sites. A nasogastric tube is kept in place overnight to allow for continuous gastric decompression and to reduce the likelihood of postoperative retching. The NG also provides a conduit to perform a diatrizoate meglumine and diatrizoate sodium solution contrast study on post-operative day 1. Provided there are no leaks or obstruction on this study, the NG is removed and a barium swallow is performed (Fig. 24.13). Should delayed emptying or obstruction be identified, the nasogastric tube is left in place and the study repeated after a few additional days. A normal swallow exam allows a clear liquid diet to be initiated and advanced to a full liquid diet prior to discharge. Patients may remain on a full liquid diet for the next 1–2 weeks and then their diet is advanced to a regular diet in the outpatient setting. Median hospital stay for a robotic assisted reduction and repair of hiatal hernia is 3–4 days. The drain is left in place for between 3 and 5 days up to 2 weeks, until the output is less than 30 ml per day.

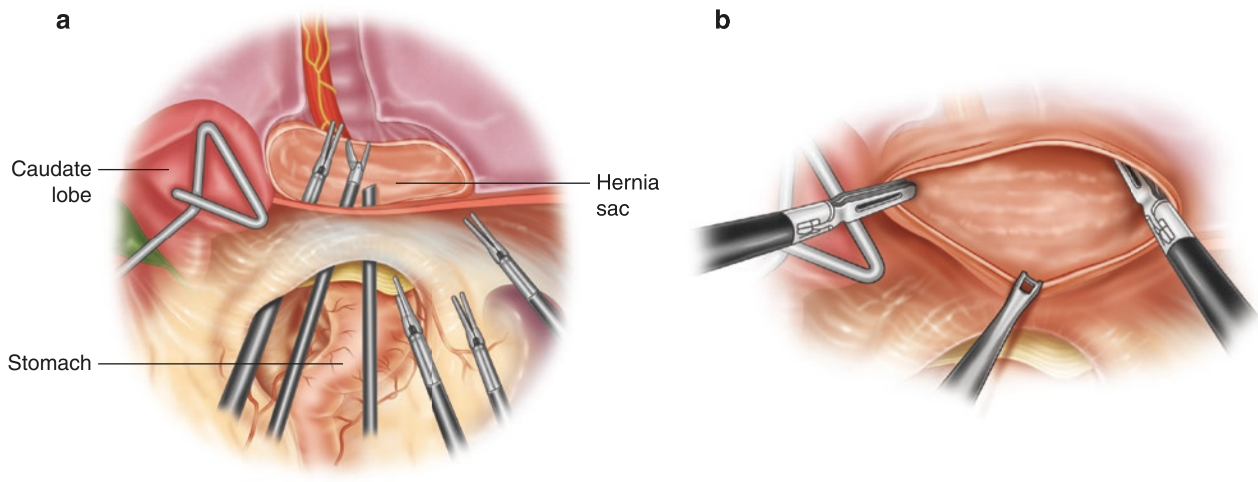


Fig. 24.4 **Intramediastinal peritoneal sac identification and eversion for resection.** To the *left*, this picture depicts the anatomy at the outset of the case. The stomach is no longer in the hernia sac and has fallen into the abdominal cavity or has been gently, hand-over-hand, pulled into the abdomen by the Bedside-Surgeon. Most often, part of the stomach still remains in the lower posterior portion of the sac. There should be no effort to pull the stomach down any further, the fibrosis in the peritoneal lining is preventing it from discending into the peritoneal cavity. Instead, the robotic videoscope should be inserted well into the hernia sac and using the robotic ProGrasps in the auxiliary port and the right and left robotic arms, and the Bedside-Surgeon managed atraumatic graspers and a as necessary laparoscopic Babcock, the peritoneal lining is identified and grasped at its highest point. CO2 insufflation may need to be decreased to as little as 8 mmHg of pressure to allow the peritoneal lining to be fully everted into the peritoneal cavity. The robotic ports may need to be "hubbed" or pushed into the peritoneal cavity to reach the apex. In one of our patients with a very lax and protuberant abdomen, we placed additional ports more cephalad and more medial to each other for this portion of the dissection, undocking and redocking the robot to those new ports for the thoracic or intramediastinal dissection for a particularly large mediastinal peritoneal hernia sac. Once the sac has been sufficiently everted, the ProGrasp that was at Port E is exchanged for a Harmonic scalpel to incise the peritoneal lining approximately 1 cm away from the edge of the crura. Most of this dissection of the peritoneal lining is performed in a blunt fashion once the initial incision is made into the sac. Dissection that occurs too deeply can lead to bleeding and only implies that a more superficial dissection needs to be developed, the lining is the only aspect it needs to be removed; it is location of the fibrotic component that is holding the stomach and other viscera into the fixed location. For those patients with a particularly large sac that at the outset of the hernia sac dissection cannot be fully everted, we typically choose the aspect just inside the anterior aspect of the left crus and from that point, we start the dissection anteriorly across to the right and posteriorly along the left crus to resect all the peritoneal lining. The troublesome locations are along the esophagus where injury to the esophagus and the Vagus nerves may occur. Small injuries to the mediastinal pleura are of no consequence and can be managed by placing a #19 or #24 fluted intrapleural chest drain into the pleural space of concern at the end of the case. There is potential of injuring the pericardium, phrenic nerves, inferior pulmonary veins, and airways. In once of our cases, the azygous vein was mobilized down with the hernia sac dissection. We have found that the sac has been a particularly helpful handle to assist in the dissection, providing counter-tension to identify the fibrotic bands attached to the sac. Early in our series, we found that excessive caudal retraction can tear the muscular esophagus and may potentially damage the Vagus nerves. It is this dissection that will allow for sufficient intraabdominal esophagus

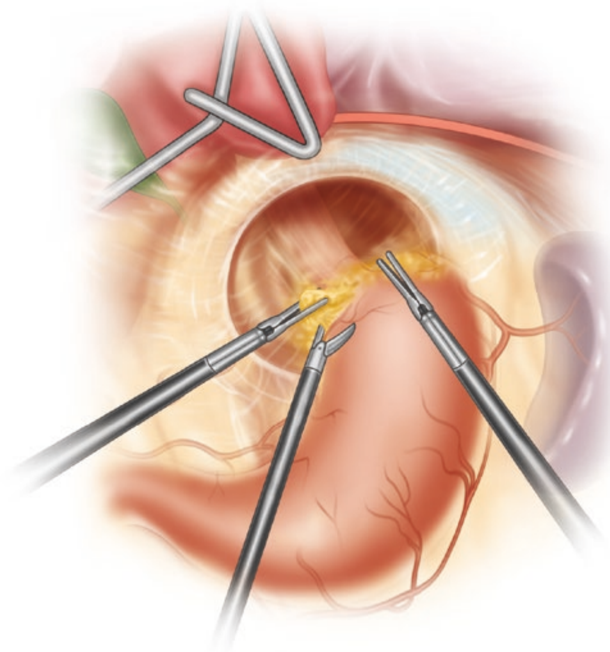


Fig. 24.5 Dissection of gastroesophageal junction fat (Belsey's Fat Pad) to expose the gastroesophageal junction. Once the hernia sac has been completely resected, potentially leaving only a small remnant along the area of the Vagus nerves, attention is turned to the GE junction. The surgeon must identify the location of the GE junction relative to the crura, the goal being to achieve at least 3–4 cm of intraperitoneal esophagus without retraction. With a ProGrasp in Port B the most leftward aspect of the anterior GE junction Fat Pad is grasped at a firm location of the anterior aspect of the Fat Pad rotating the leftward aspect of the GE junction into an anterior location. This rotation may be prevented by fibrous tissue, residual hernia sac, and short gastric vessels; all of which should be divided to provide sufficient laxity of the distal esophagus and proximal stomach. Then, with anoather ProGrasp or Bipolar Maryland Dissector that will provide very precise dissection from Port C and a Harmonic scalpel or another Bipolar Maryland in Port E to clean the longitudinal fibers of the esophagus and the smooth glistening serosa of the cardia of the anterior stomach. The dissection is initiated at the most leftward portion of the fat pad often just adjacent to the greater curvature of the cardia. Once completed, decisions can be made as to the ability to achieve adequate esophageal length in the abdominal cavity

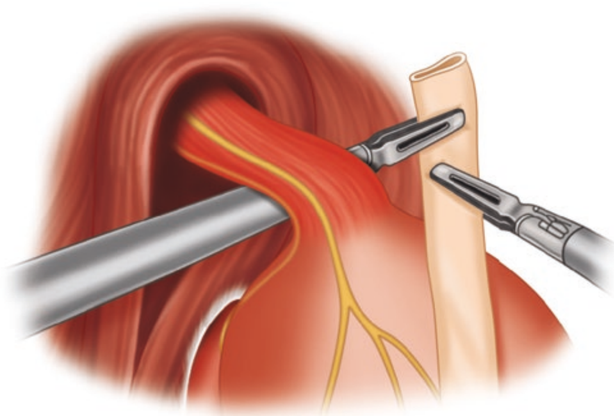


Fig. 24.6 Passage of the penrose drain around the distal esophagus. Once the gastroesophageal junction fat has been removed and the GE junction has been adequately identified and if there is no Collis gastroplasty required, a 10 cm portion of ½ to 1 in. wide Penrose drain is passed through port G to the operative area. The Penrose drain is then passed around the gastroesophageal junction and where the two ends meet a vascular load stapler fired to attach the two ends from Port G, the redundant Penrose drain is removed from the abdomen through Port G. The Bedside Surgeon through Ports F and G can then use the Penrose drain as a means of providing continuous caudal and other directional retraction to provide further retraction to identify bands along the esophagus and in the mediastinum to give more esophageal length, as necessary. In the vast majority of patients, well over 95% the dissection should be sufficient to avoid the necessity of a Collis gastroplasty

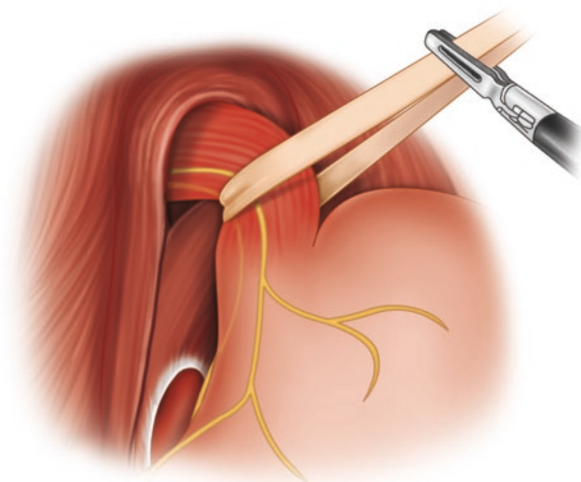


Fig. 24.7 Sufficient intra-abdominal esophagus length achieved. This picture demonstrates a sufficiently cleared hiatus with a sufficient length of intra-abdominal esophagus. Once this has been achieved, crura approximation and diaphragmatic repair can be performed

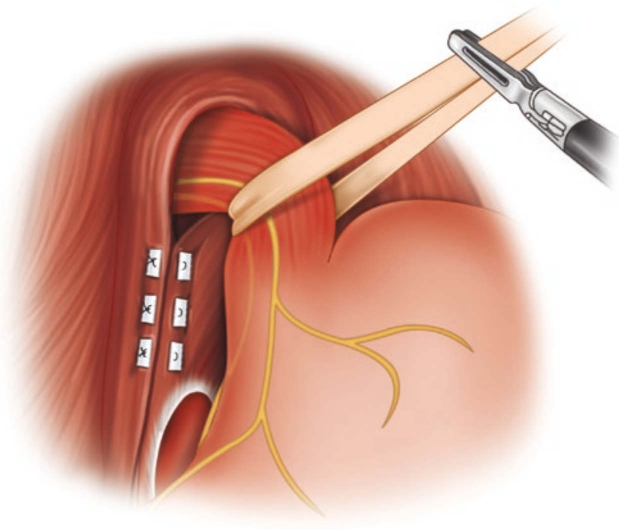


Fig. 24.8 **Primary closure of the crura.** With the upper GI endoscope pulled back and the nasogastric tube remaining in place and on continuous suction the Bedside Surgeon retracts the lower esophagus using the Penrose drain to the patient's left exposing the left and right crura. We then cut pledgets approximately 1 cm square from the Strattice® and we place multiple 8–12 cm lengths of 0 Ethibond on a SH needles pledgeted horizontal mattress sutures measured to provide just enough suture length to provide just enough suture length for tying the suture without excessive suture. After all of the sutures have been placed, the final hiatus should be 1.8–2 cm in diameter. Before placing the final hiatus sutures, tension should be released on the Penrose drain to determine if there is sufficient intra-abdominal esophagus. Retraction of the GE junction and part of the Penrose drain into the mediastinum is an indication for the performance of some means of lengthening procedure, such as a Collis gastroplasty. The final hiatal sutures are not placed until after the esophageal length has been achieved. If the Collis gastroplasty is necessary, the Penrose drain may need to be removed

24.5 Tips and Pitfalls

- Avoid operating for vague symptoms, as this could be the presentation of another condition. Perform thorough history and testing to assess for irritable bowel syndrome or psychiatric problems.
- Steep reverse-Trendelenburg bed position allows the hernia to be more easily reduced.
- Grasp the sac, not the stomach or other viscera.
- Leave peritoneum/pleura (part of the sac) around the crura.
- Mobilize the esophagus adequately to achieve more than 3–4 cm of intra-abdominal esophagus below the diaphragm hiatus. If sufficient length cannot be reached, perform an esophageal lengthening procedure.
- Sac dissection should be bloodless. If bleeding is noted, the dissection is too deep. Just the peritoneal lining needs to be resected; the sac contains the fibrotic tissue that fixes the abdominal organs in the mediastinum.
- On the leftward aspect of the sac, both the anterior and posterior aspects of the sac must be completely resected. Incomplete resection of the sac often along the posterior aspect of the hiatus and along left crus leads to recurrence.
- Along the rightward aspect of the sac, avoid injury to the vagus nerves.
- A ½" to 1″ Penrose drain placed around the distal esophagus provides an anchor to grasp the esophagus and a means to place the esophagus on stretch when performing the intra-mediastinal mobilization that will allow for sufficient intraabdominal esophagus length
- We use biological mesh for most of our repairs. We do not recommend the use of synthetic mesh. The biological mesh should not come in contact with the esophagus; normal vital tissue, such as the diaphragm hiatus muscle or omentum should be interposed between the mobile esophagus and the biological mesh for the repair.
- We do not recommend performing the combination of an antireflux procedure and an anterior gastropexy. These are two different physical means of reducing the likelihood for recurrence. Combining the two will reduce the effectiveness of principles of each of the separate procedures.
- For the first 1–2 weeks after the procedure, we recommend leaving a large fluted drain in the posterior mediastinal space. The drain is into this space through the abdomen by way of a laparoscopic or thoracoscopic port. The duration of drain use is dependent on the size of the mediastinal cavity; larger cavities require longer drainage periods. Drain output less than 30 ml/day for 3 or more days without an air fluid level in the mediastinum on chest radiograph and amylase less than 100 U/L are usually indications for drain removal.
- When gastrostomy tube is placed as a means of anterior gastropexy, we leave the gastrostomy tube in place for at least 9 months. Removing it sooner than 9 months has been associated with recurrence.
- When a Collis gastroplasty is performed, the fundus wrap should completely cover the neoesophagus staple line.

24.6 Brief Outcomes Section

Recurrence following paraesophageal hernia repair unfortunately is high, when patients are evaluated by esophagram and/or esophagoscopy. Systematic evaluation of surgical patients over time by UGI esophagram reveals a 12–60%

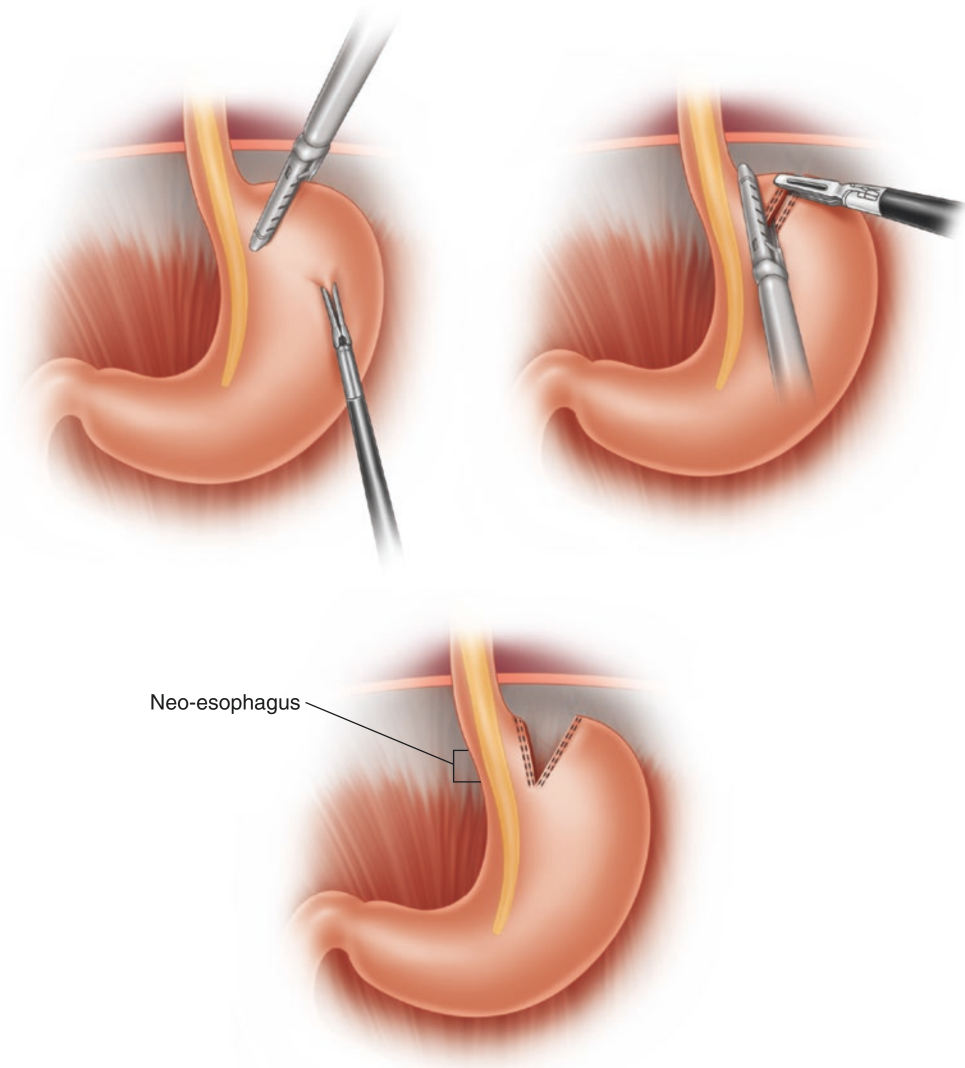


Fig. 24.9 **Performance of the wedge gastroplasty.** Prior to the crura being completely closed, the length of the esophagus is assessed, is there going to be 3–4 cm of intraabdominal esophagus. In the case of a shortened esophagus, an additional 2 cm of esophageal length may be gained by a wedge gastroplasty. Port F can be changed from a 5-mm port to a 12-mm port. The previously placed UGI endoscope is removed and a 50 French bougie is carefully placed. Avoid grasping the stomach with any robotic instruments at this time. The cardia is grasped by the Bedside Surgeon with an atraumatic grasper and from Port F multiple firings of a thick tissue stapler are performed to the previously placed bougie, until the stapler bounces off the bougie when closed. Once this transverse staple line is completed, a stapler is passed from Port G along the course of the bougie, completing the gastric tube or neoesophagus. The wedge of stomach is removed through one of the 12-mm ports

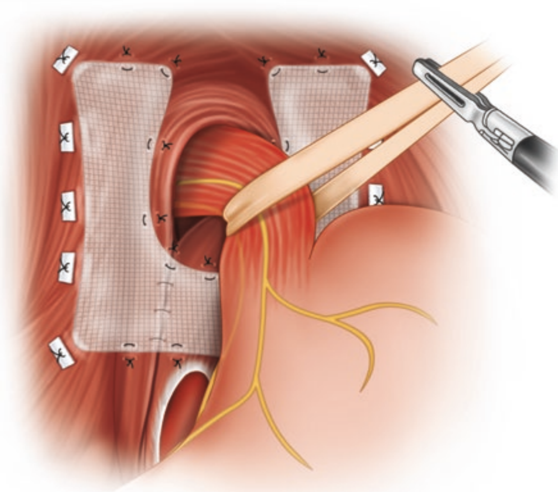


Fig. 24.10 **Reinforcement with Fashioned Multi-ply Strattice®.** The primary crura closure is then reinforced with a biological mesh. It is fixed to the diaphragmatic tissue with 10–15 0 Ethibond sutures in a horizontal mattress and simple fashion. Free interrupted sutures are placed through the thick biological mesh to the crura closure beneath. This firmly fixes the material to the surface of the diaphragm and provides strong support for postoperative healing. The mesh is fashion so that a rim of crura diaphragmatic muscle and peritoneal covering is juxtaposed between the esophagus and the mesh. Any firm material adjacent to the esophagus has been reported to erode through the esophageal wall over time and cause perforation or stricture

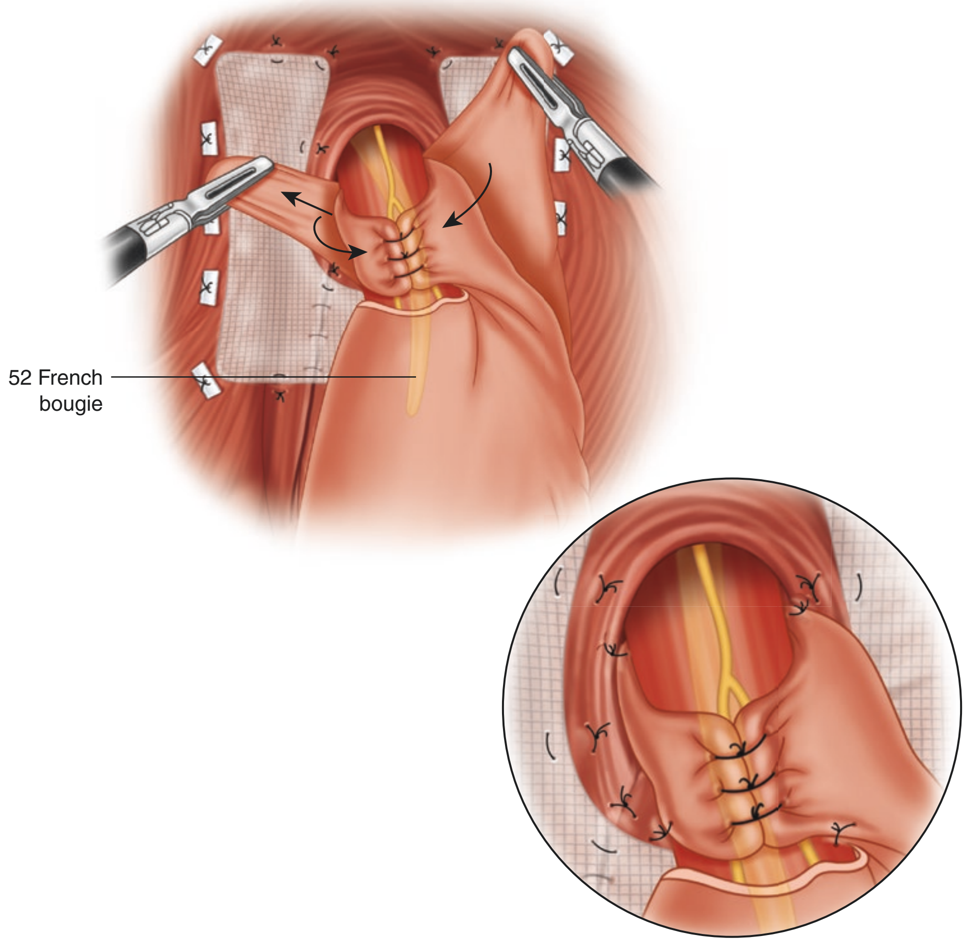


Fig. 24.11 **Gastropexy to prevent recurrence: antireflux procedure (Nissen in this case) or gastrostomy.** Given the remaining space in the mediastinum resulting from the removal of the hernia sac and the removal of the phreno-esophageal attachments, the gastroesophageal junction will have a tendency to slide back into the mediastinum. To avoid this from occurring, we typically perform a Nissen fundoplication as demonstrated. In those patients that have evidence for motility disorder or in the very elderly there more likely to develop dysphasia post operatively, we perform a gastrostomy tube placement. The gastrostomy tube was placed in a fashion so as to place the gastroesophageal junction on a moderate degree of stretch. After placement, it will remain in place for no less than 9 months

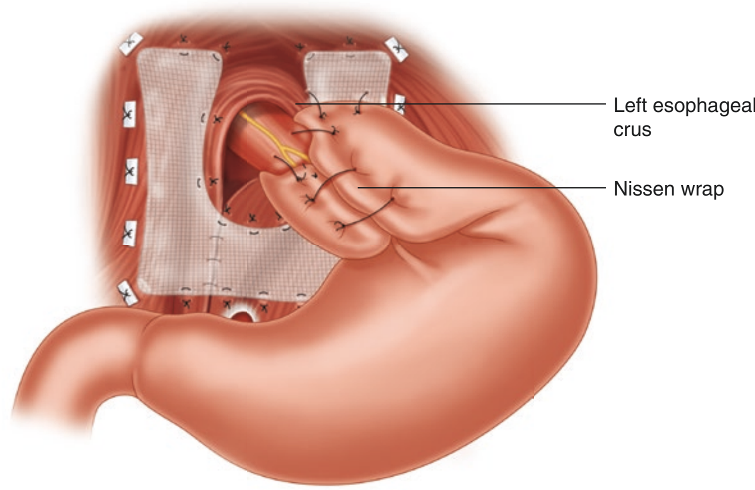


Fig. 24.12 Completed repair with a Nissen fundoplication

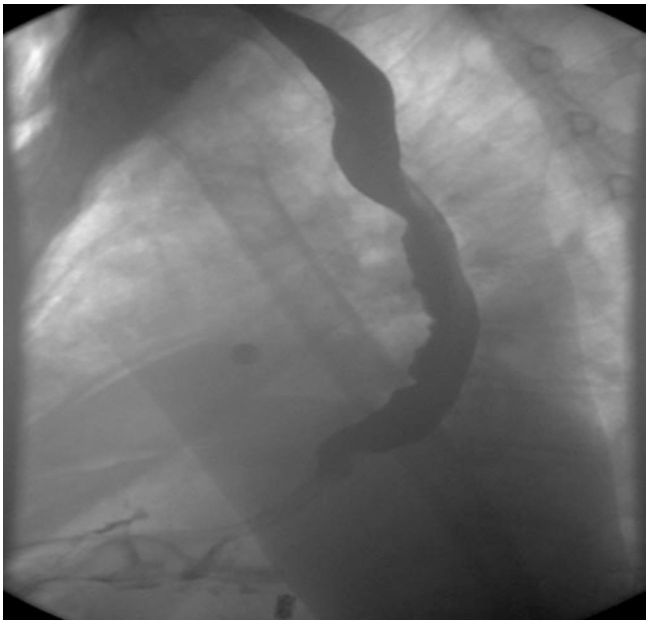


Fig. 24.13 Barium esophagram on the first postoperative day

recurrence within 1–2 years. This rate continues to rise with time. Interestingly, only 30–40% of patients that recur are symptomatic.

In spite of the advanced age and debility of many of the patients, the operative mortality is low, 1–2%, and the morbidity is 20%. With the robotic approach, compared to the open approach, there appears similar results to the laparoscopic method with a shorter hospital stay, less blood loss and an earlier return to preoperative function in patients repaired by the laparoscopic approach. Quality-of-life after laparoscopic repair appears superior to the open approach and the long-term quality-of-life appears to be similar to age-matched patients who have not had surgical repair. In earlier series, recurrence rates appear to be higher with the laparoscopic approach, but with greater knowledge and experience, the recurrence rate should be less than or similar to the open approach.

In an abstract to the International Society for Minimally Invasive Cardiothoracic Surgery, we reported our initial experience in 2008 with three patients, ages 47–73, who underwent repair of defects of maximal size from 6 to 10 cm requiring total operating room times of 4.5–6.5 h (median of 6 h) [8]. The hospital stay range was 3–8 days (median 4 days), with no post-discharge readmissions. All patients are without recurrence more than 1-year from the date of their surgery and none experienced reflux, dysphagia or debility. All returned to their preoperative status within 2 weeks of surgery. We have continued performing the procedure without any conversions to an open set up and the mean operating time is now 3–4 h. We have no evidence of recurrence in any of our 35 patients since that time.

Galvani and colleagues at the University of Arizona have recently reported their experience of 61 patients from 2010 to 2015 with a median follow-up of 17 months [9]. There was 0% mortality, 6% intraoperative complication rate, and a 23% 30-day complication rate. Length-of-stay averaged 3 days with an anatomic recurrence of 42%, a quarter of these patients were symptomatic.

References

1. Skinner DB, Belsey RH. Surgical management of esophageal reflux and hiatus hernia. Long-term results with 1,030 patients. J Thorac Cardiovasc Surg. 1967;53(1):33–54.
2. Hill LD. Incarcerated paraesophageal hernia. A surgical emergency. Am J Surg. 1973;126(2):286–91.
3. Pearson FG, Cooper JD, Ilves R, Todd TR, Jamieson WR. Massive hiatal hernia with incarceration: a report of 53 cases. Ann Thorac Surg. 1983;35(1):45–51.
4. Walther B, DeMeester TR, Lafontaine E, Courtney JV, Little AG, Skinner DB. Effect of paraesophageal hernia on sphincter function and its implication on surgical therapy. Am J Surg. 1984;147(1):111–6.
5. Allen MS, Trastek VF, Deschamps C, Pairolero PC. Intrathoracic stomach. Presentation and results of operation. J Thorac Cardiovasc Surg. 1993;105(2):253–8. discussion 258–259
6. Stylopoulos N, Gazelle GS, Rattner DW. Paraesophageal hernias: operation or observation? Ann Surg. 2002;236(4):492–500.; discussion 500–491. https://doi.org/10.1097/01.SLA.0000029000.06861.17.
7. Sihvo EI, Salo JA, Rasanen JV, Rantanen TK. Fatal complications of adult paraesophageal hernia: a population-based study. J Thorac Cardiovasc Surg. 2009;137(2):419–24.
8. Kernstine, K., Falabella, A., & Lau, C. (2008). Robotic repair of giant hiatal hernias: preliminary results. Paper presented at the International Society for Minimally Invasive Cardiothoracic Surgery, 11th Annual Scientific Meeting, Boston, Massachusetts. http://www.ismics.org/abstracts/2008Program.cgi
9. Galvani CA, Loebl H, Osuchukwu O, Samame J, Apel ME, Ghaderi I. Robotic-assisted paraesophageal hernia repair: initial experience at a single institution. J Laparoendosc Adv Surg Tech A. 2016;26(4):290–5. https://doi.org/10.1089/lap.2016.0096.

Selected Reading

Conway N, Swanstrom LL. Paraesophageal hernia: indications and technique. Antireflux Surgery. 2015:105–15.

Daigle CR, Funch-Jensen P, Calatayud D, Rask P, Jacobsen B, Grantcharov TP. Laparoscopic repair of paraesophageal hernia with anterior gastropexy: a multicenter study. Surg Endosc. 2015;29:1856–61.

Dallemagne B, Kohnen L, Perretta S, Weerts J, Markiewicz S, Jehaes C. Laparoscopic repair of paraesophageal hernia: long-term follow-up reveals good clinical outcome despite high radiological recurrence rate. Ann Surg. 2011;253:291–6.

Fuchs KH, Babic B, Breithaupt W, Dallemagne B, Fingerhut A, Furnee E, Granderath F, Horvath P, Kardos P, Pointner R, Savarino E, Van Herwaarden-Lindeboom M, Zaninotto G, European Association of Endoscopic S. EAES recommendations for the management of gastroesophageal reflux disease. Surg Endosc. 2014;28:1753–73.

Galvani CA, Loebl H, Osuchukwu O, Samame J, Apel ME, Ghaderi I. Robotic-assisted paraesophageal hernia repair: initial experience at a single institution. J Laparoendosc Adv Surg Tech A. 2016;26(4):290–5.

Kohn GP, Price RR, Demeester SR, Zehetner J, Muensterer OJ, Awad Z, Mittal SK, Richardson WS, Stefanidis D, Fanelli RD. Guidelines for the management of hiatal hernia. Surg Endosc. 2013;27:4409–28.

Luketich JD, Nason KS, Christie NA, Pennathur A, Jobe BA, Landreneau RJ, Schuchert MJ. Outcomes after a decade of laparoscopic giant paraesophageal hernia repair. J Thorac Cardiovasc Surg. 2010;139:395–404. e1

Memon MA, Memon B, Yunus RM, Khan S. Suture cruroplasty versus prosthetic hiatal herniorrhaphy for large hiatal hernia: a meta-analysis and systematic review of randomized controlled trials. Ann Surg. 2016;263:258–66.

Mori T, Nagao G, Sugiyama M. Paraesophageal hernia repair. Ann Thorac Cardiovasc Surg. 2012;18:297–305.

Morrow EH, Oelschlager BK. Laparoscopic paraesophageal hernia repair. Surg Laparosc Endosc Percutaneous Tech. 2013;23:446–8.

Tam V, Winger DG, Nason KS. A systematic review and meta-analysis of mesh vs suture cruroplasty in laparoscopic large hiatal hernia repair. Am J Surg. 2016;211:226–38.

Part VII

Repair of Esophageal Dysmotility

Robotic Heller Myotomy

25

Carlos A. Galvani and Nisha Dhanabalsamy

Abstract

Achalasia is a relatively uncommon primary motility disorder of the esophagus characterized by incomplete or absent relaxation of the Lower Esophageal Sphincter (LES). Early definitive treatment is essential to prevent potential complications of the disease as well as improve patients' quality of life. Treatment is always palliative and is aimed to decrease the outflow obstruction at the level of the LES. Heller esophageal myotomy has been considered the gold standard in the surgical management of achalasia. A minimally invasive approach offers better results in terms of minimal post operative pain, shorter hospital stay, shorter disability, lower cost, and a better cosmetic result compared to the open approach. Some of the pitfalls associated with laparoscopic Heller myotomy such as the effect of previous failed endoscopic treatments and the risk for esophageal perforation have been overcome with the emergence of robotic surgery. Several factors of robotic surgery including tremor elimination, freedom of movements, steadiness and 3-D visualization that provides a careful and more precise dissection of muscle fibers has helped ensure better safety and superior results. We have applied this technology for the treatment of esophageal achalasia with encouraging patient outcomes and no esophageal perforation. This chapter illustrates our current technique for Robotic Assisted Heller Myotomy and some of the common pearls and pitfalls.

Keywords

Achalasia • Esophageal dysmotility • Minimally invasive • Robotic surgery • Heller Myotomy

Achalasia is a rather uncommon disease process (i.e. incidence 1 in 100,000 individuals), characterized by the absence of the ganglion cells of the myenteric plexus of Auerbach with loss of postganglionic inhibitory neurons. It generally manifests with dysphagia and a variety of foregut symptoms such as regurgitation and chest pain. If untreated, the course of the disease causes a progressive stasis and dilation of the esophagus, with subsequent risk of aspiration, weight loss, and malnutrition. The same consequences could be potentially observed if treatment is suboptimal. For that reason, early definitive treatment is essential to prevent potential complications of the disease as well as improve patients' quality of life. Treatment is always palliative and is aimed to decrease the outflow obstruction at the level of the lower esophageal sphincter (LES). The treatment of the disease has undergone several modifications since 1674, when Willis first reported a patient with achalasia treated by using dilation

C. A. Galvani, M.D. (✉)
Department of Surgery, Division of General Surgery, Section of Minimally Invasive and Robotic Surgery, University of Arizona, College of Medicine, 1501 N. Campbell Ave., P.O. Box 245066, Tucson, AZ 85724-5066, USA
e-mail: cgalvani@surgery.arizona.edu

N. Dhanabalsamy
Department of Surgery, Section of Minimally Invasive and Robotic Surgery, University of Arizona, College of Medicine, Tucson, AZ, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_25

with a sponge attached to whalebone, later modified to balloon dilation after Russel's description in 1887 [1]. Subsequently, in 1913, E. Heller performed the first esophagomyotomy using an anterior and posterior esophageal myotomy [1]. Because of the excessive amount of gastroesophageal reflux resulting, this approach was later modified to a single myotomy, which is still today the mainstay of surgical treatment. Subsequently Pellegrini and Cuscheri in the early 1990s described the minimally invasive approach, showing the obvious benefits of reduced morbidity, shorter postoperative hospital stay, and decreased postoperative pain [2, 3]. The minimally invasive approach offered results at least as good as those from open procedures yielding in addition less postoperative pain, shorter hospital stay, shorter disability, lower cost, and a better cosmetic result than the open approach [4–6]. Over the years, because of the high incidence of postoperative reflux and the suboptimal distal myotomy, thoracoscopic Heller myotomy was gradually abandoned and replaced by laparoscopic myotomy. The use of this approach spread rapidly, motivating a change in the treatment algorithm of esophageal achalasia [6].

However, laparoscopic Heller myotomy is an operation difficult to learn and has a considerable learning curve. It has been suggested that after certain number of cases, technical complications tend to decrease to satisfactory levels [7]. On the other hand, the fact that esophageal achalasia being a very uncommon disease and with the existence of alternative non-surgical treatment, general surgeons are precluded from extensive exposure to many of these procedures. As a result, only a few centers worldwide have a large experience in the management of achalasia of the esophagus.

In order to obtain optimal results, important technical principles should be observed while performing the operation, such as: complete mobilization of the fundus of the stomach by dividing the short gastric vessels, adequate extension of the myotomy (i.e. 6 cm into the distal esophagus and 2–3 cm into the gastric wall), and the addition of a fundoplication (Dor or Toupet). Some of these essential technical aspects are still a matter of debate. Persistent dysphagia is a predictable consequence when the myotomy is not extended enough into the proximal stomach [8]. Yet, the extension of the myotomy on the gastric side continues to be the most difficult part of the operation. The changing in direction of the muscular fibers, from circular in the esophagus to oblique at the stomach, makes it difficult to develop the necessary submucosal plane to divide the muscular fibers and bleeding is likely. These difficulties may elucidate why, in most series, esophageal mucosa perforation took place at the gastroesophageal junction or below, and not in the mediastinum. Another controversial aspect is centered on the effect of previous endoscopic treatment on the results of laparoscopic Heller myotomy. Furthermore, previously failed endoscopic treatments have been claimed to increase the risk of esophageal perforation [9]. Nonetheless, not every esophageal perforation can be explained by this assumption. It has been suggested that factors other than merely previous endoscopic treatment could possibly play a role in the frequency of this cumbersome complication.

Perhaps some of the well-known disadvantages of laparoscopic surgery could also play a role; specifically, the need for specialized training, the use of rigid equipment with limited movements, bi-dimensional representation of a three-dimensional surgical field, and dependence from the camera operator during the surgery as well as poor ergonomic position of the surgeon. All these factors clearly impair surgeon's performance during the learning curve, but remain unfavorable due to the nature of laparoscopic surgery. For that reason, since the year 2000, robotic surgery has continuously demonstrated its utility by overcoming some of the pitfalls of laparoscopic surgery. These were probably the key reasons that made us switch from laparoscopic myotomy to robotic-assisted Heller myotomy. Several factors may play a role in decreasing the morbidity of the procedure; first of all, the elimination of the surgeon's tremor, the steadiness, and the superior control of the tip of the articulated instruments. In addition, the 3-D vision allows for visualizing and dividing each individual muscular fiber, assuring an adequate and safe myotomy. Several reports have demonstrated its superior results when compared to laparoscopic myotomy [10–13]. Nonetheless, despite superior results; it has not been widely adopted in the surgical community mostly because robotic general surgery is still a young field, in which surgeons that are comfortable with laparoscopy feel less urgency to embrace the routine use of these expensive tools. In addition, there is a perception of surgical team challenges such as: patient positioning, robot setup, limit of tableside assistant access to the patient, challenges for the anesthesia team. We applied this technology for the treatment of esophageal achalasia with encouraging patient outcomes and no esophageal perforation [11]. This chapter illustrates our current technique for Robotic Assisted Heller Myotomy and some of the common pearls and pitfalls.

25.1 Operative Technique: Robotic-Assisted Heller Myotomy

25.1.1 Anesthetic Management

25.1.1.1 Preoperative

Achalasia occurs with equal frequency in men and women and is more common in the adult population but it can also happen in children. For that reason, the preoperative evaluation should be tailored to the specific patient and their preoperative physical status. In addition, patients that undergo previous non-surgical treatment tend to have a longer duration of their disease, which can in fact worsen their physical status. It is essential for the anesthesia team to have a detailed understanding of the surgical procedure in terms of approach, the extent of the operation, and associated complications.

Preoperative cardiac and pulmonary morbidity will determine the extent of preoperative cardiac testing as well as the need for pulmonary function testing (PFT) especially in those patients with restrictive lung disease secondary to recurrent aspiration pneumonia.

25.1.1.2 Perioperative

Particular anesthetic considerations include precautions to reduce the perioperative risk for aspiration. Patients are advised to ingest only clear liquids 2 or 3 days before surgery, to decrease the risk of aspiration during induction of anesthesia. In older patients with several comorbid conditions, a Foley catheter is placed and usually removed after the case. Premedication with a prophylactic anti-aspiration is highly recommended. The patient is placed in the supine position before the induction of general endotracheal anesthesia. In order to minimize the aspiration risk during the induction of anesthesia, the airway can be secured either after a rapid sequence induction with cricoid pressure, or awake, with the aid of a fiberoptic bronchoscope. Standard intraoperative monitoring will suffice for American Society of Anesthesiologists (ASA) physical status class I and II patients. Adequate attention should be paid to the hemodynamic changes resulting from the combined effects of pneumoperitoneum and placing the patient in a reverse Trendelenburg position.

25.1.2 Patient Position

After satisfactory induction of general endotracheal anesthesia the patient is placed in the semi-lithotomy position over a “bean bag”. The beanbag is then inflated and then 4-in. tape is used to secure the patient to the table. The regular use of the “bean bag” permits to secure the patient to the table when steep reverse Trendelenburg is needed. Pneumatic compression stockings are placed on both legs routinely, and the legs are placed in stirrups. The legs and pressure points are cushioned appropriately. Once this is established, the abdomen and lower chest are prepped widely with iodine and then draped sterile. It is important that the chest is exposed, if an eventual conversion to thoracotomy is required. An orogastric tube is placed to decompress the esophagus and stomach.

25.1.3 Abdominal Access and Trocar Positioning

Trocar placement is identical for any advanced esophageal procedure. Entry into the abdominal cavity is obtained using an optical trocar technique in the periumbilical area. Three 8-mm trocars (the size of these trocars is specific for the robotic system) and two 12-mm trocars are inserted. A 0.5-cm incision is made in the subxyphoid area, and the left lobe of the liver is then retracted anteriorly using the Nathanson liver retractor. An additional 12-mm port is inserted for the bedside assistant in between the camera trocar and the robotic trocar in the left upper quadrant (Fig. 25.1). The assistant at the bedside usually performs the setup of the robot. The assistant surgeon is positioned on the patient’s left side or in between the patient’s legs. During the case, the assistant is in charge of cutting, suction, and retraction. Also, when needed, the assistant switches the robotic instruments for the operating surgeon. For this reason, basic training in laparoscopic surgery and robotics is essential. At this point, the nursing personnel approximate the robotic surgical cart into position and the arms are attached to the specific trocars. The daVinci™-specific Instruments are inserted through the three 8-mm working ports. A Cadiere Forceps is placed in the surgeon’s left hand (Arm 2), the articulated hook cautery or the Endo Wrist® One Vessel Sealer (Intuitive Surgical, Sunnyvale, CA) in the right hand (Arm 1) and another Cadiere grasper in Arm 3 (assisting port).

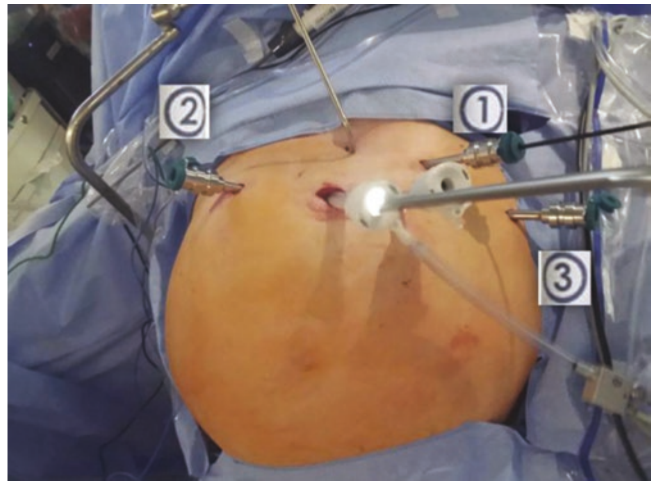


Fig. 25.1 Port positioning. Three 8-mm trocars (the size of these trocars is specific for the robotic system) and two 12-mm trocars. A 0.5 cm incision is made in the subxyphoid area, for the Nathanson liver retractor and one additional 12-mm trocar for the bedside assistant

25.1.4 Dissection of the Lower Third of the Esophagus and Division of the Short Gastric Vessels

The operation is started by dividing the peritoneum overlying the left crus of the diaphragm with the Vessel Sealer (Left Crura approach). The phreno-esophageal membrane is transected as well. In order to dissect and separate the esophagus

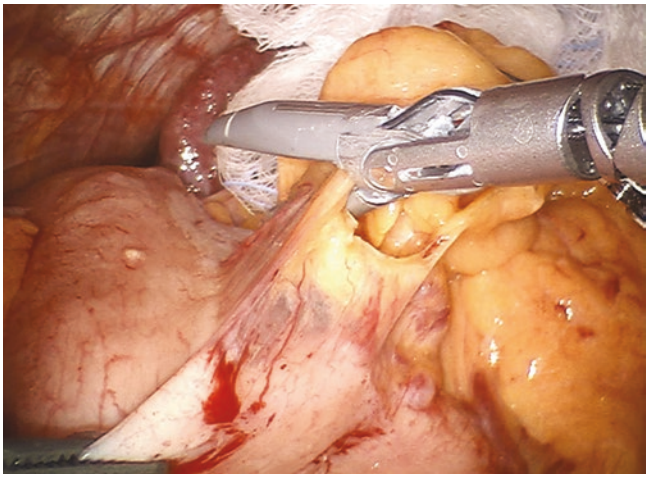


Fig. 25.2 Division of the short gastric vessels

from the left crus, a blunt technique is used to minimize the risk of inadvertent injury or perforation of the esophagus. Once access to the posterior mediastinum is obtained, the short gastric vessels are then carefully divided starting at the lower third of the spleen (Fig. 25.2). Full mobilization of the fundus is carried out by dividing posterior adhesions to the anterior capsule of the pancreas. The left side of the esophagus is identified by dissecting off the left crus from the esophagus. The dissection is continued in the posterior mediastinum lateral and anterior to expose the lower esophagus, respecting the posterior attachments. Attention is centered to the exposure of the right crus. By activating the assisting arm (Arm 3) the surgeon provides traction on the stomach; after this is completed the surgeon uses a Cadiere grasper and Vessel Sealer to divide the gastrohepatic ligament below the hepatic branch of the vagus nerve and extends the dissection upwards. The peritoneum overlying the anterior surface of the right crus of the diaphragm and the phrenoesophageal membrane is transected. The right crura is recognized and separated from the esophagus by blunt dissection, no posterior dissection is performed as well.

25.1.5 Heller Myotomy

A tapered 44 F Bougie is inserted through the mouth by the anesthesia team. It is of utmost importance to maintain extensive communication between the anesthesiologist and the surgery team to prevent esophageal perforation. The placement of the bougie also helps providing a stable surface for the myotomy. After Bougie insertion, using Arm 3 the surgeon retracts the GE-junction caudally with a Cadiere grasper to increase the length of the intra-abdominal esophagus. For the myotomy, a Cadiere Forceps is used in the surgeon's left hand (Arm 2), and the articulated hook cautery in the right hand (Arm 1). The next step is the mobilization of the epigastric fat pad and anterior vagus nerve. The anterior vagus nerve is dissected upwards in an extension of approximately 10 cm, separating it clearly from the esophageal wall. This maneuver is performed to better expose the gastroesophageal junction (GEJ) and the area of the future myotomy. After exposure of the anterior esophagus is complete, the myotomy is started out at the GEJ level at the 12 o'clock position using the articulated hook electrocautery (Fig. 25.3). Methodical marking of the area of the myotomy is performed by scoring the esophagus with the back of the hook electrocautery for about 6–7 cm above the GEJ. The submucosal plane is reached in one point by dividing the longitudinal and circular muscle layer. This is followed by extending the myotomy a minimum of 6 cm proximally and for about 2–3 cm distally into the stomach (Fig. 25.4). During the proximal extension of the myotomy it

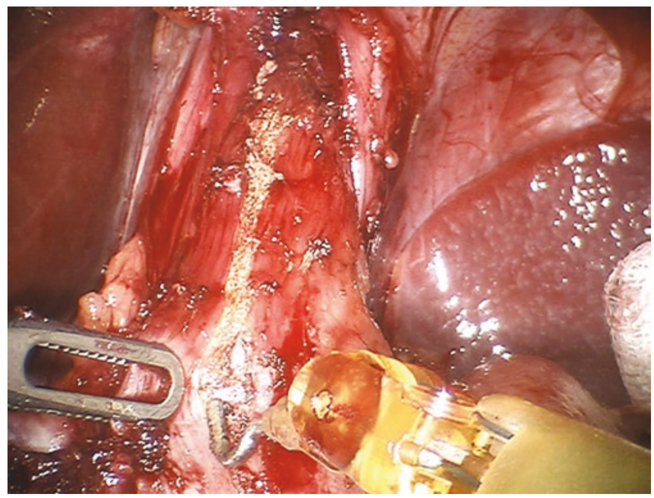


Fig. 25.3 Beginning of the esophageal myotomy. The myotomy is started out just above the gastroesophageal junction on the 12 o'clock position using the robotic articulated hook electrocautery

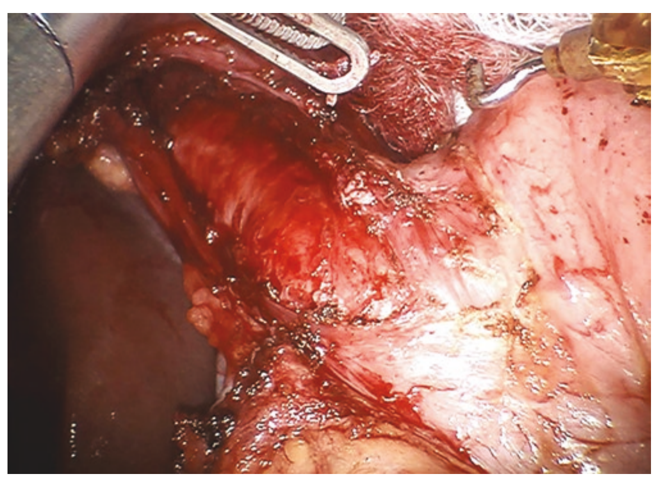


Fig. 25.4 Completed Heller myotomy, extending a minimum of 6 cm proximally and for about 2 cm distally into the stomach

is important to provide counter-traction of the circular fibers with the Cadiere grasper in order to divide the fibers with the articulated hook safely. The myotomy on the gastric side is carried down in a “hockey stick” configuration to transect the sling fibers of the stomach wall.

25.1.6 Creation of the Partial Fundoplication (Dor)

In our practice the preferred antireflux procedure is the Dor fundoplication, which is an anterior 180° fundoplication. This type of fundoplication is chosen because it covers the exposed mucosa and is an effective antireflux repair. The Dor fundoplication is composed of two rows of sutures. The first row of suture includes the gastric fundus and left side of the myotomy. The first stitch is a triangular stitch, placed between the fundus, the left pillar and left edge of the myotomy (Fig. 25.5a). Two additional stitches incorporate the gastric wall and the left side of the myotomy. Subsequently, by activating the grasper in Arm 3 the surgeon folds the stomach over the exposed mucosa, and the second row of sutures is started. The first stitch is placed between the stomach, the right edge of the myotomy, and the right pillar. The second and the third stitches are placed between the greater curvature of the stomach and the right side of the esophageal muscle (Fig. 25.5b). It is vital to avoid including the right pillar in the second and third stitches of the fundoplication since this could represent a reason for dysphagia. Two additional stitches are placed between the gastric fundus and the rim of the hiatus completing the fundoplication (Fig. 25.6). The purpose of these last stitches is to further decrease the tension of the fundoplication and to prevent the lateral rotation of the wrap.

Nevertheless, in patients with hiatal hernia, a Toupet fundoplication (posterior 180° fundoplication) is preferred. A posterior fundoplication is warranted due to the more extensive mediastinal dissection required to obtain 2–3 cm of intraabdominal esophagus and the need for posterior crural repair.

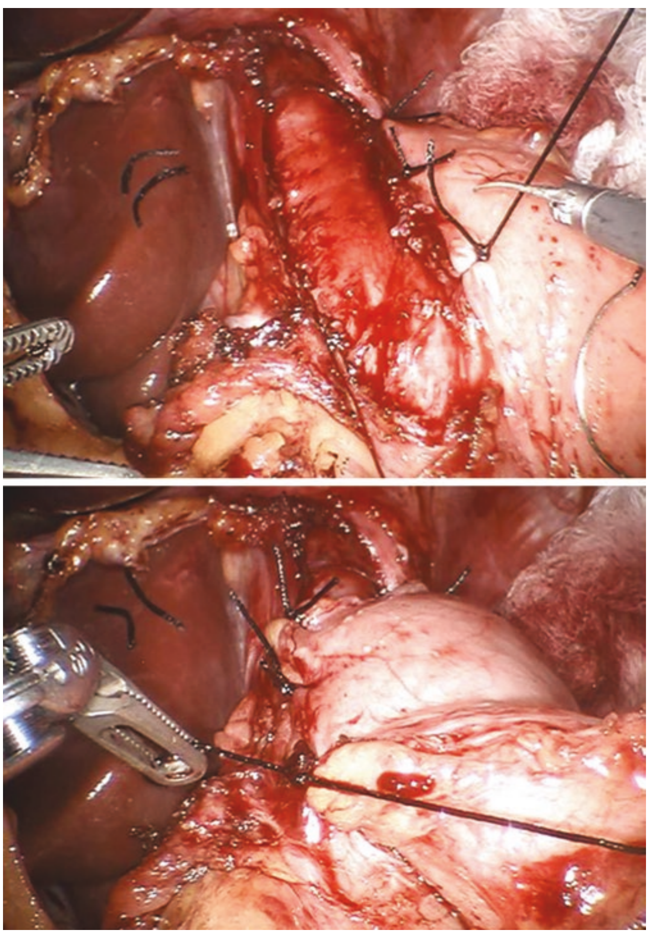


Fig. 25.5 (**a**) Dor fundoplication. First row of sutures composed of three stitches. The first stitch includes the gastric fundus, the left crura and the left side of the myotomy; (**b**) the second row of sutures are created by placing stitches between the stomach and the right edge of the myotomy

25.2 Pearls and Pitfalls

- Three days of liquid diet before surgery may prevent aspiration in patients with swallowing disorder of the esophagus.
- The insertion of a Bougie should be carefully monitored by the surgery team at all times to prevent esophageal perforation.
- In order to obtain optimal results, important technical principles should be observed while performing the operation, such as: complete mobilization of the fundus of the stomach by dividing the short gastric vessels, adequate

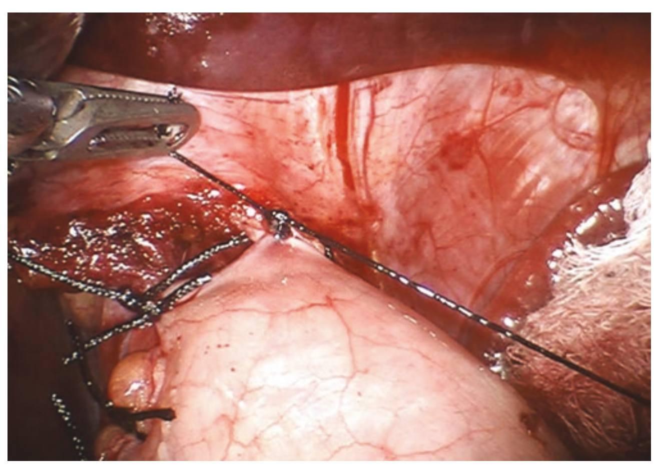


Fig. 25.6 Completed Dor (180°) fundoplication. Two additional stitches are also placed from the fundus to the rim of the hiatus

extension of the myotomy (i.e. 6 cm into the distal esophagus and 2–3 cm into the gastric wall), and the addition of a fundoplication (Dor or Toupet).

- The presence of associated hiatal hernia warrants circumferential esophageal dissection to obtain 2–3 cm of intraabdominal esophagus.
- The robotic system is especially valuable during the myotomy portion of the operation. In addition, it facilitates intracorporeal knot tying.
- At this time, in order to complete the procedure successfully, a qualified assistant is required.
- If while performing the myotomy bleeding from the muscle edges occur it is very important to avoid using electrocautery. In general, hemostasis can be achieved just by applying compression.
- It has been our experience that prior endoscopic treatment leads to a more difficult myotomy with longer operative times but otherwise has equivalent outcomes to the untreated patients.
- If recognized, esophageal perforation can generally be easily repaired at the time of surgery, using fine absorbable sutures. After the repair, the surgeon can elect to buttress the repair with a Dor fundoplication as opposed to a Toupet.
- If the myotomy was difficult, every effort should be made to identify unrecognized injuries, by using upper endoscopy.
- It is important not to use the body of the stomach while constructing the fundoplication since this could potentially lead to a tight wrap and postoperative dysphagia.

References

1. Brewer LA III. History of surgery of the esophagus. Am J Surg. 1980;139(6):730–43.
2. Pellegrini C, Wetter LA, Patti M. Thoracoscopic esophagomyotomy. Initial experience with a new approach for the treatment of achalasia. Ann Surg. 1992;216:291–6; discussion 296–9.
3. Shimi S, Nathanson LK, Cuschieri A. Laparoscopic cardiomyotomy for achalasia. J R Coll Surg Edinb. 1991;36(3):152–4.
4. Csendes A, et al. Comparison of forceful dilatation and esophagomyotomy in patients with achalasia of the esophagus. Hepatogastroenterology. 1991;38(6):502–5.
5. Patti MG, et al. Minimally invasive surgery for achalasia: an 8-year experience with 168 patients. Ann Surg. 1999;230(4):587–93; discussion 593–4.
6. Patti MG, et al. Impact of minimally invasive surgery on the treatment of esophageal achalasia: a decade of change. J Am Coll Surg. 2003;196(5):698–703; discussion 703–5.
7. Bloomston M, et al. The "learning curve" in videoscopic Heller myotomy. JSLS. 2002;6(1):41–7.
8. Oelschlager BK, Chang L, Pellegrini CA. Improved outcome after extended gastric myotomy for achalasia. Arch Surg. 2003;138(5):490–5; discussion 495–7.
9. Patti MG, et al. Effects of previous treatment on results of laparoscopic Heller myotomy for achalasia. Dig Dis Sci. 1999;44(11):2270–6.
10. Galvani C, et al. Laparoscopic Heller myotomy for achalasia facilitated by robotic assistance. Surg Endosc. 2006;20(7):1105–12.
11. Horgan S, et al. Robotic-assisted Heller myotomy versus laparoscopic Heller myotomy for the treatment of esophageal achalasia: multicenter study. J Gastrointest Surg. 2005;9(8):1020–9; discussion 1029–30.
12. Melvin WS, et al. Computer-enhanced robotic telesurgery minimizes esophageal perforation during Heller myotomy. Surgery. 2005;138(4):553–8; discussion 558–9.
13. Huffmanm LC, et al. Robotic Heller myotomy: a safe operation with higher postoperative quality-of-life indices. Surgery. 2007;142(4):613–8; discussion 618–20.

Robotic Assisted Laparoscopic Cardiomyotomy (Heller Myotomy) in Achalasia: Austria

26

Florian Augustin and Heinz Wykypiel

Abstract

Achalasia is a primary esophageal motility disorder caused by failed relaxation of the lower esophageal sphincter and impairment of peristalsis. Treatment options range from medical therapy, endoscopic dilations, botulinum injections, endoscopic myotomy to surgical treatment. Aim of surgical treatment is to relieve esophageal outflow obstruction at the LES by dividing both muscle layers of the esophagus including division of the oblique gastric muscle fibers. A fundoplication (partial posterior or anterior fundoplication) is usually added to the procedure to prevent gastroesophageal reflux. Complete division of longitudinal and circular muscle fibers at the cardia region is important. However, it increases the risk of mucosal injury. Enhanced maneuverability, three-dimensional vision and motion scaling of a surgical robotic system improve outcome in this delicate procedure. We describe the operative setup, a stepwise conduct of the operation as well as failure management and an overview of published results of this operation.

Keywords

Esophageal achalasia • Robotics • Cardia • Esophageal sphincter, lower • Fundoplication • Esophageal motility disorders • Peristalsis

26.1 Background and Specific Indications

Achalasia is a rare primary motility disorder of the esophagus affecting 1 in 100,000 individuals per year. It occurs equally in men and women, most of them between 20 and 40 years of age. Dysphagia for solid food and liquids is the cardinal symptom and is present in almost 100% of patients. Other typical findings are weight loss, chest pain, regurgitation, and nocturnal cough. The most common extraesophageal manifestations are pulmonary complications due to recurrent aspiration [1].

The causes of achalasia can be primary idiopathic or secondary. Primary achalasia is assumed to result from a total loss or relative absence of the myenteric plexus of the esophagus. Viral infections, inflammation, and autoimmune processes involving CD3/CD8 positive lymphocytes, IgM antibodies, and complement activation are involved. Moreover, a genetic predisposition is discussed as a possible cofactor. The subsequent imbalance between excitatory and inhibitory neurons causes failure of the lower esophageal sphincter (LES) to relax. The course of achalasia has a slow progression for years beginning with slight swallowing disturbances and untreated often ends in a dilated aperistaltic, so-called sigmoid- or mega-esophagus at risk for aspiration, malignancy, or perforation [2].

The most common secondary cause of achalasia is Chagas' disease, a systemic disease caused by the protozoan Trypanosoma cruzi. It is endemic in South and Central America and is considered to be the most common cause of achalasia worldwide [3]. "Pseudoachalasia" is a term used

F. Augustin, M.D. • H. Wykypiel, M.D. (✉)
Department of Visceral, Transplantation and Thoracic Surgery, Innsbruck University Hospital, Innsbruck, Tirol, Austria
e-mail: florian.augustin@tirol-kliniken.at; Heinz.wykypiel@i-med.ac.at

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_26

for cases with incomplete relaxation of the lower esophageal sphincter caused by cancer of the lower esophagus or even a narrow wrap after fundoplication.

There are three tests to confirm the diagnosis of primary achalasia: (1) esophageal manometry, (2) radiographic studies and (3) esophagogastroduodenoscopy (EGD).

Esophageal manometry remains the diagnostic modality with the highest sensitivity and should be part of the diagnostic evaluation in all patients with assumed achalasia. A poor or non-relaxing lower esophageal sphincter (LES) sometimes with a high resting pressure (above 45 mmHg) and simultaneous waves or aperistalsis in the esophageal body are typical findings. If achalasia comes with high amplitude contractions in the esophageal body the term "vigorous achalasia" is used. Recently, three subclasses of achalasia have been identified with high resolution manometry: Type I with absent peristalsis without abnormal pressure, Type II with absent peristalsis with abnormal pan-esophageal high-pressure patterns and Type III with absent peristalsis with distal esophageal spastic contractions [4]. A barium esophagogram shows a typical smooth tapering of the distal esophagus with proximal dilatation of the esophagus ("birds beak" sign) and lack of peristalsis during fluoroscopy. Endoscopy (EGD) is often normal in early stages. In more advanced stages dilatation of the esophagus and retention of food may be found. There are several different surgical and non-surgical treatment options. Pharmacological therapy is directed to achieve LES sphincter relaxation by treatment with smooth muscle relaxants like calcium channel blockers, nitrates and sildenafil. Their main limitations are lack of effectiveness, short duration, and frequent side effects. In clinical practice, they are, therefore, no real option on the long term. Endoscopic treatment options include botulinum toxin injection or pneumatic dilatation for disruption of the LES. Botulinum toxin injection (4 quadrants 100 iu total dose) is lacking a long term efficacy with recurrence rates of approximately 50% after 1 year and almost 100% within 2 years. Therefore, this is either for proof of diagnosis in uncertain cases ("Botox trial therapy") or a treatment option in patients with a high operative risk. Moreover, frequent Botox injections into the LES cause scarring that makes a later myotomy more difficult [5]. Pneumatic forceful dilatation is considered the most effective non-surgical treatment option. Initially, the "gold standard" is a 30 mm Balloon (Rigiflex®, 10 psi) in conscious sedation; in redo cases 35–40 mm may be necessary. However, published success long term rates of 42–85% can only be achieved with repeat dilatations. Moreover, a perforation rate of 5–10% per dilatation has been reported [6].

Recently, peroral endoscopic myotomy (POEM), an endoscopic approach for surgical myotomy of the lower esophageal sphincter has been introduced. This new technique results in encouraging manometric effect, short-term symptom resolution and a low rate of postprocedural reflux. However, it requires specific endoscopic expertise with a learning curve requiring more than 20 cases and the need for structured proctoring for the first cases. Further studies are needed to prove its efficacy on the long term [7].

The aim of surgical treatment is to relieve esophageal outflow obstruction at the LES by dividing both muscle layers of the esophagus including division of the oblique gastric fibers, the so-called sling fibres. The addition of an antireflux procedure, a partial posterior (Toupet) or an anterior (Dor) fundoplication is commonly suggested in order to prevent gastroesophageal reflux. Long-term remission rates of 67–85% are reported. Although the technique of a modern cardiomyotomy differs significantly from the original method described by the German surgeon Ernst Heller in 1914, it is still called "Heller myotomy" [8].

With the advent of minimally invasive approaches, the laparoscopic "Heller myotomy" has evolved to the favored primary approach in many centers, although a thoracoscopic approach may be beneficial in selected cases. However, with conventional minimally invasive methods intraoperative esophageal perforation rate has been reported to be between 1 and 15%. These perforations often occur at the Angle of His, where conventional laparoscopic tools have a disadvantageous, perpendicular angle towards the muscle fibres that have to be dissected. Therefore, it was assumed early on that robotic-assisted surgery could be beneficial in this procedure because of its enhanced three dimensional and nearly microscopic vision and the superior maneuverability in difficult angles.

26.2 Anaesthetic Management

Robot-assisted laparoscopic cardiomyotomy is performed under general anesthesia. The anesthetic management is the same as in conventional laparoscopic fundoplications. Only the position of the anesthesiologist has to be slightly more remote from the patient in order to give way to the robotic arms.

26.3 Operative Set-Up

Patients are placed in a modified lithotomy position, the so-called French position. Two monitors for the assistants are positioned on both sides of the shoulders of the patient as depicted in Fig. 26.1. The control console is positioned within the OR. After introducing the Veress needle in a

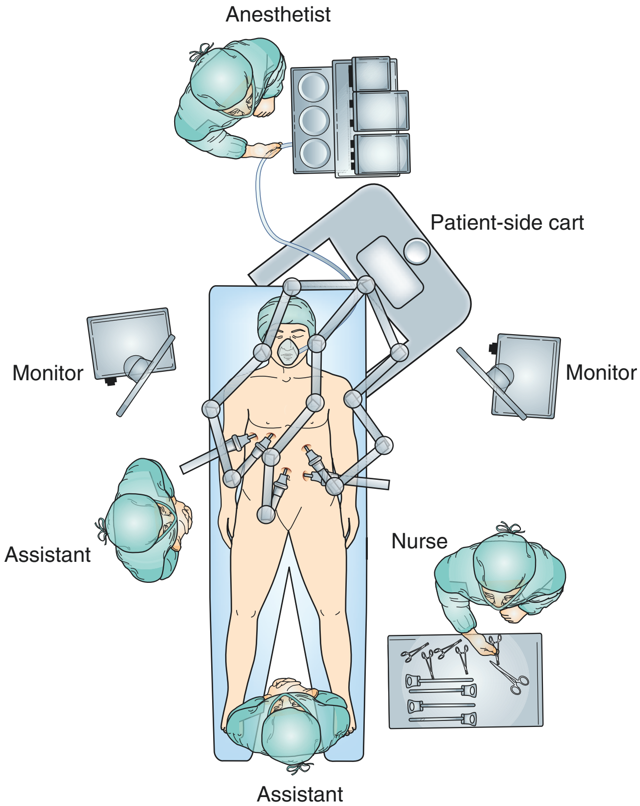


Fig. 26.1 Robotic setup in the OR

supraumbilical incision and performing the safety tests, a pneumoperitoneum of 12 mmHg is applied. Five trocars are placed through the abdominal wall as depicted in Fig. 26.2. The following description relies on the da Vinci in its first standard version, slight variations depending on the available upgrade versions might be necessary. Of note, the trocars for the right and the left hand are placed considerably more laterally and caudally than in conventional laparoscopy in order to avoid collision of the robot arms. Several options for retraction of the liver exist. A Fan retractor (Covidien, Int.) or a Cushieri retractor (Karl Storz, Tuttlingen, Germany) through a right subcostal port can be applied. Alternatively, a 5 mm Nathanson retractor (Cook Medical, USA), can be brought into place via a subxiphoidal incision, connected with one of the standard adjustable holding arms. The camera and the instruments, inserted through the left and the right subcostal ports are controlled via the robot. The camera port has to be a dilating tip trocar (Excel, Ethicon Endo-Surgery, Inc. Cincinnati, OH, USA) to fit the robot system. The right and the left subcostal ports, through which instruments are inserted and controlled by the robot, are trocars provided by the company (Intuitive Surgical, Mountain view, CA, USA). The two ports used for the liver retractor and for the Babcock forceps can be trocars of any type. As soon as all the ports are inserted into the abdominal cavity, the patient is placed in a reverse Trendelenburg position with an angle of about 25° and the mobile cart with the robot arms is positioned on the left hand side of the patient at the level of the

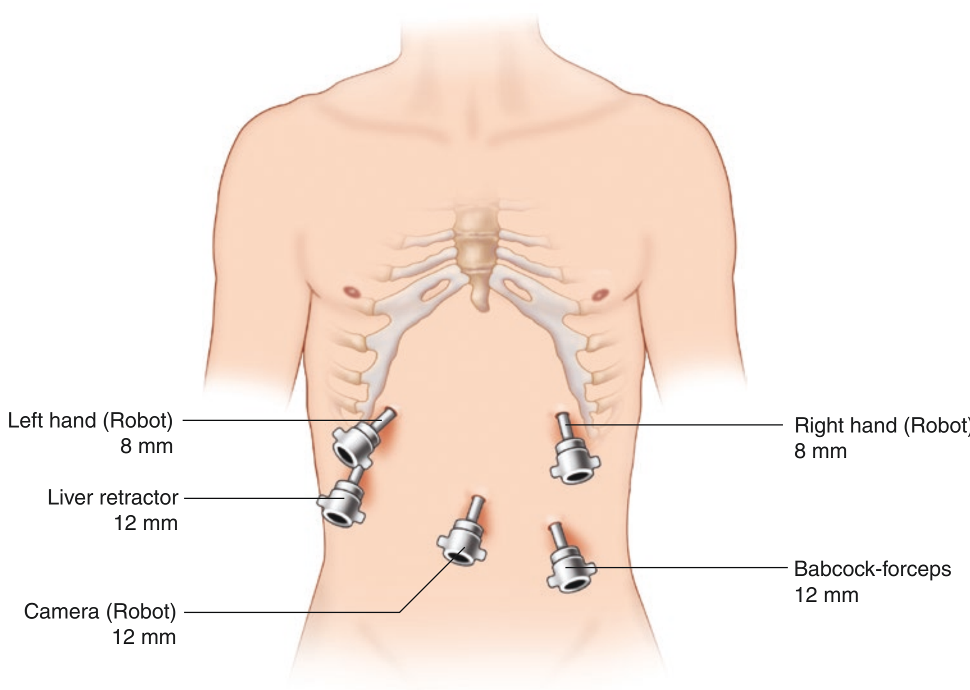


Fig. 26.2 Trocar placement

patient's head with an angle of approximately 30° to the patient's longitudinal axis (Fig. 26.1). Positioning of the patient is carried out by the technician under instruction of the surgeon. The robot arms are connected to the trocars. From now on, the table has to remain in the same position since the robot arms do not follow the table's movements. The camera which provides a three-dimensional image and the robotic instruments, usually an electrocautery hook and a grasper (Cadière, Intuitive Surgical, Mountain View, CA, USA) are inserted through the ports and connected to the robot arms.

26.4 Stepwise Conduct of the Operation

26.4.1 Exposure of the Esophageal Hiatus

The liver retractor is brought into place by the table side surgeon. For retraction of the liver during the operation, the use of a holding arm is recommended. The gastric fundus is pulled to the left by the table side surgeon using the Babcock forceps in order to expose the lesser omentum.

The lesser omentum is divided cephalad using the electrocautery hook thus providing exposure of the right crus of the diaphragm. Care must be taken to identify and to avoid damage of an aberrant left hepatic artery.

The anterior edge of the right diaphragmatic crus is identified and exactly at this site incision of the overlying peritoneum is started and continued anteriorly of the esophagus towards the left crus.

The right crus is gently peeled off the esophagus which provides access to the mediastinum.

The posterior branch of the vagus nerve has to be identified; however, we never dissect it off the esophagus.

By pulling the stomach to the right, the left crus is dissected from the esophagus using the electrocautery hook. This procedure is continued well behind the esophagus since this prepares for an easy establishment of a window behind the esophagus for a later posterior fundoplication (Fig. 26.3). In case of a planned anterior (Dor) fundoplicate, the posterior and left lateral attachments of the esophagus are left untouched. Therefore, this technique is rather advised for patients without any hiatal hernia, because in some studies, the anterior (Dor) fundoplication has shown to offer less antireflux effect than a partial posterior (Toupet) fundoplication.

26.4.2 Division of Esophageal Muscle Layers—Heller Myotomy

After identification of the anterior branch of the vagal nerve the dissection of the muscle fibers is carried out (Figs. 26.4, 26.5, and 26.6). The anterior branch of the vagal nerve is preserved and the dissection is carried out underneath it.

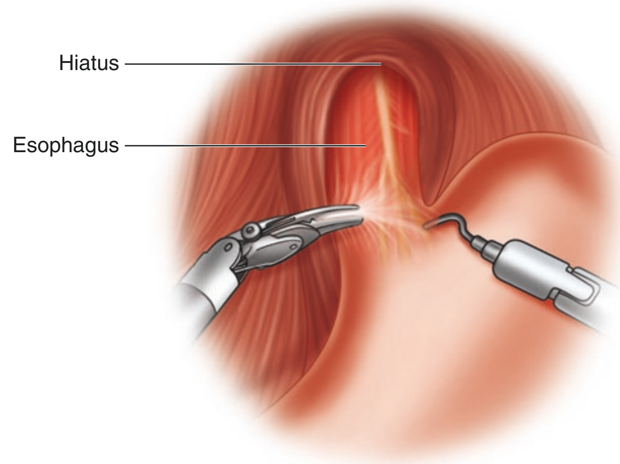


Fig. 26.3 Circular dissection of the distal oesophagus

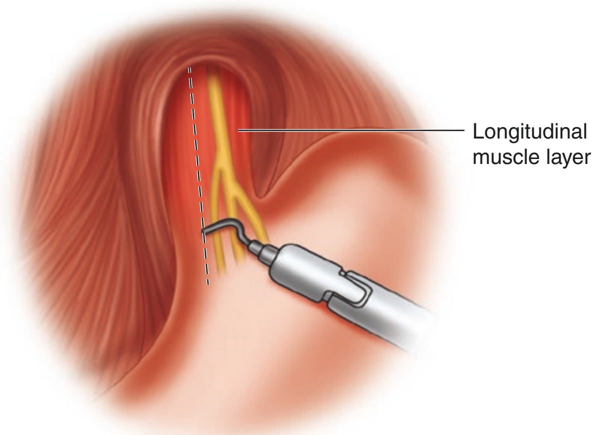


Fig. 26.4 Division of the longitudinal (outer) muscle layer at the gastroesophageal junction

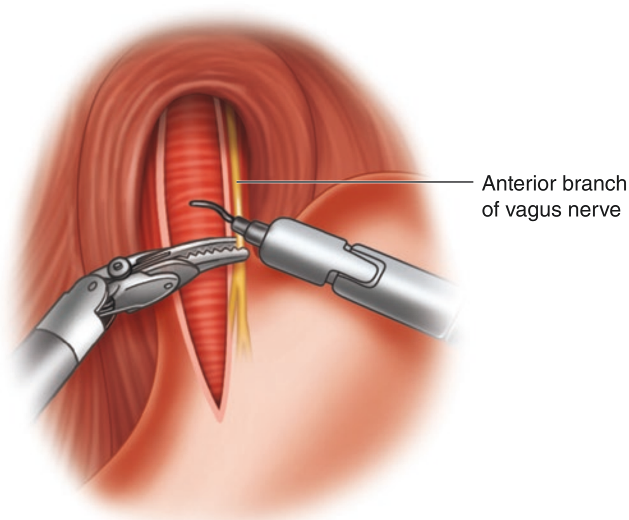


Fig. 26.5 Identification and dissection of the anterior branch of the vagus nerve

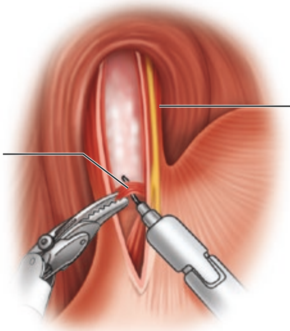


Fig. 26.6 Division of the circular (inner) muscle layer of the distal oesophagus

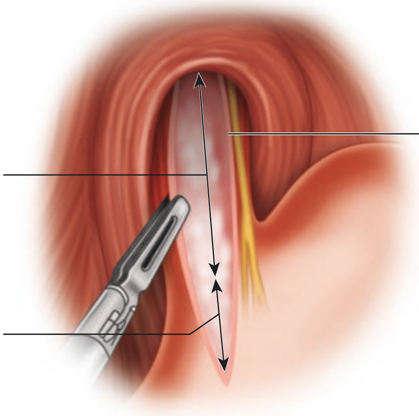


Fig. 26.8 Completed separation of the muscle fibers: 6 cm of distal esophagus and 2–3 cm of stomach

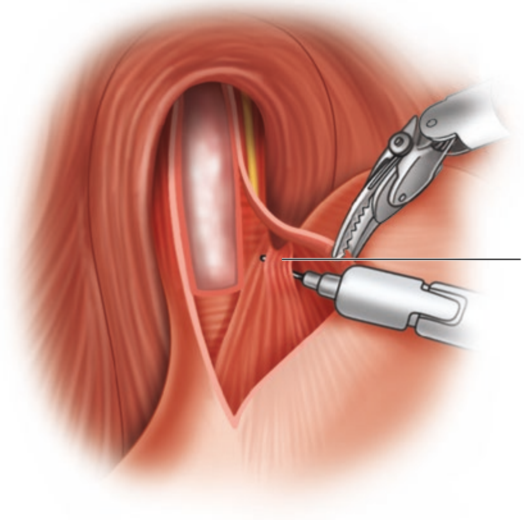


Fig. 26.7 Division of the sling fibres at the angle of His

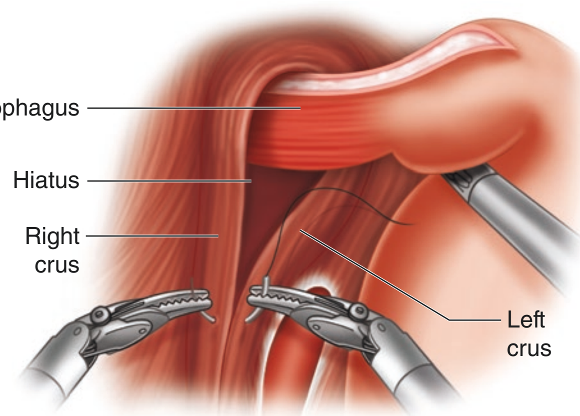


Fig. 26.9 Approximation of the crura behind the oesophagus using interrupted nonabsorbable sutures

Careful identification, separation and cutting of the muscle fibers are performed using a Cadière forceps in one hand and the electrocautery hook in the other. Dissection should be performed anteriorly on the esophagus at least 6–7 cm from the peritoneal reflection up into the mediastinum.

The myotomy is extended 3 cm onto the stomach towards the angle of His in order to identify and cut the sling fibers of the stomach (Fig. 26.7). This step requires meticulous dissection with good magnification since this is the spot where most mucosal perforations are reported in conventional laparoscopic surgery. Generally, one should be very reluctant to apply too much electrocautery direct at the esophagus since the transmission of energy through all layers of the esophagus could lead to a late leak.

After completion of the dissection and muscle division (Fig. 26.8), an intraoperative endoscopy is performed in order to ensure complete transection of all muscle fibers and to rule out a mucosal perforation with an underwater insufflation test (0.9% saline solution).

26.4.3 Closure of the Hiatus

The next step is the closure of the hiatal crura. For this purpose one non-absorbable suture (Ethibond 2–0 V-5, Johnson & Johnson Intl.) is used. The suture is placed behind the esophagus and passed deep into the muscle bundles of the crura creating a generous approximation not as narrow as we normally do in antireflux operations (Figs. 26.9 and 26.10). Care must be taken not to harm the abdominal aorta that runs well beneath the crura.

26.4.4 Creation of the Fundic Wrap

The following step of the operation is the creation of the partial posterior fundic wrap. The gastric fundus is grasped at its highest point (Fig. 26.11) and pulled through the window behind the esophagus and to the right (Fig. 26.12). This should be possible without tension; otherwise, further

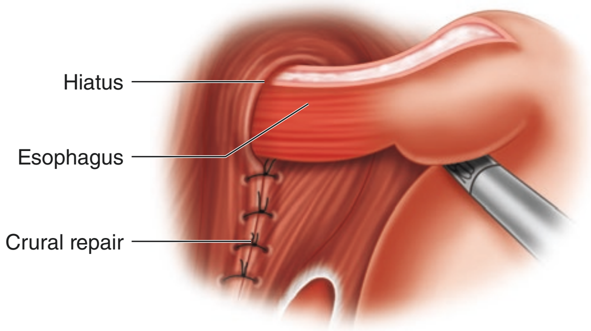


Fig. 26.10 Completed crural repair

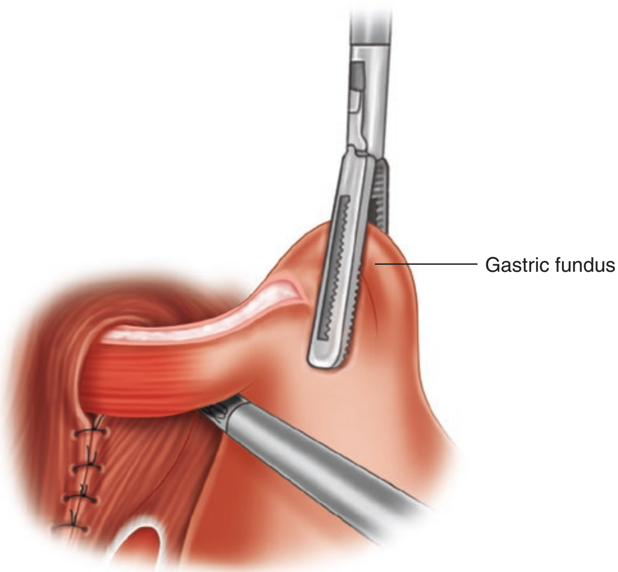


Fig. 26.11 The gastric fundus is grasped at its highest point

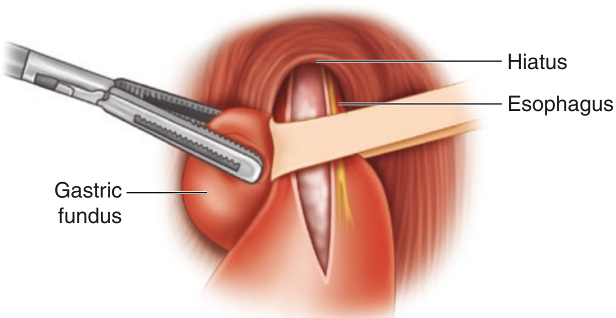


Fig. 26.12 The gastric fundus is pulled behind the retrooesophageal window to the right

dissection to free the fundus is necessary. Some advocate a thorough retroperitoneal dissection as performed with a Nissen fundoplication; we, on the other hand, never dissect the complete gastrosplenic ligament from the middle of the greater curvature upwards, since we think that this might cause denervation of the fundus resulting in postoperative gastric bloating. For a partial posterior (Toupet) fundoplication less fundus dissection is necessary. The design of the wrap can be facilitated by encircling the distal esophagus with a broad band and pulling it gently caudally.

The fundic wrap is fixed to the right crus at its right posterior aspect (Fig. 26.13) using 2–3 non-absorbable sutures (Ethibond 2–0 V-5, Johnson& Johnson Intl.). The right limb of the fundic wrap is then sutured to the anterior right limb of the myotomy (Fig. 26.14) and the left limb to the left limb of the myotomy (Fig. 26.15) using three non-absorbable sutures (Ethibond 2–0 V-5, Johnson & Johnson Intl.) on each side. Three centimeters of total wrap length should be achieved to allow for the creation of a sufficient and long- lasting partial posterior fundic wrap which provides retraction of both limbs of the myotomy and providing an antireflux mechanism at the same time (Fig. 26.16).

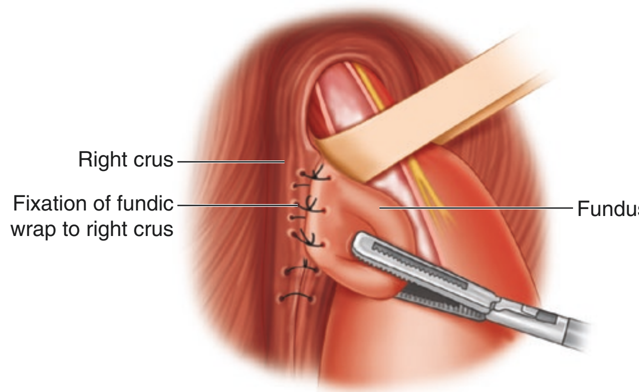


Fig. 26.13 The fundic wrap is fixed to the right crus using 2–3 non-absorbable stitches

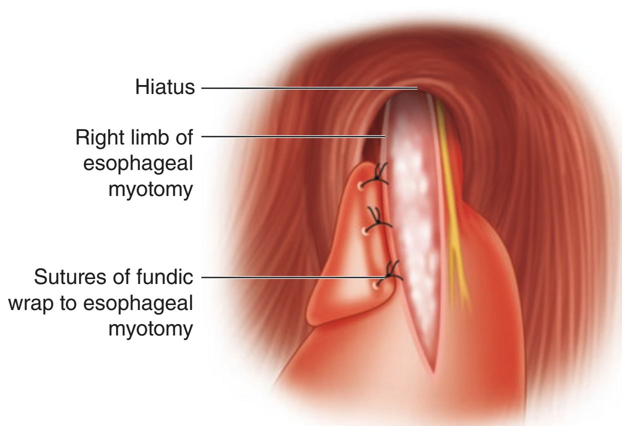


Fig. 26.14 (**a**–**d**) The right limb of the fundic wrap is sutured to the right limb of the esophageal myotomy using three nonabsorbable interrupted sutures

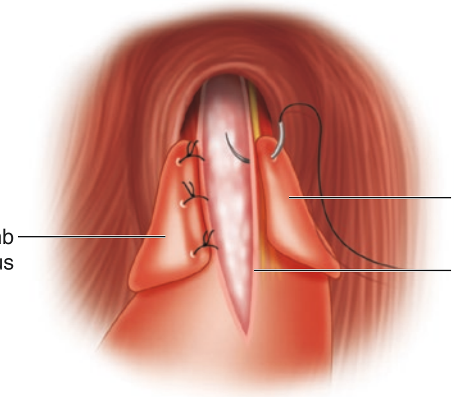


Fig. 26.15 The left limb of the fundus is sutured to the left limb of the esophageal myotomy using three non-absorbable interrupted sutures. Aim for a 3 cm wrap length

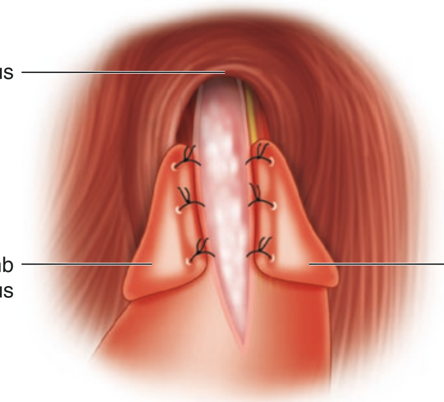


Fig. 26.16 Final aspect

Suturing is entirely accomplished by means of robotic surgery with intracorporeal knots. The sutures are introduced into the abdomen by the table side surgeon via the left subcostal port.

Finally, the abdomen is explored to rule out inadvertend lacerations and to assure complete hemostasis. Then, the ports and the liver retractor are removed by the table side surgeon under direct vision. Wounds are closed in a standard fashion.

26.5 Failure Management

In case of an inadvertent mucosal perforation (in our series, there have been none since the introduction of the robot), we would use the same strategy as in conventional laparoscopic cardiomyotomy. We close the defect with interrupted absorbable stitches. Instead of a posterior fundoplication, we then perform an anterior (Dor) fundoplication to cover the perforation site using three stitches to attach the fundus at each muscular limb and one or two stitches to anchor the fundus at the anterior portion of the hiatus.

Lacerations of the spleen can be difficult to manage. In our experience, ready to use surgical patches (e.g. Tachosil®, Nycomed Int.) followed by compression can achieve hemostasis. In more remote areas (e.g. splenic hilus), the application of a viscous hemostatic matrix (Floseal®, Baxter Int.) followed by compression has been shown to be highly effective in laparoscopic surgery on several occasions.

26.6 Postoperative Management

No nasogastric tube or intraabdominal drain is required. Prophylaxis of venous thrombembolism with low molecular heparin is started the evening before surgery [9]. After a fluoroscopic test with water soluble contrast media on postoperative day 1, the patients are allowed to start drinking. They are kept on liquid to soft diet for 2 weeks in order to avoid esophageal obstruction by a food bolus. Six months postoperatively, an endoscopy and an esophageal manometry are suggested to ensure the effective division of the LES and the creation of a well-designed wrap. Moreover, endoscopy is suggested yearly by some authors in face of the higher risk for esophageal carcinoma.

26.7 Outcomes in our Series

No intra- or postoperative mortality or morbidity occurred in our series. Of note, no mucosal perforation occurred so far since the introduction of the robot. On routine postoperative follow-up all our patients had significantly improved swallowing with significant weight gain and no evidence of reflux symptoms.

Other series of robotic assisted myotomies report similar outcomes: There are 14 original publications on robotic-assisted laparoscopic cardiomyotomy available to date with a total of 431 patients. Only two esophageal perforations are reported in two of the series so far, which gives a presumed perforation rate of less than 1% for all procedures reported (Table 26.1).

Although no randomized controlled trials exist yet, it can be stated that cardiomyotomy is the first visceral laparoscopic "standard" operation where the use of an operation robot has been proven to be clearly superior to the conventional laparoscopic technique.

As a result of our experience and in consistence with the literature, minimally invasive cardiomyotomy ("Heller myotomy") with partial posterior fundoplication using a robotic platform appears to be a more precise and safer operation than conventional laparoscopic cardiomyotomy with

Table 26.1 Available literature on robotic-assisted Heller myotomy

Study	*n*	Procedure	Operation time (min.), incl. setup	Complications	Follow-up
Melvin [10]	*1*	Heller Myotomy + Toupet	160	No complication	n.a.
Shah [11]	*1*	Heller Myotomy	n.a.	No esophageal perforation	"Asymptomatic since then"
Melvin [12]	*9*	Heller Myotomy	139 (range 99–174)	No complication	n.a.
Beninca [13]	*2*	Heller Myotomy + Dor	140 (range 139–142)	No complication	n.a.
Ruurda and Scand [14]	*14*	Heller Myotomy	105 (range 85–165)	1 esophageal perforation, sutured robotically 1 conversion to open (bad exposure)	11 (range 2–24) months 14% heartburn 14% dysphagia
Newlin [15]	*1*	Heller Myotomy	188	No complication	n.a.
Chaer [16]	*2*	Heller Myotomy + Dor (pediatric)	130 105	No esophageal perforation	"Few" months:weight gain, improved food intake
Undre [17]	*5*	Heller Myotomy	115 (range 65–160)	1 esophageal perforation, sutured robotically	9, 4 (range 3–17) months, 4 asymptomatic 1 improvement
Melvin [18]	*104*	Heller Myotomy + Dor or Toupet	140,55	No esophageal perforation, 1 conversion to open (bleeding)	16 months (76%), symptoms improved in all pat Symptom score (Likert Scale): 0.48 (before: 5.0)no reoperation, 1 balloon dilatation
Perry [19] (*long term f/u from Melvin (18))	**33*	Heller Myotomy + Dor or Toupet			Long-term f/u: median 9.1 years (3.9–12.8) 21% moderate to severe dysphagia 21% moderate to severe heartburn 56.3% on medication for reflux 95.5% satisfied with result
Horgan [20]	*59*	Heller Myotomy + Dor	141 ± 49	No esophageal perforation, (conventional laparoscopic group (n = 62): 16% esophageal perforations)	18 months: 8% dysphagia, 17% reflux symptoms, 2 balloon dilataions
Galvani [21]	*54*	Heller Myotomy + Dor (only myotomy with the robot)	162 (range 62–210)	No esophageal perforation	17 months 93% relief of dysphagia
Huffmanm [22]	*24*	Heller Myotomy + Toupet or Dor + manometry	355 ± 23	No complications, no perforation (conventional laparoscopic group (n = 37): 8% esophageal perforations)	SF-36 (emotional + General Health Perception): better than conventional Laparoscopic, p < 0.5 GRACI-score: Improvement identical
Wykypiel [23]	*6*	Heller Myotomy + Toupet	236 (220–316), setup time 38 (25–47)	No complications, no perforation	6 months, 5/6 free of dysphagia
Shaligram [24]	*149*	Heller Myotomy + Fundoplication	n.a.	Mort. 0% Morb. 4.02% Length of stay 2.42 days ± 2.69 (SD) ICU admission 3.36%	30 day readmission 2.84% Cost (USD) 9.515 ± 5.515
14 original publications	*431*			2 perforations = 0.46% (2/431) reported	

fewer complications. Therefore, robotic-assisted laparoscopic cardiomyotomy with partial posterior ("Toupet") fundoplication has become the treatment of choice in our patients with achalasia.

References

1. Pandolfino JE, Gawron AJ. Achalasia: a systematic review. JAMA. 2015;313(18):1841–52.
2. Boeckxstaens GE, Jonge WD, van den Wijngaard RM, Benninga MA. Achalasia: from new insights in pathophysiology to treatment. J Pediatr Gastroenterol Nutr. 2005;41(Suppl 1):S36–7.
3. de Oliveira RB, Rezende Filho J, Dantas RO, Iazigi N. The spectrum of esophageal motor disorders in Chagas' disease. Am J Gastroenterol. 1995;90(7):1119–24.
4. Pandolfino JE, Kwiatek MA, Nealis T, Bulsiewicz W, Post J, Kahrilas PJ. Achalasia: a new clinically relevant classification by high-resolution manometry. Gastroenterology. 2008;135(5):1526–33.
5. Zaninotto G, Annese V, Costantini M, Del Genio A, Costantino M, Epifani M, et al. Randomized controlled trial of botulinum toxin versus laparoscopic Heller myotomy for esophageal achalasia. Ann Surg. 2004;239(3):364–70.
6. Khan AA, Shah SW, Alam A, Butt AK, Shafqat F. Sixteen years follow up of achalasia: a prospective study of graded dilatation using Rigiflex balloon. Dis Esophagus. 2005;18(1):41–5.
7. Swanstrom LL, Kurian A, Dunst CM, Sharata A, Bhayani N, Rieder E. Long-term outcomes of an endoscopic myotomy for achalasia: the POEM procedure. Ann Surg. 2012;256(4):659–67.
8. Crookes PF, Wilkinson AJ, Johnston GW. Heller's myotomy with partial fundoplication. Br J Surg. 1989;76(1):99–100.
9. Pabinger I, Eichinger S, Minar E, Niessner E. Austrian guidelines for prophylaxis of venous thrombembolism. Wien Klin Wochenschr. 2007;119(23–24):739–46.
10. Melvin WS, Needleman BJ, Krause KR, Wolf RK, Michler RE, Ellison EC. Computer-assisted robotic Heller myotomy: initial case report. J Laparoendosc Adv Surg Tech A. 2001;11(4):251–3.
11. Shah J, Rockall T, Darzi A. Robot-assisted laparoscopic Heller's cardiomyotomy. Surg Laparosc Endosc Percutan Tech. 2002;12(1):30–2.
12. Melvin WS, Needleman BJ, Krause KR, Schneider C, Wolf RK, Michler RE, et al. Computer-enhanced robotic telesurgery. Initial experience in foregut surgery. Surg Endosc. 2002;16(12):1790–2.
13. Beninca G, Garrone C, Rebecchi F, Giaccone C, Morino M. [Robot-assisted laparoscopic surgery. Preliminary results at our Center]. Chir Ital. 2003;55(3):321–31.
14. Ruurda JP, Gooszen HG, Broeders IA. Early experience in robot-assisted laparoscopic Heller myotomy. Scand J Gastroenterol Suppl. 2004;241:4–8.
15. Newlin ME, Mikami DJ, Melvin SW. Initial experience with the four-arm computer-enhanced telesurgery device in foregut surgery. J Laparoendosc Adv Surg Tech A. 2004;14(3):121–4.
16. Chaer RA, Jacobsen G, Elli F, Harris J, Goldstein A, Horgan S. Robotic-assisted laparoscopic pediatric Heller's cardiomyotomy: initial case report. J Laparoendosc Adv Surg Tech A. 2004;14(5):270–3.
17. Undre S, Moorthy K, Munz Y, Aggarwal R, Hance J, Rockall T, et al. Robot-assisted laparoscopic Heller cardiomyotomy: preliminary UK results. Dig Surg. 2004;21(5–6):396–400.
18. Melvin WS, Dundon JM, Talamini M, Horgan S. Computer-enhanced robotic telesurgery minimizes esophageal perforation during Heller myotomy. Surgery. 2005;138(4):553–8; discussion 8–9.
19. Perry KA, Kanji A, Drosdeck JM, Linn JG, Chan A, Muscarella P, et al. Efficacy and durability of robotic Heller myotomy for achalasia: patient symptoms and satisfaction at long-term follow-up. Surg Endosc. 2014;28(11):3162–7.
20. Horgan S, Galvani C, Gorodner MV, Omelanczuck P, Elli F, Moser F, et al. Robotic-assisted Heller myotomy versus laparoscopic Heller myotomy for the treatment of esophageal achalasia: multicenter study. J Gastrointest Surg. 2005;9(8):1020–9; discussion 9–30.
21. Galvani C, Gorodner MV, Moser F, Baptista M, Donahue P, Horgan S. Laparoscopic Heller myotomy for achalasia facilitated by robotic assistance. Surg Endosc. 2006;20(7):1105–12.
22. Huffmanm LC, Pandalai PK, Boulton BJ, James L, Starnes SL, Reed MF, et al. Robotic Heller myotomy: a safe operation with higher postoperative quality-of-life indices. Surgery. 2007;142(4):613–8; discussion 8–20.
23. Wykypiel HF, Bodner J, Augustin F, Renz O, Hoeller E, Schmid T. Robot-assisted laparoscopic cardiomyotomy. Wien Klin Wochenschr. 2009;121(21–22):707–14.
24. Shaligram A, Unnirevi J, Simorov A, Kothari VM, Oleynikov D. How does the robot affect outcomes? A retrospective review of open, laparoscopic, and robotic Heller myotomy for achalasia. Surg Endosc. 2012;26(4):1047–50.

Part VIII

Miscellaneous

Robotic-Assisted Esophageal Epiphrenic Diverticulectomy

27

Carlos A. Galvani, Nisha Dhanabalsamy, and Pier Cristoforo Giulianotti

Abstract

Epiphrenic diverticula represent an uncommon pathology and are considered pulsion diverticula, characterized by a mucosal and submucosal outpouching through the muscular layers of the esophageal wall. Nowadays, it is widely accepted that symptomatic patients should receive surgical treatment. Over the years controversy persisted concerning the adequate surgical management. Proposed surgical options include either (1) Diverticulectomy with long myotomy in every patient with the addition of a partial fundoplication or (2) Diverticulectomy with no myotomy if no motility disorder is found on preoperative workup. Historically all these procedures were performed by approaching the diverticulum through either a right or a left thoracotomy. Transhiatal laparoscopic approach for the treatment of epiphrenic diverticula has become widespread. More recently with the introduction of robotic surgery, we started performing robotic-assisted transhiatal dissection and resection of epiphrenic diverticulum. Herein we report our operative technique as well as pitfalls and pearls.

Keywords

Epiphrenic diverticula • Diverticulectomy • Myotomy • Transhiatal approach • Robotic surgery

27.1 Background

Epiphrenic diverticula arise from the distal 10 cm of the thoracic esophagus just above the diaphragm. They represent an uncommon pathology and are considered pulsion diverticula, characterized by a mucosal and submucosal outpouching through the muscular layers of the esophageal wall (Fig. 27.1a, b). Currently, there is consensus among centers that these diverticula are most frequently associated with an underlying esophageal motility disorder [1, 2]. The pathogenesis remains unclear; however, a motor disorder or a mechanical obstruction increasing the intraluminal esophageal pressure is the most likely underlying cause of the diverticulum.

The size of the diverticula and the underlying motility disorder determine the clinical symptoms, which can include dysphagia, odynophagia, regurgitation, chest pain, cachexia, halitosis, and chronic aspiration. Nowadays, it is widely accepted that symptomatic patients should receive surgical treatment [3]. Nonetheless, over the years controversy persisted concerning the adequate surgical management. Proposed surgical options include: (1) either Diverticulectomy with long myotomy in every patient with the addition of a partial fundoplication or (2) Diverticulectomy with no myotomy if no motility disorder is found on preoperative workup. The latter being the less attractive alternative on the basis

C. A. Galvani, M.D. (✉) • N. Dhanabalsamy, M.D.
Department of Surgery, Section of Minimally Invasive and Robotic Surgery, University of Arizona, College of Medicine, 1501 N. Campbell Ave., P.O. Box 245066, Tucson, AZ 85724-5066, USA
e-mail: cgalvani@surgery.arizona.edu

P. C. Giulianotti, M.D., F.A.C.S.
Division of General, Minimally Invasive and Robotic Surgery, Department of Surgery, University of Illinois Hospital and Health Sciences System, Chicago, IL, USA
e-mail: piercg@uic.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_27

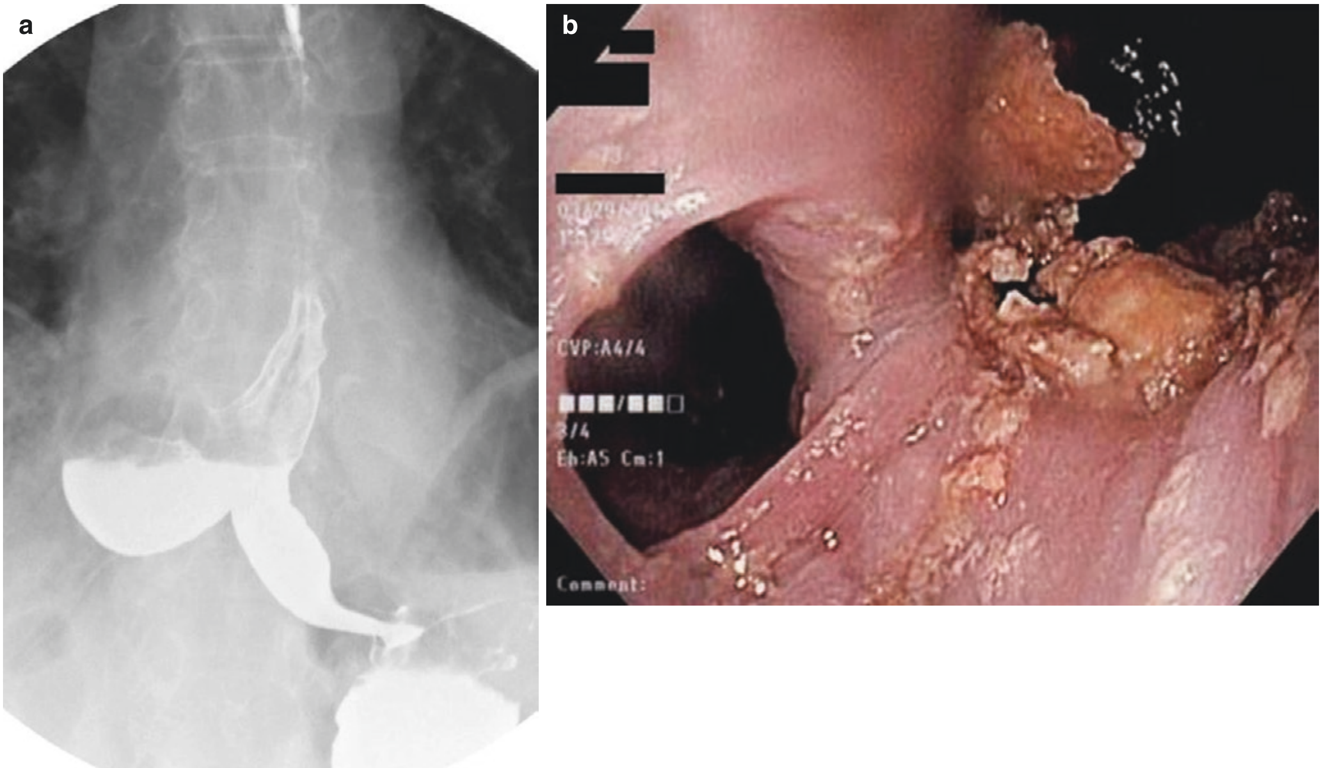


Fig. 27.1 (**a**) Epiphrenic diverticulum arising from the thoracic esophagus just above the diaphragm as shown on upper gastrointestinal study; (**b**) upper endoscopy showing a large esophageal diverticulum at 35 cm from the incisors, containing a large amount of food

that the sole excision of the diverticulum without treating the cause of the increased intraluminal pressure increases the risk of recurrence of the disease and staple line leak [2]. Nehra and colleagues demonstrated that standard esophageal manometry might not consistently identify intermittent motility disorders such as diffuse esophageal spasm [1]. Consequently, an esophageal myotomy starting at the diverticular neck and extending 2–3 cm onto the gastric wall is recommended in all patients [1, 2, 4].

Historically all these procedures were performed by approaching the diverticulum through either a right or a left thoracotomy [3, 4]. Patients subjected to this operation were exposed to the postoperative sequelae of a thoracotomy as well as the risk of intra-thoracic leakage. The high morbidity and mortality of this operation served as an impetus, driving the search for alternative solutions. Rosatti et al., employing their previous experience with minimally invasive esophageal surgery, developed a transhiatal laparoscopic approach for the treatment of epiphrenic diverticula [5]. The authors encountered several advantages with this new technique, such as parallel alignment between the esophageal axis and the endoscopic stapler, and enhanced exposure of the distal esophagus and proximal stomach therefore facilitating the myotomy and fundoplication. After this initial report, the technique became widespread and good results have been reported by a number of authors in the literature [2, 6–8].

The application of this approach is not without disadvantages, however, and these disadvantages are for the most part technical aspects. First, in many patients clear visualization of the whole diverticulum, may not be feasible through the laparoscopic approach and therefore in these situations the dissection of the upper portion of the diverticulum can be challenging. Secondly, the laparoscopic approach to epiphrenic diverticula can have a steep learning curve mostly due to the fact that conventional equipment restricts the ability of the surgeon to perform the transhiatal dissection. In addition, the rarity of this disease entity prevents surgeons from familiarizing themselves with its surgical treatment. For that reason, it has been recommended that these operations should be performed at centers with extensive experience in minimally invasive esophageal surgery [9].

The introduction of robotic systems in the year 2000 revolutionized minimally invasive surgery. It was obvious to us that the application of robotic technology for the performance of operations that required a higher degree of skills (e.g. esophageal myotomy) was a logical evolution. Our experience treating esophageal diseases such as achalasia, paraesophageal hernia, and gastroesophageal reflux disease with this technology has been invaluable in preparing our team to embark on esophageal diverticulectomy.

Although the operation can be performed using advanced laparoscopic techniques, with this approach surgeons are still faced with the inherent boundaries of laparoscopy including visual field limitations, limited instrument rotational freedom, difficulty in performing the mediastinal dissection and the challenge of multipositional suturing. Therefore, we believe that robotic-assistance provides a distinct advantage in the upper mediastinum through a transhiatal approach.

27.2 Operative Technique: Robotic-Assisted Epiphrenic Diverticulectomy

27.2.1 Anesthetic Management

27.2.1.1 Preoperative

The preoperative physical status of the patient dictates anesthetic management of patients with epiphrenic diverticulum. Patients suffering from this disease have frequent obstruction with dysphagia and they often develop malnutrition. In addition, patients can suffer from chronic aspiration leading to a poor preoperative respiratory status. Consideration of co-morbid conditions is equally important, as the diagnosis is frequently made in older debilitated patients and preoperative evaluation is essential for assessing the operative risk in the individual patient. It is essential for the anesthesia team to have a detailed understanding of the surgical procedure in terms of approach, the extent of the operation, and associated complications. Special emphasis should be placed on the assessment of cardiopulmonary function, because intraabdominal CO_2 insufflation may be poorly tolerated in patients with severe cardiopulmonary compromise. Preoperative cardiac and pulmonary morbidity will determine the extent of preoperative cardiac testing as well as the need for pulmonary function testing (PFT), especially in those patients with restrictive lung disease secondary to recurrent aspiration pneumonia.

27.2.1.2 Perioperative

Patients with epiphrenic diverticula are at increased risk for aspiration by the nature of their disease. Patients are advised to ingest only clear liquids 2 or 3 days before surgery, to decrease the risk of aspiration during induction of anesthesia. In older patients with several comorbid conditions, a Foley catheter is placed and usually removed after the case. Premedication with a prophylactic anti-aspiration is highly recommended. The patient is placed in the supine position before the induction of general endotracheal anesthesia. In order to minimize the aspiration risk during the induction of anesthesia, the airway can be secured either after a rapid sequence induction with cricoid pressure; or awake, with the aid of a fiberoptic bronchoscope. Every effort should be made to avoid the use of the use of nitrous oxide during general anesthesia to optimize surgical exposure and to decrease postoperative nausea and vomiting. With the identification of risk factors, patients undergoing esophageal surgery could be stratified. Standard intraoperative monitoring will suffice for American Society of Anesthesiologists (ASA) physical status class I and II patients. More invasive monitoring may be required in patients with underlying cardiopulmonary pathology [10]. Adequate attention should be paid to the hemodynamic changes resulting from the combined effects of pneumoperitoneum and placing the patient in a reverse Trendelenburg position. Venous stasis in the lower extremities during the head-up position may be aggravated in the lithotomy position. Consequently, prophylactic measures to minimize the risk for deep venous thrombosis and pulmonary embolism must be considered.

27.2.2 Patient Position

After satisfactory induction of general endotracheal anesthesia, the patient is placed in the semi-lithotomy position over a "bean bag". The beanbag is then inflated and 4-in. tape is used to secure the patient to the table. The regular use of the "bean bag" helps secure the patient to the table when steep reverse Trendelenburg is needed. Pneumatic compression stockings are placed on both legs routinely, and the legs are placed in stirrups. The legs and pressure points are cushioned appropriately. Once this is established, the abdomen and lower chest are prepped widely with iodine and then draped sterile. It is important that the chest is exposed, if an eventual conversion to thoracotomy is required. An orogastric tube is placed to decompress the esophagus and stomach.

27.2.3 Abdominal Access and Trocar Positioning

Trocar placement is identical for any advanced esophageal procedure. Entry into the abdominal cavity is obtained using an optical trocar technique in the periumbilical area. Three 8-mm trocars (the size of these trocars is specific for the robotic system) and two 12-mm trocars are inserted. A 0.5-cm incision is made in the subxyphoid area, and the left lobe of the liver is then retracted anteriorly using the Nathanson liver retractor. An additional 12-mm port is inserted for the bedside assistant in between the camera trocar and the robotic trocar in the left upper quadrant (Fig. 27.2). The assistant at the bedside usually performs the setup of the robot. The assistant surgeon is positioned on the patient's left side or in between the patient's legs. During the case, the assistant is in charge of cutting, suction, and retraction. Also, when needed, the assistant switches the robotic instruments for the operating surgeon. For this reason, basic training in laparoscopic surgery and robotics is essential. At

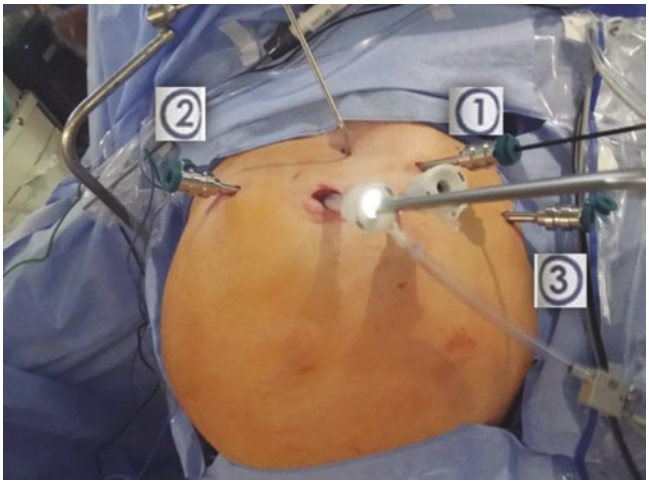


Fig. 27.2 Port positioning. Three 8-mm trocars (the size of these trocars is specific for the robotic system) and two 12-mm trocars. A 0.5 cm incision is made in the subxyphoid area for the Nathanson liver retractor. An additional 12 mm port is for the bedside assistant

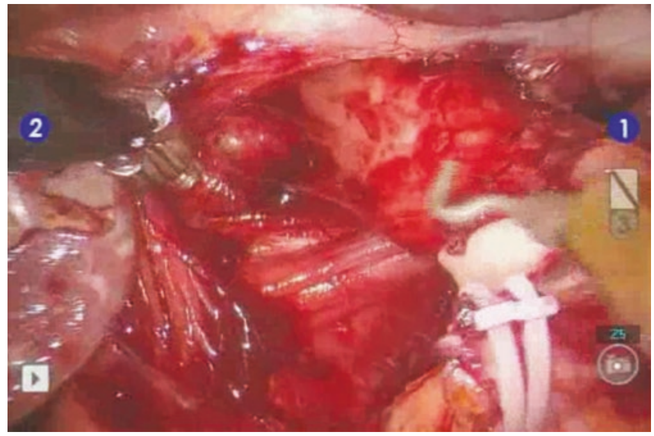


Fig. 27.3 A Penrose drain encircling the esophagus including both vagus nerves, and grasped with Arm 3

this point, the nursing personnel approximate the robotic surgical cart into position and the arms are attached to the specific trocars. The daVinci™-specific Instruments are inserted through the three 8-mm working ports. A Cadiere Forceps is placed in the surgeon's left hand (Arm 2), the articulated hook cautery or the Endo Wrist® One Vessel Sealer (Intuitive Surgical, Sunnyvale, CA) in the right hand (Arm 1) and another Cadiere grasper in Arm 3 (assisting port).

27.2.4 Dissection of the Lower Third of the Esophagus in the Posterior Mediastinum and Transection of the Short Gastric Vessels

The operation is started by dividing the peritoneum overlying the left crus of the diaphragm with the Vessel Sealer (Left Crura approach). The phreno-esophageal membrane is transected as well. In order to dissect and separate the esophagus from the left crus, a blunt technique is used to minimize the risk of inadvertent injury or perforation of the esophagus. Once access to the posterior mediastinum is obtained, the short gastric vessels are then carefully divided starting at the lower third of the spleen. Full mobilization of the fundus is carried out by dividing posterior adhesions to the anterior capsule of the pancreas. The left side of the esophagus is identified by dissecting off the left crus from the esophagus. This dissection is continued along its border with the esophagus inferiorly to the junction of the right and left crus. The dissection is continued in the posterior mediastinum lateral and anterior to expose the lower esophagus. Attention is centered to the exposure of the right crus. By activating the assisting arm (Arm 3) the surgeon provides traction on the stomach; after this is completed the surgeon uses a Cadiere grasper and Vessel Sealer to divide the gastrohepatic ligament below the hepatic branch of the vagus nerve and extend the dissection upwards. The peritoneum overlying the anterior surface of the right crus of the diaphragm and the phrenoesophageal membrane is transected. The right crura is recognized and separated from the esophagus with blunt dissection to create the retroesophageal window. This dissection is carried out to the bottom of the crus. It is important during this part of the dissection to identify and preserve the anterior and posterior branches of the vagus nerve. A Penrose drain is used to encircle the esophagus including both vagus nerves, and is grasped with Arm 3 to provide adequate retraction of the esophagus without causing any major injury (Fig. 27.3).

27.2.5 Isolation of the Diverticular Pouch

The mobilization is continued cephalad with the circumferential dissection of the esophagus. The diverticulum is usually identified on the right side of the esophagus, extending into the right posterior mediastinum. If not readily identified at this point, it is advisable to perform an upper endoscopy and with transillumination identify the anatomical structures. Circumferential dissection of the diverticulum is carried out carefully to prevent perforation of the diverticulum. The diverticulum is dissected off its mediastinal attachments with a combination of blunt maneuvers and electrocautery. After the complete mobilization of the diverticular sac is achieved, the neck of the diverticulum is cleared, and the edges of the esophageal musculature through which the diverticulum emerges are identified (Fig. 27.4). Robotic technology is fundamental during this step of the operation not only due to the length of the instrumentation but also the articulation of the instruments. The possibility to self-control

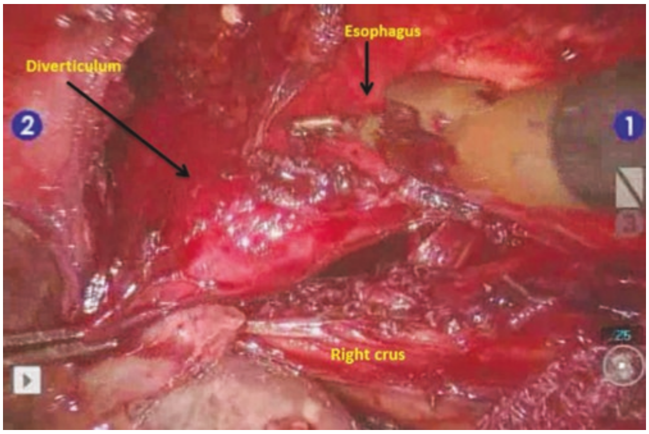


Fig. 27.4 Dissection of the diverticulum off its mediastinal attachments

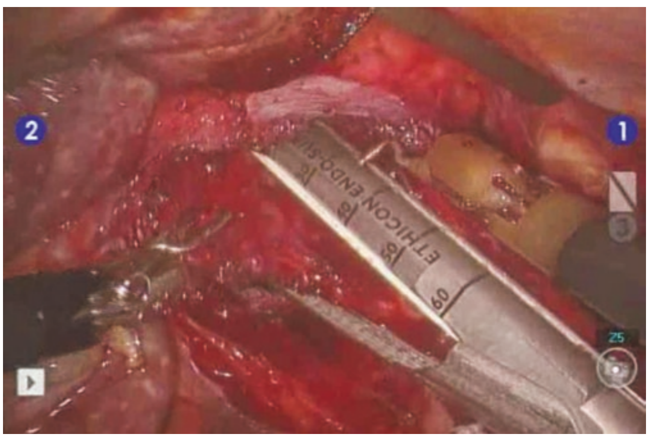


Fig. 27.5 Resection of the diverticular neck with endoscopic linear stapler (vascular cartridge)

the camera is also of much value to the operating surgeon mainly during the intra mediastinal dissection.

27.2.6 Transection the Diverticular Neck

A 44 French bougie is inserted into the esophagus while occluding the neck of the diverticulum. The bougie is advanced all the way to the stomach. Once the bougie is in place it is essential the lateral retraction of the diverticular sac before starting the transection. However, it is also critical to prevent excessive retraction to avoid stricture of the esophageal lumen. Then, the transection of the diverticular neck is started with endoscopic linear stapler (vascular cartridge) (Fig. 27.5). One or two fires may be required to completely transect the diverticular neck depending on the diverticular size. This maneuver needs to be performed by an experienced bedside assistant unless the robotic stapler is available. Then, the esophageal muscle layers over the staple line are oversewn using 2–0 silk interrupted sutures. For this particular step of the operation, three different energy devices can be used such as hook cautery, Metzenbaum scissors or the vessel sealer.

27.2.7 Heller Myotomy

With the 44 F bougie in the patient's esophagus down to the stomach, the removal of the epigastric fat pad is performed to better expose the gastroesophageal junction (GEJ). Using Arm 3, the surgeon retracts the GEJ caudally with a Cadiere grasper to increase the length of the intra-abdominal esophagus. For the myotomy, a Cadiere Forceps is used in the surgeon's left hand (Arm 2), and the articulated hook cautery in the right hand (Arm 1). The next step is the mobilization of the epigastric fat pad and anterior vagus nerve. The anterior vagus nerve is dissected upwards in an extension of approximately 10 cm, separating it clearly from the esophageal wall. This maneuver is performed to better expose the GEJ and the area of the future myotomy. After exposure of the anterior esophagus is complete, the myotomy is started out at the GEJ level at the 12 o'clock position using the articulated hook electrocautery. Methodically marking of the area of the myotomy is performed by scoring the esophagus with the back of the hook electrocautery for about 6–7 cm above the GEJ. The submucosal plane is reached in one point by dividing the longitudinal and circular muscle layer. This is followed by extending the myotomy a minimum of 6 cm proximally and for about 2–3 cm distally into the stomach. During the proximal extension of the myotomy it is important to provide-counter traction of the circular fibers with the Cadiere grasper in order to divide the fibers with the articulated hook safely. The myotomy on the gastric side is carried down in a "hockey stick" configuration to transect the sling fibers of the stomach wall (Fig. 27.6).

Fig. 27.6 Heller myotomy, extending a minimum of 6 cm proximally and for about 2–3 cm distally into the stomach

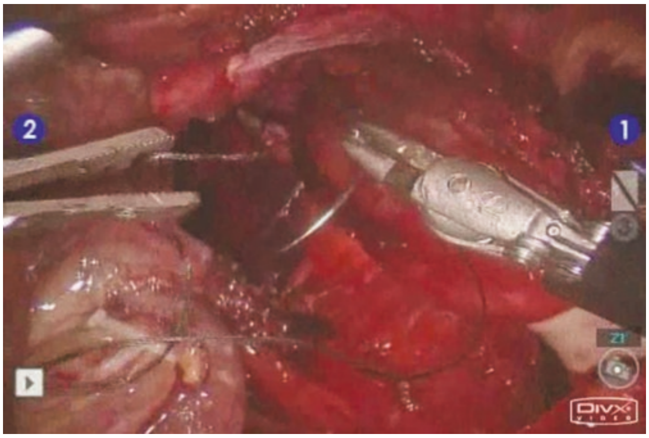


Fig. 27.7 Closure of the esophageal hiatus. Three or four interrupted stitches placed using intracorporeal knot tying technique

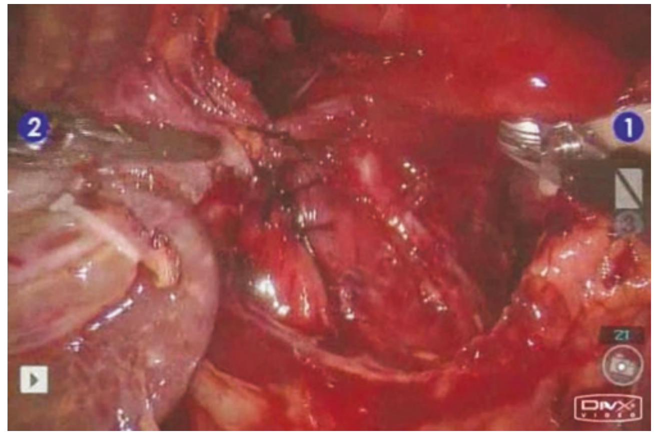


Fig. 27.8 Dor fundoplication. Composed of two rows of sutures, of three stitches each

27.2.8 Closure of the Esophageal Hiatus

After the completion of the myotomy, the reconstruction of the esophageal hiatus begins. The right hand instrument of the surgeon is changed to a needle driver. The assistant passes a 15-cm long 0-silk suture to the surgeon. The esophagus is retracted anteriorly with Arm 3 using the Penrose drain. Starting just above the junction of the right and left crura three or four interrupted stitches are placed using intracorporeal knot tying technique (Fig. 27.7). For this part of the procedure, the bougie is pulled back into the esophagus. The use of the robot may improve crura closure, since it allows for more precise performance of intracorporeal knot tying.

27.2.9 Dor Fundoplication

The preferred antireflux operation is the Dor fundoplication, which is an anterior 180° fundoplication. This fundoplication is chosen because it covers the exposed mucosa and is an effective antireflux repair. The bougie is now gently advanced into the stomach. The Dor fundoplication is composed of two rows of sutures, three stitches each. The first row of suture includes the gastric fundus and left side of the myotomy. The first stitch is placed between the fundus, the left pillar and left edge of the myotomy. Two more stitches incorporate the gastric wall and the left side of the myotomy. Subsequently, the surgeon folds the stomach over the exposed mucosa. The assistant brings the second suture and the surgeon holds the wrap in place by activating Arm 3. The second row of suture is created. The first stitch of the second row of suture is placed between the stomach, the right edge of the myotomy, and the right pillar. Finally, the second and the third stitches are placed between the greater curvature of the stomach and the right side of the esophageal muscle (Fig. 27.8). Two additional stitches are placed between the fundus of the stomach and the rim of the hiatus to decrease tension and the possibility of unfolding of the fundoplication. At the completion of the procedure, the bougie is carefully removed and an upper endoscopy is discretionary to corroborate the indemnity of the esophageal and gastric mucosa.

27.3 Postoperative Care

Patients are admitted to the regular floor for postoperative care. A contrast esophagram is performed on postoperative day #1 to rule out staple line leak (Fig. 27.9). If the contrast study is normal, a clear liquid diet is initiated and advanced as tolerated. Patients are discharged on a specific post-esophageal surgery diet for 4–6 weeks that is advanced progressively to solid food.

27.3.1 Management of Postoperative Leaks

Staple line leak remains a major diagnostic and therapeutic challenge. The clinical presentation is variable; whereas some patients may present with obvious mediastinitis and sepsis that can lead to multi-organ failure, others present with subtle signs and symptoms that can lead to treatment delays. For that reason, it is important to have a high index of suspicion since a delay in diagnosis greater than 24 h post-perforation doubles the risk of mortality. If stable, the patients should be evaluated with water-soluble contrast study as well as CT scan to evaluate for fluid collections. After the confirmation of the diagnosis and stabilization of the patient (NPO, IV fluids, broad spectrum antibiotics) the surgeon must decide whether to opt for operative or conservative management. Historically, postoperative leaks have been considered a surgical emergency. Nonetheless, changes

Fig. 27.9 Postoperative upper gastrointestinal study after resection of epiphrenic diverticulum of the esophagus

in surgical practice have occurred in recent years, expanding the management options. The stability of the patient is an important factor at the time of deciding for treatment. In stable patients with minimal extra luminal contamination, conservative treatment is an acceptable alternative. On the other hand, patients with extensive mediastinal/peritoneal contamination require emergency surgery. At the time of the exploration primary repair can be attempted. Often times, primary repair cannot be accomplished because of the delayed presentation of the perforation and the widespread contamination. If primary repair is not feasible, either percutaneous or surgical drainage should be attempted in conjunction with stenting. Coated stents have demonstrated to be useful for the treatment of leaks. Stents are left in place for an average of 6–8 weeks. PEG tube or jejunostomy feeding can be implemented while progressing to oral feeding with the stent in place.

27.4 Pitfalls and Pearls

Despite the fact that no strong evidence is available in this matter, opinions of respected experts in the field seem to be in agreement concerning the important aspects of the operation, such as resection of the diverticula, oversewing of the esophageal muscle layers over the staple line, extended myotomy, and partial fundoplication.

Specific pearls and pitfalls for epiphrenic diverticulectomy are described below:

- The operation should not be offered without complete evaluation including endoscopy, barium swallow, esophageal manometry and 24 h pH monitoring if necessary.
- Extraesophageal symptoms (cough, aspiration, COPD, etc.) may be an indication for Diverticulectomy.
- Recognize the location of the diverticulum and use the approach that is most convenient to the specific patient.
- Patients must be positioned with care to prevent nerve injuries since these procedures can be lengthy. The common peroneal and femoral nerves are especially vulnerable in the lithotomy position.
- In large diverticula extending into the proximal esophagus a combined transthoracic and transabdominal approach may be required in order to address the diverticulum, the extended myotomy and the partial fundoplication.
- Trocar placement should include the addition of a fourth robotic port for retraction of the esophagus. Thereby, the assistant at the bedside can aspirate the smoke or any eventual bleeding during the intramediastinal dissection. Alternatively, gauze can be introduced and used by the surgeon to keep the working field dry.
- The assistant's port should always be 12 mm in diameter in order to introduce the endoscopic linear stapler without difficulties.
- Intraoperatively, it is important to avoid speculating the location of the diverticula. If there is any doubt, repeat endoscopy and with transillumination identify the anatomical structures. At the completion of the procedure, if necessary, upper endoscopy can be helpful to check for air leaks and to determine if the fundoplication or the crura closure are too tight.
- The daVinci™ robotic system is critical for the proximal dissection of the diverticulum. In order to take full advantage of the articulation of the tip of the instruments, hook electrocautery or "hot" scissors are advised. Other energy sources such as harmonic scalpel do not count with Endo Wrist technology and the Endo Wrist® One Vessel Sealer is recommended instead.
- If performed improperly this dissection can result in injury to the parietal pleura and pneumothorax or significant bleeding which can obscure the surgeon's field. In the event of pleural injury, approximation of the pleural edges with robotic locking clips can prevent tension pneumothorax and enlargement of the opening.
- If long esophageal myotomy is required, the transhiatal approach can still be used as the robotic-assistance enhances the ability of the surgeon to perform an adequate middle and upper esophageal dissection.
- To avoid tearing or perforation, grasping of the diverticula or esophagus should be minimized due to the lack of haptics in the current robotic systems.
- In case of perforation of the diverticula, it is important to prevent spillage of its contents since it can result in mediastinitis.

- In the event that staple line leak develops, transthoracic drainage of the posterior mediastinum may be required. Thoracotomy or thoracoscopy can be used according to the experience of the operating team. In addition, placement of a coated esophageal stent may hasten recovery and the return to oral feedings. Placement of a naso-jejunal feeding tube or feeding jejunostomy is highly recommended at this time as well.
- If while performing the myotomy bleeding from the muscle edges occur, it is very important to avoid using electrocautery. For the most part the bleeding subsides just by applying compression.
- Avoidance of injury to the vagus nerve is imperative.
- Passage of the esophageal bougie can be a hazardous point in the operation, as it may perforate the esophagus or the diverticula. This procedure can be halted by the presence of the robotic cart at the patient's head. For that reason, bougie insertion should always be done with extreme caution and attempted under direct supervision of surgical team or should be inserted by a surgeon.
- The esophageal bougie has marks indicating distance from the tip to guide the operator and surgeon while advancing the bougie down the esophagus and into the stomach. The surgeon may fold the diverticulum over the esophagus in order to shut the mouth of the diverticulum while the dilator passes into the stomach. Generous lubrication should be utilized.
- In light of the remaining risk for gastric acid aspiration at the end of the operation, extubation should only be considered in the patient who is fully awake and able to protect the airway.

References

1. Nehra D, et al. Physiologic basis for the treatment of epiphrenic diverticulum. Ann Surg. 2002;235(3):346–54.
2. Tedesco P, et al. Cause and treatment of epiphrenic diverticula. Am J Surg. 2005;190(6):891–4.
3. Benacci JC, et al. Epiphrenic diverticulum: results of surgical treatment. Ann Thorac Surg. 1993;55(5):1109–13; discussion 1114.
4. Varghese TK Jr, et al. Surgical treatment of epiphrenic diverticula: a 30-year experience. Ann Thorac Surg. 2007;84(6):1801–9; discussion 1801–9.
5. Rosati R, et al. Diverticulectomy, myotomy, and fundoplication through laparoscopy: a new option to treat epiphrenic esophageal diverticula? Ann Surg. 1998;227(2):174–8.
6. Melman L, et al. Esophageal manometric characteristics and outcomes for laparoscopic esophageal diverticulectomy, myotomy, and partial fundoplication for epiphrenic diverticula. Surg Endosc. 2009;23(6):1337–41.
7. Rosati R, et al. Laparoscopic treatment of epiphrenic diverticula. J Laparoendosc Adv Surg Tech A. 2001;11(6):371–5.
8. Del Genio A, et al. Laparoscopic approach in the treatment of epiphrenic diverticula: long-term results. Surg Endosc. 2004;18(5):741–5.
9. Fernando HC, et al. Minimally invasive operation for esophageal diverticula. Ann Thorac Surg. 2005;80(6):2076–80.
10. Dupont FW. Anesthesia for esophageal surgery. Semin Cardiothorac Vasc Anesth. 2000;4(1):2–17.
11. Benacci JC, et al. Epiphrenic diverticulum: results of surgical treatment [see comment]. Ann Thorac Surg. 1993;55(5):1109–13; discussion 1114.
12. Fekete F, Vonns C. Surgical management of esophageal thoracic diverticula [see comment]. Hepato-Gastroenterology. 1992;39(2):97–9.
13. Matthews BD, et al. Minimally invasive management of epiphrenic esophageal diverticula. Am Surg. 2003;69(6):465–70; discussion 470.

28 Esophageal Leiomyoma

Thomas Schmid and Florian Augustin

Abstract

Esophageal leiomyoma is a benign tumor originating from the muscularis propia. Patients complain of dysphagia or chest pain. Malignant transformation is rare. Surgical resection is recommended. Integrity of the esophageal mucosa during dissection is of utmost importance. A robotic approach with improved three-dimensional vision and dexterity might improve outcome in minimally invasive leiomyoma resection. We report our institutional approach to robotic leiomyoma resection and provide a stepwise instruction on how to perform the procedure.

Keywords

Leiomyoma • Robotic approach • Mucosal integrity

Leiomyomas account for 70% of all benign tumors of the esophagus [1]. They show an intramural growth pattern originating from the muscularis propria. Fifty percent of patients complain about dysphagia and atypical chest pain [2]. Malignant transformation is rare, but cannot be excluded. Thus, surgical resection is emphasized also for asymptomatic cases [3].

Open enucleation remains the "gold standard." However, in recent years the video-assisted thoracoscopic surgical approach has shown to be a feasible alternative [4]. The use of the da Vinci robotic system allows for meticulous preparation and better preservation of the mucosal integrity, which is a crucial step of the operation [5].

Preoperative workup consists of esophagogatroscopy (EGD), endoluminal ultrasound (EUS) and CT scan. A barium swallow is helpful, but not mandatory. If preoperative findings are consistent, a needle biopsy should be omitted as endoscopic or EUS guided transmucosal biopsies complicate dissection and result in a higher rate of intraoperative mucosal perforation [4].

The surgical approach in our institution is generally performed via a robotic-assisted thoracoscopy with the patient in a left lateral decubitus position. Ninety percent of the lesions are located in the middle or lower third of the esophagus. When the tumor is situated near the gastroesophageal junction, a laparoscopic approach in conjunction with a fundoplication is advised [2, 4].

The ten phases of the operation:

1. Positioning of the patient in a left lateral decubitus position
2. Introduction of the trocars and connection to the robot
3. Identification of the leiomyoma by endoscopic translumination
4. Circular dissection of the esophagus in the respective area
5. Incision of the muscular layer above the tumor (if still intact)
6. Grasping the leiomyoma anchored with a 0-silk stay suture or directly with a Cardiere forceps
7. Division of the tumor from the mucosal tube under direct view and/or translumination

T. Schmid, M.D. (✉) • F. Augustin, M.D.
Department of Visceral, Transplantation and Thoracic Surgery, Center of Operative Medicine, Innsbruck University Hospital, Innsbruck, Tirol, Austria
e-mail: thomas.schmid@tirol-kliniken.at

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_28

8. Saline submersion test to ensure mucosal integrity
9. Approximation of the muscular layers with single suture stitches
10. Introduction of a 24 Fr. chest tube with its inner end being loosely attached to the direct operating field

Typical endoluminal and CT view of a leiomyoma in the middle third of the esophagus. The tumor presents as a solid, bulging, intramural mass with intact mucosa (Fig. 28.1).

The patient is brought in a left lateral decubitus position. The Robot is approached from cephaled, slightly from the right side (11 o'clock position). The table-side surgeon sits on the ventral side of the patient. The camera trocar is introduced through the eighth intercostal space (ICS) in the anterior axillary line. The trocar for the right robotic arm is brought in through the sixth ICS more anteriorly, and for the left arm through the ninth ICS in the posterior axillary line. An additional thoracoport for the suction device is performed between the camera and the left arm (Fig. 28.2).

After incision of the intact muscle wall, the tumor is anchored with a 0-silk stay suture or directly grasped with a Cardiere forceps (left robotic arm) and gently divided with the cautery hook (right robotic arm) from the mucosal tube (Fig. 28.3). The introduction of an gastroscope helps to identify the structures by translumination. Extensive care must be taken not to perforate the mucosal tube. If this happens, the mucosal defect is closed with stitches (Fig. 28.4).

The muscular layer is approximated after complete enucleation of the tumor by absorbable single stitch sutures. The creation of a stenosis must be avoided. In case, approximation of the muscle can be abandoned if the mucosal layer remained intact.

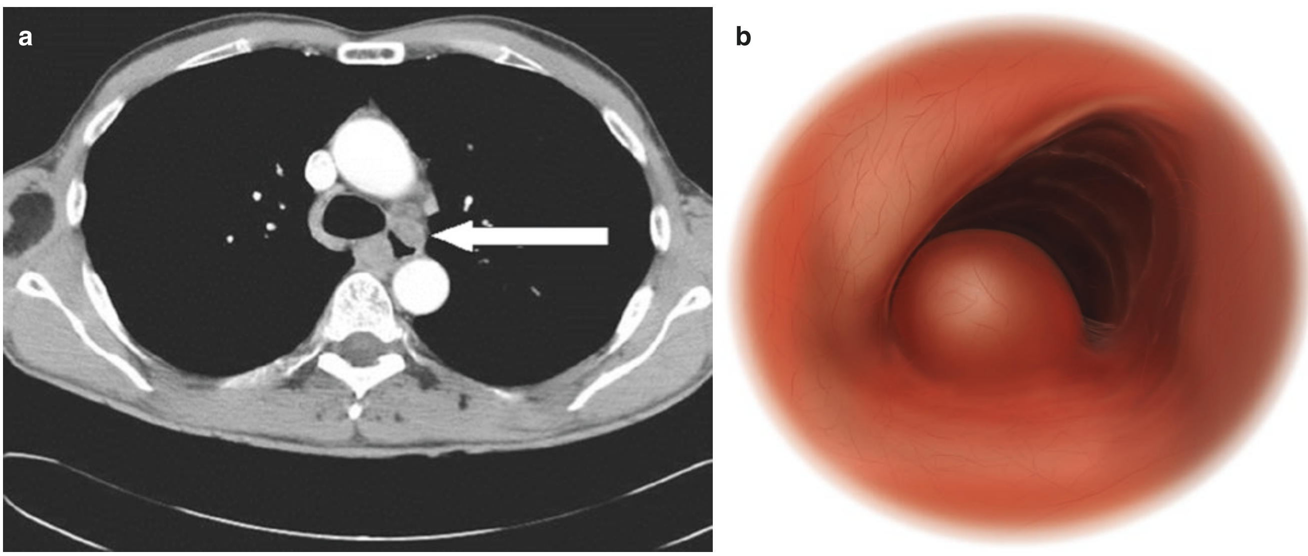


Fig. 28.1 Picture of endoluminal (**a**) and CT (**b**) view of the lesion

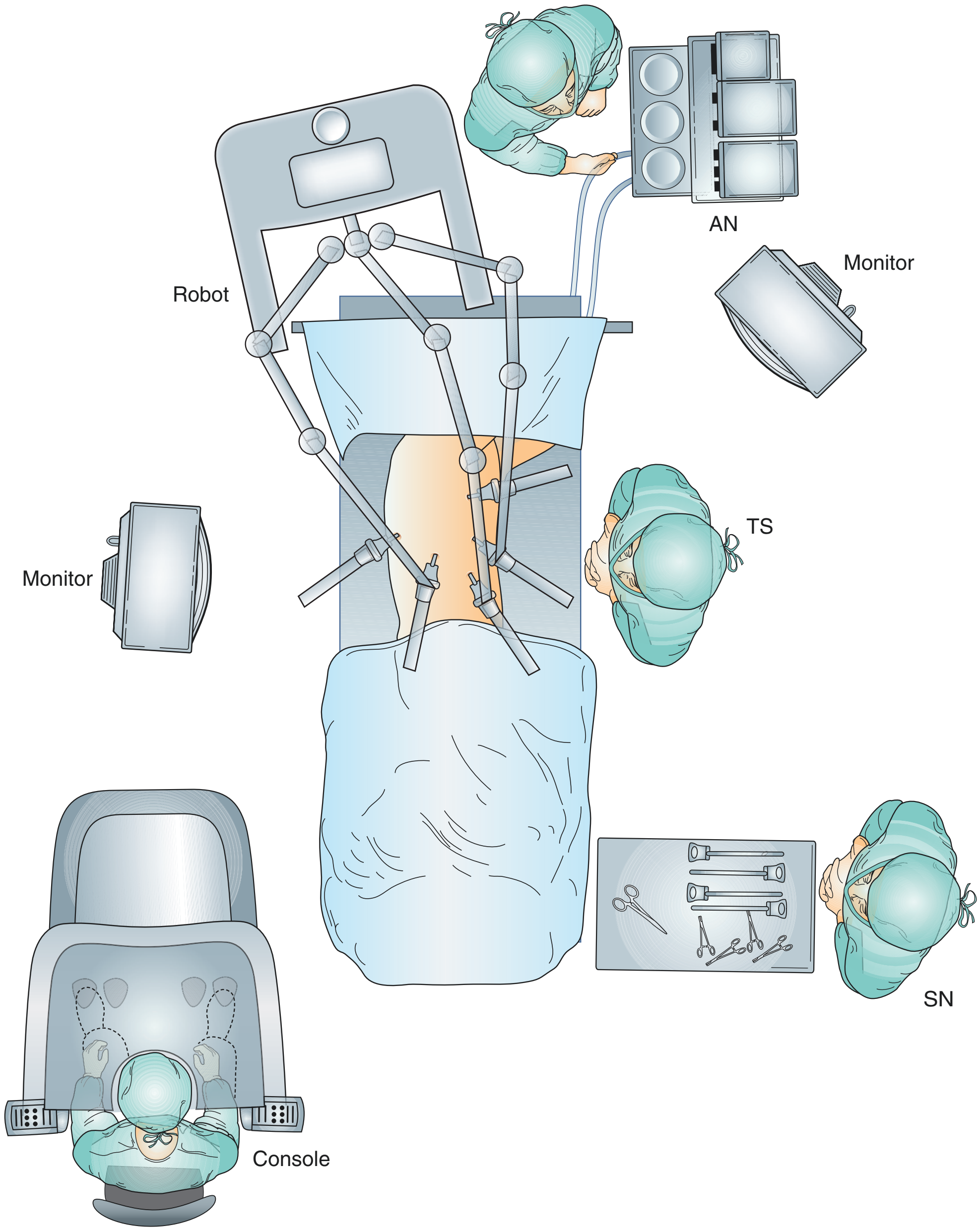


Fig. 28.2 Picture of robot positioning

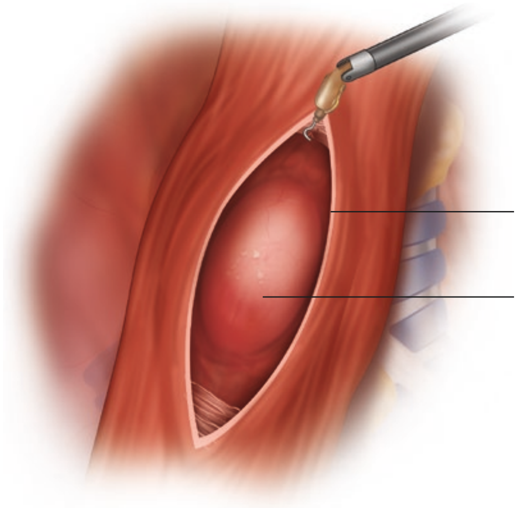


Fig. 28.3 Picture showing the excision of the leiomyoma with the robotic cautery hook

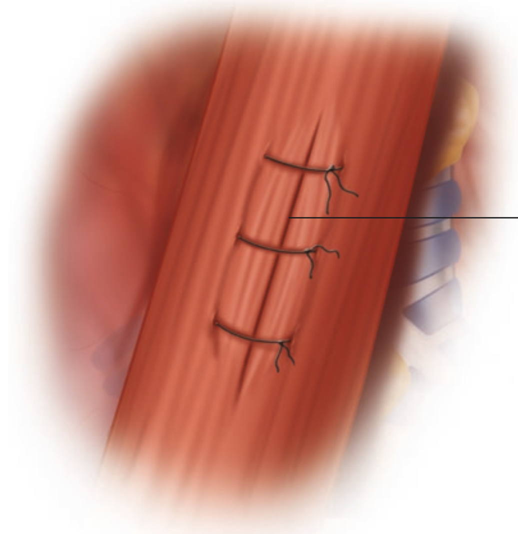


Fig. 28.4 Picture showing the final result with the muscular layer of the esophagus closed

References

1. Nguyen NT, Alcocer JJ, Luketich JD. Thoracoscopic enucleation of en esophageal leiomyoma. J Clin Gastroent. 2000;31:89–90.
2. Elli E, Espat NJ, Berger R, et al. Robotic-assisted thoracoscopic resection of esophageal leiomyoma. Surg Endosc. 2004;18:713–6.
3. Aurea P, Grazia M, Petrella F, et al. Giant leiomyoma of the esophagus. Eur J Cardiothorac Surg. 2002;22:1008–10.
4. Zaninotto G, Portale G, Costantini R, et al. Minimally invasive enucleation of the esophageal leiomyoma. Surg Endosc. 2006;20:1904–8.
5. Bodner JC, Zitt M, Ott H, et al. Robotic assisted thoracoscopic surgery (RATS) for benign and malignant esophageal tumors. Ann Thorac Surg. 2005;80:1202–6.

Robotic Transthoracic Esophageal Leiomyoma Resection

29

Kemp Kernstine Sr.

Abstract

Esophageal leiomyoma is the most common benign esophageal tumor. It is of smooth muscle origin. Dysphagia is the most common symptom. Many are found incidentally. Upper gastrointestinal endoscopy, barium swallow, endoscopic ultrasound, and computed tomography are the most frequent methods to evaluate them; other tests might be necessary to clarify the differential. Surgical resection is indicated for symptoms, possibility of malignancy, enlarging lesions and for patients request removal of the lesions. Less than 10% need to be removed. The details of robotic resection are described. For simple esophageal leiomyoma, hospital stays are brief, less than 3 days.

Keywords

Esophageal leiomyoma • Esophagus • Neoplasm • Enucleation • Laparoscopic • Thoracoscopic • Robotic surgery • Esophageal diseases • Dysphagia • Minimally invasive • Benign tumor of the esophagus

29.1 Background

Leiomyoma of the esophagus is a rare esophageal neoplasm and is the most common benign esophageal tumor, accounting for more than 60–70% of all benign esophageal lesions. Thorough examination of the esophagus at autopsy has found esophageal leiomyoma to be present in as many as 5% of patients. It is frequently asymptomatic and most often found during routine symptom-driven gastroenterology evaluations, unrelated to the leiomyoma. Histologically, it is characterized as an encapsulated well-defined nodule or mass that is composed of fibrous connective tissue and disorganized muscle fibers and is of smooth muscle origin. In nearly 95%, it is derived from the inner aspect of the muscularis propria and the remainder from the muscularis mucosa. In 80%, the growth pattern is intramural, less commonly intraluminal or extraluminal. The differential diagnosis includes esophageal cancer, gastrointestinal stromal tumor (GIST), leiomyosarcoma, leiomyoblastoma, angioma, fibroma, angiokeratoma, lipoma, hamartoma, neurofibroma, schwannoma, granular cell tumor lymphangioma, intramural cysts; such as duplication cysts; polypoid lesions that include squamous papilloma or fibrovascular polyps, and extrinsic compression or displacement from mediastinal abnormalities, such as mediastinal tumors, lymphadenopathy, cysts or aneurysms. Approximately 60% of esophageal leiomyomas are located in the lower third of the esophagus, 30% in the middle third and 10% in the upper third. The size is most often 2–6 cm in greatest dimension, the average size of resected lesions being 4–5 cm. In 95%, they are solitary, the remainder is multiple leiomyomas. The character is most commonly oval and solid; some may be complex bulbous

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Department of Cardiovascular and Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th Floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_29

lesions that in about 13% can partially encircle the esophageal lumen, referred to as a horseshoe leiomyoma. The most common symptom is dysphagia, present in nearly 50% of patients, but rarely completely obstructs. They rarely ulcerate. The evaluation of the potential leiomyoma is driven to determine the whether there is a possibility of esophageal cancer or GIST; either may be treated with multimodal preoperative therapy. The workup of a potential esophageal leiomyoma may include:

1. Esophagoscopy provides a direct view of the esophageal mucosa assessing for ulceration, location from the incisors and is the most helpful in differentiating from esophageal cancer.
2. Barium swallow provides information on the function and the anatomy of the esophagus and assesses for mucosal irregularity. An esophageal leiomyoma is a smooth, crescent shaped defect into the esophageal lumen that moves with swallowing. Hiatal hernia is present in about 2–25% of patients and there may be associated diverticula and reflux that may impact on the surgical treatment planning.
3. Endoscopic ultrasound (EUS) provides information about the lesion character such as homogeneity and sharpness of the margins, depth of invasion, involvement of the mediastinum and any associated lymphadenopathy. Biopsy of the lesion is not recommended. Fine needle aspiration does not provide sufficient accuracy in these cases to confirm the absence of malignancy.
4. Computed tomogram (CT) with intravenous and oral contrast can provide helpful structural anatomical information and the association with mediastinal structures and provides information to develop an operative approach.
5. Magnetic resonance imaging may be helpful to determine the presence of malignancy. In a leiomyoma, the T2-weighted image is isointense with the esophageal wall, where esophageal cancer has higher intensity.
6. Fluorodeoxyglucose (FDG)-Positron Emission Tomography (PET)-CT may be performed when there is suspicion of malignancy, assessing the FDG-avidity of the primary lesion and for any evidence of regional or systemic metastatic disease.
7. pH and esophageal manometry may be indicated in patients that appear to have significant swallowing dysfunction and/or evidence of reflux esophagitis and possible hiatal hernia or barium swallow or esophagoscopy.

Surgical resection is recommended for the following reasons:

1. To resolve symptoms,
2. To determine the presence of malignancy, more commonly in lesions larger than 3 cm and heterogeneous on CT and/or EUS
3. To prevent the possibility of malignant transformation, and
4. To minimize the development of symptoms and later difficulties removing the tumors that may enlarge.
5. To address patient-related issues. Some patients may be uncomfortable being followed for lesions that might be malignant. There may be patients who may not be capable of regular examinations to assess their esophageal lesions.

Today, given the quality of noninvasive testing, fewer than 10% of the leiomyomas require resection, small and asymptomatic esophageal lesions can be safely observed for growth and/or malignant degeneration. In many cases, histology, rather than cytology, is necessary to differentiate esophageal leiomyoma from other tumor types, such as GIST. Immunohistochemistry is helpful in differentiating GIST from leiomyoma; GIST stains for CD34 and CD117 (also referred to as c-kit) and a leiomyoma stains for smooth muscle actin and desmin. A biopsy of these submucosal lesions prior to resection is not recommended due to potential of transmucosal scarring, a defect that may increase the likelihood of mucosal injury at the time of surgical resection and the fact that the biopsy tissue is most often insufficient confirm the lack of malignancy.

Esophageal leiomyomas have been removed via thoracotomy and laparotomy; enucleation is the usual technique, but more complex lesions may require an esophagectomy or replacement with a segment of small or large intestine. In enucleation, mucosal injury is reportedly as high as 7% and is likely under-reported. Injury appears to increase the morbidity and length-of-stay. The complication rate is approximately 12% and the average length-of-stay is nearly 9 days. Lesions up to 8–10 cm in size have been resected without any evidence of esophageal dysfunction. In addition, the surgical access incisions, dissection and esophageal mobilization necessary with thoracotomy and laparotomy may all result in prolonged hospital stay and return to preoperative function. Innovations in surgical technology have resulted in video-assisted visibility and instrumentation. In 1992, the thoracoscopic approach was introduced and in our review the rate of mucosal injury is reported to be 5% and the procedure takes slightly more than 2 h with a complication rate of 13% and an average length-of-stay of 6 days. The conversion rate to thoracotomy was 3%. Computer-assisted technology, robotic-assisted surgery has provided additional visibility, stable magnification and multiple arcs of rotational freedom to precisely resect leiomyomas avoiding mucosal injury. In our review of the literature, six leiomyoma cases recorded to have used robotic-assisted surgery, there have been no reports of esophageal mucosal injury, morbidity or mortality.

For leiomyomas within the area of the gastroesophageal junction, they are best removed laparoscopically. For those that are beyond the reach of a laparoscope, more than 4–5 cm above the gastroesophageal junction, they are approached through the chest. The side of the chest to approach the tumors is directed to avoid major structures and to direct the dissection to the major bulk of the disease. Upper, middle and lower third tumors may be approached through the right chest. Lower third tumors and middle third tumors that are associated with a hiatal hernia may be approached via the left chest. Placing an esophageal endoscope may assist in localizing the tumor and providing a means of assessing the integrity of the remaining surgically treated esophageal mucosa after resection.

29.2 Operative Setup and Stepwise Conduct of the Operation

To transthoracically enucleate an intrathoracic esophageal leiomyoma, a four-arm robotic technique was developed; (1) robotic videoscope, (2 and 3) two arms for the surgical dissection, and (4) an additional arm for retraction of an intra-leiomyoma placed stitch. After double-lumen endotracheal tube intubation, an esophagoscope is passed to the level of the esophageal mass, the patient is placed in the left lateral decubitus position, rotated slightly forward to near prone and slightly in reverse Trendlenberg. Five to six thoracoports are placed in the right chest (Figs. 29.1 and 29.2)—two 12-mm ports, one for the videoscope and one for placing the fan retractor (Ethicon Inc., Cincinnati, OH, A Johnson and Johnson Company) and passing sutures; three 8-mm robotic ports for the three functioning robotic arms using the

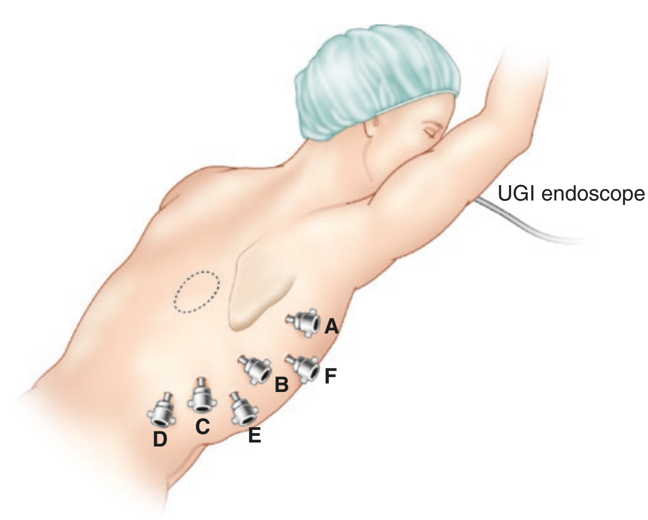


Fig. 29.1 In this case, with a middle esophageal "apparent" leiomyoma with the greatest proportion of the mass toward the right chest on the preoperative chest CT, the right chest approach is chosen for the removal of the esophageal mass. The patient is placed in the left lateral decubitus position after the esophagoscope is placed to the upper most portion of the esophageal mass. The patient is rotated about 30° anteriorly and raised in a reverse Trendelenburg fashion 30° head up. Five to six thoracoports are placed. First, using the CT scan and the bony anatomy draw with an indelible marker where the esophageal mass to be resected is located. In this case, where the mass is located adjacent to the azygous vein, the best view was chosen just inferior and anterior to the tip of the scapula usually in the sixth–seventh intercostal space; site B. Site B, the video thoracoport site, is marked first. Site A is then marked; it is just anterior to the scapula in the third-fourth intercostal space, about 6 cm cephalad along the same longitudinal plane just anterior to the scapula in the third-fourth intercostal space. Site C is marked caudad along the same longitudinal plan 5–6 cm and Site D is marked caudad to Site C another 5–6 cm. A fifth port, Site E, is marked exactly 6 cm anterior to the longitudinal plane midway between Sites B and C. A sixth port, Site F, should be marked along the same longitudinal plane as Site E, midway between Site A and B. The chest, back and shoulder are then prepped and draped in the usual fashion. Marking the chest first will help the entire team know the plan and the positioning of the drapes

ProGrasp, Hook Cautery, and Cadiere Grasper (all three instruments, Intuitive Surgical, Inc.) for dissection, maintaining tension on the tumor retraction stitch and suturing; one 5-mm port for retraction and suctioning (Fig. 29.2). The direction of the robot is directly from the back or directed from the back of the neck. Prior to surgically prepping the skin, we place a mark on the skin where we estimate the target is located, the target being the esophageal mass in relation to the bony landmarks on the chest wall. Using the

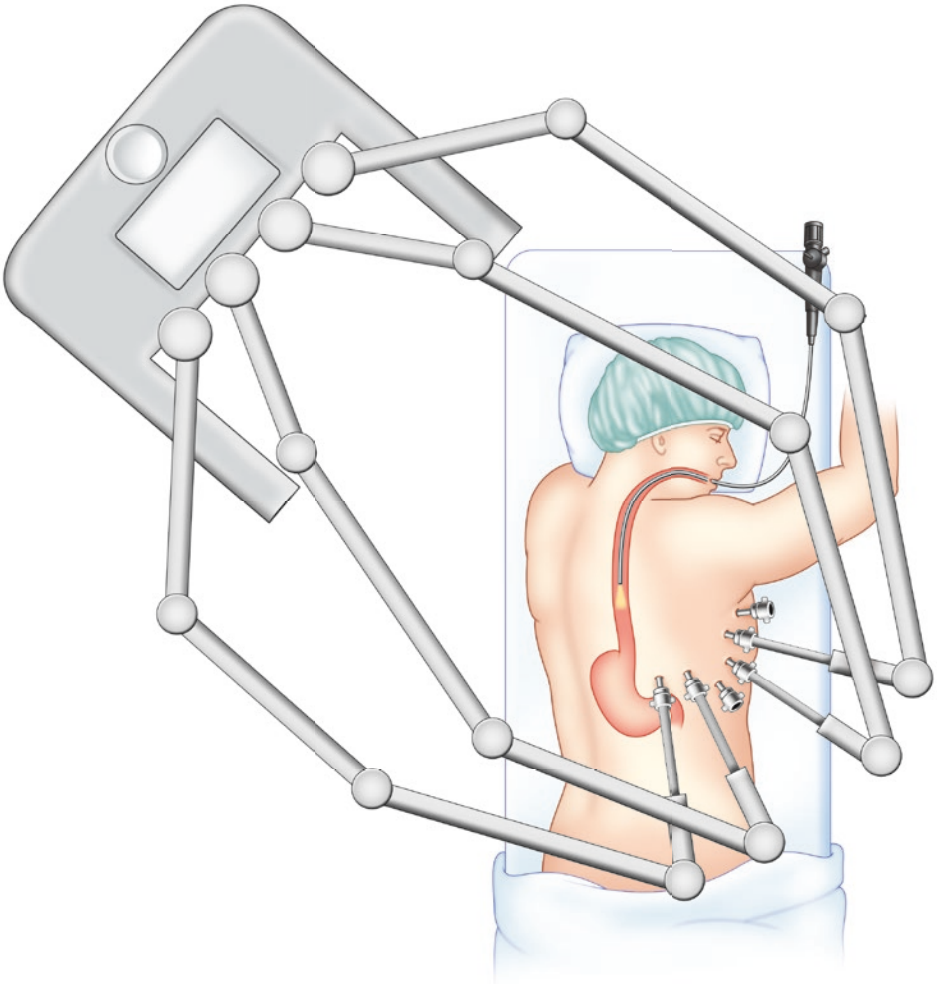


Fig. 29.2 Again, in this case, the patient position and the direction the robot or bedside cart is determined by the location of the esophageal leiomyoma along the course of the esophagus, location of the predominance of the esophageal mass bulk and the location of the mass in relation to the major mediastinal structures; vessels, nerves and airway. In this case the predominance of the mass is to the right chest. First, all ventilation is stopped, at Site B, 0.125% bupivacaine with epinephrine is injected liberally into the skin and intercostal space and an incision is made at the port site. A tonsil clamp is used to carefully and gently puncture the intercostal space and allow air to enter the pleural space. The lack of any lung or mediastinal movement minimizes the risk of lung injury on entry into the chest. A 12 mm thoracoport is placed into the chest. The robotic of videoscope is then passed and the chest cavity explored for any unsuspected pathology. Finding none, the CO_2 is infused to 10 mmHg through the side port allowing the lung and diaphragm to collapse and the mediastinum to shift away from the planned operative area. At Site A, under near-direct vision, after injection with the bupivacaine/epinephrine and a transverse incision, the robotic 8-mm thoracoport is placed just cephalad to the adjacent rib. The same process is performed for Sites C through F. The robot is brought into position from the patient's back along a line with the "target," the esophageal leiomyoma, and the base of the robot or bedside cart and the videoscope in Site B. The robot arms at then attached to the ports in Sites A through D, with the videoscope arm attached to the 12 mm thoracoport at Site B. A 12-mm thoracoport is place into Site E and a 5-mm thoracoport is placed into Site F. The robot is positioned a sufficient distance away from the patient to allow for adequate mobility of the arms and to minimize arm conflict

computed tomogram, esophagram and thoracoscopic view and upper gastrointestinal (UGI) endoscopic direct visualization of the mass (Fig. 29.3), with a hook cautery on a setting of 30–45, the mediastinal pleura is sufficiently incised and the esophagus mobilized as necessary to expose the lesion. Unlike the open thoracotomy approach, there is no need to fully mobilize the esophagus. Then, the hook cautery is used to incise the longitudinal and attenuated circular muscle over the mass dividing them lengthwise along the esophagus and separated from the mass. Once exposed and

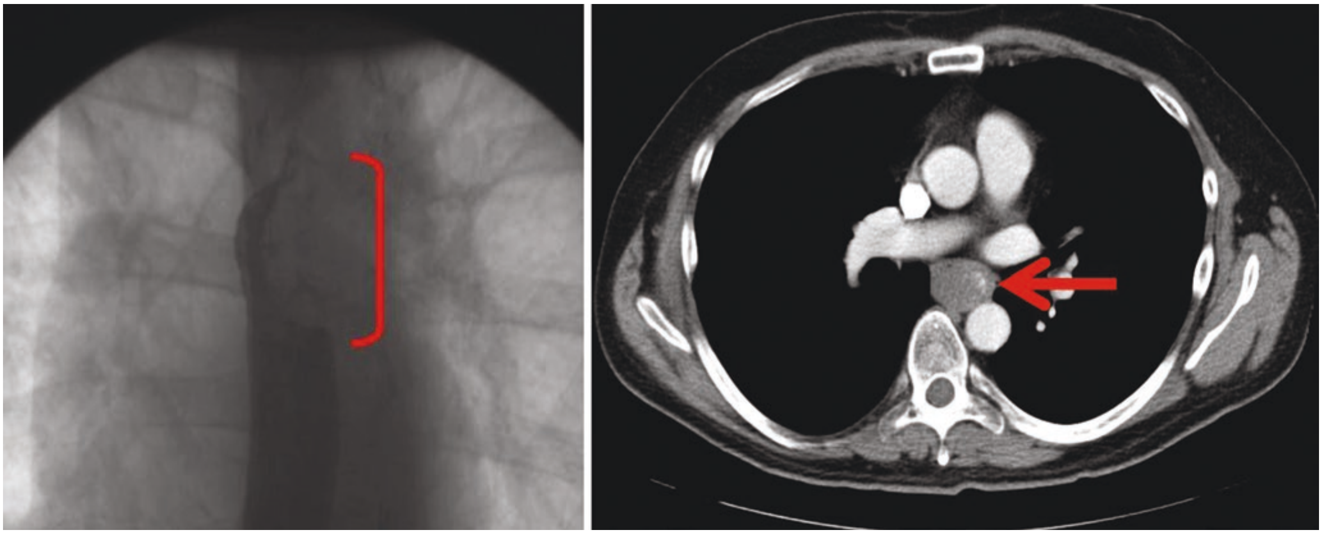


Fig. 29.3 A barium swallow, chest CT and upper gastrointestinal endoscopy with endoscopic ultrasound are performed preoperatively. In the case of this patient we find a middle esophageal mass that is nonobstructive immediately adjacent to the arch of the azygous vein and the greatest predominance of the mass toward the right chest. There was no evidence of any reflux, there was normal appearing motility and no evidence of any mucosal irregularity, esophagitis, Barrett's esophagus or obstruction. The mass was based on the layer of the circular muscle and it was homogenous and was felt to be likely a leiomyoma. No needle biopsy was performed given the inability needle biopsy to provide sufficient negative predictive value for malignancy. Because of the dysphagia, resection, rather than continued observation, was chosen to treat this mass. Given this location, a right chest, rather than left chest or abdominal, removal of the mass was chosen

separated from the esophageal wall at the superior and inferior aspect of the lesion, an 8–10 cm length of 0-Ethibond on an SH needle (Ethicon Inc.) is sutured into the mass as a retraction suture, either in a simple or figure-of-8 fashion dependent upon the firmness of the lesion, and held by the fourth arm with the Cadiere Grasper with sufficient tension to pull the lesion up and away from the esophageal wall. Appropriate tension and angle of retraction can be adjusted by the surgeon during the next phase of the procedure. Then, under direct and UGI endoscopic visualization, the esophageal wall muscular tissue and the mucosa are carefully teased from the mass under the three-dimensional vision and the tremorless precision of the robotic instrumentation without injury to the mucosa. After the mass is removed, the muscular layer and mediastinal pleura are loosely reapproximated with running or interrupted 3–0 Vicryl sutures on an SH needle (Figs. 29.4, 29.5 and 29.6). The pleura and region are drained with two adjacently placed 19-French round Blake drains sutured into position with one to three 6 cm long 5–0 chromic sutures on an RB-1 needle. We then perform an intercostal block with 0.125% bupivacaine with epinephrine from T2 to T10. The operating room time is typically less than 2 h, and the estimated blood loss is usually less than 50 mL. The tumor is removed in a protective endobag (Anchor, Inc., Columbus, Ohio) through one of the most anterior superior 12-mm port sites. Patients typically require minimal narcotics for pain control on the first postoperative day and discharged the day after the procedure. A barium swallow is performed the next morning to assess esophageal mucosal integrity. The drains were subsequently pulled, and the patient was discharged on a full liquid diet for 5 days and then a soft diet for the next week and then advanced to a regular diet. He has had no recurrent symptoms and has remained fully functional since the procedure, 3 years ago.

29.3 Tips and Pitfalls

For lesions resected at the gastroesophageal junction, dysfunction of the lower esophageal sphincter should be anticipated and it is recommended that an anti-reflux procedure be performed. For large lesions, a segment of the esophagus may need to be resected and replaced with a segment of isoperistaltic colon or small bowel. In the rare cases in which lesions are larger than 8 cm and have an annular growth pattern, have significant adherence to the adjacent muscular wall, or in cases in which there is a large mucosal defect/tear after leiomyoma excision, an esophagectomy may be necessary. A vagal-sparing esophagectomy may offer less postoperative symptoms. Large lesions up to 8–10 cm have been resected without any esophageal dysfunction. In routine cases, a drain is left adjacent to the resection site until a swallowing study is performed on the first or second postoperative day or, in cases where there is concern over the integrity of the esophageal wall, even longer. Many surgeons do not routinely use nasogastric tube decompression. Typically, we

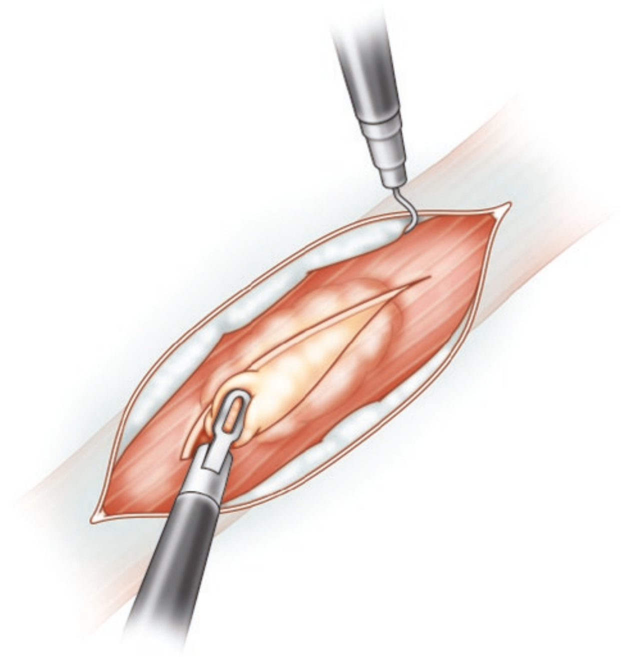


Fig. 29.4 In port A, we first place a Hook cautery, port C and D each have a ProGrasp or Cadiere Grasper placed. Through the 12-mm thoracoport in Site E a fan retractor is placed and through the 5-mm thoracoport at Site F a endoscopic peanut dissector is used to position the lung anteriorly, exposing the posterior mediastinum. The light on the esophagoscope is turned on at this point to help identify the site of the mass, should there be difficulty finding it. Once the esophageal mass is identified, the pleura and the adjacent mediastinal tissue are incised and dissected away from the longitudinal muscle With the cautery set at 30–45, the mediastinal pleural is incised longitudinally along the esophagus directly over the area of the mass, extended 1-cm caudad and cephalad to the mass. The azygous vein may need to be divided to gain exposure and/or allow for the esophagus to be rotated to achieve direct access to the tumor. This dissection is continued to the surface of the esophagus. Once the outer wall of the esophagus is reached the esophagus at that point is mobilized immediately adjacent to the esophagus and with a sufficient circumferential dissection to fully visualize the leiomyoma. Then, the longitudinal muscle is incised along the course of the esophagus over the thickest portion of the mass, this may require mobilization of the leiomyoma into the operative field, rotating the esophagus sufficiently so that the mass is in full view. The cautery is turned down to 15 and with judicious use of the cautery the longitudinal fibers of the esophagus are teased away from the mass with judicious use of the cautery. Most of this dissection will be bloodless. Both sharp and blunt dissection is used to separate the tumor from the adjacent muscle fibers. Electrocautery should be avoided to reduce the likelihood for mucosal injury. If a small perforation occurs it may be primarily repaired, reapproximating the muscular layer over it. For larger defects, a pedicled intercostal muscle, thymic or omental flap may be used in the esophageal repair. For extensive tumors such as the “horseshoe” leiomyomas, the leiomyoma may need to be divided to facilitate removal

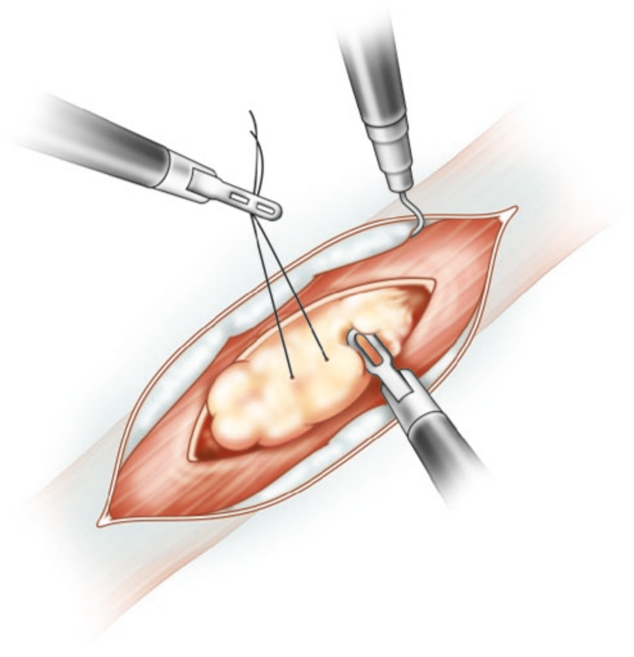


Fig. 29.5 Once the lateral, upper and lower aspects of the leiomyoma are mobilized from the longitudinal muscle, areolar tissue is often encountered at the upper and lower pole of the leiomyoma, again without cautery these areas are teased away from the leiomyoma. Once the leiomyoma is fairly mobile within the wall of the esophagus, the Hook cautery is removed from the thoracoport in Site A and replaced with a robotic needle holder. After removal of the fan retractor, a 8–10-cm length of 0 Ethibond on an SH needle is passed to the needle holder and a stitch is placed deeply into the leiomyoma; the needle is cut from the suture and the free ends held by the ProGrasp in thoracoport at Site D are handed the suture for slight and continuous retraction of the leiomyoma up and away from the esophagus. The Hook cautery is replaced in the Site A thoracoport arm and with the light on in the esophagoscope to gauge the location of the esophageal mucosa relative to the leiomyoma, the leiomyoma is carefully teased away from the mucosa. The tension on the stitch may need to be adjusted from time to time to gain a better view

place a nasogastric tube to decompress the stomach and reduce the likelihood of retching that might disturb the esophageal repair. Too, at the time of the postoperative esophageal swallowing study, the radiologist pulls the tube back beneath the repair and injects gastrografin under pressure to evaluate for a leak. Once the nasogastric tube is removed, the diet is advanced slowly, leaving patients on a soft or liquid diet for several postoperative days to weeks dependent upon the surgeon’s confidence in the repair. Mucosal tear is reported to occur in 8%, but the rate increases to 40–50% if prior endoscopic biopsy has been performed. Other potential complications include: diverticula, fistulas, reflux, esophagitis, ulceration, and stenosis. Recurrence is rare. Approximately 90% of patients are symptom-free at 5 years. If a GIST is found on final pathology, a chest and liver computed tomogram with a liver ultrasound should be performed. Esophageal GISTs had been resected with long-term follow-up without evidence of recurrence. Unless there is other GIST disease or residual margin, the use of adjuvant chemotherapy or targeted therapy, such as imatinib, is controversial.

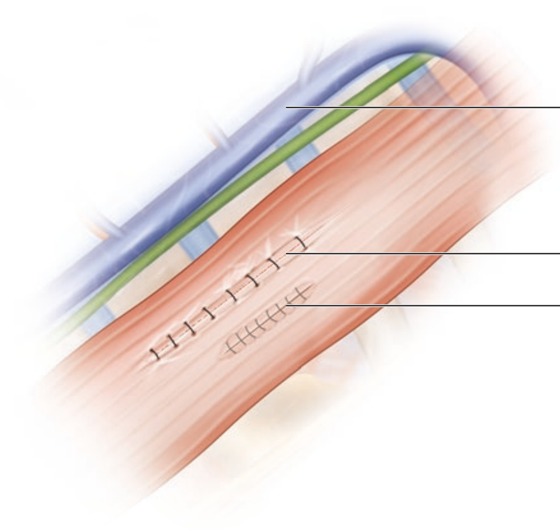


Fig. 29.6 Once the leiomyoma is completely removed from the wall of the esophagus, separated from the esophageal mucosa it is held by the fourth arm out of the way of the operative field. The operative area is then flooded with saline irrigation and air is insufflated through the esophagoscope to check for air bubbles. Then, if none is found and, if possible, the esophageal mucosa is covered by placing running and interrupted sutures of 2–3 × 6–10 cm segments of 3–0 Vicryl on SH needles to reapproximate the longitudinal muscle and periesophageal tissue performed in a fashion to avoid narrowing the esophagus. Although controversial, this covering over the mucosa maneuver may assist in repairing missed mucosal injuries missed during the saline submersion esophageal mucosal insufflation procedure; it may prevent later mucosal herniation and improve the some feel that it may prevent mucosal herniation and improve the post-resection esophageal muscular propulsive function. After the first coverage layer, the mediastinal pleura is reapproximated in a similar fashion to the first layer. The leiomyoma is then placed into a small retrieval bag and brought out through one of the port sites, the arm removed and a #19 round Blake passed through thoracoport D and drainage aspect of the drain sutured into place with interrupted 6 cm segments of 5–0 Chromic on a RB1 needle. The robot is pulled away and through a long endoscopic needle 0.125% bupivacaine with epinephrine is injected from T2 to T10. Another drain may be placed as necessary into the pleural space. All the ports are removed and the wounds closed with Vicryl or surgical glue

29.4 Outcomes

Minimally invasive surgical removal of leiomyomas produces less discomfort and allows for earlier return to preoperative function. Given the minimal esophageal and periesophageal dissection necessary with the approach, there may be many other advantages, not yet discovered. Operating time for thoracotomy and the minimally invasive approach appears to be similar, approximately 1 ½ to 2 ½ h. Small retrospective case series comparing the video-assisted, nonrobotic technique has shown a drop in the length-of-stay from 10 days for thoracotomy to 7 days for the video-assisted. There was also less pain and less analgesic requirement. Most have preoperative symptom resolution in the first few days to weeks (although it may take up to 2 years to resolve) and no mortality and minimal morbidity. For lesions within 4–5 cm of the lower esophageal sphincter, the laparoscopic approach appears preferable to the thoracoscopic approach for visibility, simplicity and recovery. There may be more discomfort with the transthoracic approach due to the torque on the instrumentation. Iatrogenic perforations that occur intraoperatively can be safely treated by intracorporeal suture placement. Esophagectomy may be necessary for severe perforations with minimal risk of mortality. Pedicled-vascular flaps of intercostal muscle-parietal pleura, thymus-pericardial fat, or omentum may be used to reinforce the repair and provide supplemental blood supply. Techniques to reduce the likelihood or mucosal damage include the placement of an illuminating endoscope or an endoscopic balloon to assist in pushing the lesion out and away from the lumen. The hand-assisted laparoscopic technique is thought to reduce the operative time for laparoscopic resection, but there is no prospective trial to confirm this supposition. The three-dimensional view and multiple arcs of rotation may reduce the likelihood for mucosal perforation. As technologies advance, resection of esophageal leiomyomas will become simpler and safer.

In summary, the leiomyoma of the esophagus is relatively rare. It is a distinct pathologic entity, which is unlikely to degenerate into malignancy. Resection should be reserved for thoroughly evaluated patients with symptoms or those in whom malignancy cannot be ruled out, usually lesions larger than 3 cm. Typically, surgical resection can be performed by a minimally invasive approach with minimal morbidity and mortality. The long-term outlook for enucleation of esophageal leiomyoma is good to excellent.

Selected References

Grover RS, Kernstine K, Krishnan A. A case of diffuse large B-cell lymphoma in association with paraesophageal leiomyoma: highlighting false-positivity of PET scan and importance of tissue diagnosis. J Natl Compr Cancer Netw. 2012;10(5):577–81.

Kernstine KH, Weiss LM. Esophageal cancer: principles and practice. Benign: Leiomyoma; 2009. p. 315.

Kernstine KH, Andersen ES, Falabella A, Ramirez NA, Anderson CA, Beblawi I. Robotic fourth-arm enucleation of an esophageal leiomyoma and review of literature. Innovations. 2009;4(6):354–7.

Robotic First Rib Resection: Paget-Schroetter Syndrome

30

Kemp Kernstine Sr. and John K. Waters

Abstract

Effort-induced thrombosis of the upper extremity is a relatively rare condition and one aspect of thoracic outlet syndrome. It accounts for 10% of all deep venous thromboses. In the vast majority of cases the etiology is repetitive motion of the upper extremity resulting in trauma to the axillo-subclavian vein as it passes through the thoracic outlet resulting in injury to the venous intima and the surrounding supportive tissue. A secondary cause is catheter-induced injury from central venous instrumentation. Patients usually present with swelling of the affected upper extremity and complaints of heaviness and pain. Diagnosis is confirmed by duplex ultrasonography and/or contrast venography. Computed tomogram and magnetic resonance imaging are complimentary. Treatment usually involves a combination of anticoagulation, thrombolysis, and surgical decompression. Of the different techniques to surgically decompress the axillo-subclavian vein, robotic technology offers an opportunity to precisely resect the first rib and a portion of the anterior scalene muscle along with the division of the costoclavicular ligament and surrounding venous scar. The details of the technique are described with a description of the outcomes.

Keywords

Robotics • Thoracic outlet syndrome • Thrombolytic therapy • Fibrinolysis • Anticoagulation • Effort-induced thrombosis • Hypercoagulability • First-rib resection • Deep vein thrombosis of the upper extremity • Axillo-subclavian vein thrombosis • Paget Schroetter syndrome

30.1 Background, Specific Indications

Thoracic outlet compression syndrome is well described. This term was originally used by Drs. C.G. Rob and A. Standeven at St. Mary's Hospital in London to detail upper extremity arterial compression and compromise in a series of ten patients. The condition currently describes clinically significant axillo-subclavian artery and vein and brachial plexus compression at the thoracic aperture.

The brachial plexus and subclavian vessels cross the cervicoaxillary canal to enter the upper extremity. The cervicoaxillary canal is composed of two parts—proximal and distal. The proximal consists of the scalene triangle and the costoclavicular space. The distal is composed of the axilla. Compression of structures in this area cause symptoms for many patients. Risk factors include local trauma, bony anomalies, scalene muscle hypertrophy and narrowed interscalene triangular and costoclavicular spaces.

Thoracic outlet compression predominantly causes neurologic symptoms (95%). Most of these can be managed with physical therapy and medication. Only refractory cases

K. Kernstine Sr., M.D., Ph.D. (✉)
Division of Thoracic Surgery, Department of Cardiovascular and Thoracic Surgery, Robert Tucker Hayes Foundation Distinguished Chair in Cardiothoracic Surgery, University of Texas Southwestern Medical Center, 5959 Harry Hines Blvd, POB1-10th Floor, Suite HP10.110, Dallas, TX 75390-8879, USA
e-mail: kemp.kernstine@utsouthwestern.edu

J. K. Waters
Cardiothoracic Surgery, University of Texas Southwestern Medical Center, Dallas, TX, USA

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7_30

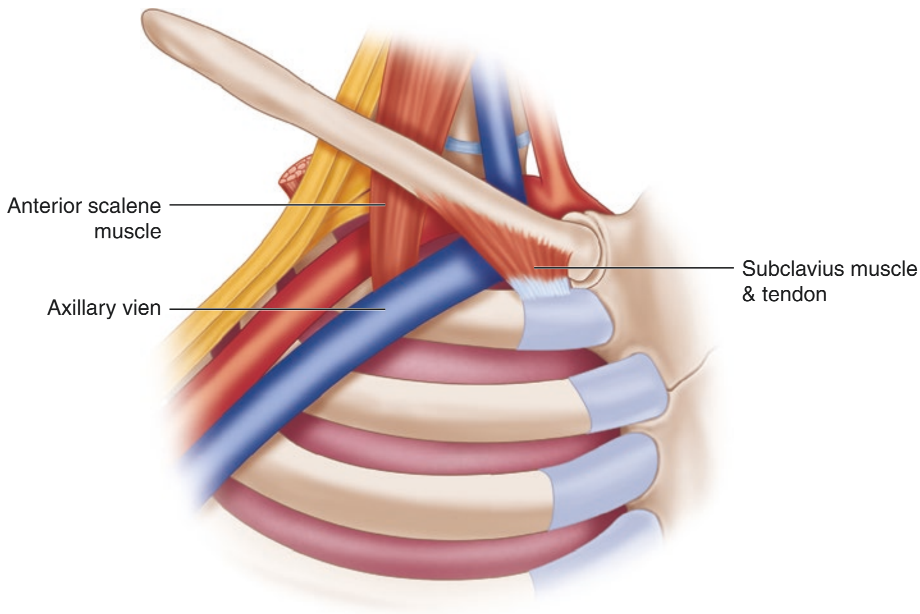


Fig. 30.1 The axillo-subclavian vein is bounded by the anterior scalene muscle, first rib, clavicle and the costoclavicular ligament. The surgical treatment of effort induced thrombosis involves enlargement of this space by removal of a portion of the rib, a portion of the anterior scalene muscle, the costoclavicular ligament, and the perivenous fibrous tissue

are referred for surgical evaluation. Five percent of patients experience vascular problems.

Axillo-subclavian compression affects approximately 3% of patients with thoracic outlet syndrome. There are two types of axillary-subclavian venous thrombosis: primary and secondary. Primary is caused by repetitive trauma to the subclavian vein in the anterior compartment of the thoracic outlet (Fig. 30.1). Intimal damage, inflammation, fibrosis and chronic scar result. This initiates the coagulation cascade, leading to localized thrombosis. Associated hypercoagulability affects between 7 and 67% of patients. Secondary venous thrombosis occurs from central venous catheterization or vein manipulation/injury.

Effort thrombosis—Paget-Schroetter Syndrome—affects a subset of patients with venous outflow flow obstruction in the thoracic outlet due to repetitive use of the upper extremity. This is often seen in young, male patients who perform competitive sports like baseball, football, swimming and sailing. The condition can also be seen in house painters, carpenters, plumbers, and auto mechanics, who perform extensive arm lifting as part of their daily work. The right upper extremity is affected more than the left, most likely due to hand dominance. Sixty to 80% of patients report symptom onset immediately following vigorous exercise.

Venous obstruction of the upper extremity can cause many symptoms: subjective feelings of extremity weakness and heaviness, chronic arm and shoulder discomfort, arm swelling and discoloration. On exam, arm veins can be distended and prominent, often with telangiectasias. Tenderness may be elicited over areas of inflammation such as the supraclavicular fossa.

Duplex ultrasonography is recommended as the first test to assess subclavian vein thrombosis. The sensitivity is estimated to be 78–100% and the specificity 82–100%. The false negative rate is nearly 30%. In cases where there is significant clinical suspicion, catheter-directed venography should be performed in the neutral and the 90° abducted positions. For those patients or situations where invasive testing is undesirable, contrast-enhanced MR venography is 100% and 97% specific.

Initially, the treatment of acute axillo-subclavian vein thrombosis includes arm elevation, compression, and systemic anticoagulation. In the past, this strategy alone led to poor outcomes: 41–91% had persistent symptoms, 39–68% were permanently disabled, and 6–15% of patients developed pulmonary emboli. Surgical resection of the first rib has traditionally been recommended to relieve anatomic compression of the axillo-subclavian vein.

Patients with axillo-subclavian vein thrombosis are classified into one of three groups: acute, subacute, and chronic. The acute group describes patients who present within 14 days of developing symptoms. Subacute describes patients experiencing between 2 and 6 weeks of symptoms. Chronic refers to patients presenting beyond 6 weeks.

Timing of surgical decompression is controversial as randomized data is lacking and recommendations are based on results of case series. Catheter-delivered thrombolytics is considered a reasonable first step to open acutely or subacutely occluded veins. Surgical decompression during the index hospitalization is thought to be most effective in patients with acute thrombosis. Oral anticoagulation for 6 weeks prior to surgical decompression is effective for subacute patients. Chronic patients treated with thrombolytics have a high failure rate (approximately 40%) and may be better served by at least 6 months of systemic anticoagulation.

Surgical decompression of the anterior compartment of the thoracic outlet can be performed with a transaxillary first rib resection with or without an endoscopic view through the axillary incision or via a transpleural video-assisted technique. The next most commonly used method is the supraclavicular approach. Resection of the medial portion of the clavicle should be reserved for situations where the first rib cannot be resected safely. The supraclavicular approach is likely superior for neurogenic thoracic outlet syndrome given the exposure it provides to the brachial plexus. Equally, the weakness of transaxillary surgery is visualization of all structures of the thoracic outlet.

First rib resection is particularly well-suited for robotics. Robotics provides an excellent view of the anatomy and allows the angles necessary to perform a very precise resection of the rib and division of bands and ligaments that narrow the vein.

30.2 Operative Setup

Patients are placed in a lateral decubitus position, with the operative side up. The upper arm is raised over the face, padded, and placed under no tension. The bedside cart or robot is brought over the head. It is best for the head to be positioned toward the anesthesia team for easy access. We use five ports for this procedure: three ports for the robotic arms and two accessory ports. Port position is demonstrated in Fig. 30.2. Equipment required for this procedure includes two robotic hook cauteries, two ProGrasp graspers, a Bipolar Maryland, a robotic Harmonic scalpel, two robotic needle holders, Kerrison Bone Rongeur, and a Stryker Maestro Precision Drill Round Bone Bur by Stryker 4 and 5 mm sizes (https://www.stryker.com/en-us/products/NeurosurgicalSpineENT/HighSpeedDrills/MaestroDrill/index.htm), 5 and 10 mm Single Tooth Tenaculum graspers and a self-retraining wide grasper LA 8275 (https://catalog.carefusion.com/vmueller/tenaculum-grasper-la8237.html), two laparoscopic needle holders, 2 × 12 mm thoracoports, 2 × 8 mm robotic ports and 1–2 × 5 mm thoracoports, and a laparoscopic suction irrigator, a 12-mm endo-paddle retractor (http://products.covidien.com/pages.aspx?page=ProductDetail&id=13466&cat=Devices&cat2=Model), sturdy retrieval bag (http://www.anchorsurgical.com/trs/), adjustable locking laparoscopic graspers and umbilical tape. Although we have not had any hemorrhage from the vascular structures, we are prepared with Surgicel rolled up into a tight 2 cm long roll and tied with 3–0 Vicryl in two locations and 5–0 Prolene on an RB-1 needle.

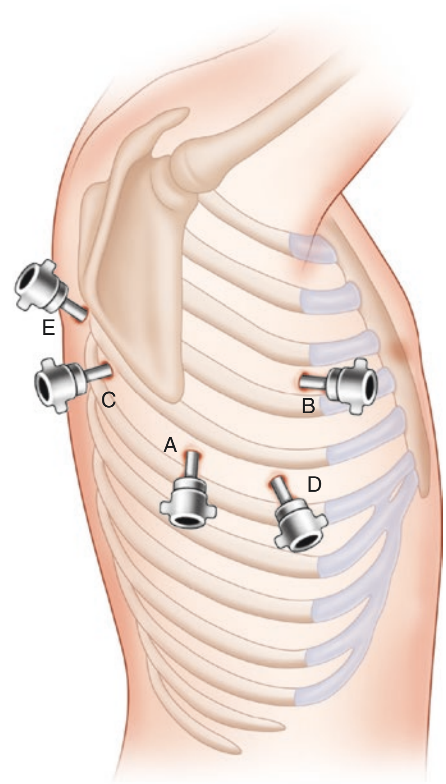


Fig. 30.2 Robotic port position for the first rib resection. The first port (Port *A*), a 12 mm port, is placed just inferior to the tip of the scapula in the fifth intercostal space. The second port (Port *B*), a 8 mm robotic port, is placed toward anterior a hand breadth away and slightly cephalad. The third port (Port *C*), another 8 mm robotic port, is placed a hand breadth away and slightly cephalad and in the same transverse parallel line as Port *B*. Port *D*, a 12 mm port, is placed midway and caudad below the parallel line below Port *A* and *B*, inferior and out of the way of the robotic arms. The final port is usually a 5 mm port placed either anteriorly or posteriorly (in this case) to allow the passage of a long rongeur or a bone burr as necessary to take the rib widely. The robot is brought from the cephalad aspect of the patient and the patient is placed in reverse Trendlenberg. CO_2 is infused at 10 mmHg

30.3 Anesthetic Management

We prefer double-lumen endotracheal tube, single lung ventilation for this procedure. Single-lumen tube ventilation can be used with CO_2 insufflation. The majority of these patients are young and active, so the anesthetic problems are less common.

30.4 Stepwise Conduct of the Operation

Once the patient is in position, the chest is prepped and draped. Four to five ports are placed into the affected hemithorax (Fig. 30.2). The robot is then brought over the patient's head and the patient is placed in steep reverse Trendelenburg position. The robot arms are then attached to the ports. We first use a hook cautery in the right arm and a ProGrasp in the left arm with a 0° video view; this view allows visualization over the cephalad aspect of the rib, as the attachments surrounding the rib are divided (Figs. 30.3 and 30.4) One of the most important aspects of the surgery is to correctly identify the first rib. We have found it particularly helpful to identify the pulse of the subclavian artery, crossing over the first rib as an anatomic landmark. The hook cautery is set at a mid-energy level and the parietal pleura is incised cephalad and caudad over the rib from the costochondral junction to approximately 1–2 cm posterior to the subclavian artery pulse. Once the pleura is incised, the inferior or caudad aspect of the rib is cleared of its attachments and the surrounding areolar tissue. We then switch to the Harmonic scalpel to minimize the risk of cautery injury to adjacent structures. Usually, we are able to take the costochondral cartilage and joint with the Harmonic scalpel allowing the cephalad aspects of the rib to be better visualized. We sometimes pass a 12 cm strip of umbilical tape around the rib to allow the bedside surgeon to grasp the rib and pull it down to provide better exposure to the cephalad aspect of the rib. We use a Kerrison bone rongeur to divide the rib as necessary (Fig. 30.5). Once the rib is divided, it is placed adjacent to the operative field for later retrieval. We then examine the rib for any sharp edges and use the rongeur or the bone burr to soften the edges. Areas of most concern are near to the subclavian-axillary artery and the brachial plexus. After this is completed, we examine the subclavian vein for bands of scar and remnant normal tissue. These are carefully divided with either a hook cautery or a Harmonic scalpel. We attempt to free not only the full length of the visible subclavian-axillary vein, but a good deal of the inferior circumference as well (Fig. 30.6). The Bipolar Maryland may be placed through the right or left arm to gain the advantage necessary to carefully grasp any small bands that might be difficult to grasp with the more commonly used ProGrasp. In the case of particularly bulky anterior scalene muscle, the most inferior portion can be resected from this approach. Once all of the attachments are freed from the subclavian vein, a small sturdy bag is passed through the inferior anterior 12 mm accessory port and the rib is placed into it. Once this is completed the robot is undocked and the robotic videoscope is used to view the removal of the bagged rib in the correct orientation to be removed through the accessory port. The pleural space can be irrigated to remove any further debris. An intercostal nerve block is performed in the usual fashion to provide postoperative analgesia at each of the port sites. One chest tube is left in the pleural space.

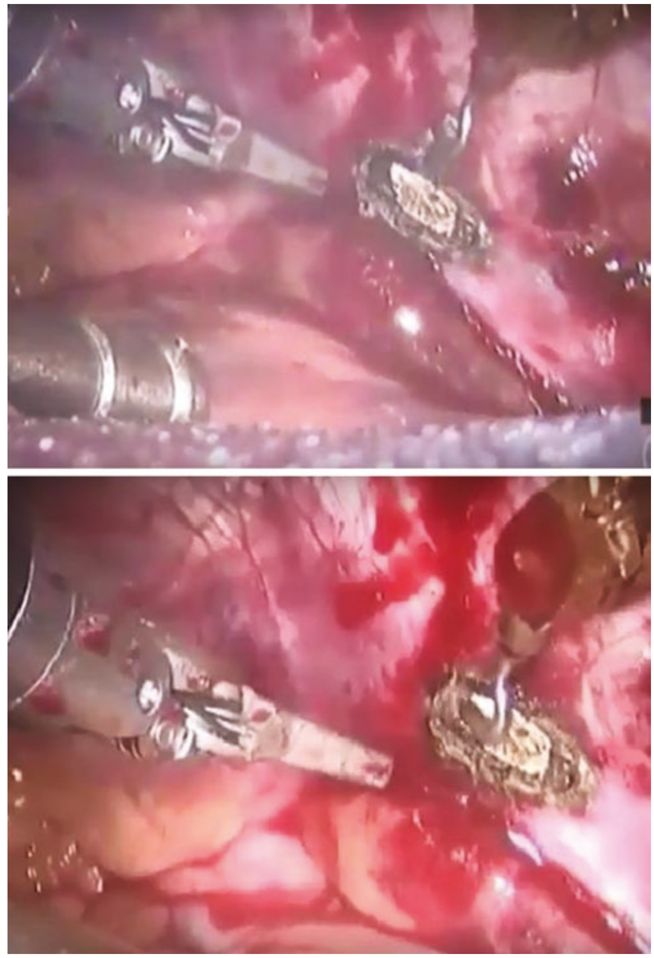


Fig. 30.4 Defining the first rib. With a ProGrasp in the left arm, a Hook cautery in the right arm and a 0° 10-mm robotic videoscope and a Paddle retractor to hold the apex of the lung away from the operative area and a suction to clear the smoke, the cephalad and caudad portions of the mid to the anterior portion of the rib dividing the parietal pleura and intercostal muscle

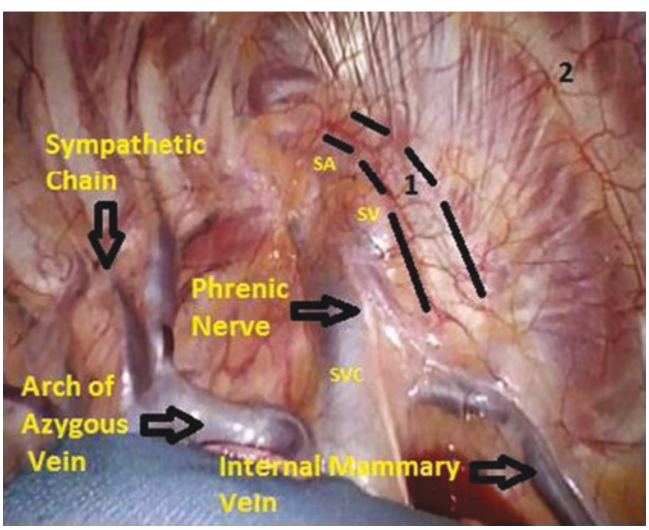


Fig. 30.3 Identification of the key structures in the superior sulcus. Identification of the target, the antero-lateral aspect of the first rib and the associated structures is one of the most important aspects to an efficient surgical resection of the first rib. Pictured are the location of the superior vena cava, the azygous vein, the phrenic nerve, the internal mammary artery, and the locations of the subclavian artery and vein

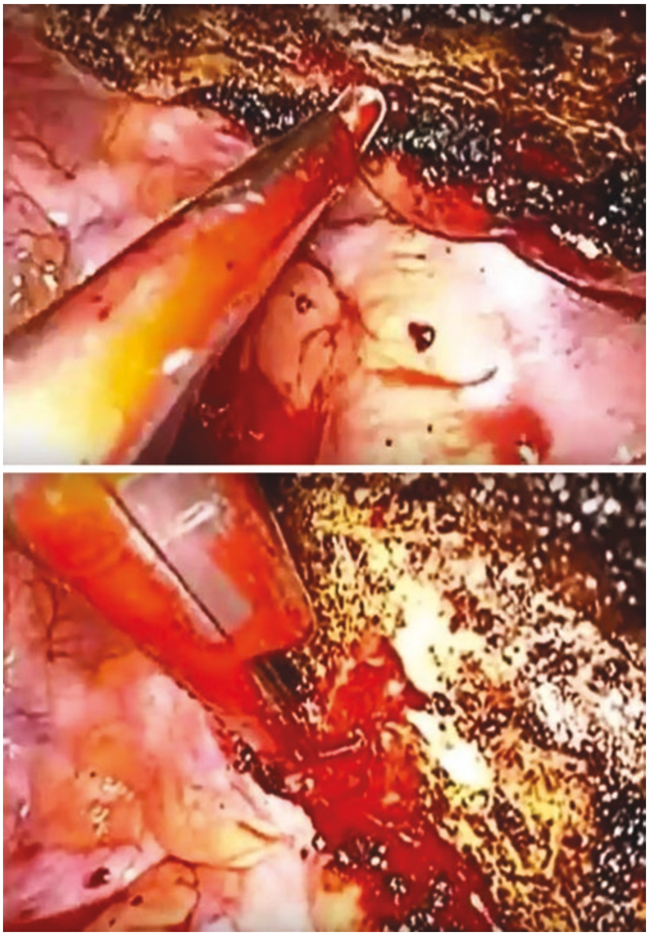


Fig. 30.5 Incision of the first rib. The Kerrison Rongeur is used to divide the midportion of the rib. Once completed the ProGrasp and Harmonic scalpel are used to pull the rib away from key structures and expose the areolar tissue and allow the dissection along the course of the rib

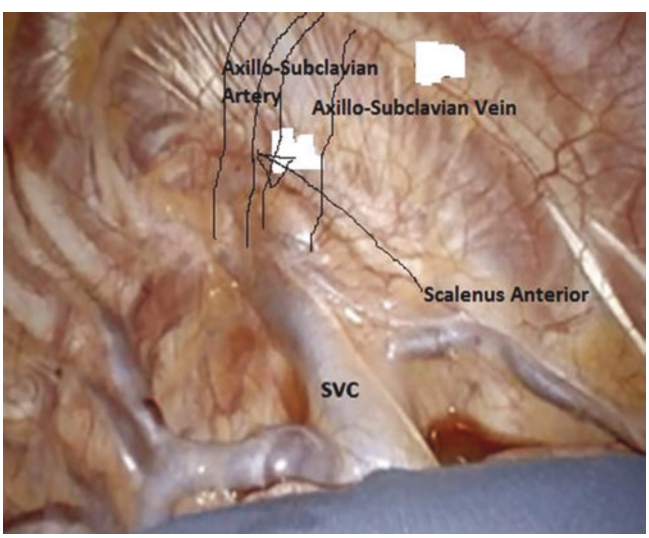


Fig. 30.6 Using the Harmonic scalpel and judicious use of the Hook cautery, bands of fibrotic tissue are identified and incised to expose the axillo-subclavian vein. After completion of the procedure and assuring no bleeding, a #19 round fluted drain is placed at the apex of the chest cavity through one of the port sites

30.5 Tips and Pitfalls

- Avoid using cautery on the cephalad aspects of the rib to reduce the likelihood for neural or vascular injury.
- These patients are often placed on anticoagulation after the resection of the first rib, so a great deal of time should be taken to achieve careful hemostasis during the procedure.
- In patients who have thrombosis, we do not address the thrombosis at the time of the procedure; instead, we take the patients back to the interventional radiology suite and treat the vein aggressively and stent the vein, as necessary.
- When using the bone burr, we wet the mat retractor prior to placing it in the 12 mm port and use it to cover the lung to collect any bone fragments. The mat is removed, cleaned, and replaced as necessary to achieve the necessary collection of the fragments.

30.6 Brief Outcomes Section

We have performed five robotic first rib resections. The procedure takes less than 2 h, most approximately 1 h, and has been simple to perform. There has been no major vascular injury and bleeding is less than 30 mL. The greatest hurdle has been the resection of the rib with the rongeur. The rongeur, in some patients, is not sufficiently long and the handle and the angle can be challenging for the bedside surgeon to manipulate to get the correct angles of resection. All patients have been extubated immediately after the procedure. Pain has been moderate in most, but one patient had excessive discomfort for the first 2 days. Most patient have been discharged on the second postoperative day; one was discharged on the fourth postoperative day. In one patient 2 months after the rib was removed noted mild to moderate pain and paresthesias in the T1 location. MRI demonstrated a seroma at the operative location.

Selected References

Gharagozloo F, Meyer M, Tempesta BJ, Margolis M, Strother ET, Tummala S. Robotic en bloc first-rib resection for Paget-Schroetter disease, a form of thoracic outlet syndrome: technique and initial results. Innovations (Phila). 2012;7:39–44.

Illig KA, Doyle AJ. A comprehensive review of Paget-Schroetter syndrome. J Vasc Surg. 2010;51:1538–47.

Lugo J, Tanious A, Armstrong P, Back M, Johnson B, Shames M, Moudgill N, Nelson P, Illig KA. Acute paget-schroetter syndrome: does the first rib routinely need to be removed after thrombolysis? Presented at the second annual International Society for Vascular Surgery Meeting, Miami, FL, 2013. Ann Vasc Surg. 2015;29:1073–7.

Moore R, Wei Lum Y. Venous thoracic outlet syndrome. Vasc Med (United Kingdom). 2015;20:182–9.

Index

K. Kernstine (ed.), *Atlas of Robotic Thoracic Surgery*, https://doi.org/10.1007/978-3-319-64508-7