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Mark K. Ferguson
Editors

Atlas of Minimally Invasive Surgery for Lung and Esophageal Cancer

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Contents

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1 Introduction

Mark K. Ferguson

Contents

1.1 Background

Minimally invasive surgery (MIS) of the thorax was introduced about 100 years before the publication of this atlas. It began primarily as a diagnostic modality, and was taught to me during my training in the late 1970s. The applications of thoracoscopy 40 years ago were limited to pleura biopsies and drainage of pleural effusions. There were no dedicated instruments other than a suction cannula and biopsy forceps, and viewing was limited to the operator looking directly through a small diameter low resolution telescope. Thus the technique was not used commonly. Technological advances in the late 1980s and beyond offered improved telescope optics, compact high resolution video cameras, and instrumentation including tissue and vascular staplers. These advances permitted performance of complex procedures such as lobectomy, esophagectomy, and mediastinal operations. A small number of adventurous surgeons were pioneers in establishing the safety and utility of these operations, from which many other surgeons and their patients have benefitted.

The first MIS operations included lung biopsy and pleural procedures for pneumothorax and empyema. In the early 1990s the first major lung resections were reported, which initially in many centers were non-anatomic resections—SIS lobectomy, or stapled in-situ lobectomy—in which most hilar structures associated with a lobe were stapled collectively. Anatomic resections as they are now performed followed quickly, however, and reports from single institutions of large experiences with outstanding results were first published in 2006 [1]. Esophagectomies performed with hybrid procedures or exclusive minimally invasive approaches were first reported in the early 1990s, with the first large series of successful cases published in 2003 [2].

Despite these advances, general adoption of minimally invasive thoracic surgery was slow. The majority of surgeons in the West who had routine access to minimally invasive resources had not been trained to do MIS surgery and were reluctant to take time from their busy practices to develop MIS skills. Training in MIS general surgery was in its infancy, and the variety of procedures thought to be appropriate for MIS techniques was limited to cholecystectomy in carefully selected patients and biopsies. Thus, even younger thoracic surgeons didn't have a very extensive background in MIS resulting from their general surgery training. No certified training courses existed early on, and surgeons interested in learning the techniques had to search out an

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experienced mentor and arrange to spend the necessary time observing; such mentors were soon overwhelmed with requests by potential observers and found it difficult to meet the demand. A system of sponsored training courses for thoracic surgeons in practice wasn't introduced until 1992, when the Society of Thoracic Surgeons created an infrastructure and curriculum for MIS training in thoracic surgery that served the needs of the physicians until training during fellowship became routinely available.

Training in MIS thoracic surgery remains less regulated than training in MIS general surgery. The latter effort includes a skills course (Fundamentals of Laparoscopic Surgery), the successful completion of which is required prior to graduation from residency and obtaining board certification in the United States [3]. No such curriculum for MIS thoracic surgery has been developed in the US. Efforts in other regions of the world are similarly underdeveloped. Skills needed for MIS thoracic surgery are demonstrably different than those learned during abdominal surgical training. However, we expect our graduating thoracic trainees to be skilled in MIS techniques without having developed skills definitions, the infrastructure for simulation training, or methods of determining competency. Clearly there is considerable room for improvement in how we train and certify young thoracic surgeons in MIS abilities.

1.2 Frequency of MIS Thoracic Surgery in Developed Countries

It is difficult to determine exactly how many lung and esophageal resections are performed annually using minimally invasive techniques. Outside of the United States there are no large databases that mandate recording of such practices. Even within the US the collection of such data are often inaccurate and analyses of such data can be misleading. A few resources in the US that help provide some insights include the Nationwide Inpatient Sample (NIS), the SEER (the Surveillance, Epidemiology, and End Results) Program, NSQIP (the National Surgical Quality Improvement Program of the American College of Surgeons), the State Inpatient Database (SID) and the Society of Thoracic Surgeons (STS). These data sets are not available for direct inspection, and so we must assess outcomes from reports published in scientific journals.

1.3 Video Assisted Thoracic Surgery (VATS) Lobectomy

The incidence of VATS is related in part to the percentage of patients with early stage lung cancer and reflects to some extent the expertise of the contributing surgeons, which is greater in the STS, NSQIP and SID datasets (Table 1.1) [4–9]. The NIS demonstrated an increase in VATS usage from 26 % early in the study to 39 % in the final year of the study [8]. Overall, the percentage of major lung resections performed by VATS in the US is moderate, is increasing over time, and likely will have exceeded 50 % at the time of this publication.

Assessment of the frequency of MIS resections performed in Europe is a little more difficult because of the fragmented nature of the data. A review of published results demonstrates surprising differences among countries in the use of VATS for lobectomy. The EPITHOR project in France demonstrated a fourfold increase in the use of VATS for lobectomy from 2005 to 2012, culminating in an incidence of nearly 11 % [10]. In Denmark from 2007 to 2011, clinical stage I lung cancer was treated by VATS lobectomy in 47 % of patients [11]. The European Society of Thoracic Surgeons (ESTS) Database, a large voluntary effort including nearly all European countries, demonstrates a very variable penetration of VATS techniques at present, with Denmark having the highest percentage and many countries lacking centers of excellence [12]. The overall rate is between 10 % and 15 % (Table 1.2) [10–14].

The rates of VATS use for lobectomy in other developed countries are difficult to determine. From an analysis of the literature, no nationwide databases reporting such results were available from Japan, Taiwan, South Korea, or Australia.

Table 1.1 Frequency of use of VATS for lung resection among large US databases

Author	Database	Time period	Total patients	VATS patients
Paul [4]	STS	2002–2007	6,323	20 %
Paul [5]	SEER	2007–2009	6,008	22 %
Farivar [6]	STS	2010–2011	10,525	44 %
Mungo [7]	NSQIP	2005–2012	6,567	37 %
Harrison [8]	NIS	2008–2011	19,353	32 %
Kent [9]	SID	2008–2010	33,095	38 %

STS Society of Thoracic Surgeons, *SEER* Surveillance Epidemiology and End Results Program, *NSQIP* National Surgical Quality Improvement Program, *NIS* Nationwide Inpatient Sample, *SID* State Inpatient Database

Table 1.2 Frequency of use of VATS for lobectomy in European databases

Author	Database	Time period	Total patients	VATS patients
Thorsteinsson [13]	Iceland	1994–2008	404	0 %
Licht [11]	DLCR	2007–2011	2,230	47 %
Morgant [10]	Epithor	2005–2012	34,006	3.2 %
Begum [12]	ESTS	2010–2012	Not stated	11.3 %
Falcoz [14]	ESTS	2007–2013	28,771	9.5 %

DLCR Danish Lung Cancer Registry, *ESTS* European Society of Thoracic Surgeons

1.4 Minimally Invasive Esophagectomy (MIE)

The very low relative frequency of esophageal cancer compared to lung cancer, especially in Western countries, makes identification of rates of MIE quite difficult. In a survey of esophageal surgeons reported in 2010, the frequency of minimally invasive approaches worldwide was about 30 %. This figure varied considerably according to surgeon specialty, being highest for general surgeons (57 %) and lowest for surgical oncologists and cardiothoracic surgeons (20 %) [15]. Data from the STS Database for 2001–2011 indicate that 14 % of patients underwent MIE [16]. In Japan in 2011, the frequency of hybrid or totally minimally invasive esophagectomy was 33 % [17]. From these limited data it appears that the acceptance of minimally invasive approaches in developed countries remains limited.

1.5 Growth of MIS Thoracic Surgery in Developing Countries

Penetration of minimally invasive techniques into developing countries is very uneven. Obstacles to growth include lack of resources (equipment for thoracoscopy or laparoscopy; trained support staff; non-specialist anesthesiologists) and lack of training for surgeons. Whereas in most developed countries trainee instruction in thoracic MIS is routine and usually required, such is not the case in many developing countries. In centers of excellence that have high volumes of practice, particularly in India and China, VATS lobectomy and MIE are routine. In such centers more than 80 % of lobectomies are performed using VATS, and more than 90 % of esophagectomies are done via MIE.

1.6 Status of MIS Thoracic Surgery

There can be little doubt that VATS lobectomy and MIE are accepted as standard approaches to surgery for lung and esophageal cancer. The chapters in this atlas clearly identify outcomes after MIS and demonstrate numerous advantages over open surgery. Short-term benefits have been conclusively demonstrated, oncologic equivalence in terms of nodal harvest is similar to open operations, and oncologic equivalence in terms of long-term survival is apparent. What remains to be fully elucidated is relative costs, or cost-effectiveness, particularly for robotic thoracic MIS.

1.7 Future Areas of Study

Complex minimally invasive thoracic surgery was introduced in the early 1990s, less than 25 years before the publication of this atlas. In that short span of time its growth and acceptance have been remarkable. We can anticipate continued growth of this application in the developing world, and will also see rapid advancement in a variety of elements of MIS, including education, technology, and outcomes (Table 1.3).

Table 1.3 Target areas for future study of thoracic minimally invasive surgery

Education and training
Learning curves for competency and proficiency
With mentoring
Without mentoring
Current approaches to education
Training program
Centers of excellence
Specialized fellowships
Simulation training
How much can this shorten the learning curve?
Models
Animal models
Tissue models (perfused, unperfused)
3-D printed models, other artificial materials
Virtual models
Improved performance
Ergonomics
Double or single port techniques
More advanced complex operations including double sleeve resections
Advanced technology
Powered staplers
Tissue site marking
Measurement of perfusion for tumor, lymph node, or vessel identification
Ultrasound applications
Hybrid procedures
Robotics
Standard resections
Advanced resections
Single port or hybrid approaches
Technological enhancements (tissue perfusion, ultrasound, automated processes)
Improved clinical care
Fast tracking to discharge
Cost-effectiveness

1.8 Education

Education is the primary means by which MIS thoracic surgery will expand and evolve. How we provide education to our trainees and to practicing surgeons who haven't yet learned the techniques is an ongoing challenge. In most developed countries there is sufficient expertise and volume in training programs to permit all trainees to emerge having achieved competence in MIS thoracic surgery. Whether this goal is sufficient is unclear. We would all like our trainees to achieve a higher level of performance than mere competence by the time of their graduation. Whether this could be achieved through increased use of simulation training needs to be investigated. A number of models are currently or soon will be available, and identification of appropriate targets for simulation training is underway.

For practicing surgeons who have not previously learned MIS techniques, training is available in short courses, but application of the lessons learned in such courses is likely to be slow and fraught with difficulty without proper ongoing mentoring. The learning curve under such circumstances can be steep, putting the surgeon and patients at risk (medical-legal/financial risk for the former, personal health risk for the latter). Society needs to identify improved methods of training practicing surgeons in new approaches and technologies that minimizes threats to surgeons' income and practice integrity, optimizes opportunities for ongoing mentoring, and minimizes patient risk.

1.9 Surgeon Performance

Improving performance should be every surgeon's lifelong goal. This may be accomplished through a variety of means, including using new instruments, new approaches, or by varying the steps of an operation. Surgeons are studying comparative surgeon ergonomics of different patient positions for minimally invasive operations. Advances in thoracoscopy for complex operations include growing use of double and single port techniques, and studies are needed to determine whether these provide benefit to our patients. As surgeon experience with minimally invasive surgery grows, increasingly complex operations are being done more routinely, including sleeve resection, double sleeve resection, and en bloc chest wall resection, to name a few.

1.10 Advances in Technology

A variety of technological enhancements are becoming available for minimally invasive surgery. Powered staplers may provide improved access of staplers to difficult areas, and may improve the consistency and quality of staple lines. Tissue perfusion for assessment of vessel anatomy, identification of regional lymph nodes, and evaluation for reconstructive organ ischemia is increasingly being used. Ultrasound for identification of tumors, nodes, and regional vessels is currently used sporadically, but as technological enhancements and surgeon familiarity grow, ultrasound use is likely to increase dramatically. Finally, advances in chemical testing of plume from electrocautery has the possibility of determining whether tissue is malignant or benign without frozen section and can help assess adequacy of resection margins.

1.11 Robotics

Robotic operations are growing in frequency and popularity. This technology is cost-prohibitive at present for many institutions and certainly for most developing countries. As the technology improves and use grows, costs are likely to decrease substantially, providing access to most levels of the market. We have yet to determine appropriate applications of robotics in thoracic surgery. Certainly many experienced surgeons are capable of performing almost any operation using the robot, but whether this adds benefit to the patient in terms of costs or outcomes has not been determined for most operations. Potential benefits of the robot include decreased operating time (experienced surgeons only), improved accuracy of dissection (wide range of wristed movements; minimization of surgeon tremor and tissue movements related to heart beat, etc; three-dimensional imaging; image magnification), better ergonomics, and availability of advanced technologies (tissue/vessel perfusion, powered staplers), to name a few. There remain concerns about added costs, added OR time when inexperienced users or operating room teams are involved, and patient safety when there is an increased risk of technological malfunctions.

1.12 Improved Patient Care

Our ultimate goals as surgeons are to improve patient care and the outcomes of care. Minimally invasive techniques offer shorter operative times, faster recovery from anesthesia, reduced pain, reduced risk of postoperative complications, shortened duration of hospital stay, and faster return to activity. The predictability of these outcomes permits patients to be "fast-tracked" to discharge, which helps reduce unnecessary testing, further reduces duration of hospital stay, and is associated with a decreased risk of complications. Resources are conserved and overall costs are substantially reduced.

Identifying practices that are cost-effective benefits all patients by enabling better distribution of resources. This process can help reduce the overall costs of healthcare and lessen the financial burden of healthcare on society. It is incumbent on surgeons who are endeavoring to advance the art and science of minimally invasive surgery to consider evaluation of cost-effectiveness as part of their efforts. It is often easier to make such evaluations during the growth of a new technology or application rather than after such as become a standard of care.

Conclusion

There have been remarkable advances in minimally invasive thoracic surgery in the past 25 years. Despite this, utilization of this approach remains limited. This atlas has the potential to help expand the growth of minimally invasive thoracic surgery by providing a background including indications, limitations, and benefits, and by offering detailed descriptions for virtually all aspects of minimally invasive surgical care of lung and esophageal cancer. For surgeons who are relatively unfamiliar with VATS or MIE, this atlas will encourage them to use these approaches more often. For surgeons who understand the basics of VATS and MIE, the atlas will enable them to take on more complex operations with confidence.

There is considerable opportunity for advancing techniques and technology in minimally invasive thoracic surgery. Hopefully this atlas will stimulate surgeons to identify ways of enhancing patient care. Imagine the future, and work towards that future for the benefit of our patients.

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Part I

Minimally Invasive Surgery for Lung Cancer

General Considerations

2

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Michael J. Liptay, Yi Feng, and Juan Zhu

Contents

2.1 Overview of Minimally Invasive Surgery in Lung Cancer

Yin-Kai Chao and Hui-Ping Liu

2.1.1 History of Development of Minimal Invasive Thoracic Surgery

The application of thoracoscopy can be traced back to 100 years ago, when Dr. Jacobaeus first reported his experiences in the diagnosis and treatment of pleural effusions by thoracoscope in 1909 [1]. Most patients who needed to undergo thoracoscopy at that time suffered from pulmonary tuberculosis [2]. The development of fibro-optic light transmission, the illumination and the image processing techniques, as well as the refinement of related instruments made video-assisted thoracoscopy more easily and broadly applied after the 1990s [3, 4]. And now video-assisted thoracic surgery (VATS) has become a basic and important technique for a thoracic surgeon.

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2.1.2 Definition of VATS Lobectomy

Frequently, minimal invasive thoracic surgery for lung cancer includes three approaches: (1) VATS, (2) Hybrid VATS and (3) Hand-assisted VATS. VATS usually refers to thoracic surgery that involves insertion of instruments through one (Uniport) or two to four small chest incisions under two-dimensional video images, and hand-assisted VATS mainly refers to thoracic surgery performed by inserting the surgeon's hand into the chest cavity through one of the chest incisions to control the target organs under a two-dimensional video images. A "Hybrid VATS" was defined as using a rib spreading retractor and operates directly through the thoracotomy (usually 8–10 cm in length). In these cases the camera is only used for illumination. Recently VATS can be performed through uniportal or subxiphoid approach for lung lesion.

In 2012, the VATS Lobectomy Consensus Meeting was held in Edinburgh, UK, which marked the 20th anniversary of this procedure. For the first time in history, consensus agreements on several important issues on VATS lobectomy, including its definition, patient eligibility, surgical standard of care were reached [5]. Since then, the Cancer and Leukemia Group B (CALGB) definition has become the globally accepted state-of-the-art VATS lobectomy technique [6], which comprised (1) no use of rib-spreading, (2) a maximum length of 8 cm for the utility incision (3) individual dissection of pulmonary vessels and bronchus. While a small retractor isonly acceptable in selected circumstances, such as conducting complex procedures (e.g. sleeve resection) or delivery of a large specimen.

2.1.3 Minimally Invasive Surgery in Lung Cancer: Current Evidence

In the current era, a prospective, randomized comparison of open versus VATS lobectomy for lung cancer will likely never occur, leaving us to rely on the best available current evidence to draw meaningful clinical conclusions. In the following sections, several important studies to address this issue.

2.1.3.1 Impact on Perioperative Outcome

Perioperative outcomes of VATS versus open lobectomy have been compared in one small prospective trial and five retrospective case control series, and one large systematic review including more than 6,000 patients [7–12]. All of these studies indicate less perioperative morbidity for VATS lobectomy (10–30 %) than for open lobectomy (20–50 %). The mortality rates are similar between the two procedures. Table 2.1 summarizes the published studies that directly compare VATS versus open lobectomy.

2.1.3.2 Oncological Perspective

Critics of VATS lobectomy suggest that inadequate nodal sampling and the potential for port site contamination by tumor will lead to inferior survival compared to open lobectomy. Important studies comparing nodal clearance and survival between VATS and open lobectomy were discussed in the following sections.

Nodal Clearance: VATS Versus Open

Three prospective trials have investigated the adequacy of nodal sampling during VATS lobectomy. The first is a small trial of 29 patients [13]. What is unique about this study is that following VATS dissection, a thoracotomy was carried out by another surgeon and any remaining mediastinal lymph nodes were removed. Based on weight and number of nodes, the authors concluded that only 2–3 % of nodal tissue was "missed" with thoracoscopic techniques. Two other randomized studies have also documented a equal degree of lymph node clearance between VATS and open procedure. In the second trial, the mean number of hilar and mediastinal nodes removed during open lobectomy were 8 and 13 respectively, exactly the same as in the VATS group. Furthermore, an equal number of patients were upstaged to N1 or N2 disease in each group [14]. In the third trial, 39 patients were randomized to undergo either a complete VATS or an "Hybrid-VATS" (in which the thoracotomy was 10 cm in length and rib-spreading was used) [15]. In the complete VATS group 32 nodes were submitted for pathologic review, compared to 29 in the control group ($p = 0.12$).

Table 2.1 Studies comparing perioperative outcome between VATS and open procedure

Author/year	Study design	Procedure	N	Morbidity rate (%)	Mortality rate	LOS (days)
Kirby, 1995	Prospective	VATS	25	24	0 %	7.1
		Open	30	53	0 %	8.3
Whitson, 2008	Systematic review	VATS	3114	16.4	NA	8.3
		Open	3256	31.2	NA	13.3
Handy, 2009	Retrospective	VATS	49	10	4.1 %	5.2
		Open	192	22.5	2.6 %	6.6
Villamizar, 2009	Retrospective	VATS	284	31	3 %	4
		Open	284	51	5 %	5
Flores, 2009	Retrospective	VATS	398	23	0.3 %	5
		Open	343	33	0.3 %	7
Stephens, 2014	Retrospective[a]	VATS	307	37	<1 %	4
		Open	307	19	2 %	6
Nwogu, 2015	Retrospective[a]	VATS	175	14.9	1.7 %	5.4
		Open	175	25.1	1.7 %	8

[a]Propensity matched analysis; *LOS* Length of Stay, *VATS* Video-assisted thoracoscopic surgery

Long Term Survival

The first and only randomized trial to report survival data was published in 2000 from Japan [14]. In this trial 100 patients with clinical stage IA lung cancer were randomized to either a VATS or open lobectomy. With the median follow-up of 4.9 years, 6 % of patients in both group developed a local recurrence. The 5-year survival was 85 % in the open group and 90 % in the VATS group (p = 0.91).

Several retrospective reports support the aforementioned findings. In these separate reports, the 5-year survival for VATS lobectomy is near 80 %, similar to that for open lobectomy (75–82 %). In a 2008 systematic review, Whitson and colleagues provided an analysis of 39 studies comparing VATS with open lobectomy [16]. In this study, patients with VATS lobectomy had similar survival when compared with those who underwent open resection. At 4 years, patients who underwent VATS lobectomy even had improved survival versus patients with open lobectomy (88.4 % vs 71 %; p = 0.003), suggesting that VATS lobectomy is at least oncologically equivalent to open lobectomy. Table 2.2 summarized the major findings from the aforementioned studies.

Table 2.2 Studies comparing survival of VATS versus open lobectomy for early-stage non-small cell lung cancer

Author/year	Study design	Procedure	N	5 years-survival (%)	P value
Sugi, 2000	Prospective randomized	VATS	48	90	N.S
		Open	52	85	
Yang, 2009	Retrospective	VATS	43	79	N.S
		Open	98	82	
Flores, 2009	Retrospective	VATS	398	79	N.S
		Open	343	75	
Whitson, 2008	Systematic review	VATS	3114	80	N.S
		Open	3256	65.6	
Stephens, 2014	Retrospective	VATS	307	78	N.S
		Open	307	73	

VATS Video-assisted thoracoscopic surgery, *N.S* Not significant

2.1.4 Summary

To the best of my knowledge, there has been no publication thus far demonstrating inferior outcomes of VATS lobectomy compared to open thoracotomy. Without a doubt, VATS has completely revolutionized modern thoracic surgery and significantly improved patient outcomes over the last two decades.

2.2 Physiologic Evaluation of Candidates for Lung Cancer Resection

Sean C. Wightman and Mark K. Ferguson

2.2.1 Introduction

One goal of perioperative surgical care is to minimize postoperative complications. This process includes preoperative decision making, intraoperative judgment and technical considerations, and postoperative care. Knowing which clinical factors are associated with complications permits physicians to assess which candidates are appropriate for major surgery. Furthermore, it allows patients to both understand the risk of procedures and make an informed decision on agreeing to a planned operation versus pursuing an alternative treatment modality. The development and standardization of algorithms for evaluation of risk has made risk estimation more uniform. There is increasing understanding of how to mitigate risk through appropriate preoperative interventions or through altering standard surgical approaches to minimize risk while maintaining the original treatment objectives. Knowing potential risks for a given patient allows the treatment teams to allocate intraoperative and postoperative resources to identify and treat complications more efficiently, thus increasing resiliency.

2.2.2 Background

After pulmonary resection, there are substantial changes in the physiology of the cardiopulmonary system. Lung resection decreases postoperative pulmonary function as measured by forced expiratory volume in the first second (FEV1) and the shuttle walk test [17]. While FEV1 decreases maximally the first few days postoperatively, it improves to only 75 % of predicted values at 1 month and 85 % at 3 and 6 months [17]. Similarly, the shuttle walk test is 70 % of its preoperative value when assessed at 1 month and improves to 84 % of preoperative values when reassessed at 6 months [17]. The immediate postoperative decrease is related to reduced respiratory mobility of the ribs and diaphragm after a thoracic operation, predominantly due to pain. This subsequently leads to decreased pulmonary expansion, alveolar collapse, and subsequent atelectasis [18].

The changes in pulmonary spirometry are associated with the degree of pulmonary resection performed. For patients undergoing a segmentectomy, FEV1 and forced vital capacity (FVC) are relatively preserved [19]. After lobectomy, and once recovered from the initial postoperative period, spirometry values for FVC, FEV1 and total lung capacity (TLC) are reduced by 7–10 % [20]. For those patients undergoing pneumonectomy, FVC, FEV1, and TLC are typically decreased by 30–35 % [20]. In patients undergoing wedge or lobectomy, no postoperative changes in cardiac hemodynamics are observed [21]. Pneumonectomy is associated with elevated right ventricular volumes at end-systole and end-diastole, while right ventricular ejection fraction is decreased by 10 % [21]. The decreased ejection fraction after pneumonectomy is likely due to the increased afterload, while the increased right heart volume compensates to improve ejection based on the Frank-Starling Curve. These changes underline the importance of preoperative evaluation to determine which patients are likely to tolerate surgery without increased cardiopulmonary risk.

General anesthesia adversely affects pulmonary function by relaxing respiratory muscles leading to a reduction in functional residual lung volume. This in turn collapses bronchioles leading to atelectasis [22]. These changes contribute to postoperative hypoxemia and can last many days after surgery. A thoracotomy incision reduces chest wall compliance leading to decreased total lung volume due to limited expansion. Appropriate pain control and minimally invasive procedures are thought to limit this physiologic restriction.

Induction chemotherapy reduces diffusion capacity of the lung for carbon monoxide (DLCO) in 15 % of patients [23]. This reduction does not typically affect clinical symptoms and only 2 % of patients are ineligible to proceed with surgery based on the change in DLCO. For heavy smokers, the reduction after induction chemotherapy is greater. The relation of induction chemotherapy to increased post-operative complications is controversial [23, 24]. Due to pulmonary changes after induction chemotherapy, an updated assessment of the patient's lung function should be obtained [25].

Lung resection is associated with the development of postoperative complications including pulmonary, cardiovascular, infectious, surgical, and others (Table 2.3). Some postoperative complications are associated with specific preoperative patient characteristics, permitting risk stratification. The two most common categories of complications, pulmonary and cardiovascular, are listed in Table 2.4 with their preoperative predictive variables. Aside from demographics, significant predictive ability is found in cardiac and pulmonary function. For this reason, specific evaluation of these parameters should be performed in all patients undergoing major lung resection regardless of the surgical approach [26].

Table 2.3 Classification of postoperative complications after lung resection

Category	Components
Pulmonary	Prolong postoperative intubation
	Reintubation for respiratory insufficiency
	Prolonged postoperative air leak
	Atelectasis requiring bronchoscopy
	Pleural effusion requiring drainage
	Pneumonia
	Adult respiratory distress syndrome
	Pneumothorax required intervention
Cardiovascular	Arrhythmia requiring intervention
	Myocardial infarction
	Pulmonary embolism
	Use of inotropic agents
	Deep venous thrombosis requiring therapy
Cerebrovascular	Cerebrovascular accident
	Transient ischemic attack
	Delirium
Surgical	Bronchopleural fistula
	Chylothorax
	Recurrent nerve injury
	Bleeding requiring reoperation
	Other reoperation
Infectious	Emypema
	Wound infection
	Sepsis
Other	Acute renal insufficiency
	Urinary retention
	Postoperative transfusion

Table 2.4 Preoperative parameters associated with complication categories

Complication category	Preoperative parameters
Pulmonary	FEV1, FEV1%
	DLCO%
	Stair climb, shuttle walk, 6 min walk
	Peak VO_2
	Age
	Smoking status
	Induction therapy
	Body mass index (BMI)
Cardiovascular	FEV1, FEV1%
	Age
	Diabetes mellitus
	Coronary artery disease
	Renal insufficiency
	Cerebrovascular disease

2.2.3 Pulmonary Assessment

Physiologic assessment of lung function includes measurement of both ventilatory capacity and gas exchange capacity. Each of these is an independent predictor of postoperative complications, especially cardiopulmonary complications [27–32]. The most useful spirometric parameters are the forced expiratory volume during the first second expressed as a percent of predicted (FEV1%) and the predicted postoperative value for this parameter estimated based on the amount of lung to be resected (ppoFEV1%). Gas exchange capacity is assessed by measurement of the diffusing capacity of the lung for carbon monoxide (DLCO), which is an estimate of pulmonary capillary surface area or pulmonary capillary blood volume. The value is often corrected for hemoglobin, which provides a more accurate assessment of gas exchange ability. In contrast, corrections for lung volume are not typically performed, as the basis for such corrections are not physiologically sound. DLCO is usually expressed as a percent of predicted (DLCO%) or as an estimate of expected postoperative function (ppoDLCO%).

Predicted postoperative values are more accurate than preoperative values in estimating the risk of postoperative complications as well as long-term survival [33, 34]. Preoperative alterations in FEV1% may be related to underlying lung disease, neuromuscular disorders, prior lung surgery, extreme obesity, and other conditions (Table 2.5). Alterations in DLCO% may be related to serum hemoglobin level, primary lung disease, disorders of the pulmonary vasculature, and cardiac insufficiency. Predicted postoperative values of FEV1% and DLCO% usually can be accurately estimated using the functional segment counting technique [35].

$$\text{Postoperative value} = \text{Preoperative value} \times \left(\text{Postoperative segments} / \text{Functional preoperative segments}\right)$$

The accuracy of such estimates can be affected by the location of the resected lobe (upper versus lower) and the presence of heterogeneous distribution of emphysematous changes [36]. In patients with heterogeneous lung disease, prior lung resection, or major airway obstruction, more accurate estimates are obtained using quantitative ventilation/perfusion scans or quantitative computed tomography [37–39].

Exercising testing is also a useful method for evaluating patients' postoperative risk after lung resection, as it assesses the interactive function of the respiratory and cardiovascular systems [40–45]. Although the routine use of exercising testing provides slightly more accurate risks of postoperative complications, its use is usually reserved for patients who are identified as being at increased risk based on pulmonary function testing. Selective use decreases the costs and duration of the preoperative evaluation. Exercise testing can be performed using low technology methods (stair climb, 6 min walk test, shuttle test) or using high technology testing, usually measurement of peak oxygen consumption during maximal exercise (peak VO_2), which is typically performed during cycle ergometry. Exercise testing may not be possible in some patients because of lower extremity weakness, cardiovascular disease, or other physical limitations, and is often precluded because of the lack of availability the required equipment and expertise to use it.

Table 2.5 Causes of abnormal lung function tests

Parameter tested	Cause of abnormal result	Etiology
FEV1%	Chronic obstructive pulmonary disease	Decreased air flow
	Asthma	Decreased air flow
	Interstitial lung disease	Loss of alveoli
	Major airway obstruction	Decrease air flow
	Chest wall disorders	Loss of lung volume
	Severe obesity	Impaired diaphragm excursion
	Prior lung resection	Loss of lung volume
	Phrenic nerve dysfunction	Impaired diaphragm excursion
	Dysfunction of respiratory muscles	Impaired air flow
DLCO%	Anemia	Low oxygen carrying capacity
	Polycythemia	Increased oxygen carrying capacity
	Emphysema	Loss of pulmonary capillary surface area
	Obstructive lung disease	Gas trapping
	Interstitial lung disease	Increased alveolar wall thickness
	Pulmonary edema	Increased alveolar wall thickness
	Congestive heart failure	Increased alveolar wall thickness
	Pulmonary hypertension	Increased vascular wall thickness
	Low cardiac output	Low blood flow limiting gas delivery
	Restrictive lung disease	Loss of pulmonary capillary surface area
	Pulmonary embolism	Decreased pulmonary blood flow

2.2.4 Cardiac Assessment

The American College of Cardiology and the American Heart Association (ACC/AHA) guidelines stratify procedures by their level of risk and in turn identify patients who have clinical risk factors placing the patient at increased cardiac risk during non-cardiac procedures [46]. According to the ACC/AHA, major lung resection qualifies as having intermediate risk (a cardiac risk of 1–5 %). If patients are undergoing an elective lung resection, they should be evaluated and screened for severe or increasing angina, recent myocardial infarction (MI), decompensated heart failure, severe arrhythmias, or severe valvular disease. If any of these symptoms or history is present, the patients should have an appropriate cardiac work-up and management prior to an elective lung resection. If no history is present, patients are then evaluated for typical physical activity levels based on metabolic equivalents (METs). One MET is expended during effectively taking care of one's self daily by dressing and feeding. Four METs are expended doing light work around the house or climbing a flight of stairs. If a patient meets the 4 MET threshold, the likelihood of important cardiovascular disease in the absence of symptoms is low and the operation can be planned. If less than 4 METs are typically expended or if METs are unknown, clinical risk factors of ischemic heart disease, heart failure, stroke, diabetes, and renal insufficiency are evaluated. If none is present, proceeding with the operation is appropriate. If one or more risk factors are present, a non-invasive stress test should be considered prior to scheduling an operation.

2.2.5 Perioperative Risk

2.2.5.1 Cardiac Risk Scoring Systems

The European Respiratory Society (ERS), the European Society of Thoracic Surgery (ESTS), and the American College of Chest Physicians (ACCP) recommend cardiac evaluation prior to lung assessment as recommended by the ACC/AHA. An index was developed to identify patients at high risk for complications in patients undergoing major noncardiac surgery [47]. The Revised Cardiac Risk Index (RCRI) identifies patients at increased risk for cardiac death, myocardial infarction, and cardiac arrest. The index is based on preoperative risk factors including a history of ischemic heart disease, congestive heart failure, cerebrovascular disease (stroke or TIA), the presence of diabetes mellitus requiring insulin therapy, the presence of chronic kidney disease with a creatinine >2 mg/dL, and planned high risk surgery including intrathoracic surgery [47]. Patients with 0, 1, 2, or more risk factors are divided into classes I, II, III, or IV respectively. This correlates with progressively increasing risks of major cardiac complications.

Recalibration of the RCRI to a system for risk estimation specific to lung resection was recently performed, resulting in the Thoracic RCRI (ThRCRI). The ThRCRI is a four-class risk score based on weighted values for serum creatinine, coronary artery disease, cerebrovascular disease, and extent of lung resection. Classes A, B, C, and D are assigned from the cumulative risk score, which correlates well with an increasing incidence of major cardiovascular complications [48–51]. This risk score also is predictive of the long-term risk of death in patients undergoing resection for lung cancer [52].

2.2.5.2 Cardiopulmonary Risk Algorithms

Algorithms for risk assessment and preoperative pulmonary evaluation were developed by both the ERS/ESTS and the ACCP [25, 45, 53]. Both recommend cardiac risk assessment for all patients; those found to be at increased risk should undergo a preoperative cardiology evaluation. The ACCP recommends pulmonary assessment of FEV1 and diffusion capacity for carbon monoxide (DLCO) with calculation of the predicted post-operative values (Fig. 2.1). If both the ppoFEV1% and ppoDLCO% are >60 %, no further testing is needed. If either the ppoFEV1% or ppoDLCO% is <60 %, but both are >30 %, a stair climb or shuttle walk test should be performed. If either of the predicted post-operative values is <30 %, a formal cardiopulmonary exercise test with maximal oxygen consumption assessment (peak VO_2) is recommended. Those patients with <25 shuttles or <22 m climbed in low-tech testing should proceed to high-tech cardiopulmonary exercise testing with measurement of peak VO_2. Patients with a peak VO_2 >15 mL/kg/min do not have importantly increased risk. Those with a peak VO_2 10–15 mL/kg/min are at increased risk, and a detailed discussion of the relative risks and benefits associated with surgery as well as alternative treatments should take place. Those patients found to have a peak VO_2 of <10 mL/kg/min are at substantially increased risk and non-operative treatment should be seriously considered.

The ERS/ESTS guidelines also rely on FEV1, DLCO, and measurement of peak VO_2 [25, 45]. The ERS/ESTS guideline starts with assessment of a patient's of FEV1 and DLCO (Fig. 2.2). If the values are >80 % of predicted, surgery can proceed without further testing. If one of the values are <80 % of predicted, then a measurement of peak VO_2 is obtained. If this is >20 mL/kg/min, then the recommendation is for surgery. If it is <10 mL/kg/min, then non-operative management is recommended. If it is 10–20 mL/kg/min, then ppoFEV1 and ppoDLCO are reviewed. If both the ppoFEV1% and ppoDLCO% are >30 %, then it is reasonable to proceed with surgery. If one or both are <30 %, then surgery is only performed if the predicted post-operative peak VO_2 is >10 mL/kg/min.

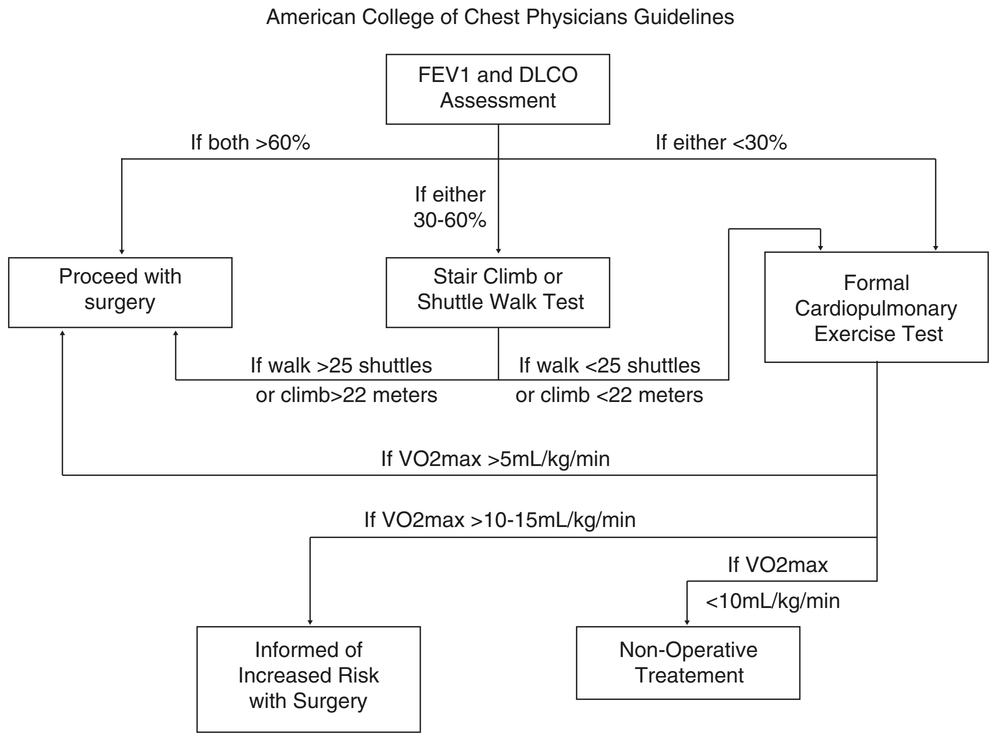


Fig. 2.1 The American College of Chest Physicians algorithm for preoperative cardiopulmonary function assessment [37]

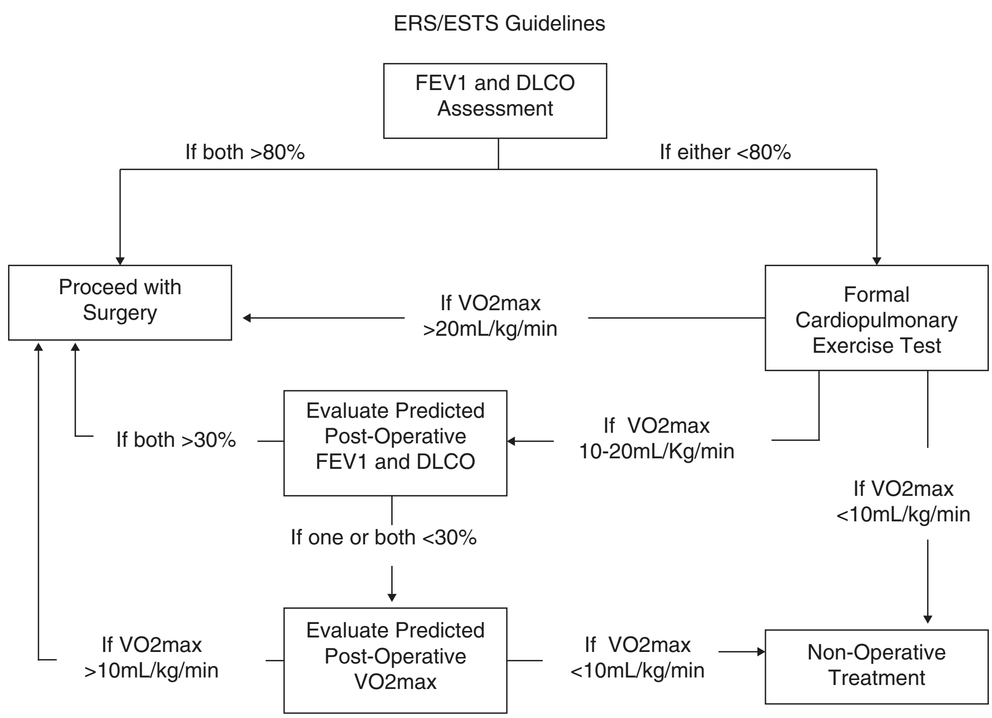


Fig. 2.2 The European Respiratory Society and the European Society of Thoracic Surgery algorithm for preoperative cardiopulmonary function assessment [29]

The main differences between the AACP and ERS/ESTS guidelines are that that the ERS/ESTS is quicker to obtain the measurement of peak VO_2 and doesn't utilize a stair climb or shuttle walk test. The AACP also recommends initially using the ppoFEV1% and ppoDLCO% while the ESTS guidelines utilize this later in the algorithm.

Utilization of these guidelines has been variable and a review of the compliance to the ERS/ESTS guidelines demonstrated that nearly 20% of cases were non-compliant due to the omission of the exercise test [54].

2.2.6 Preoperative Risk Reduction

2.2.6.1 Smoking

A Society of Thoracic Surgeons database study evaluated the impact of patient's smoking on perioperative risk [55]. Many patients undergoing lung resection are either current or past smokers. Perioperative mortality decreased in relation to the interval of smoking cessation. Major pulmonary complications were more frequent in current or past smokers [55]. Over time, smoking cessation mitigates these risks but no optimal time interval was identified.

2.2.6.2 Preoperative Physical Rehabilitation

Preoperative exercise therapy in lung cancer patients undergoing resection demonstrates mixed results [56]. Some studies demonstrate decreased hospital length of stay and pulmonary complications while others demonstrate no difference between the groups. Using the patient's mean distance walked per day to calculate an estimated peak VO_2, also including age and DLCO%, is more predictive of postoperative cardiorespiratory complications than the peak VO_2 measured during a standard exercise test [57]. Due to a narrow preoperative window after cancer diagnosis, it is difficult to determine if an intense program will strengthen or simply fatigue those with poor preoperative conditioning. Furthermore, it is difficult to know if frequent outpatient sessions are feasible due to patient commitment, and inpatient rehabilitation is often cost prohibitive. Because of the limited and conflicting data surrounding preoperative rehabilitation, future research is needed in the area.

2.2.6.3 Frailty

Frailty is a clinical state with decreased physical function and low physiologic reserves [58]. It is the frail patient's low organ system reserves, due to diseases, decreases activity, inadequate nutrition, and physiologic changes that are attributed to poor clinical outcomes. These poor reserves make physical compensation difficult in times of acute stress; like undergoing pulmonary resection. Assessment of frailty ranges from in-person encounters, usually in the form of an office visit, to a developed frailty index involving functional, medical, and cognitive health. More than 50% of potential lung resection candidates are pre-frail or frail. Frailty is associated with adverse perioperative outcomes after lung resection; as an aging-frailty index increases, both morbidity and mortality increased incrementally [59].

There is increasing interest in identifying methods of mitigating frailty preoperatively, which theoretically may reduce perioperative risk. These include nutritional, pharmacologic, and physical interventions such as strength and/or endurance training. Early results demonstrate that physical interventions provide the most consistent positive results, and that results can be achieved in a time period suitable for planning lung cancer surgery [60].

Conclusions

Utilization of algorithms guide risk assessment and help quantify risk probability for an individual patient in the perioperative period. Research continues to change the assessment protocols of patients and their estimated risk. Algorithms not only aide surgeons in selecting appropriate patients for operations, but also allow patients to make informed decisions on risks and benefits prior to lung resection or alternate therapy. Future research is still needed in areas of patient optimization prior to surgery after cancer diagnosis as well as continued improvement in preoperative risk stratification for postoperative complications.

2.3 Staging and Selection of Patients for Minimally Invasive Lung Cancer Resection

Christopher W. Seder and Michael J. Liptay

2.3.1 Introduction

Lung cancer remains the leading cause of death from malignancy worldwide [61]. Accurate staging of non-small cell lung cancer (NSCLC) is essential for prognostication and determination of the optimal treatment strategy. Proper risk stratification and patient selection is equally important; every patient must be assessed for both operability and resectability. The terms operability and resectability are often used interchangeably, however they represent different concepts [62]. Operability refers to a patient's cardiopulmonary fitness and physiologic ability to undergo the required surgery. Alternatively, resectability describes the tumor characteristics and how that relates to the ability to achieve a curative operation. A given patient being considered for pulmonary resection can have any combination of operability and resectability.

All patients with lung cancer should be evaluated, staged, and treated in a multidisciplinary fashion, which includes input from thoracic surgeons, medical and radiation oncologists, pathologists, radiologists, and palliative care specialists [63]. The thoracic surgeon is an integral part of this process and is primarily responsible for the selection of patients for lung resection and technique in which it is performed. With rapid technologic advances instrumentation and increasing experience with advanced endoscopy and video-assisted thoracoscopic surgery (VATS), the range of operations able to be performed in a minimally invasive fashion is growing. There is emerging evidence that VATS may actually expand the patient population able to benefit from anatomic pulmonary resection [64–68].

2.3.2 Staging

Accurate staging is essential in the evaluation, prognostication, and treatment of patients with NSCLC. The Table 2.6 details the 7th edition of the TNM classification for non-small cell lung cancer [69]. In the absence of systemic metastases, the status of a patient's mediastinal lymph nodes directs the overall treatment strategy, since those with N2 metastasis are often treated with induction therapy prior to surgical consideration and those with N3 disease are not offered surgical intervention.

2.3.2.1 Radiographic Staging

While modern computed tomography (CT) scanners provide excellent anatomic detail relative to tumor location and surrounding structures, its ability to identify mediastinal nodal metastases in patients with NSCLC is marginal, with a sensitivity and specificity of 55 % and 81 %, respectively [70]. Accordingly, the American College of Chest Physicians (ACCP) clinical staging guidelines recommended that all patients with NSCLC and no suspicious extrathoracic abnormalities on chest CT undergo positron emission tomography (PET) imaging to evaluate for metastases, with the exception of peripheral clinical stage IA tumors and ground glass opacities [70]. 18F-flouro-2-deoxy-D-glucose (FDG) is injected intravenously and its metabolite accumulates in cells with relatively high metabolic activity, such as malignant or inflammatory cells. This provides a qualitative estimate of cellular activity and a standardized uptake value (SUV) can be calculated. Although there is a high degree of variability between scanners, centers, and interpreting radiologists, an SUV less than 2.5 is generally considered normal.

Multiple early studies, including the American College of Surgeons Oncology Group (ACOSOG) Z0050 and PET in Lung Cancer Staging (PLUS) trial, demonstrated the ability of PET and integrated PET-CT scan to reduce the number of "unnecessary thoracotomies" compared to conventional imaging [71–73]. These studies demonstrated a number needed to scan of only five patients to avoid 1 non-therapeutic thoracotomy, defined as thoracotomy for benign disease or pathologic N2 disease, exploratory thoracotomy, or that resulting in recurrence or death within 1 year. Although the use of PET-CT has been shown to accurately upstage patients with N2 disease not recognized by conventional imaging, the risk of identifying false positive mediastinal activity and potentially denying patients curative resection also exists. A subgroup analysis of the Early Lung Positron Emission Tomography (ELPET) trial [74] examining 149 patients who underwent both PET-CT and mediastinoscopy with or without thoracotomy with lymph node sampling demonstrated positive and negative predictive values of 64 % and 95 %, respectively for PET-CT scans [75]. Eight patients in this trial had a positive PET-CT, but no evidence of pathologic nodal involvement. The modest positive predictive value of current PET-CT imaging reinforces the importance of pathologic confirmation of mediastinal lymph node involvement. On the contrary, the high negative predictive value of PET-CT, demonstrated across multiple studies, suggests that in patients with clinically T1N0 NSCLC, preoperative pathologic assessment can reasonably be omitted [76]. This is supported by the National Comprehensive Cancer Network (NCCN) clinical practice guidelines, which recommend preoperative pathologic staging in all cases except clinical stage IA NSCLC [77].

Table 2.6 TNM classification for non-small cell lung cancer (7th Edition) [69]

Primary tumor (T)	
Tx	Primary tumor cannot be assessed, or the tumor is proven by the presence of malignant cells in sputum or bronchial washing but is not visualized by imaging or bronchoscopy
T0	No evidence of primary tumor
Tis	Carcinoma in situ
T1	Tumor ≤3 cm in greatest dimension, surrounded by lung or visceral pleura, no bronchoscopic evidence of invasion more proximal than the lobar bronchus (not in the main bronchus); superficial spreading of tumor in the central airways (confined to the bronchial wall)
T1a	Tumor ≤2 cm in the greatest dimension
T1b	Tumor >2 cm but ≤3 cm in the greatest dimension
T2	Tumor >3 cm but ≤7 cm or tumor with any of the following:
	Invades visceral pleura
	Involves the main bronchus ≥2 cm distal to the carina
	Associated with atelectasis/obstructive pneumonitis extending to hilar region but not involving the entire lung
T2a	Tumor >3 cm but ≤5 cm in the greatest dimension
T2b	Tumor >5 cm but ≤7 cm in the greatest dimension
T3	Tumor >7 cm or one that directly invades any of the following: chest wall (including superior sulcus tumors), diaphragm, phrenic nerve, mediastinal pleura, or parietal pericardium;
	Or tumor in the main bronchus <2 cm distal to the carina but without involvement of the carina
	Or associated atelectasis/obstructive pneumonitis of the entire lung or separate tumor nodule(s) in the same lobe
T4	Tumor of any size that invades any of the following: mediastinum, heart, great vessels, trachea, recurrent laryngeal nerve, esophagus, vertebral body, or carina
	Or separate tumor nodule(s) in a different ipsilateral lobe
Regional lymph nodes (N)	
Nx	Regional lymph nodes cannot be assessed
N0	No regional node metastasis
N1	Metastasis in ipsilateralperibronchial and/or ipsilateralhilar lymph nodes and intrapulmonary nodes, including involvement by direct extension
N2	Metastasis in the ipsilateralmediastinal and/or subcarinal lymph node(s)
N3	Metastasis in the contralateral mediastinal, contralateral hilar, ipsilateral or contralateral scalene, or supraclavicular lymph nodes
Distant metastasis (M)	
Mx	Distant metastasis cannot be assessed
M0	No distant metastasis
M1	Distant metastasis
M1a	Separate tumor nodule(s) in a contralateral lobe; tumor with pleural nodules or malignant pleural (or pericardial) effusion
M1b	Distant metastasis

Stage	T	N	M
IA	T1a	N0	M0
	T1b	N0	M0
IB	T2a	N0	M0
IIA	T1a	N1	M0
	T1b	N1	M0
	T2a	N1	M0
	T2b	N0	M0
IIB	T2b	N1	M0
	T3	N0	M0

(continued)

Table 2.6 (continued)

Stage	T	N	M
IIIA	T1	N2	M0
	T2	N2	M0
	T3	N2	M0
	T3	N1	M0
	T4	N0	M0
	T4	N1	M0
IIIB	T4	N2	M0
	T1	N3	M0
	T2	N3	M0
	T3	N3	M0
	T4	N3	M0
IV	Any T	Any N	M1a or 1b

Studies have reported the presence of occult brain metastasis in about 3 % of patients with NSCLC and a normal neurologic exam [78–81]. The incidence is higher with a positive neurologic exam, presence of N2 disease, and adenocarcinoma histology [79–81]. While magnetic resonance imaging (MRI) is more sensitive than CT scan for the detection of brain metastases, a survival benefit has not been established for brain MRI over CT scan [82, 83]. Accordingly, the NCCN makes a category 2A recommendation for brain MRI in all cases of clinical stage II and higher NSCLC and a category 2B recommendation for patients with clinical stage IB NSCLC [77]. The ACCP recommends brain MRI, or CT scan if MRI is not available, in patients with clinical stage III or IV NSCLC, even if the patient has a negative clinical evaluation [70].

2.3.2.2 Pathologic Staging

Despite advances in imaging technology, pathologic confirmation of mediastinal lymphadenopathy for all patients with greater than clinical T1N0 NSCLC is recommended [70, 77]. Cervical mediastinoscopy has played a key role in invasive mediastinal staging for decades, with a sensitivity of nearly 90 % and a specificity of 100 % [84]. Mediastinoscopy is a low-risk procedure that can be performed on an outpatient basis [85]. In experienced hands, the procedure has a morbidity of less than 2.5 % and mortality below 0.5 % [86].

However, the emergence of minimally invasive endoscopic techniques and instrumentation has challenged the routine use of cervical mediastinoscopy. Both endobronchial ultrasound (EBUS) and endoscopic ultrasound (EUS) allow fine-needle aspiration (FNA) of nodal tissue using real-time ultrasound guidance and a 21- or 22-gauge needle. Applying a combination of EBUS and EUS, most N1, N2, and N3 mediastinal lymph nodes can be sampled. EUS allows visualization and biopsy of stations 2R, 2L, 4R, 4L, 7, 8, and 9, while EBUS can access stations 2R, 2L, 4R, 4L, 7, 10, and 11. The diameter of the EBUS probe is too large to fit beyond the lobar airways, precluding deeper intrapulmonary lymph node biopsies. Although EBUS and EUS can be performed under conscious sedation or laryngeal mask airway, using a general anesthetic has the distinct advantage of minimizing the patient's cough reflex and eliminates the risk of laryngospasm. However, the endotracheal tube tends to center the EBUS probe, making the necessary airway sidewall contact more difficult, and can preclude biopsy of the highest paratracheal nodes. A size 8.0 endotracheal tube is required to accommodate most EBUS probes; the balloon should be inflated just distal to the vocal cords to allow the greatest distance of trachea for nodal evaluation. All FNA specimens should be judged for cellular adequacy intraoperatively.

Multiple reports have demonstrated a high diagnostic accuracy and an acceptable safety profile for EBUS when performed by an experienced endoscopic ultrasonographer [87–89]. In a study examining 153 patients with potentially resectable NSCLC who underwent EBUS followed by mediastinoscopy, the two modalities had an agreement rate of 91 % and both had a specificity and positive predictive values of 100 % [90]. Likewise, there was no difference in sensitivity or negative predictive value and both EBUS and mediastinoscopy had a diagnostic accuracy of 93 %.

Unlike EBUS, EUS is rarely used alone to stage the mediastinum due to its negative predictive value of only 70–75 %. In addition, EUS has demonstrated variable sensitivity based on nodal station and the lymph node size [91, 92]. However, despite these limitations, EUS should be considered if imaging is suggestive of metastatic disease at station 8 or 9, as neither EBUS nor mediastinoscopy can access these sites.

Using EBUS, EUS, and mediastinoscopy in combination has been shown to have superior performance compared to any singular modality [93]. In a multicenter, randomized controlled trial ($n = 241$), patients with potentially resectable NSCLC were randomized to either (1) mediastinoscopy, or (2) EBUS and EUS then mediastinoscopy, if EBUS and EUS were negative. If mediastinal staging did not reveal evidence of pathologic nodal involvement, patients went on to lobectomy and mediastinal lymph node dissection. The primary end point was sensitivity for detecting N2 or N3 disease. The authors found that using a combination of EBUS, EUS, and mediastinoscopy, they were able to improve sensitivity from 79 % to 94 % ($p = 0.04$) and decrease the number of futile thoracotomies over mediastinoscopy alone from 18 % to 7 % ($p = 0.02$). Based on these data, the ACCP has recommended that, in patients with suspected N2 or N3 disease, a needle technique (EBUS, EUS, or both) is the best initial test [70]. However, in cases where the clinical suspicion of mediastinal lymph node involvement remains high after a negative needle biopsy, surgical staging should be performed.

2.3.3 Patient Selection

Every patient being considered for lung resection must be risk stratified prior to surgery with a complete and individualized work up. Proper risk stratification is not only necessary for the patient to provide informed consent, but it helps the surgeon decide between recommending surgery and other non-operative therapies, such as stereotactic body radiotherapy. Multiple thoracic societies have published evidence-based guidelines to aid clinicians in the appropriate preoperative evaluation [63, 94].

Although the term “minimally invasive” lung resection has had many meanings over the years, the Cancer and Leukemia Group B (CALGB) definition of that which “requires no rib spreading, less than an 8 cm utility incision, individual vessel and bronchus dissection, and standard node dissection or sampling” is most commonly accepted [95]. This can be performed using standard VATS instrumentation or robot-assisted thoracic surgery. The use of a minimally invasive approach for lung resections has been shown to result in less pain, reduced complications, shorter hospital length of stay, and earlier return to function compared to thoracotomy [96–99]. The reduced tissue trauma caused with a minimally invasive approach may facilitate operability in a select group of marginal patients that are predicted to struggle with recovery from a thoracotomy [64–68]. Despite this, every patient must demonstrate adequate cardiopulmonary fitness and reserve to be considered for pulmonary resection, irrespective of surgical approach used.

2.3.3.1 Operability: Assessment of Cardiopulmonary Fitness

The preoperative assessment of cardiopulmonary fitness prior to lung surgery is beyond the scope of this chapter and is described in Chap. "Frequency of MIS Thoracic Surgery in Developed Countries". The ACCP has developed functional algorithms based on the best available evidence for the physiologic evaluation of patients being considered for lung resection [63]. These algorithms (Fig. 2.3) incorporate history, physical, electrocardiogram, and calculation of a Thoracic Revised Cardiac Risk Index (ThRCRI) score to determine if a patient needs a formal cardiology consultation and treatment per the AHA/ACC guidelines [100]. If the patient is deemed to have a low cardiac risk profile, they proceed to pulmonary function testing, which determines their need for cardiopulmonary exercise testing (CPET) and stair climbing for overall risk stratification (Fig. 2.4). If the patient is deemed high risk from a cardiac perspective, they proceed directly to CPET to determine if they are low (<1 % risk of mortality), intermediate (1–10 % risk of mortality), or high risk (>10 % risk of mortality) for anatomic pulmonary resection [63].

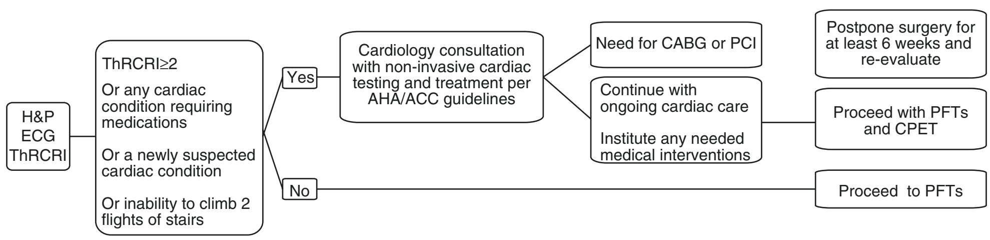


Fig. 2.3 American College of Chest Physicians Algorithm for Cardiac Evaluation Prior to Anatomic Pulmonary Resection (Figure adapted from [63] with permission; *H&P* history and physical exam, *ECG* electrocardiogram, *ThRCRI* Thoracic revised cardiac risk index, *AHA* American Heart Association, *ACC* American College of Cardiology, *CABG* coronary artery bypass grafting, *PCI* percutaneous coronary intervention, *PFTs* pulmonary function testing, *CPET* cardiopulmonary exercise testing)

2.3.3.2 Resectability: Tumor Characteristics

The list of absolute contraindications to performing minimally invasive lung resections continues to shorten as surgeons gain more experience with complex thoracoscopic procedures. Whereas prior thoracic surgery, endobronchial lesions, and induction therapy were once considered contraindications to thoracoscopic lobectomy, many surgeons no longer consider this to be the case. With the exception of very large tumors (>7 cm) that cannot be removed without rib spreading, superior sulcus tumors, most T4 lesions, and the inability to achieve and tolerate single lung ventilation, nearly any pulmonary resection is able to be performed in a minimally invasive fashion by surgeons with the proper experience.

Most surgeons agree that tumor size >7 cm is a contraindication to a VATS lobectomy [95]. Although it may be technically possible to perform a minimally invasive hilar dissection in patients with tumors >7 cm, proceeding to a rib-spreading thoracotomy to extract the specimen certainly negates some of the benefit provided by a VATS dissection. Pleural adhesive disease so severe that it requires thoracotomy for pneumolysis is rarely encountered. In most cases, the magnification and 30° angulation provided by a thoracoscope allows lysis of adhesions to be performed at least as well as via thoracotomy. Adhesions can be divided with a combination of blunt, sharply and electrocautery dissection. A variety of energy devices are available that may facilitate pneumolysis, while minimizing parenchymal injury. Redo VATS procedures after thoracotomy are often feasible, therefore prior surgery and pleural adhesions generally should not be considered a contraindication to attempting a minimally invasive approach.

Likewise, the lack of an identifiable interlobar fissure can also present a technical challenge, but should not be considered a contraindication to attempting a VATS resection. When performing an upper or middle lobectomy, the best approach is individual ligation of the venous, arterial, and bronchial branches from an anterior approach, followed by creation of the fissure by stapling the parenchyma just above the ongoing pulmonary artery. During a VATS right middle lobectomy, the major fissure may have to be opened with a stapler anteriorly prior to dividing the arterial branches to achieve the proper staple angle. When performing a lower lobectomy in patients with fused fissures, the artery must be identified anteriorly in the hilum and the major fissure divided above the basilar and superior segmental branches first. This will allow safe arterial dissection and ligation, which will expose the lower lobe bronchus.

The presence of benign or malignant hilar lymphadenopathy can complicate minimally invasive vascular dissections. Bulky or calcified hilar lymph nodes, such as seen with histoplasmosis, can make pulmonary vascular dissection more difficult. The surgeon must assess their ability to safely isolate the necessary structures and convert to thoracotomy when appropriate in such situations. The role for VATS in patients with N2 disease remains controversial. Traditionally, it was believed to be most appropriate to convert to thoracotomy upon identification of occult N2 disease due to concerns over the ability to perform a complete lymphadenectomy. However, it remains uncertain that complete lymphadenectomy provides short or long-term benefit over systematic thoracic nodal sampling [101, 102]. In addition, mounting evidence suggests that nodal dissections equivalent to open can be performed with both VATS and robotic assistance [103–105]. Wantanabe et al. reported similar outcomes in patients with NSCLC and occult N2 disease, regardless if VATS or open lung resection was performed [106].

Induction therapy was once considered a relative contraindication to VATS anatomic resection due to the increased vascular fragility and associated fibrosis, which limits hilar mobility. However, thoracoscopic lobectomy has been shown to be both safe and effective in this setting, when performed by experienced minimally invasive thoracic surgeons [107]. Advanced thoracoscopic techniques, such as VATS lobectomy with chest wall resection and VATS sleeve resections have also been described [108]. These procedures should only be attempted after achieving mastery of standard VATS anatomic resections. Proponents of VATS lobectomy with chest wall resection cite the ability to perform a minimally invasive hilar dissection and divide intercostal musculature with high-resolution cameras and magnification, minimizing the size of the required counter-incision for rib division and specimen removal [108]. This does not apply to superior sulcus tumors or those invading the vertebral bodies, where the fixed tumor limits visualization of the apex of the chest or spine. As a general rule, resection of T4 tumors should not be attempted with VATS, with the possible exception of patients with minimal mediastinal invasion that can be dissected thoracoscopically*en bloc* with the specimen. Although small case series of thoracoscopic sleeve resections have been reported, this procedure should only be attempted by experienced minimally invasive surgeons after achieving mastery of standard VATS pulmonary resections [109, 110].

To consider a patient with NSCLC for anatomic resection, the surgeon should believe that an R0 resection can be achieved and, with rare exception, patients must have no evidence of distant disease. In addition, standard medical contraindications, such as severe coagulopathy or recent myocardial infarction may act as absolute contraindications to a VATS lung resection. Finally, most surgeons agree that an FEV_1 or DLCO <30 % predicted is a contraindication to lobectomy [95]. However, emerging evidence suggests that FEV_1 and DLCO may not correlate as well with outcome following VATS pulmonary resection as with pulmonary resection via thoracotomy [64–68]. Almost all studies establishing relationships between pulmonary function testing and postoperative complications were with patients who underwent thoracotomy. Since then, numerous single and multi-institutional meta-analyses have established lower rates of postoperative complications and shorter hospital length of stay with VATS lobectomy compared to open lobectomy [96–99]. In a Society of Thoracic Surgeons (STS) database analysis of 12,970 lobectomies, including 4531 VATS lobectomies, the rate of increase in pulmonary complications with decreasing FEV_1 was higher in open than VATS lobectomy [65]. The authors suggest that using a VATS technique may allow certain patients to tolerate an operation that otherwise would be denied surgery based on their pulmonary function. Another study compared postoperative complications in patients with a PPO FEV_1 <40 % who underwent VATS (n = 47) or open (n = 23) lobectomy, finding a lower rate of pneumonia (4.3 % vs. 21.7 %; $p = 0.04$) and shorter intensive care unit stay (2 vs. 4 days; $p = 0.05$) [66]. A similar study of patients with a PPO FEV_1 <40 % reported an improved 5-year survival in patients who underwent VATS lobectomy or open segmentectomy vs. those who received open lobectomy (42 % vs. 18 %, respectively; $p = 0.02$) [67]. As an increasing number of surgeons embrace minimally invasive pulmonary resections, the traditional pulmonary function test parameters relied upon to predict postoperative outcomes may begin to shift.

Although a minimally invasive approach may increase operability in certain cases [64–68], it is unlikely to increase resectability. However, with growing experience, increasingly complex pulmonary resections can be performed safely in a minimally invasive fashion. Initially, non-obese patients with <3 cm peripheral lesions, clinical N0 or N1 disease, complete fissures, and no induction therapy should be attempted thoracoscopically. As experience grows, the spectrum of patients that can be approached with a minimally invasive intent widens considerably. Early in a surgeon's experience, conversion from VATS to open should not be consideredto be a failure on the surgeon's part, but instead as a marker of good judgment. When conversion occurs, insight is often gained that can be applied in similar situations in the future [111].

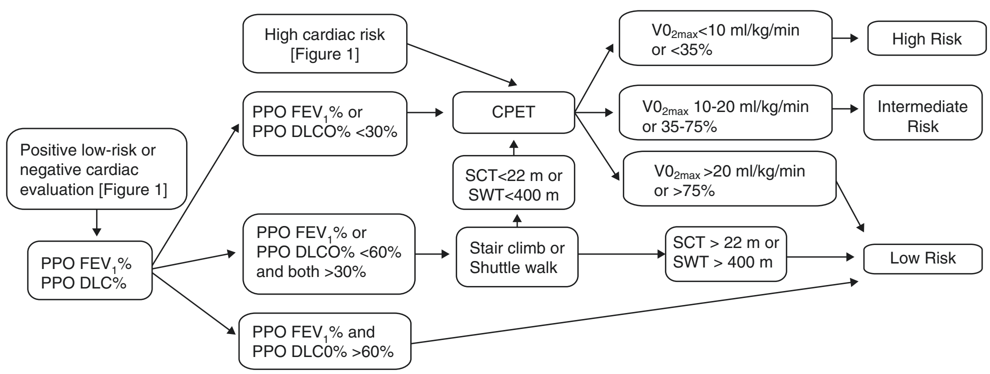


Fig. 2.4 American College of Chest Physicians Algorithm for Assessing Cardiopulmonary Fitness Prior to Anatomic Pulmonary Resection (Figure adapted from [63] with permission. PPO FEV_1, predicted postoperative forced expiratory volume in 1 s; *PPO DLCO* predicted postoperative diffusion lung capacity of carbon monoxide, *CPET* cardiopulmonary exercise testing, *SCT* stair climb test, *SWT* shuttle walk test, *VO2max* maximal oxygen consumption)

2.4 Type and Conduction of the Anaesthesia

Yi Feng and Juan Zhu

2.4.1 Introduction

General anesthesia with endotracheal intubation is the first choice of anesthesia for video-assisted thoracoscopic surgery. Double-lumen endotracheal intubation is the most commonly used method for isolated lung ventilation. The bronchial blocker is an inflatable device that can be passed through a single-lumen endotracheal tube to selectively occlude the right or left main bronchus. Proper anesthesia management can reduce the severity of acute lung injury to some extent. The acknowledgement of common practices and risks associated with anesthesia would help surgeons determine the optimal timing of the surgery, prepare patients for surgeries. Some common considerations in perioperative anesthesia management are outlined below. Postoperative pain is the main independent factor affecting postoperative rehabilitation. Many factors can lead to chronic pain. Hence, individualized and multimodal analgesia is recommended.

2.4.2 General Considerations of Anesthesia

General anesthesia with endotracheal intubation is the first choice of anesthesia for video-assisted thoracoscopic pneumonectomy. Although video-assisted thoracoscopic surgery (VATS) greatly decreases surgical trauma as compared to open chest surgery, it has no effect on certain pathophysiological changes, such as ipsilateral lung collapse, one-lung ventilation (OLV) and postoperative pain due to injury of the intercostal nerve(s) during trocar placement, especially in patients with pulmonary diseases, ischemic heart diseases and pulmonary hypertension. In such patients, OLV might further aggravate their condition, and minimally invasive thoracoscopic surgery may not lower the risks associated with intraoperative anesthesia. The incidence of acute lung injury (ALI) is higher with pneumonectomy than with other operations. The main reasons for this include OLV, lung collapse, surgical trauma, preoperative pulmonary dysfunction, large amount of fluid infusion and allogeneic blood transfusion. Proper management can reduce the severity of ALI to some extent. The acknowledgement of common practices and risks associated with anesthesia would help surgeons determine the optimal timing of the surgery, prepare patients for surgeries. Some common considerations in perioperative anesthesia management are outlined below.

2.4.3 Pre-anesthesia Assessment and Preparation

Surgeons must carefully evaluate residual lung function before pneumonectomy (see details in chapter "Physiologic Evaluation of Candidates for Lung Cancer Resection"). A Anesthesiologists tend to be more concerned about difficulties in anesthesia management, such as difficult airway and cardiopulmonary decompensation. However, damage to the recurrent laryngeal nerve, phrenic nerve, sympathetic chain or superior vena cava and airway compromise by the metastasis of the tumor can all greatly hinder anesthesia management and increase the incidence of intraoperative complications.

Active cardiac diseases such as unstable coronary syndrome (unstable angina or severe angina), recent myocardial infarction, decompensated heart failure, arrhythmia and severe valve diseases are risk factors for perioperative cardiovascular events. In patients with these diseases, surgery, except for life-saving surgeries, should be postponed.

Double-lumen endotracheal intubation is the most commonly used method for isolated lung ventilation. Anesthesiologists must carefully reevaluate patients with risk factors, such as restricted mouth opening, neck movement, sleep apnea syndrome and morbid obesity, and prepare measures to overcome difficult airway maneuvers.

2.4.4 Patient Positioning and Superficial Organ Protection

Thoracic surgeries generally require the patient to be in the lateral position (Fig. 2.5), as this position tends to provide the best view. In the case of operations performed with the patient in the lateral position, special attention should be paid to the protection of the skin, peripheral nerves and superficial tissue.

Thoracic surgery relies on OLV to achieve collapse of the lung on the operative side and expose the operative field. Upon lung collapse, the ventilation/perfusion ratio is changed, which can result in compression atelectasis and absorptive atelectasis of the collapsed lung. Accurate tracheal intubation and satisfactory pulmonary isolation are essential to reduce the incidence of ALI and hypoxemia.

OLV is commonly achieved using either a double-lumen endobronchial tube or a single-lumen endotracheal tube with a bronchial blocker. The double-lumen bronchial tube is widely used, easy to place and enables the selective ventilation of the left or right lung, because of which it can protect the non-operative lung from infarctions or bleeding in the operated lung (Fig. 2.6). It is important to choose the right type of tube for each patient.

Double lung auscultation is a basic method to determine whether a double-lumen endotracheal tube has been correctly placed, but the gold standard for determining proper catheter position is fiberoptic bronchoscopy. A fiberoptic bronchoscope is inserted into the double-lumen endobronchial tube to visualize the carina and bronchial cuff edge (usually blue). Figure 2.7 shows the best location of a left double-lumen endobronchial tube. The placement of the right double-lumen tube is more difficult due to the opening of the right main bronchus Fiberoptic bronchoscopy can be used to determine the position of a right double-lumen tube in relation to the trachea/bronchus (Fig. 2.8).

The bronchial blocker (Fig. 2.9) is an inflatable device that can be passed through a single-lumen endotracheal tube to selectively occlude the right or left main bronchus. Numerous types of bronchial blockers are available. These tubes must be positioned under fiberoptic bronchoscopic guidance (Figs. 2.10 and 11).

The relatively large lumen of double-lumen tubes facilitates rapid lung collapse. A suction tube can then be placed for easy suction, and continuous positive pressure ventilation can be applicated to the collapsed lung. The most obvious advantage of a bronchial blocker is in patients with difficult airways. The internal diameter of double-lumen tubes is wider than that of single-lumen tubes; the placement of the former is therefore more difficult and may cause tracheal mucosal damage. An alternative is to isolate the surgical lung with a single-lumen tube and a bronchial blocker.

Fig. 2.5 Patient positioning during thoracic surgery. To avoid brachial plexus injury, shoulder abduction must not exceed 90°. Pads are placed (1) around the forearm to protect the brachial plexus, (2) over the external genitalia (in males) to fix their position, (3) between the legs to reduce pressure sores of the legs and (4) in the axillary region on the operative side to improve exposure and avoid pressure injury of the upper limb resting on the operation table

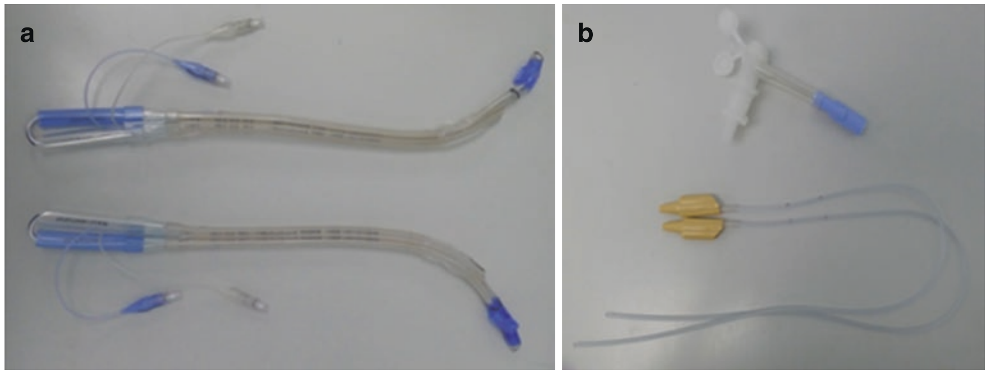


Fig. 2.6 Double-lumen tubes (**a**), transfer joint and suction tubes (**b**). In figure (**a**), the upper tube is a left double-lumen tube, and the lower tube is a right double-lumen tube

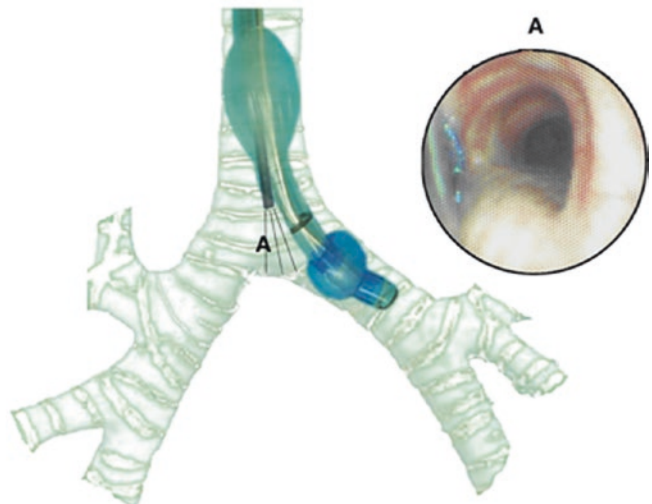


Fig. 2.7 Fiberoptic bronchoscopic view of a correctly placed left double-lumen tube

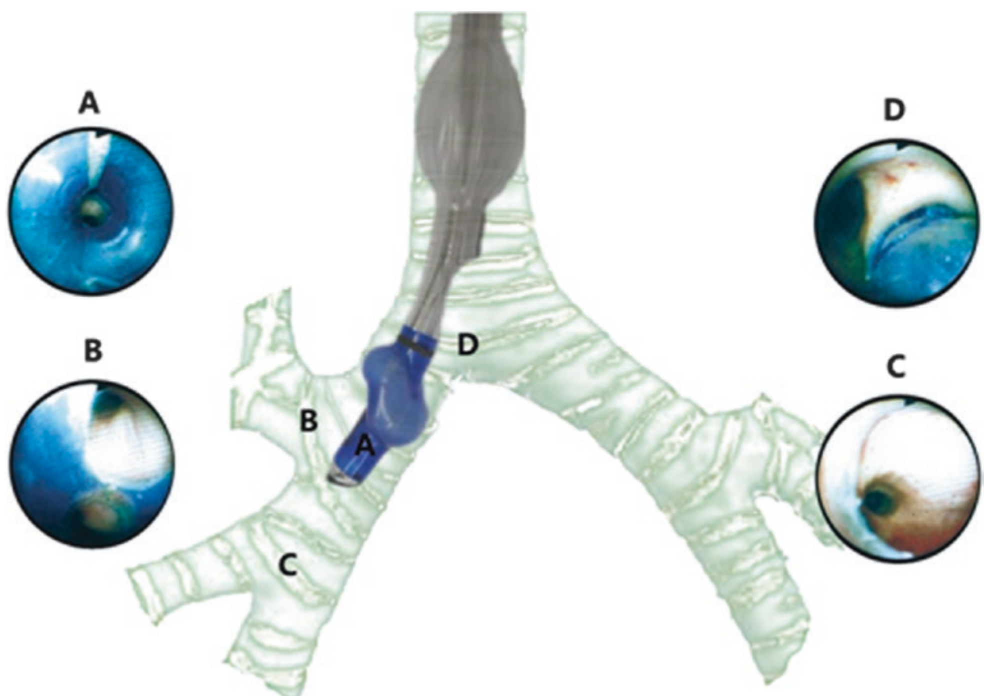
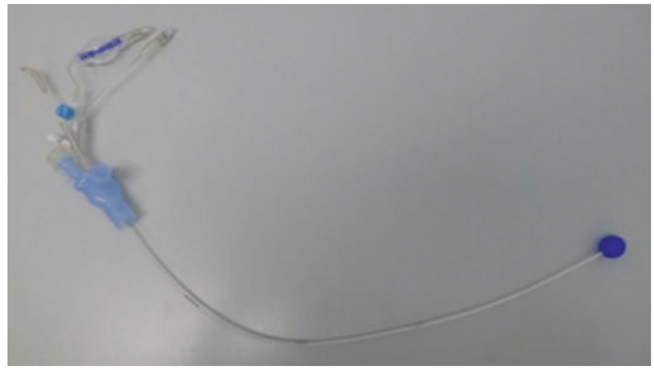


Fig. 2.8 Fiberoptic bronchoscopic views of a correctly placed right double-lumen endobronchial tube

Fig. 2.9 Bronchial blocker



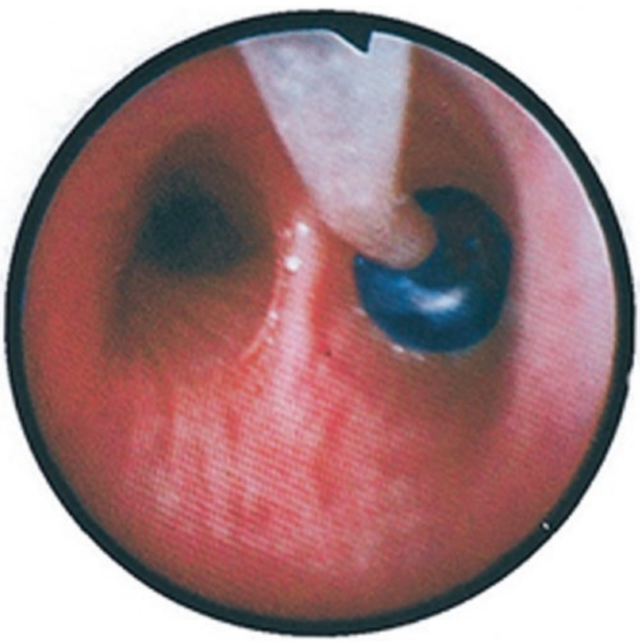


Fig. 2.10 Correct positioning of a bronchial blocker in the right main bronchus

Fig. 2.11 Correct positioning of a bronchial blocker in the left main bronchus

2.4.5 Intraoperative Hypoxia

Although the incidence of intraoperative hypoxia has considerably reduced, regardless of the selected posture, thoracic surgery continues to pose a risk of intraoperative hypoxia. The application of pure oxygen is thought to prevent and relieve hypoxia during OLV, and maximize the ventilation/perfusion ratio, which in turn can improve peripheral tissue oxygenation. However, the inhalation of high oxygen concentrations can increase the incidence of absorptive atelectasis, while the use of very low oxygen concentrations will lead to ALI. It is recommended that during two-lung ventilation, the fraction of inspired oxygen be set at approximately 50 %. During OLV, this value should be increased to 80 %, and if hypoxemia occurs (SaO_2 <90 %), the oxygen concentration should be increased to 100 %. Too high a tidal volume or pressure may cause lung injury during mechanical ventilation, so in recent years, protective lung ventilation (PLV) has gradually replaced conventional OLV. PLV includes the application of low tidal volumes (4–6 ml/kg), an inspiratory plateau pressure maintained at 20–25 cm H_2O, a peak pressure of <35 cm H_2O and positive end-expiratory pressure (PEEP) of 5–10 cm H_2O. PEEP should be adjusted according to the respiratory and circulatory changes during anesthesia, and permissive hypercapnia ($PaCO_2$ <65 mmHg) is acceptable.

Hypoxic pulmonary vasoconstriction (HPV) is a paradoxical, physiological phenomenon in which the pulmonary arteries constrict in the presence of hypoxia (low oxygen levels) without hypercapnia (high carbon dioxide levels), redirecting blood flow to the alveoli that have higher oxygen content. After OLV, the intrapulmonary shunt rate begins to increase, and HPV is initiated and peaks after 30–60 min. HPV can improve oxygen saturation during OLV. The majority of general anesthetics in current use have little effect on HPV, except for high concentrations of inhaled anesthetics.

If the above measures do not improve hypoxemia, the following steps can be taken: continuous positive airway pressure (CPAP; 5–10 cm H_2O) to the operated lung; intermittent ventilation of the operated lung (which is the most effective method); and pulmonary arterial blockage or ligation to rapidly alter the ventilation/perfusion ratio and thus improve the oxygenation status.

2.4.6 Intraoperative Hypothermia

Although pleural exposure is considerably less during thoracoscopic surgery than during open chest surgery, intraoperative hypothermia is a common event in both surgeries. This is because the aspirator continues to lower the temperature inside the thorax, and the cool air in the operating room is introduced into the thorax (21–24 °C). If insulation measures are not taken, video-assisted thoracoscopic surgery is likely to result in low body temperature (core temperature <36 °C). Other factors that affect body temperature include fluid infusion, skin disinfection, evaporation form the body surface, loss of the ability to adjust body temperature in the anesthetic state (the temperature regulation center is inhibited) and reduced metabolic heating (by approximately 20–30 %). Low body temperature slows down metabolism of the anesthetic drug, delays recovery from anesthesia and can cause blood coagulation dysfunction, tissue hypoxia, wound infection, increased cardiac load, chills and other complications after surgery, which seriously affect patients' prognosis and outcomes. Therefore, maintenance of body temperature is a crucial part of anesthesia management. Methods to stabilize body temperature include infusion of warm fluids, the use of heating materials (e.g., – warming blankets to cover the body, heat radiation, circulating-water warming blankets placed under the body), and airway warming and humidification.

2.4.7 Postoperative Pain

Early rehabilitation exercise is key to the recovery of pulmonary function after video-assisted thoracoscopic pneumonectomy. Postoperative pain is the main independent factor affecting postoperative rehabilitation. Multiple factors contribute to postoperative pain in patients who have undergone thoracoscopic surgery, including surgical trauma, inflammation, intercostal nerve compression and stimulation of the pleura by the chest tube. All of these factors can lead to chronic pain. Hence, individualized and multimodal analgesia is recommended.

2.4.7.1 Multimodal Analgesia

Multimodal pain management is the combination of different analgesic techniques, different classes of analgesics and different sites of analgesic administration to achieve additive analgesia without increasing, or even reducing, analgesic-related side effects. The combined application of nerve block (or infiltration of the surgical incision with a local anesthetic) and non-steroidal anti-inflammatory drugs can reduce opioid dosage and adverse events, such as nausea, vomiting, dizziness and constipation.

Commonly used analgesic techniques include nerve block analgesia, intravenous patient-controlled analgesia (PCA) and oral analgesia. Commonly used analgesics include narcotics (opioids such as tramadol), non-steroidal anti-inflammatory drugs (paracetamol), local anesthetics, compound preparations (oxycodone and acetaminophen) and different combinations of these drugs. Commonly used nerve block analgesia techniques include paravertebral nerve block, intercostal nerve block and peripheral nerve block (local infiltration).

Paravertebral analgesia is the best alternative to thoracic epidural analgesia. It can be administered as a single injection or a continuous infusion. When combined with intravenous PCA, paravertebral analgesia provides excellent pain relief after thoracoscopic surgery. Paravertebral block is usually performed by anesthesiologists, and can be done before or after the surgery.

Interpleural block is a type of intercostal nerve block, achieved by the injection of local anesthetics into the subpleural tissue. Intercostal nerve block and interpleural block are simple techniques, and are usually performed by surgeons. Thoracic epidural analgesia is more suitable for patients in whom conversion to open chest surgery is likely and for patients undergoing bilateral lung surgery.

2.4.7.2 Treatment of Analgesic-Related Side Effects

Nerve block is a safe technique provided that careful aspiration is performed, so that injection of the anesthetic into the vessels and the resultant toxic reaction can be avoided. The most common side effects of opioids are dizziness, nausea and vomiting. A fatal side effect of opioids is respiratory depression. Appropriate rehydration (positive fluid balance of not more than 20 ml/kg on the first day after operation), treatment of hypotension and the administration of prophylactic antiemetics such as 5-HT3 receptor antagonists can effectively prevent nausea and vomiting. Combination with non-opioids can reduce the dosage and, therefore, the side effects of opioids.

2.4.7.3 Treatment of Referred Shoulder Pain

Effective treatments include ketorolac, acetaminophen, phrenic nerve block and interscalene brachial plexus block. Although shoulder discomfort after thoracoscopic surgery is not as severe as that after conventional thoracotomy, local anesthetic infiltration of the fat pad around the diaphragm is still recommended. Local infiltration is easy to perform and unlike interscalene brachial plexus block, does not lead to shoulder disability. The combination of the above technique with ketorolac or acetaminophen will minimize shoulder discomfort without affecting shoulder function. If severe shoulder discomfort persists after phrenic nerve block, interscalene brachial plexus block can be considered.

2.4.7.4 Prevention of Chronic Pain

Although thoracoscopic surgery is a minimally invasive technique, the incidence of chronic pain after this procedure can be as high as 40 %. However, by analyzing the outcomes of single-center studies, we found that although the incidence of chronic pain after thoracoscopic surgery was high, the pain intensity was greatly reduced. Thus far, there is no certain way to prevent chronic pain after thoracoscopic surgery. A small, single-center study has shown that using smaller surgical tube, using smaller trocar nd monitoring intercostal nerve function may be beneficial. More studies are required to determine the optimal method to reduce the incidence and severity of chronic pain after thoracoscopic surgery.

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Wedge Resection

3

K. Robert Shen, Kezhong Chen, Xizhao Sui, Hui Zhao, and Jun Wang

Contents

3.1 Localization Techniques to Facilitate Surgical Resection of Small Indeterminate Lung Nodules

K. Robert Shen and Xizhao Sui

3.1.1 Technical Points

Localization techniques are very helpful for guiding resection of small indeterminate lung nodules, particularly if minimally invasive surgical techniques such as video-assisted thoracic surgery (VATS) or robotic-assisted thoracic surgery (RATS) are utilized. Various techniques have been adopted, but there is no consensus about the best technique to localize small nodules in the lung. In this section, two different localization techniques are reviewed:

- Microcoil localization is a CT-guided localization technique performed prior to VATS. The "Trailing method" for microcoil localization is to deploy the microcoil with the proximal part coiling beyond the parietal pleura while the distal part of the microcoil is anchored in the lung parenchyma.
- Radio nucleotide-guided localization is a technique where a small amount of radio nucleotide is injected adjacent to

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the lung nodule of interest using a trans-thoracic CT-guidance technique. Intraoperatively a specially-designed thoracoscopic radio probe is used along with a Navigator GPS™ Control Unit capable of detecting and quantifying gamma photons from gamma-emitting isotopes to localize the indeterminate small lung nodule.

3.1.2 Microcoil Localization

3.1.2.1 Equipment

Embolization Microcoil (Cook incorporated, Bloomington, IN 47404, USA) with a wire diameter of 0.18″ and a length of 7 cm and a 21-gauge Chiba needle. Before puncturing, the desired length of the guide-wire was prepared with the whole length of the loading cannula connecting with the Chiba needle.

3.1.2.2 Technique of Placing the Microcoil

1. Position the patient in an appropriate body position. Perform a guiding CT focusing on the lesion. Select the best needle route to avoid large vessels and important structures and the best site for microcoil placement.
2. Mark the skin entry spot. Sterile and drape the field on the patient's skin. Administer local anesthetic at the marked spot.

3.1.2.3 "Trailing Method" for Microcoil Deployment

1. Insert the Chiba needle to the planned site. Measure the distance between needle tip and outside the parietal pleura (Fig. 3.1). Mark the premeasured distance on the prepared guide-wire.
2. Insert the guide-wire into the needle and push it to the marked location. At this point the distal part of the microcoil has been deployed and coiled in the lung parenchyma.
3. Hold the guide-wire in place and withdraw the needle slowly. When the needle has been withdrawn beyond the marked location on the guide-wire, withdraw the needle and guide-wire simultaneously. At this point, the microcoil has been fully deployed with the proximal part coiling beyond the parietal pleura and the distal part anchoring in the lung parenchyma (Fig. 3.2).
4. Recheck a CT to confirm the position of microcoil and to identify any complications.

Fig. 3.1 Measure the distance between needle tip and outside the parietal pleura

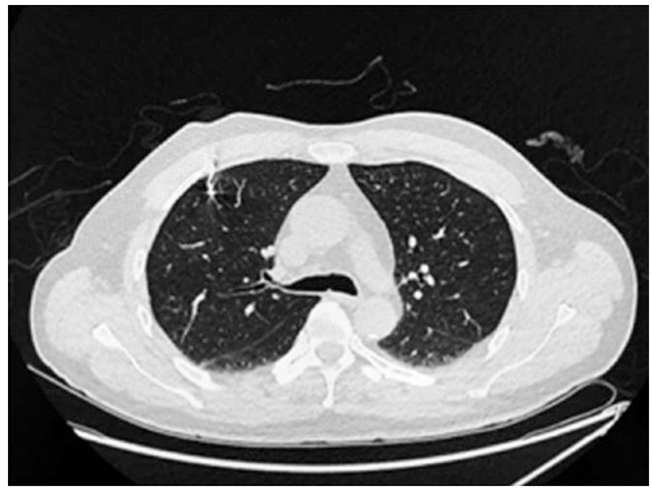

Fig. 3.2 The microcoil deployed by "tailing method"

3.1.2.4 Operative Procedure

1. Visual examination: explore for the proximal end of the microcoil beyond the visceral pleura (Fig. 3.3).
2. Palpation: If the marker has not been found, palpation should be conducted for the implanted microcoil or lesions bypassing the main operating port.
3. Fluoroscopy: For cases with unsuccessful palpation, fluoroscopy should be utilized to find the microcoil.
4. Resection: for cases with successful localization, VATS wedge resection or segmentectomy using endoscopic staplers can be performed

Fig. 3.3 Trailing part of microcoil on pleural surface

Tips

For Patients with CT-guided microcoil localization, a time duration of 1–3 days between localization procedure and surgery seems to be safe. However, for patients with surgery not on the same day, a chest X-ray is recommended on surgical day to confirm the position of the microcoil and to identify the Late-onset pneumothorax.

3.1.3 Radionucleotide-Guided Localization

3.1.3.1 Equipment

20-guage coaxial needle and 22-guage spinal needle
0.1 ml Technetium Tc-99MAA (macro-aggregated albumin) (0.3 mCi)
Daniel Probe™ (RMD Instruments, Watertown, Massachusetts, USA) (Fig. 3.4)
Navigator GPS™ Control Unit (RMD Instruments, Watertown, Massachusetts, USA) (Fig. 3.5)

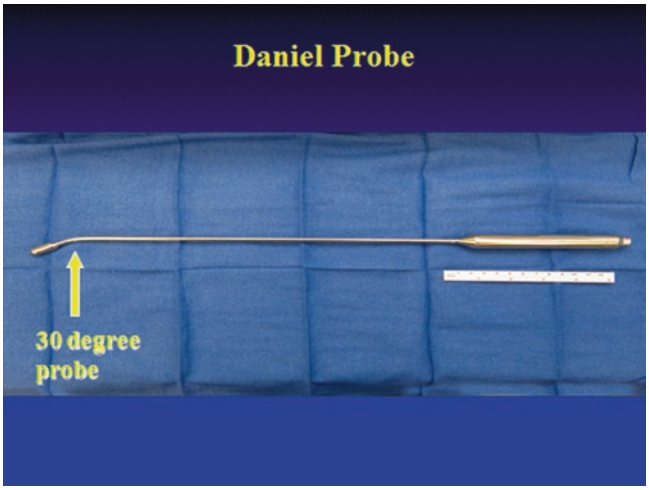

Fig. 3.4 Daniel™ radioprobe

Fig. 3.5 Navigator GPS™ control unit

3.1.3.2 Technique of Placing Radionucleotide

On the morning of planned surgery, patient undergoes limited chest CT scan (GE Lightspeed 16 (GE Healthcare, Waukesha, Wisconsin, USA) without intravenous contrast to confirm lung nodule location. The operating surgeon and the interventional radiologist mutually decide on the exact lung site and the best approach angle for radionucleotide placement. The ideal location for placement of the radionucleotide is on the deep side of the nodule relative to the pleural surface. This ensures that if the area of maximum radiation is resected, the nodule will be between the area of maximum radiation and the pleural surface. After confirmation, a 20-guage coaxial needle is positioned in the chest wall just proximal to the pleural cavity. A 22-guage spinal needle is then advanced through the coaxial needle into or adjacent to the lung nodule under CT fluroscopy. Once properly positioned, 0.3 mCi of Technetium Tc-99MAA is then injected (Fig. 3.6). An immediate post-injection scintigram is obtained to confirm intraparenchymal position of the radionucleotide (Fig. 3.7).

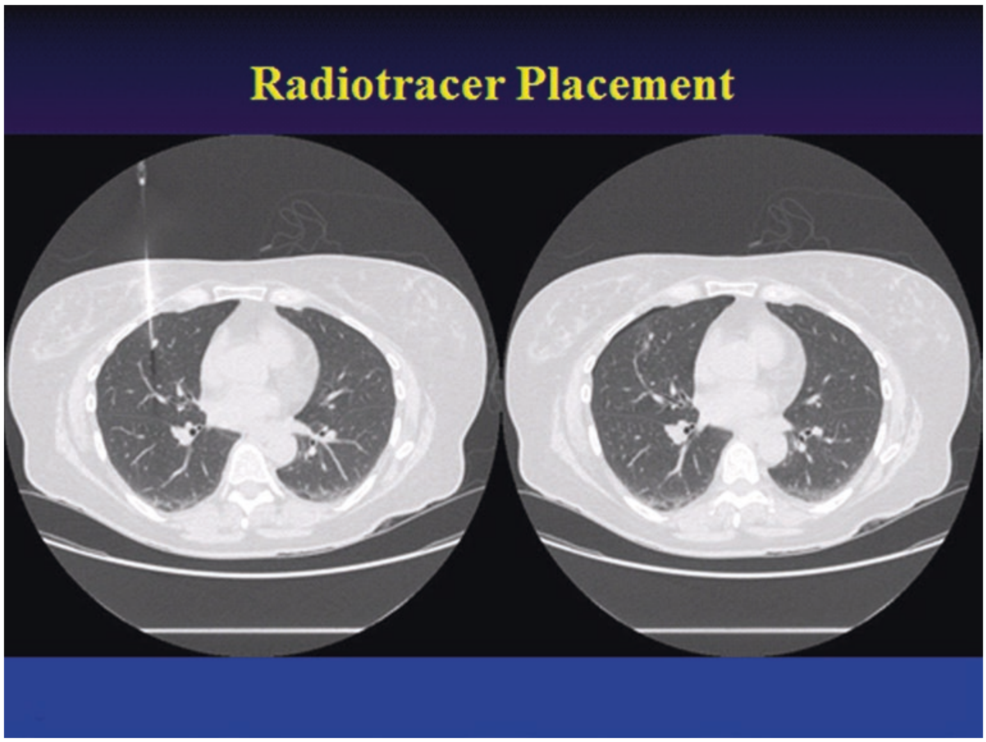

Fig. 3.6 Placement of radiotracer

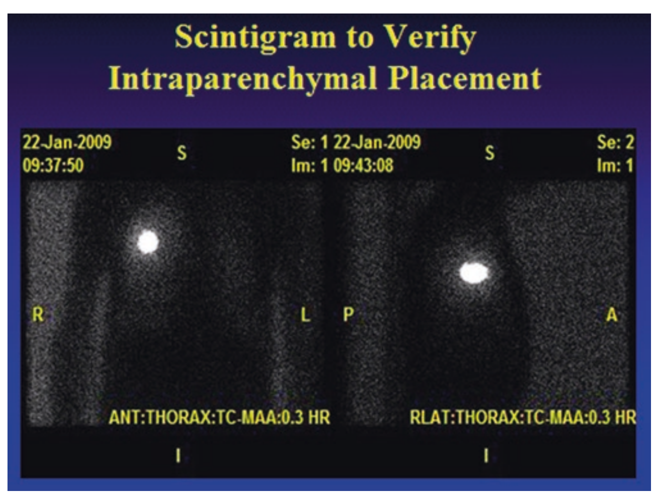

Fig. 3.7 Nuclear medicine scintigram to verify intraparenchymal placement of radionucleotide

3.1.3.3 Operative Procedure

The patient is brought to the operating room once correct radionucleotide placement has been confirmed in radiology. General anesthesia with single-lung ventilation is then induced. Once VATS ports have been placed, a 19-cm-long sterile Daniel™ radioprobe with a 30° angled head and 6 mm shaft is used to localize the area of lung with the maximum radioactive signal. Three thoracoscopic ports are used: one for a 10 mm 30-degree thoracoscope, one for an endoscopic grasper, and one of the gamma probe and endoscopic stapler used sequentially. Once the area of lung with the maximum radioactive signal is identified, that area of lung is grasped and elevated with the endoscopic grasper, and the radioprobe is used to confirm the lesion's location from multiple angles. The radioprobe is reintroduced as often as necessary during the resection of the lung wedge to assure that the lung tissue being removed contains the maximum radioactive signal. On the wedge containing the lung nodule has been removed, the radioprobe is used to confirm absence or minimal radioactive signal in the remaining lung.

3.2 Results and Discussion

Xizhao Sui and K. Robert Shen

3.2.1 Preoperative Localization

The increased use of chest computed tomography (CT) in lung cancer screening programs and for various clinical applications has led to identification of significant numbers of indeterminate lung nodules. Improved CT technology allows diagnosis of not only more nodules, but also increasingly smaller nodules. Thoracic surgeons are now being called on to evaluate these lesions for the possibility of malignancy, often in the setting of high-risk patients with significant smoking histories. Although short-term follow-up imaging may often suggest either benignity or malignancy, caution should be exercised in accepting a benign diagnosis without tissue confirmation. Additionally, given evidence that tumor size directly impacts survival even within subgroups of stage IA tumors, it makes intuitive sense to attempt to treat potential cancers as early as possible.

We and others have found that small lung nodules, particularly subcentimeter nodules, cannot be reliably biopsied percutaneously [1]. Often, the most expedient and direct path to definitive management of a suspicious indeterminate small pulmonary nodule is to proceed with surgical excisional biopsy. Thoracoscopic surgery carries less morbidity than diagnostic procedures performed through thoracotomy, but is limited by the frequent inability to see or palpate (digitally or instrumentally) small subpleural lesions. To overcome this limitation, several different thoracoscopic nodule localization techniques have been developed and have been reported to improve the ease and accuracy of thoracoscopic biopsy. These include the use of visual markers, such as methylene blue and hook wires, fluoroscopic localization using various radiopaque markers, radiotracer localization techniques, and more recently, thoracic endosonography. All of these techniques have their own advantages and disadvantages, as well as significant learning curves. To date, there is no consensus on the "best" localization technique.

3.2.1.1 Preoperative Technique

Most preoperative localization techniques utilize some form of image guidance, most commonly, CT scanning. Various liquid materials have been used for preoperative localization such as lipiodol [2], methylene blue [3] and barium [4]. However, the success rates of injected dyes may be affected by the density of coloration of the target area and rapid diffusion of these liquids. The contrast method necessitates intraoperative fluoroscopy. One disadvantage of techniques using liquid injectable localizing agents is that unintentional injection of liquid materials into the systemic or pulmonary circulation can cause potentially fatal complications like anaphylactoid reactions or embolisms.

Preoperative localization using hook wires is a common technique and yields reasonable technical success rates [5–7]. However, a relatively higher failure rate due to the dislodgment of the wire has also been reported [8]. Problem of percutaneous hook wire localization besides the dislodgment is the relatively high morbidity rate resulting from wire rigidity such as wire migration. Problematic complications include pneumothorax, pulmonary hematoma, hemoptysis, and air embolism. In a study included 417 patients, 49 % presented with pneumothorax, of which 4.6 % required pumping treatment, 10.3 % presented with hemoptysis and hematoma was 10.3 % while 0.24 % presented with air embolism [6]. One potential limitation of hook wire localization is that the time between hook wire localization and thoracoscopy needs to be minimized in order to reduce the chance of wire dislodgement.

3.2.1.2 Microcoil Localization

Microcoil is a platinum coil designed for embolization of vessel supply in vascular intervention surgery, and have been identified as a useful localizer for preoperatively localization [9, 10]. Microcoil localization may make up for some deficiencies of other techniques. Compared with hook wires, microcoils are not rigid and clinically proven material that can safely be sustained in the human body, so it is not necessary to perform surgery immediately after the localization. Compared with liquid materials, complications caused by intravascular injection and solvent diffusion effects on microcoil localization are not relevant. To be deployed by "tailing method" introduced in the previous section, the microcoil can be detected by visual inspection, palpation, and fluoroscopy during VATS exploration.

We reviewed the data of 98 nodules in our institution and microcoil dislocation were identified on VATS exploration in three patients (3.1 %), resulting a successful localization rate of 96.9 % [11]. The risk factor of microcoil dislocation needed for further study. We suggested a sufficient depth of the implanted microcoil should be ensured and the depth is recommended to be between 1 and 2.5 cm from pleural surface. The types of complications in microcoil localization are similar with hook wire localization, of which pneumothorax usually occurred in lesions adjacent to the pleura or repeated puncture in multiple lesions, while hematoma was more common in lesions with deep location and longer traveling distance of needle. The severity of complications may be less using microcoil compared with hook wire. It is believed that the structural characteristics of the microcoil might help in reducing the severity of complications. The thrombogenic coating of synthetic nylon fibers on the surface of the microcoil may promote blood coagulation of the surrounding lung tissues, block the needle pathway, and decrease the severity of pneumothorax and bleeding caused by the puncture needle damaging the lung tissues, which has been proven in animal experiments [12].

In summary, CT-guided microcoil localization by "trailing method" prior to thoracoscopic resection is a feasible, safe, and effective method for localization of small nodules.

3.2.1.3 Radionucleotide Localization

At our institution, CT-guided radionucleotide injection followed by intraoperative thoracoscopic radioprobe localization is the preferred technique for localizing small lung nodules that we anticipate preoperatively will be difficult to visualize or palpate. Since we began using this technique in October of 2008, we have performed 174 cases (Fig. 3.8). There has been only one technical failure where we were not able to use the radionucleotide placement technique to identify the lung nodule, so our technical success rate is 99.4 %. Two patients (1.1 %) have developed a pneumothorax after radionucleotide placement that necessitate placement of a small pigtail drain prior to surgery. In 65 % of cases, the nodules were solid lesions and in 35 % the nodules were ground glass lesions. The median size of the lung nodule has been 9 mm (range 3, 23 mm). Median depth of the nodule from the chest wall 59 mm (range 5–124 mm). 15.5 % of the nodules were palpable. The indication for surgery in the 174 cases was: rule out lung cancer in 43.5 %, rule out lung metastasis in 39.7 %, lung cancer versus lung metastases in 14.1 %, other in 2.6 %. On final pathology, lung cancer was the diagnosis in 46.2 %, benign etiology in 15.4 %, and metastatic disease in 38.5 %.

Patients found to have primary lung cancers with adequate lung reserve underwent definitive lobectomy or segmentectomy and nodal staging.

One of the advantages of the radionucleotide localization technique is that it allows marking of lesions anywhere in the lung up to 12 cm deep from the chest wall or 5 cm deep from the pleural surface. The technique does not require intraoperative fluoroscopy, does not require a skilled ultrasonographer in the operating room, and does not require an exotic or expensive radionucleotide. Technetium 99 MAA (Tc99-MAA) is the most widely utilized radionucleotide in nuclear medicine and is widely available. The radioisotope dose required for this technique (0.3 mCi) is only one third the dose of the same isotope used in breast lymphoscintigraphy (1 mCi) and much less than that used for nuclear lung scans (4–5 mCi) and bone scans (10–20 mCi). The half-life of the Tc99 is 8 h, which allows the radionucleotide to be stable once it is placed in the lung for up to 12 h. Furthermore, the radionucleotide emits a gamma particle and does not present any radiation safety hazard to the personnel in the operating room or pathology room. We believe we have overcome the problem of radionucleotide diffusion with the Tc99 MAA solution. Binding the Tc99 to a macro aggregate albumin molecule (MAA) prevents the radionucleotide from dissipating rapidly into the lymphatic system or surrounding parenchyma.

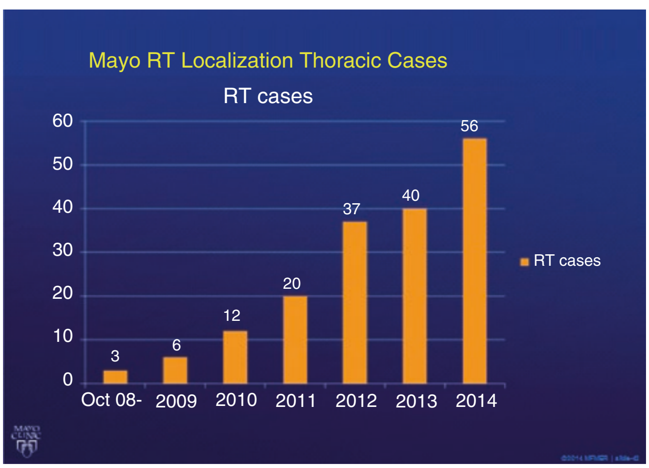

Fig. 3.8 Mayo Clinic experience with radionucleotide localization cases

3.3 Management of Multiple Pulmonary Nodules

Kezhong Chen and Jun Wang

The frequency of recorded multiple pulmonary nodules, especially multifocal ground glass opacities (GGO), has steadily increased in recent years due to improved resolution of CT imaging and the widespread use of positron emission tomography (PET). The main evidence-based guidelines for additional nodules and multiple primary lung cancers (MPLC) are those outlined in the third edition of 'Guidelines of Diagnosis and Management of Lung Cancer' by the American College of Chest Physicians (ACCP) and the guidelines addressed by European Society for Medical Oncology (ESMO) [13]. However, even with these guidelines, there is a lack of high level evidence-based studies; therefore treatment and survival of lung cancer patients is controversial. Moreover, many clinicians are more likely to follow the standard TNM staging guidelines in the core components of the AJCC staging system, in which patients with additional tumor nodules in the same lobe would be staged as T3; an ipsilateral tumor in a separate lobe would be considered as T4 and M1a if contralateral [14]. However, this could lead to patients with multifocal in situ tumors, who may benefit from surgical resection, are misdiagnosed in higher TNM stages and are offered inappropriate therapies.

Therefore, the appropriate treatment strategies targeted toward patients with multiple pulmonary nodules of these subtypes have been a particular concern to clinicians. This article reviews the clinical behavior of multiple nodules with different CT characteristics and discusses the treatment strategy aimed for patients with each of these categories of multiple pulmonary nodules. It is our belief that since multifocal GGOs and multiple solid lung cancers are different in biology, surgical resection should be performed discriminately to suitable patients.

3.3.1 Multifocal Pure GGOs or Predominantly Non-solid Tumors

Most multifocal GGOs typically turn out to be adenocarcinoma in situ (AIS), minimally invasive adenocarcinoma (MIA), or lepidic predominant adenocarcinoma (LPA), which are considered multiple and distinct primary disease clones with few metastatic capabilities. The clinical feature of these multifocal GGOs suggests a difference from multiple solid tumors as reported in previous reports. Some studies have shown that these multifocal GGOs have a tendency to occur in patients who are nonsmokers, or Asian women who bear epidermal growth factor receptor (EGFR) mutations [15].

Several studies addressing these increasingly common patients have reported excellent prognosis. Kim [16] evaluated the clinical characteristics and long-term outcome of 23 patients with multiple pure ground-glass opacities, of whom no death occurred during the 40.3 months' follow-up period. Only one patient developed a new lesion and none of the GGOs that not resected changed in size or feature. Mun [17] reported thoracoscopic resection for 27 patients with pure GGOs or predominately nonsolid lesions. No deaths but new GGOs developed in seven patients at 46 months' postoperative observation period. In Shimada's retrospective study [18], 24 patients had multiple GGO-dominant lesions. No recurrence happened and the 5-year OS were 95.8 %. In our database, all patients with multifocal pure GGOs or predominantly non-solid tumors survived 5 years without recurrence, a rate that was similar with previous studies (Table 3.1).

These growing data demonstrated an approximate 100 % overall survival (OS) and a very low recurrence rate after resection of multifocal lung cancers. The Fleischner Society [19] recommend limited video-assisted thoracoscopic surgical wedge or segmental resections should be considered in these patients for whom surgery is indicated. This recommendation is supported by the following evidence: (i) limited resection has shown good outcomes for single GGO lesions

Table 3.1 Long-term survival of different radiographical multiple pulmonary nodules after surgery

Author	Date	Number	CT findings	3-year OS (%)	5-year OS (%)
Kim [16]	2010	23	MG	100	100
Shimada [18]	2015	67	MG	/	95.8
			DT	/	68
Castiglioni [21]	2015	87	DT	/	93.8
Yu Y [24]	2013	97	DT+MS	83.1	69.6
Fabian [23]	2011	67	MS	64	53
Our institution (K Chen)	2015	96	MG DT MS	100 88.9 75.2	100 66.7 50.7

MG Multifocal pure ground glass lesions or predominantly non-solid tumors, *DT* A dominant adenocarcinoma with multiple ground glass lesions, *MS* Multiple solid tumors

(≤2 cm) and low chance for nodal and systemic metastases; and (ii), a certain percentage of patients with untreated nodules which become more invasive or develop new lesions, which will require additional resections. Therefore, treating the lesion at the initial operation with a sub-lobar resection in order to preserve lung tissue for future local therapy is an ideal strategy. Besides, since a secondary surgery in a previously operated region is likely to be more complicated, all accessible ipsilateral lesions should ideally be resected at the same time, unless they are located too deep to be resected by wedge. Contralateral pure, small GGOs can be left in place and followed for growth over time based on the relatively slow rate of progression of non-resected GGOs [15].

3.3.2 A Dominant Invasive Lesion with Multiple Ground Glass Lesions

Due to the increasing proportion of these multifocal GGOs, we have been experiencing a more common situation in which patients present with a predominant solid lesion containing an invasive focus, along with multiple synchronous, scattered pure GGOs [20]. These scattered lesions do not behave like metastatic lesions, but rather like multiple sites of premalignant (AIS) or very early malignant (MIA) lesions. This presentation must not be considered as stage IV disease.

Castiglioni et al. [21] compared patients who have a solitary lesion with patients that have a dominant lesion with additional nodules. The results showed no statistically significant differences in 5-year disease-free survival (82.3 *vs.* 83.8 %, $p=0.254$) and overall survival (86.7 *vs.* 93.8 %, $p=0.096$) between the two groups. This demonstrated that patients with lepidic growth pattern adenocarcinoma presenting as a dominant lesion with associated secondary nodules behave similarly to patients with a solitary adenocarcinoma. Similar results were presented in the study by Gu et al. [20], which showed that patients who underwent resection of the dominant invasive adenocarcinoma and wedge resection of accessible GGOs had a favorable survival at 2.6 years mean follow-up time. Shimada et al. [22] analyzed 43 synchronous multiple lung cancers patients with the main cancer showing solid-dominant lesion and showed that the 5-year OS was 68 %, which was similar to our data. We collected a total of 35 patients with a dominant invasive lesion with multiple nodules, the Kaplan-Meier curves showed the 5-year OS was 66.7 %.

According to the available data, resection of the dominant invasive lesion in the presence of other multifocal GGOs is an appropriate disease management strategy. The decision whether a lobectomy or sub-lobar resection of the dominant invasive lesion should be performed is based on tumor size and location.

3.3.3 Multiple Solid Tumors

Multiple solid tumors are tumors that are predominantly solid on CT scan, upon which our current official staging system is based. With the technological advancements of imaging technology, improved treatment of lung cancer and the deeper disease understanding by clinicians, data from older studies that suggested that multiple solid tumors represent <5 % of all non-small cell lung cancers (NSCLCs) are likely to be an underestimation of the true incidence of the condition [22]. The diagnosis of multiple solid tumors is on the basis of criteria proposed by Martini et al. and modified by ACCP in 2003. These tumors are presumed to represent squamous cell carcinomas or invasive adenocarcinomas, with substantial potential for lymph node metastasis and distant metastasis. Thus, patients believed to have multiple solid tumors should undergo a careful clinical and radiographic assessment for distant and mediastinal node metastases.

The outcomes of synchronous multiple primary lung cancer (SMPLC) reported in the last 25 years were of much difference. The average 5-year survival of patients who undergo resection was only about 25 % (range: 12–52 %), and that of patients with stage I disease was about 40 %, which appeared better than the natural outcome of untreated lung cancer [13], thus demonstrated the inclusion of surgery in the treatment of SMPLC. Fabian et al. [24] suggested that using their preoperative assessment and surgical strategies, the overall 5-year survival of SMPLC was 53 %, which was much better than published 5-year survival for SMPLC. In view of the strict inclusion and exclusion criteria, their report may reflect the true expected outcomes for patients undergoing resection of SMPLC who are N2 negative. Similarly, of the 37 patients with SMPLC in our study, we found that their overall 5-year survival was 50.2 %.

Therefore, accurate evaluation is essential to identify multiple solid tumors patients and to avoid inappropriately referring them to oncologists for chemotherapy or targeted therapy. It is reasonable to proceed with a resection of each lesion if there is no N2 nodal disease. Lobectomy of the main lesion is suitable, while a sub-lobar resection of one or both lesions may be necessary, depending on the patient's pulmonary reserve.

3.3.4 Treatment Strategy

Based on the different characteristics of multiple pulmonary nodules, surgical procedures should be performed discriminately to suitable patients. Our basic treatment strategy for synchronous multiple pulmonary nodules were as follows (Fig. 3.9):

1. The site and size of the nodule, radiographical characteristics and estimated post-operative respiratory function should be initially ascertained.
2. If tumors were ipsilateral, single-stage operation should be performed. Wedge resection or segmentectomy was preferred when the nodules were all pure GGOs or GGO-dominant tumors ≤2 cm. In cases with multiple sub-solid nodules with a dominant solid lesion, radical resection of the dominant nodule along with limited resection to the other scattered lesions was the common procedure. Limited resection for the dominant lesion was performed only if it was ≤2 cm. In instances where there were two or more solid nodules, lobectomy was recommended for the main lesion. The decision to perform bilobectomy, pneumonectomy, or sub-lobar resection for the other lesions was determined by the location of the tumor and pulmonary function. Sub-lobar resection may be more appropriate for nodules ≤2 cm in order to avoid the high perioperative risk of pneumonectomy. Besides, all accessible ipsilateral lesions should be resected at the same time, unless for deeply embedded GGOs that cannot be resected by wedge
3. When tumors were contralateral, two-stage surgical treatment was commonly recommended. For some young patients with good pulmonary function, one-stage surgical treatment was also a choice. Generally, resect the more invasive tumor which may mainly impact the survival. However, given the prerequisite of pulmonary function for bilateral surgery, in cases where the patient was unable to tolerate one-lung ventilation following primary surgery, tumor resection which would have minimal impact on pulmonary function was considered. However, if contralateral lesions were all small pure GGOs, a wait-and-see approach was undertaken wherein they were left in place and monitored for growth and invasion.

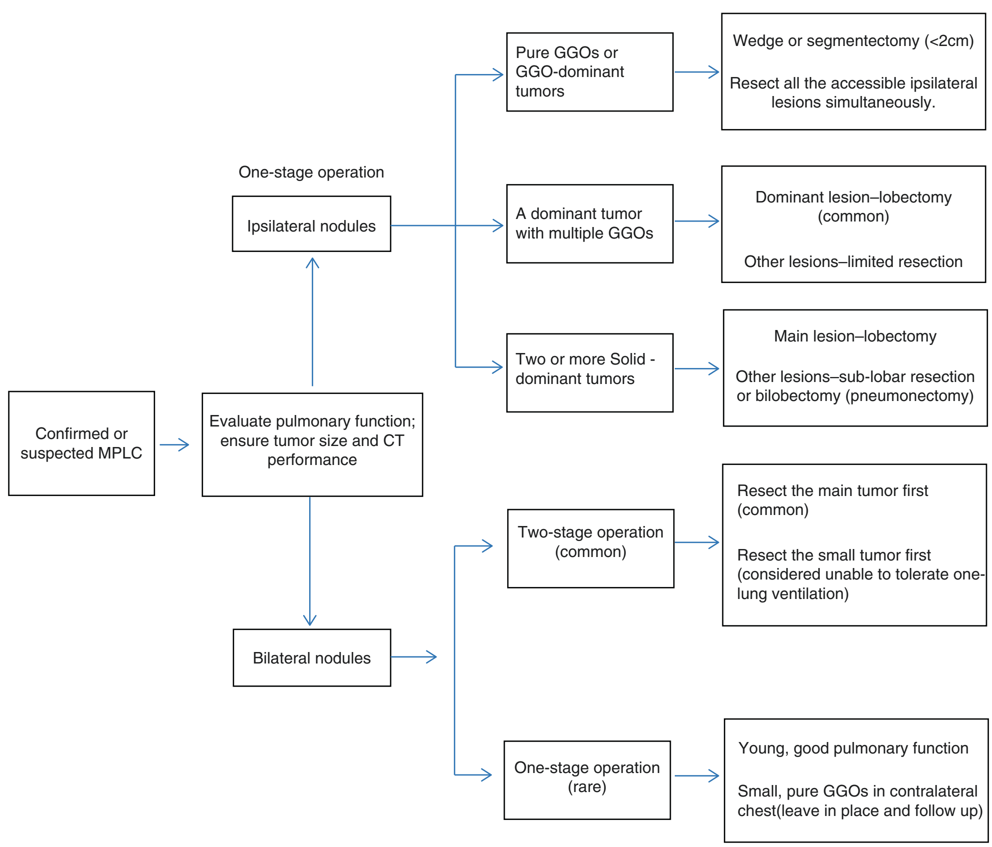

Fig. 3.9 Treatment strategy of patients with different categories of multiple primary lung cancers

3.4 Wedge Resection Techniques

Xizhao Sui and Hui Zhao

3.4.1 Technical Points

The wedge resection is a basic and common used technique in video-assisted thoracoscopic surgery. Endoscopic stapler is an indispensable instrument that facilitate VATS wedge resection. Wedge resection margin distance is associated with locoregional recurrence, and a sufficient margin distance is considered as no less than 2 cm or tumor diameter. In this section, some important technical points for stapled wedge resection will be introduced:

- How to evaluate the feasibility of stapled wedge resection for peripheral nodule.
- How to confirm a sufficient resection margin intraoperatively.

3.4.2 Anatomical Landmarks

According to the anatomy of lungs and the nodule location, the feasibility of stapled wedge resection for peripheral nodule can be classified into four types: (Fig. 3.10).

- **Peripheral sharp edge:** nodules located near the sharp edge of the lung, such as the oblique fissure and the horizontal fissure, the anterior border and the inferior border of the lung. Nodules in these positions can be easily removed by stapled wedge resection.
- **Peripheral obtuse surface**: nodules located at the peripheral surface of the lung, equal to costal surface, but not near the border of the lung. Nodules in these positions can be removed by stapled wedge resection, but sufficient resection margin should be noted.
- **Basel surface:** nodules located at the basel surface of the lung, but not near the inferior border of the lung. Stapled wedge resection for nodules in these area is technically difficult, extended range of healthy lung tissue may be removed by stapled wedge resection, and sufficient resection margin should be noted.
- **Central surface**: nodules located at the medial surface or near the posterior border of the lung. Stapled wedge resection may be not feasible or facing technically difficulty of sufficient resection margin for nodules in these area.

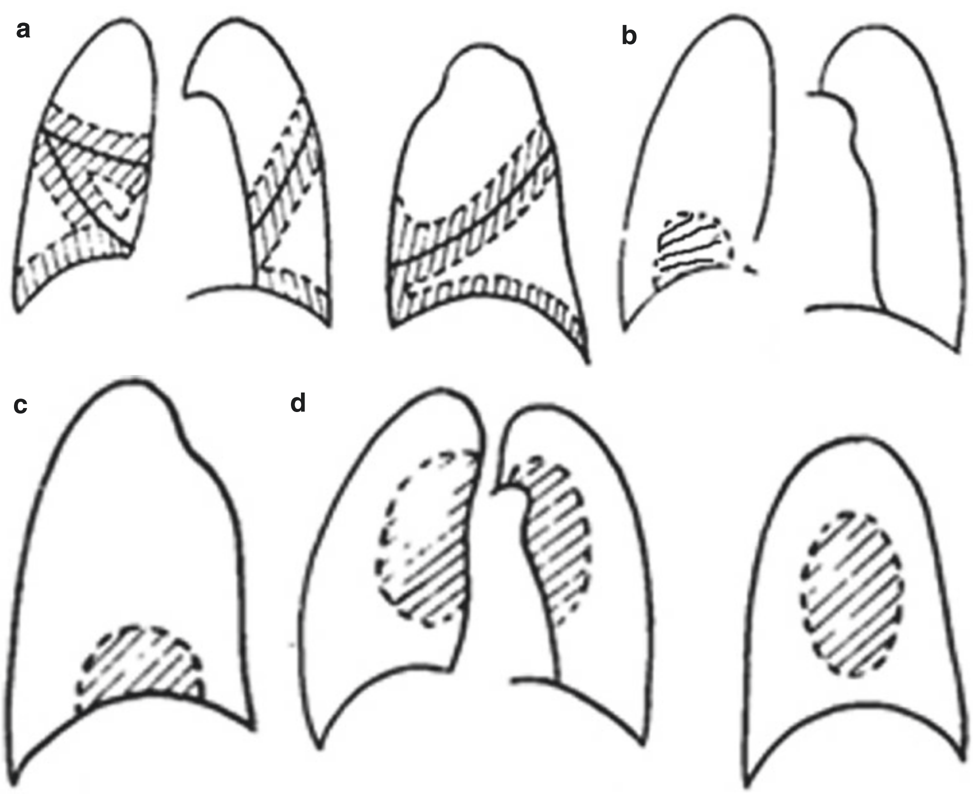

Fig. 3.10 Anatomical classification for stapled wedge resection. (**a**) Peripheral sharp edge. (**b**) Peripheral obtuse surface. (**c**) Basel surface. (**d**) Central surface

3.4.3 Operating Procedure

1. Locate the nodule by visual inspection, palpation, or by the marker (see the previous section). Evaluate the feasibility of wedge resection, determine the removed range and the margin distance.
2. Grasp the involved lung by a long oval forceps along the planned cutting line under thoracoscopic guidance (Fig. 3.11).
3. Place the endoscopic stapler beyond the forceps, confirm the resection margin is sufficient (Fig. 3.12).
4. Finish the wedge resection by endoscopic stapler (Fig. 3.13). Generally speaking, the distance from the cutting margin to the forceps is about 1 cm. So the distance from the nodule to the forceps is essential for the sufficient margin.
5. For nodules located deeply in the lung parenchyma, preoperative CT-guided microcoil localization will be helpful to mark a sufficient margin distance for stapled limited resection (Fig. 3.14).

Tips
A forceps is very helpful for determine the margin distance of wedge resection before endoscopic stapling.

Fig. 3.11 Grasp the involved lung using the long oval forceps.1. The nodule

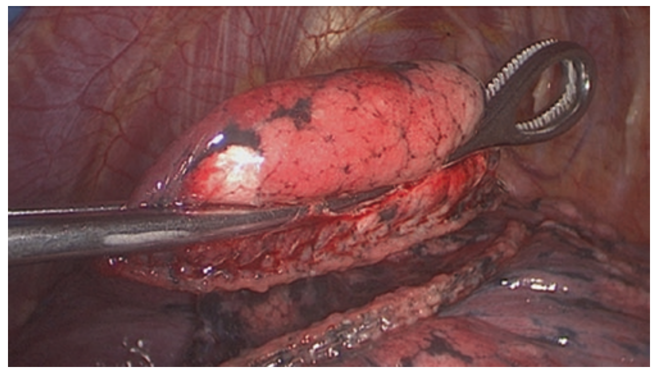

Fig. 3.13 Hold the forceps and remove the endoscopic stapler

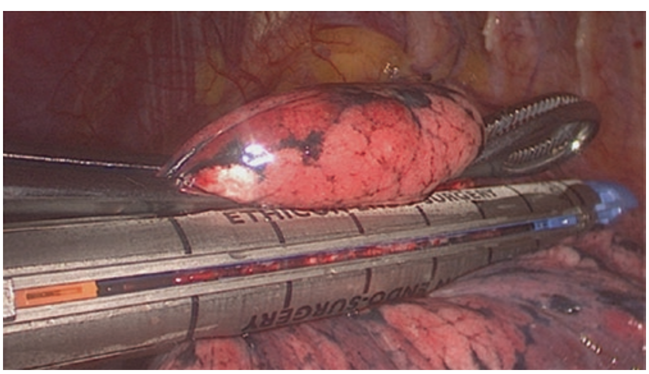

Fig. 3.12 Place the endoscopic stapler along the forceps

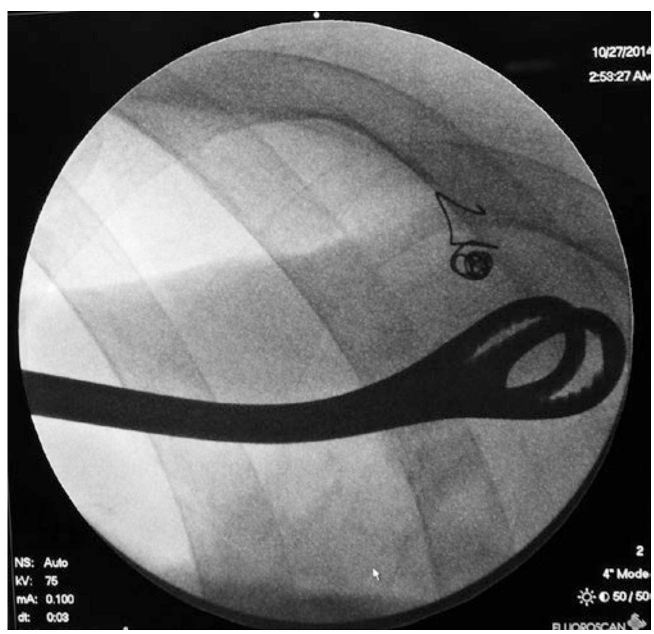

Fig. 3.14 Confirm the margin distance under fluoroscopic guidance before stapled resection. The microcoil is placed at the bottom of the nodule

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Lobectomy

4

Thomas A. D'Amico, Fan Yang, James Huang, Tiejun Zhao, Zuli Zhou, Jun Wang, Pamela Samson, and Traves Crabtree

Contents

4.1 The Rationale for Minimally Invasive Lobectomy

Thomas A. D'Amico

4.1.1 Introduction

The surgical approach in the management of lung cancer continues to evolve and improve. Conventional surgical approaches remain viable options for some patients with resectable lung cancer. However, minimally invasive procedures have increasingly gained acceptance as a standard surgical modality for early-stage lung cancer, with increasing application to more advanced disease, as a means of minimizing operative morbidity without sacrificing oncologic efficacy.

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4.1.2 Definition

Minimally invasive procedures, using operative telescopes and video technology, are referred to synonymously as *thoracoscopic* procedures or *video-assisted thoracic surgery* (VATS). For clarity, the terms *VATS* and *thoracoscopic* refer to totally thoracoscopic approaches, where rib spreading is avoided, and visualization depends on video monitors [1]. The application of thoracoscopic anatomic resections is increasingly used internationally. In a recent analysis of the Society of Thoracic Surgeons (STS) General Thoracic Surgery Database, thoracoscopic lobectomy constituted 45 % of all lobectomies performed [2].

Thoracoscopic lobectomy is defined as the anatomic resection of an entire lobe of the lung, using a videoscope and an access incision (<8 cm), without the use of a mechanical retractor and without rib spreading [1]. The anatomic resection includes individual dissection and stapling of the involved pulmonary vein, pulmonary artery, and bronchus and appropriate management of the mediastinal lymph nodes, as would be performed with thoracotomy. In selected patients, thoracoscopic anatomic segmentectomy may be performed, adhering to the same oncologic principles that guide resection at thoracotomy [3]. Theoretical advantages to minimally invasive resection include reduced surgical trauma and inflammation, decreased postoperative pain, shorter chest tube duration, shorter length of stay, preserved pulmonary function, and numerous short-term and long-term outcomes [4–9].

4.1.3 Indications

In general, the indications for thoracoscopic lobectomy are similar to those for lobectomy using the open approach [1, 10–13]. Thus, the procedure is applied to patients with known or suspected lung cancer (clinical stage I–II) if the disease appears amenable to complete resection by lobectomy. Preoperative staging and patient selection for thoracoscopic lobectomy should be conducted as for conventional thoracotomy [14]. With increasing focus on operative planning and experience with the VATS techniques, the indications for thoracoscopic lobectomy are evolving. Whereas initially a history of prior surgery, the presence of an endobronchial lesion, or even the administration of induction chemotherapy were once regarded as contraindications, the experience that has since been gained, together with improvements in instrumentation and thoracoscopic imaging, have now changed this situation in most hospitals with experience in VATS. Recent studies have shown that thoracoscopic lobectomy in cases of locally advanced lung cancer including patients treated with induction chemotherapy can be performed safely and effectively, without an increase in the rate of complications [15–17]. And although endobronchial lesions were previously considered a contraindication to VATS resections, sleeve bronchial resection (Fig. 4.1), sleeve lobectomy (Fig. 4.2), and pneumonectomy are now commonly performed minimally invasively [15, 18].

Tumor size may preclude the option of thoracoscopic lobectomy in some patients, as some large specimens (tumors greater than 6–8 cm in diameter) may not be amenable to removal without rib spreading, possibly negating the benefit of minimal access surgery. However, no absolute size criteria have been applied. Although it is controversial, some have also argued that the thoracoscopic approach may allow recruitment and resection of some patients considered medically inoperable, who could not undergo conventional thoracotomy [1, 16, 19, 20]. A report by Cattaneo et al. demonstrated improved tolerance of thoracoscopic lobectomy as compared with thoracotomy lobectomy in patients older than 70 years of age [21]. Several authors have further demonstrated that VATS lobectomy is beneficial in reducing pulmonary complications in patients with poor preoperative pulmonary function [2, 22]. The minimal physiologic requirements for resection have not been agreed on; however, the selection of patients for thoracoscopic lobectomy must take into account that conversion to thoracotomy may be necessary. Finally, chest wall involvement would obviate thoracoscopic resection for most patients, but successful hybrid thoracoscopic lobectomy with en bloc chest wall resection has been demonstrated to be safe and feasible [23].

The efficacy of mediastinal lymph node dissection has been questioned [24]. Several studies have examined the extent of mediastinal lymph node dissection (MLND) by VATS versus open lobectomy. In one study by Kondo et al., thoracotomy was performed for reassessment of lymph nodes following MLND using VATS and yielded few additional lymph nodes (mean = 1.3 lymph nodes, median 0 lymph nodes) [25]. Similarly, Sugi et al. found no difference between the number of lymph nodes dissected among VATS (mean = 8.4 ± 1.0) vs. open (mean = 8.2 ± 1.5) group during lobectomy [26]. More recently, a retrospective review of 770 patients with cN0-pN2 non-small cell lung cancer (VATS = 450, open = 320) by Watanabe et al. examined the total

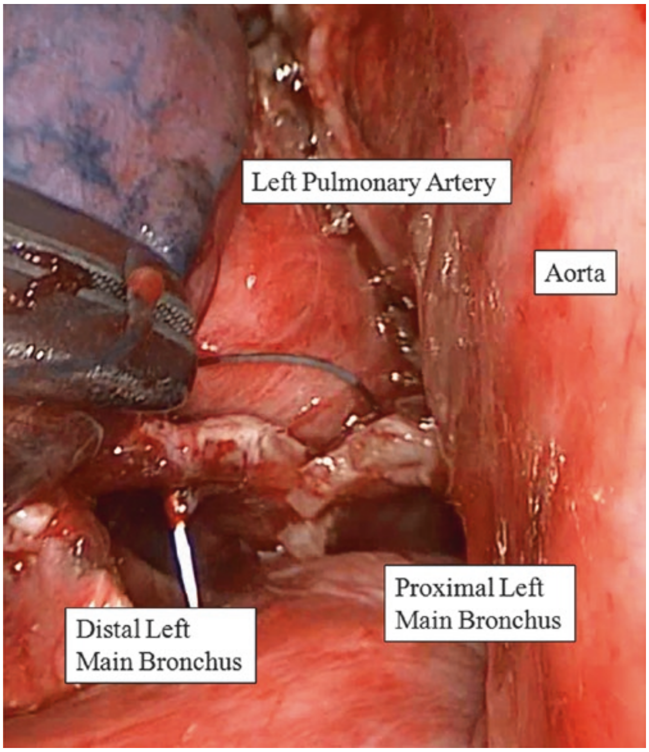

Fig. 4.1 Left bronchial sleeve resection for carcinoid (without parenchymal resection)

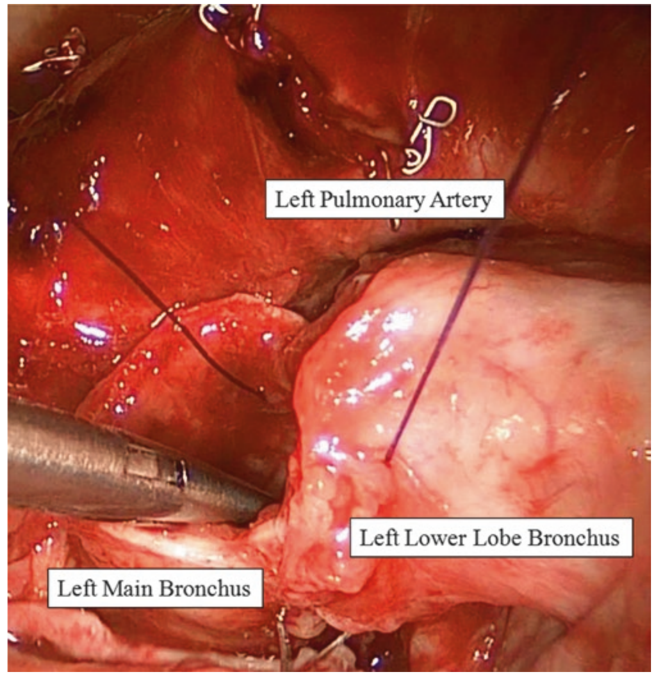

Fig. 4.2 Left sleeve upper lobectomy for lung cancer

number of lymph nodes, number of lymph node stations, number of mediastinal nodes and mediastinal stations by VATS vs. open lobectomy, and found no difference in any of these categories [27]. Data from the recent American College of Surgeons Oncology Group Z0030 trial (n = 752, VATS = 66, open = 686) has also confirmed the efficacy of MLND during VATS procedures by demonstrating similar number of lymph nodes removed and lymph node stations assessed as compared to thoracotomy [28].

Other studies have compared the efficacy of a lymph node dissection of a VATS lobectomy with standard thoracotomy and have demonstrated that the results are similar [29, 30]. Nevertheless, it remains that some surgeons doubt the efficacy of VATS MLND. To date, few studies have disputed the efficacy of MLND by VATS, with one study by Denlinger et al. (VATS = 79, open = 464) showing a fewer number of lymph nodes sampled by VATS compared to thoracotomy (7.4 ± 0.6 versus 8.9 ± 0.2, p = 0.03) and fewer number of N2 nodes (2.5 ± 3.0 versus 3.7 ± 3.0, p = 0.004) [31]. In a study from the National Comprehensive Cancer Network database with a more balanced number of VATS versus open procedures (n = 388, VATS = 199, open = 189), VATS and thoracotomy were found to result in a similar number of mediastinal lymph nodes resected (median = 4 for both groups) and N2 nodes resected (median = 3 for both groups) [32]. The percentage of patients with at least three mediastinal lymph node stations assessed, as recommended by the current guidelines, was also similar in the VATS and open group (66 % VATS versus 58 % open, p = 0.12).

4.1.4 Results

The safety and efficacy of thoracoscopic lobectomy for patients with early-stage lung cancer have been established. Although there are no prospective, randomized series that compare thoracoscopic lobectomy with conventional approaches, a sufficient number of series have been published, including single-institution and multi-institution experiences, as well as meta-analyses, to conclude that thoracoscopic lobectomy is a reasonable strategy for patients with clinical stage I lung cancer.

The Cancer and Leukemia Group B (CALGB) reported on the results of a prospective, multi-institutional registry series of 127 patients who underwent thoracoscopic lobectomy [1]. In this series, the mortality was 2.7 %, the operative time was 130 min, and the median length of stay was 3 days. Since that first multi-institutional study demonstrated the safety and feasibility of minimally invasive lobectomy, numerous subsequent studies have analyzed the potential advantages of this approach.

4.1.4.1 Postoperative Pain

One of the most well-studied advantages of thoracoscopic lobectomy is a reduction in postoperative pain [8, 9, 33–35]. Nomori and colleagues compared a group of age- and sex-matched patients who underwent thoracoscopic lobectomy ($n = 33$) or limited anterior thoracotomy ($n = 33$) [33]. The patients who underwent thoracoscopic lobectomy experienced less pain between postoperative day (POD) 1 and POD 7 ($p < 0.05$–0.001) and had lower analgesic requirements up to POD 7 ($p < 0.001$). Demmy and colleagues reported on their results in a series of patients who underwent either thoracoscopic lobectomy or conventional thoracotomy [19]. In this series, the percentage of patients reporting severe pain was 6 % after thoracoscopic lobectomy and 65 % after thoracotomy. Moreover, the percentage of patients reporting minimal or no pain was 63 % after thoracoscopic lobectomy and 6 % after thoracotomy.

Chronic discomfort is also an important issue in postoperative recovery. Although more difficult to measure than acute pain, chronic pain and shoulder dysfunction have been studied. Stammberger and colleagues, in addressing long-term quality of life following VATS, reported that 53 % of 173 patients undergoing VATS had insignificant pain 2 weeks after the operation [34, 35]. At 6 months, 75 % had no complaints, and only 4 % had mild or moderate discomfort at 2 years.

4.1.4.2 Postoperative Pulmonary Function

Many have theorized that smaller incisions and absence of rib spreading may improve lung function in the postoperative period, and several studies have reported pulmonary function test (PFT) data after thoracoscopic resection. Two studies examined postoperative arterial oxygen tension (PaO_2) after both VATS and muscle-sparing thoracotomy and found that VATS patients had better oxygenation during the first postoperative week [36, 37]. Others have demonstrated improvements in early postoperative forced expiratory volume in 1 s (FEV_1) and forced vital capacity in the first weeks and months after VATS [8, 19].

4.1.4.3 Systemic Inflammatory Effects

Minimally invasive procedures appear to produce less of a systemic insult than more conventional, invasive procedures [7, 8, 38–42]. Many groups have studied inflammatory mediators after VATS and open resection and have found lower levels of C-reactive protein and interleukins (IL) in those having undergone VATS. Yim and colleagues analyzed the cytokine responses in a series of 36 matched patients who underwent thoracoscopic lobectomy or conventional thoracotomy and lobectomy [7]. Analgesic requirements were significantly lower in the patients who underwent VATS lobectomy. In addition, the levels of IL-6 and IL-8 were lower in the VATS group than in the group that underwent thoracotomy. Leaver and coworkers examined immunosuppression due to systemic effects of surgery and found higher numbers of CD4 lymphocytes and natural killer cells and less suppression of lymphocyte oxidation in the VATS group [38]. These studies have shown that VATS lobectomy leads to a reduced inflammatory response, less postoperative reduction in immunosuppression, and less impairment of cellular cytotoxicity than open lobectomy. These findings could partially explain why perioperative outcomes of VATS lobectomy are superior to the perioperative outcomes of open lobectomy. Whether these trends toward more effective immune function after VATS resection lead to faster recovery or toward better long-term oncologic outcomes will be important endpoints of future studies, but is currently not known.

4.1.4.4 Oncologic Effectiveness

The ultimate acceptance of thoracoscopic lobectomy will be dependent on its oncologic effectiveness as compared with conventional lobectomy. To date, only one small prospective, randomized trial has compared oncologic results of VATS with open lobectomy [26]. In this study published in 2000, Sugi and colleagues reported that for 100 patients with stage IA non-small cell lung cancer undergoing either open ($n = 52$) or VATS ($n = 48$) lobectomy, there was no difference in 3- and 5-year survival rates. Though this trial is without sufficient power to assess differences between the operations, several additional retrospective studies performed are sufficient for limited analysis. Some analyses have further documented improved survival when VATS was used [4, 5, 43]. Reasons for the possible differences are unclear, but it has been postulated that preservation of immune function and less systemic release of inflammatory cytokines may be contributing factors [34]. In addition, the benefit of adjuvant treatment for resected stage II lung cancer necessitates attempts to maximize planned chemotherapy doses postoperatively. Thoracoscopic lobectomy, with its lower morbidity rates, allows a high proportion of patients to receive all intended doses [44, 45].

4.1.4.5 Cost-Effectiveness

The assessment of cost-effectiveness is controversial because of the difficulty in identifying and including all costs. Clearly, VATS can be associated with high costs of disposables and with longer operative times in inexperienced hands. However, numerous disposable instruments essential to performing thoracoscopic lobectomies, such as linear endoscopic staplers, are also employed by many in performing either conventional or limited thoracotomies. Nakajima and colleagues published a study from Japan demonstrating that hospital charges were actually lower for the VATS approach [46]. One important variable in the assessment of cost-effectiveness is length of hospital stay. In most series of thoracoscopic lobectomy, the median length of stay was only 3 days [1–3, 6, 13, 14]. As surgeon experience increases with thoracoscopic lobectomy, the operative times will become comparable to that of conventional approaches. In fact, the mean operative time in the CALGB multi-institutional study was only 130 min [1].

A recent study by Swanson et al. used the Premier Perspective Database to compare hospital costs for VATS and open lobectomy procedures in the United States [47]. A total of 3,961 patients underwent either open lobectomy (n = 2,907) or VATS lobectomy (n = 1,054). Hospital costs took into account costs associated with the operation, length of stay, and with adverse events. Hospital costs were found to be significantly higher for open versus VATS lobectomy, though costs associated with VATS lobectomy were influenced by surgeon experience, whereas this was not the case with open lobectomy.

4.1.4.6 Overall Complications

The observation that thoracoscopic lobectomy may have a lower complication profile has been supported in multiple studies analyzing outcomes of series including patients undergoing thoracoscopic lobectomy and patients undergoing open lobectomy. In one study, 122 patients undergoing thoracoscopic lobectomy and 122 patients undergoing thoracotomy were compared [48]. Overall, the incidence of postoperative complications was lower in the thoracoscopic group (17.2 % versus 27.9 %, $p = 0.046$); however, these patients were matched for age and sex only, and there was no significant difference in the incidence of any of the specific complications reported. Whitson and colleagues analyzed the outcomes of 147 (unmatched) patients who underwent lobectomy, including 88 by thoracotomy and 59 by thoracoscopy. Thoracoscopic lobectomy was associated with a lower incidence of pneumonia but with no difference in other complications, including blood loss, atrial fibrillation, or number of ventilator days.

Using a prospective database, the outcomes of patients who underwent lobectomy at Duke from 1999 to 2009 were analyzed with respect to postoperative complications [49]. Propensity-matched groups were analyzed, based on preoperative variables and stage. Of the 1,079 patients in the study, 697 underwent thoracoscopic lobectomy and 382 underwent lobectomy by thoracotomy. In the overall analysis, thoracoscopic lobectomy was associated with a lower incidence of prolonged air leak ($p = 0.0004$), atrial fibrillation ($p = 0.01$), atelectasis ($p = 0.0001$), transfusion ($p = 0.0001$), pneumonia ($p = 0.001$), sepsis ($p = 0.008$), renal failure ($p = 0.003$), and death ($p = 0.003$). In the propensity-matched analysis based on preoperative variables comparing 284 patients in each group, 196 patients (69 %) who underwent thoracoscopic lobectomy had no complications, versus 144 patients (51 %) who underwent thoracotomy ($p = 0.0001$). In addition, thoracoscopic lobectomy was associated with fewer prolonged air leaks (13 % versus 19 %; $p = 0.05$), a lower incidence of atrial fibrillation (13 % versus 21 %; $p = 0.01$), less atelectasis (5 % versus 12 %; $p = 0.006$), fewer transfusions (4 % versus 13 %; $p = 0.002$), less pneumonia (5 % versus 10 %; $p = 0.05$), less renal failure (1.4 % versus 5 %; $p = 0.02$), shorter chest tube duration (median 3 versus 4 days; $p < 0.0001$) and shorter length of hospital stay (median 4 vs 5 days; $p < 0.0001$) [3].

Similar results were obtained when the STS database was analyzed by Paul and colleagues [6]. All patients undergoing lobectomy as the primary procedure via thoracoscopy or thoracotomy were identified in the STS database from 2002 to 2007. After exclusions, 6,323 patients were identified: 5,042 underwent thoracotomy, 1,281 underwent VATS. A propensity analysis was performed, incorporating preoperative variables, and the incidence of postoperative complications was compared. Matching based on propensity scores produced 1,281 patients in each group for analysis of postoperative outcomes. After VATS lobectomy, 945 patients (73.8 %) had no complications, compared to 847 patients (65.3 %) that had lobectomy via thoracotomy ($p < 0.0001$). Compared to open lobectomy, VATS lobectomy was associated with a lower incidence of arrhythmias [n = 93 (7.3 %) versus = 147 (11.5 %); $p = 0.0004$], re-intubation [n = 18 (1.4 %) versus n = 40 (3.1 %); $p = 0.0046$], and blood transfusion [n = 31 (2.4 %) versus n = 60 (4.7 %); $p = 0.0028$], as well as a shorter length of stay (4.0 versus 6.0 days; $p < 0.0001$) and chest tube duration (3.0 versus 4.0 days; $p < 0.0001$). There was no difference in operative mortality between the two groups [4].

Finally, two important meta-analyses have been done to assess the advantages of the thoracoscopic approach. In the first, analyzing the outcomes of 21 studies comparing VATS and open approaches, Yan and colleagues demonstrated that there were no significant difference in locoregional recurrence, but that VATS lobectomy was associated with a reduced systemic recurrence rate ($p=0.03$) and improved 5-year mortality rate ($p=0.04$) [4]. Cao and colleagues performed a similar analysis, focusing on studies that included propensity matching [5]. In this meta-analysis, VATS was associated with a lower risk of perioperative morbidity ($p=0.0004$), confirming the single and multiple institution series in the literature [6, 16].

4.1.5 Summary

Minimally invasive approaches to lung cancer treatment have been demonstrated to be safe and effective for patients with early-stage lung cancer. Thoracoscopic lobectomy is designed to achieve the same oncologic result as conventional lobectomy: complete hilar dissection and individual vessel control. The recognized advantages of thoracoscopic anatomic resection include less short-term postoperative pain, shorter hospital stay, and preserved pulmonary function, better compliance with adjuvant chemotherapy, and fewer complications. As techniques evolve, thoracoscopic strategies are increasingly applied to locally advanced lung cancer as well. Although there are no sufficiently powered prospective randomized studies comparing the thoracoscopic approach with conventional thoracotomy, there are no data from published series to suggest any difference in oncologic efficacy.

4.2 Right Upper Lobe

Fan Yang and Jun Wang

4.2.1 Technical Points

The right upper lobectomy is a difficult endoscopic procedure in all VATS lobectomies. Right upper lobe has many arterial branches, especially some thin branches, so the bleeding risk is relatively high during dissection. Besides, the operative field is large, so the scope has to switch from the anterior to the posterior mediastinum and from the apex to the diaphragm. In addition, the following difficulties may be faced:

- The horizontal fissure is frequently fused and sometimes crossed by posterior venous branches from the superior vein. In that situation, it's hard to show the branches of pulmonary artery through the fissure, so the order of events is the superior vein, the truncus anterior, the bronchus, the ascending artery, and finally the fissure.
- The ascending artery may have anatomic anomalies with more than one branches. If the ascending artery is too thin to use staple, it could be divided by Hem-o-lok, titanium clip or LigaSure.
- Lymph nodes are frequently present at the space between upper bronchus and truncus anterior, especially some calcified lymph nodes which can lead to troublesome hemorrhage during dissection.
- Sometimes it is not easy to identify the interlobar plane between the right upper lobe and the middle lobe. Dissection of the horizontal fissure is difficult.

Two different approaches can be used: (1) a classic anterior approach in which the truncus arteriosus and the superior pulmonary vein are controlled first and (2) a posterior approach in which the bronchus is divided first. If necessary, these two approaches can be combined.

4.2.2 Anatomical Landmarks

- **Bronchus**: In some patients, it may be advisable to divide the bronchus first from the posterior of the hilum which is called posterior approach. Especially for patients whose major fissure is fused. The posterior ascending artery can be exposed well after cutting off the right upper bronchus. Paying more attention on the lymph nodes between upper bronchus and truncus anterior is needed.
- **Arteries**: The upper lobe arterial include two main branches: the truncus anterior, which originates from the hilum and gives the apical and anterior segmental arteries, and the posterior ascending artery, which supplies the posterior segment. The truncus anterior can be divided separately or as a stem. It is very important to check that one does not mix up this stem with the main pulmonary artery. The posterior segmental branch arises from the posterior aspect of the pulmonary artery. In most patients, this artery is single but it can vary from zero to three branches. The artery is sometimes covered by the posterior branch of the superior pulmonary vein, which adds difficulty to the dissection of the artery.
- **Veins**: The superior pulmonary vein is the most anterior element. It is sometimes close to the truncus anterior of the hilum. It is sometimes close to the truncus anterior, making its dissection difficult. The position of the middle lobe vein must be verified before any division of the three segmental veins, which can be done separately or, more often, as a stem (Fig. 4.3).

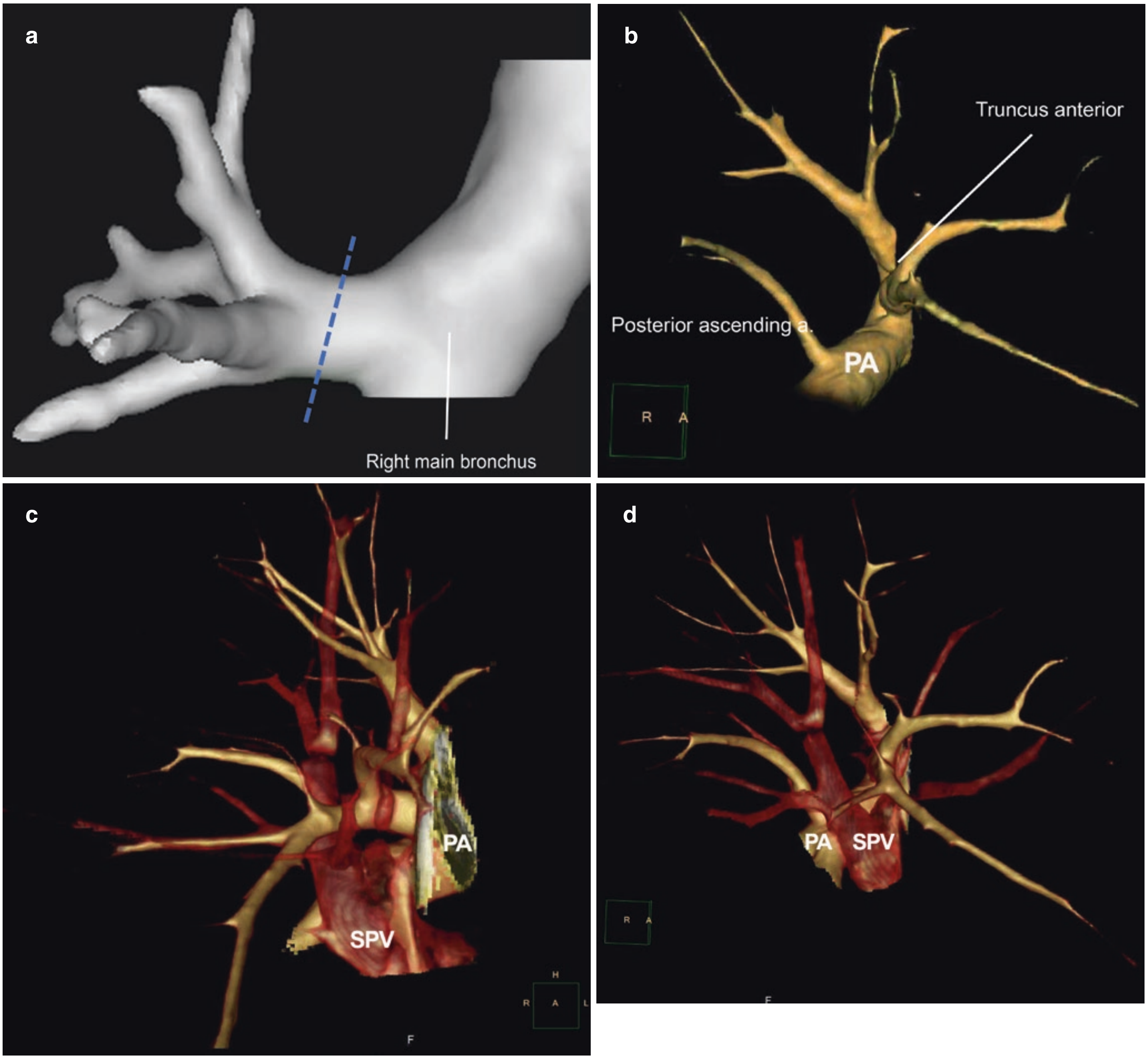

Fig. 4.3 Anatomical landmarks. (**a**) Upper lobe bronchus (*anterior view*). (**b**) Upper lobe arteries (*right lateral view*). (**c**) Relationships between arteries and veins of the right upper lobe (*anterior view*). (**d**) Relationships between arteries and veins of the right upper lobe (*right lateral view*)

4.2.3 Operating Procedure

1. Incisions: Incision 1 is about 1.5 cm in the seventh intercostal space in the midaxillary line. Incision 2 is about 4 cm in the fourth intercostal space in the anterior axillary line. And incision 3 is about 1.5 cm in the seventh intercostal space in the infrascapular line.
2. The three lobes of right lung are pushed to the apex using oval forceps. The pulmonary ligament is exposed and dissected till to the inferior pulmonary veinus by hook. The group 9 lymph nodes are divided at the same time (Fig. 4.4).
3. The right lower lobe is stretched forward, and the posterior mediastinal pleura is fully exposed. The pleura is divided till to the inferior board of arch of azygos vein. The bronchial arteries both superior and inferior to the right main bronchus are cut off at the same time (Fig. 4.5).
4. The group 7 lymph nodes can be dissected either at this step or after finishing the lobectomy.
5. The right upper lobe is pulled backward. The mediastinal pleura is incised posterior to the phrenic nerve, down to the superior pulmonary vein, and the superior pulmonary vein is dissected by an electric hook (Fig. 4.6).

Tips
It is not recommended to cut off the superior pulmonary vein now since this may lead to venous congestion.

6. The right upper lobe is pulled to the posterior chest wall and the truncus anterior which above the superior pulmonary vein is divided by an electric hook. The truncus anterior and the main pulmonary artery should be recognized clearly, especially the crossing angle between the two arteries. Then the truncus anterior is cut off by stapler through the operate hole (Fig. 4.7).
7. The right upper lobe is retracted to the apex of lungs, and the posterior part of the major fissure is divided. The ascending branches to the upper lobe are dissected and cut off by stapler (Fig. 4.8).

Tips
When the fissure is incomplete or inflammatory, this step can be tedious. Opening the fissure may lead to troublesome minor pulmonary tears and oozing.

8. The superior pulmonary vein is thoroughly divided using a right angle clamp, and cut off by endo-stapler (Fig. 4.9).
9. Retract the right upper lobe to the apex of lungs, and divide the minor fissure using "tunnel" method. The tunnel is just through the plane upon the main pulmonary artery, from the hilar to the posterior part of the minor fissure. The minor fissure is divided by stapler through the tunnel (Fig. 4.10).
10. The upper lobe bronchus is dissected using a combination of electric hook and blunt dissection. The surrounding soft tissue and lymph nodes around are divided by endo-peanut and oval forceps. The bronchus is cut off by the stapler. The right upper lobe resection is finished by now (Fig. 4.11)
11. The resected right upper lobe is put into a specimen bag and taken out of the thoracic cavity.

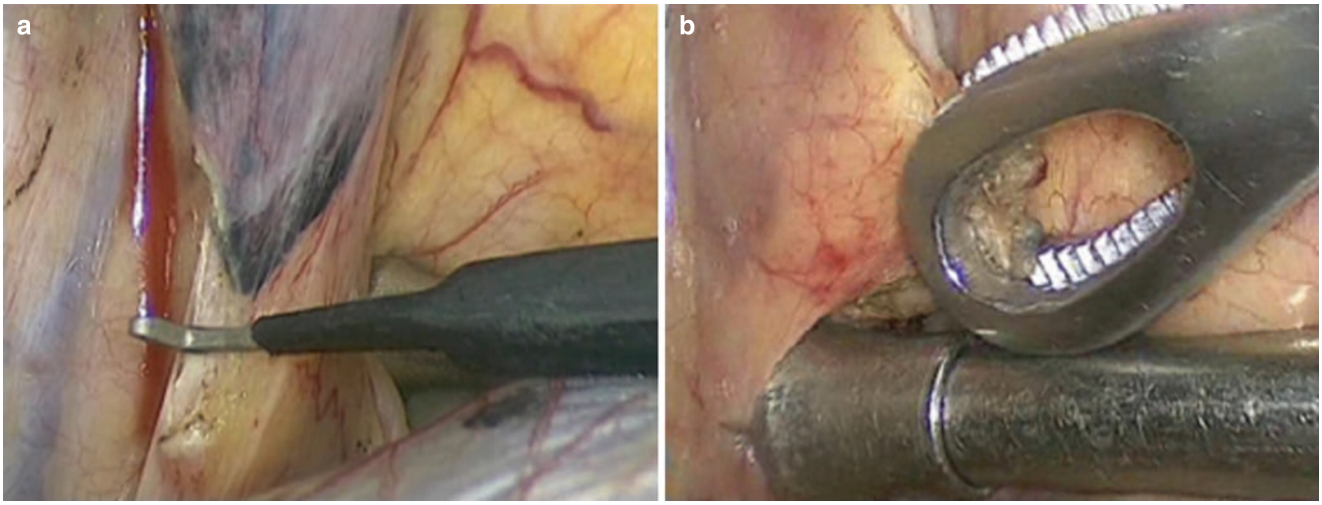

Fig. 4.4 (**a**) Dissect the pulmonary ligament. (**b**) Resect the group 9 lymph nodes

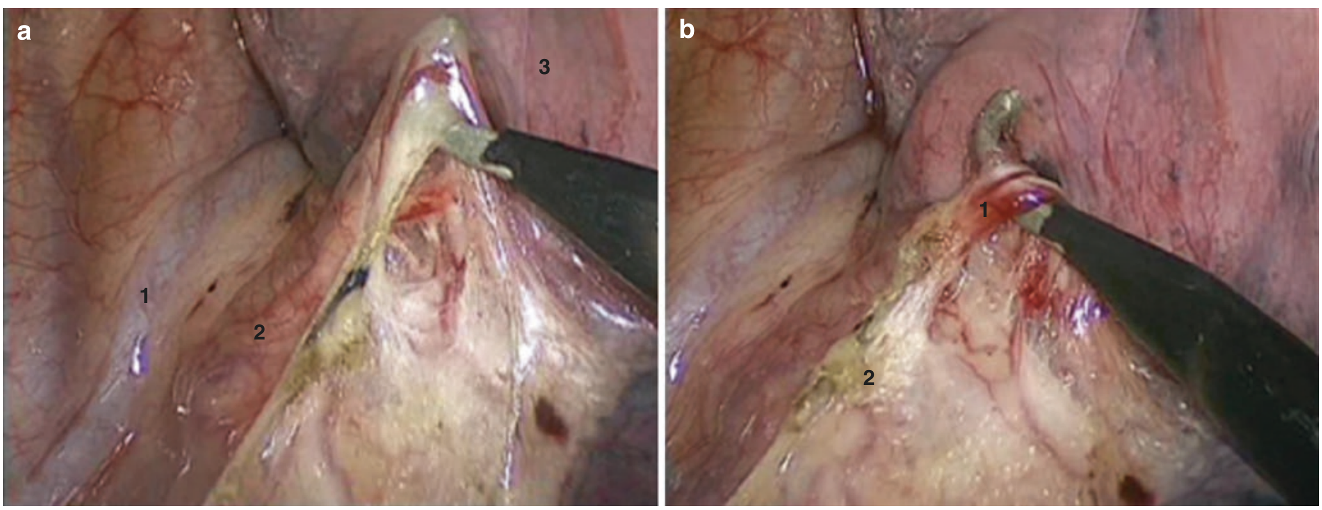

Fig. 4.5 (**a**) Open the posterior mediastinal pleura. *1* Azygos vein. *2* Right main bronchus. *3* Right upper lobe. (**b**) Dissect and cut off the bronchial arteries. *1* Bronchial artery. *2* Right main bronchus

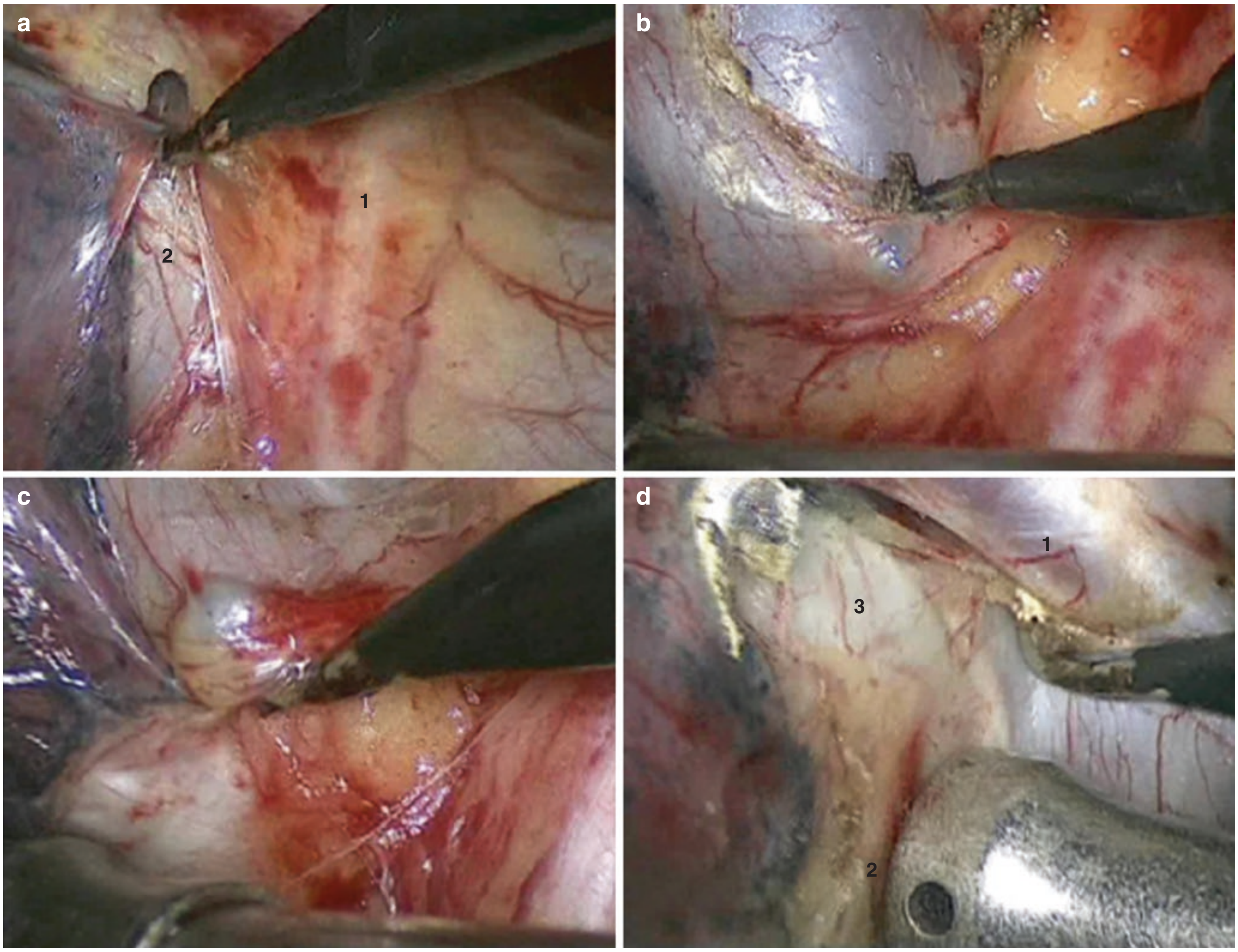

Fig. 4.6 (**a**) Open the anterior mediastinal pleura between superior pulmonary vein and phrenic nerve. *1* Phrenic nerve. *2* Superior pulmonary vein. (**b**) Dissect the superior pulmonary vein. (**c**) Dissect the superior pulmonary vein. (**d**) Dissect between the superior pulmonary vein and middle lobe vein. *1* Superior pulmonary vein. *2* Middle lobe vein. *3* Main pulmonary artery

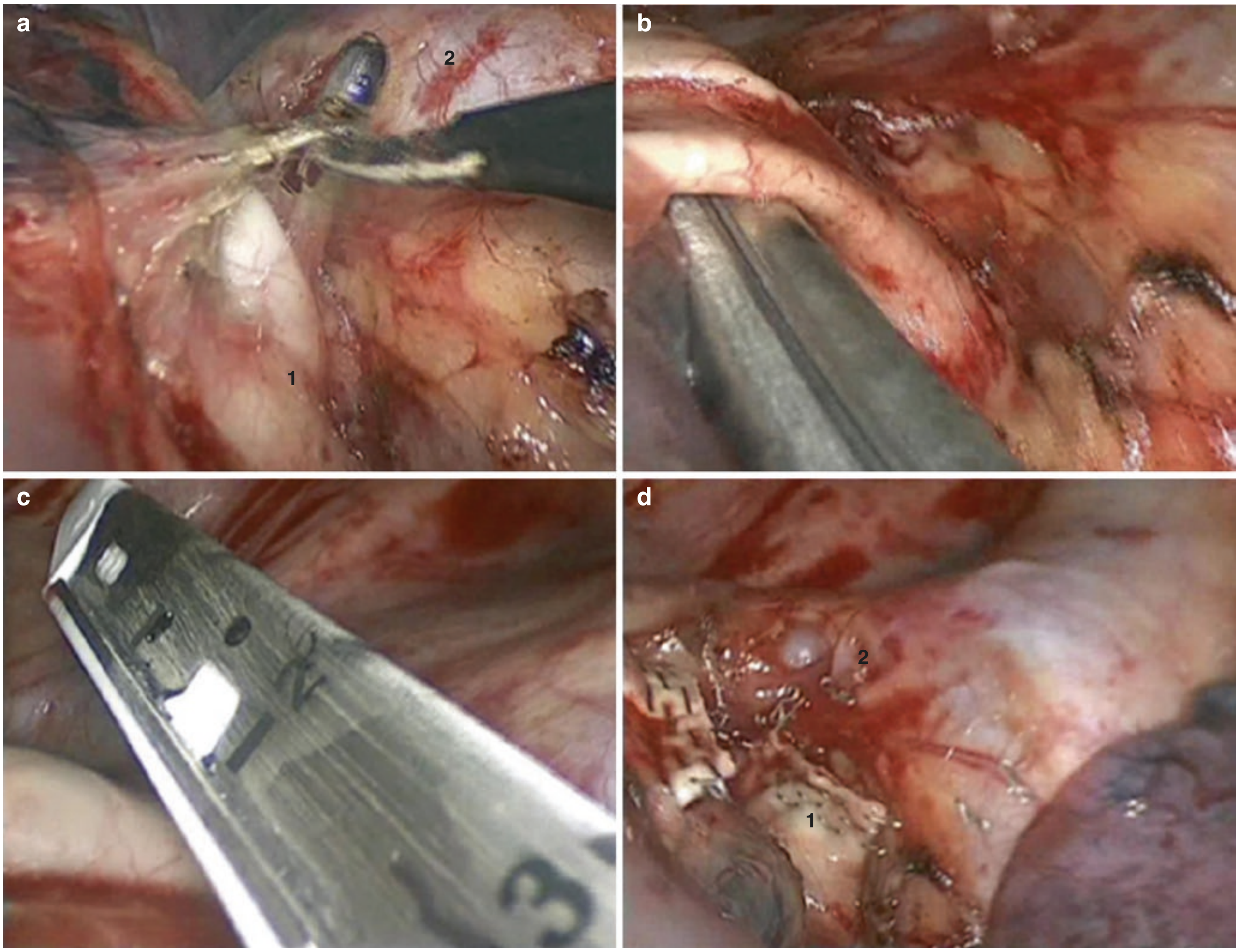

Fig. 4.7 (**a**) Dissect the truncus anterior. *1* The truncus anterior. *2* Arch of azygos vein. (**b**) Dissect the truncus anterior with curved forceps. (**c**) Cut off the truncus anterior with stapler. (**d**) The truncus anterior after cut off. *1* The truncus anterior. *2* Arch of azygos vein

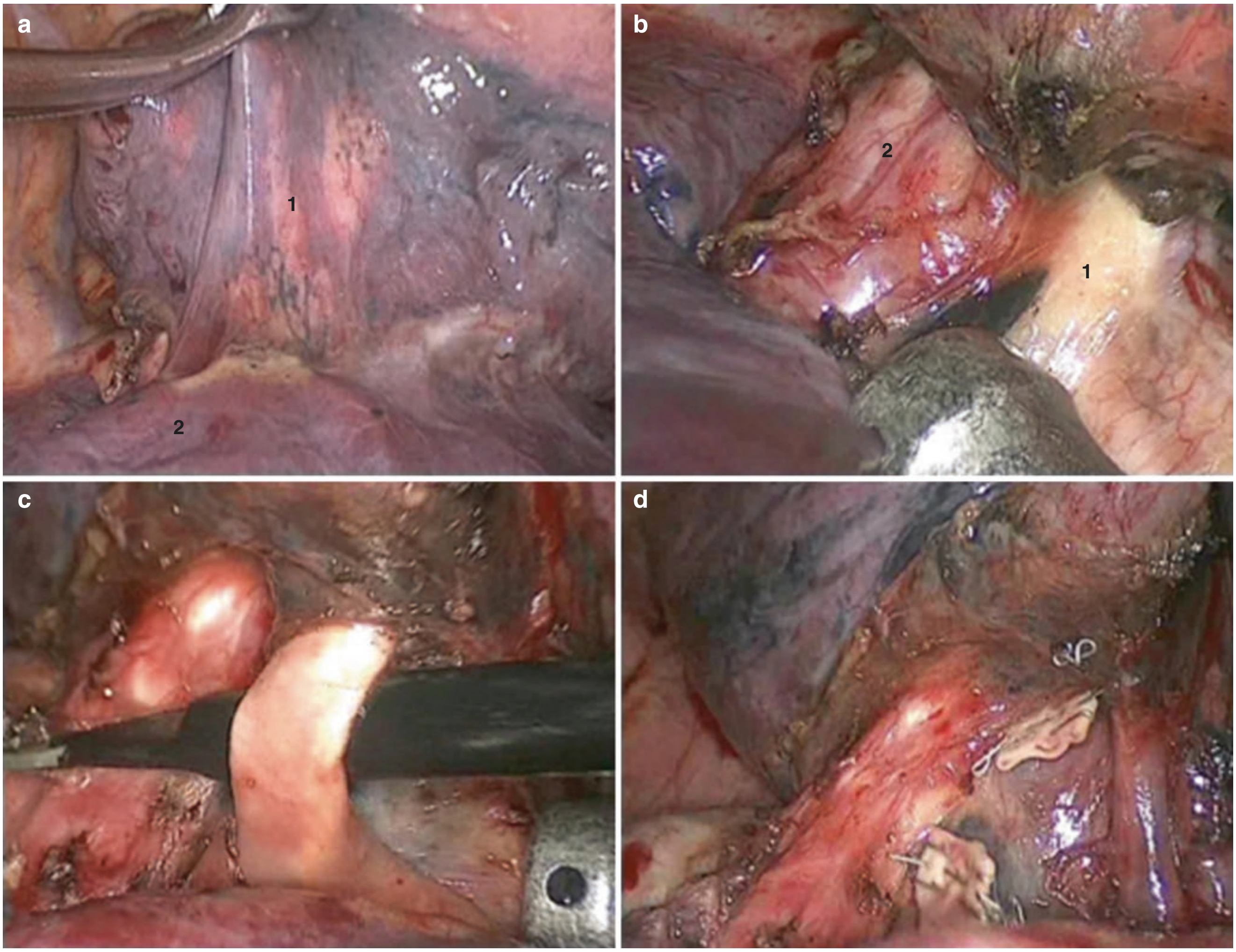

Fig. 4.8 (**a**) Retract the right upper lobe to the apex of lungs, and expose the posterior part of the major fissure. *1* RUL. *2* RLL (**b**) Divide the posterior part of the major fissure. *1* Ascending branches. *2* RUL bronchus. (**c**) The ascending branches to the upper lobe are dissected. (**d**) The ascending branches are cut off by stapler

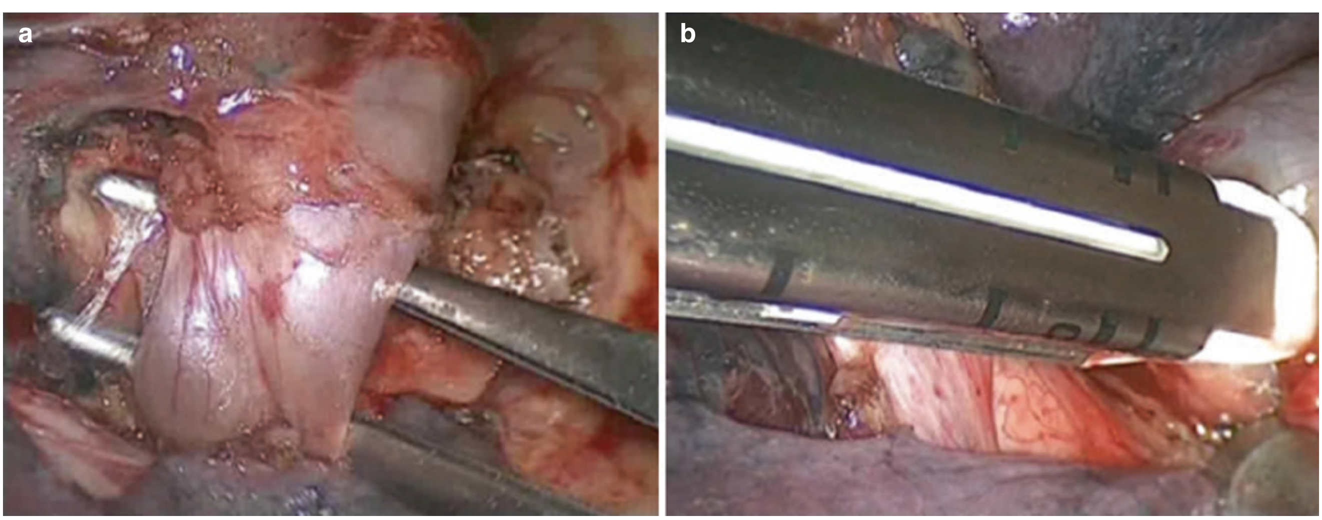

Fig. 4.9 (**a**) Divide the superior pulmonary vein by a right angle clamp. (**b**) Cut off the superior pulmonary vein by endo-stapler

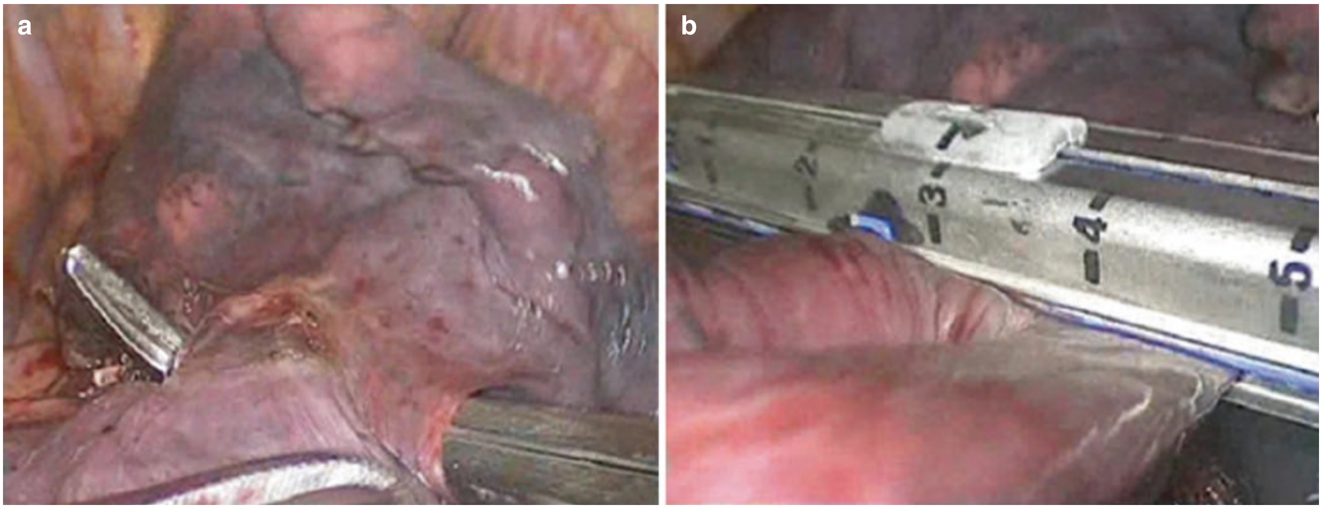

Fig. 4.10 (**a**) Divide the minor fissure using "tunnel" method by a right angled clamps. (**b**) The minor fissure is divided by stapler through the tunnel

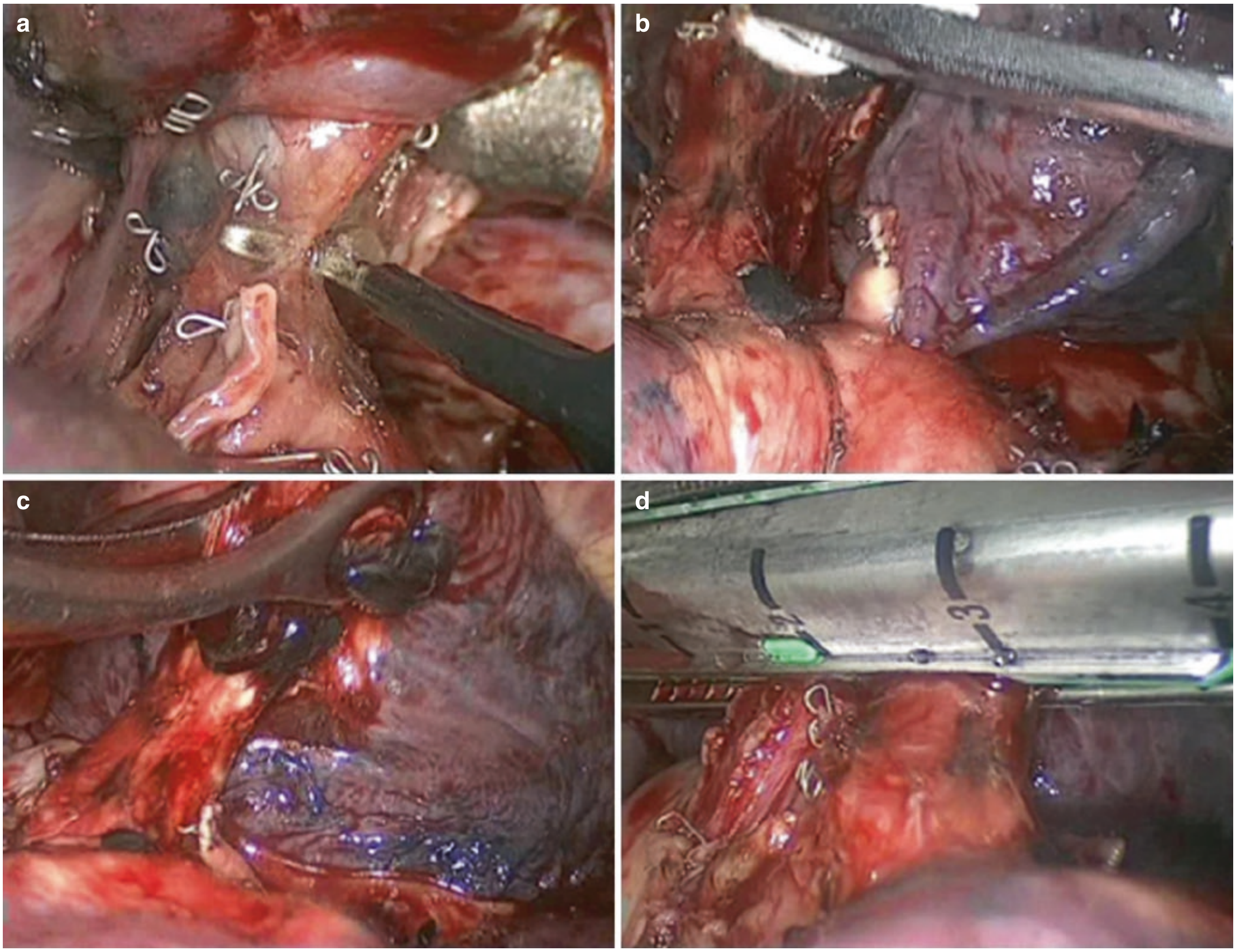

Fig. 4.11 (**a**) The upper lobe bronchus is dissected by electric hook. (**b**) The upper lobe bronchus is dissected by an endo-peanut. *1* Upper lobe bronchus. *2* Main pulmonary artery. (**c**) The lymph nodes are dissected by oval forceps. (**d**) The upper lobe bronchus is cut off by stapler

4.3 Right Middle Lobe

Fan Yang and Jun Wang

4.3.1 Technical Points

The right middle lobe is as small as one-fifth to the total volume of the right lung. It is anatomically parallel to the lingular segment of the left upper lobe. The whole lobe is located in the anterior part of the lung, so that lobectomy could be done by only dissecting the front pulmonary hilum. Tumor located in this lobe is relatively rare, and the procedure of right middle lobectomy is therefore unfamiliar to many surgeons.

1. In some cases, the horizontal fissure is so well differentiated that the right middle artery can be exposed by splitting the fissure tissue. Then a sequence of vein – artery – bronchus (or artery – vein – bronchus) should be followed to ligate the main structures, and the dissection of the horizontal fissure itself comes at last. If the right middle artery cannot be exposed to a sufficient length, then the bronchus should be ligated before further exposing of the artery (Fig. 4.12).
2. In cases which the horizontal fissure is poorly differentiated, and the right middle artery is difficult to expose, the bronchus is usually ligated so that the right middle artery could be seen. So the procedure should follow the altered sequence of vein – bronchus – artery – fissure. Sometimes it is acceptable to ligate the artery and fissure simultaneously (Fig. 4.13).

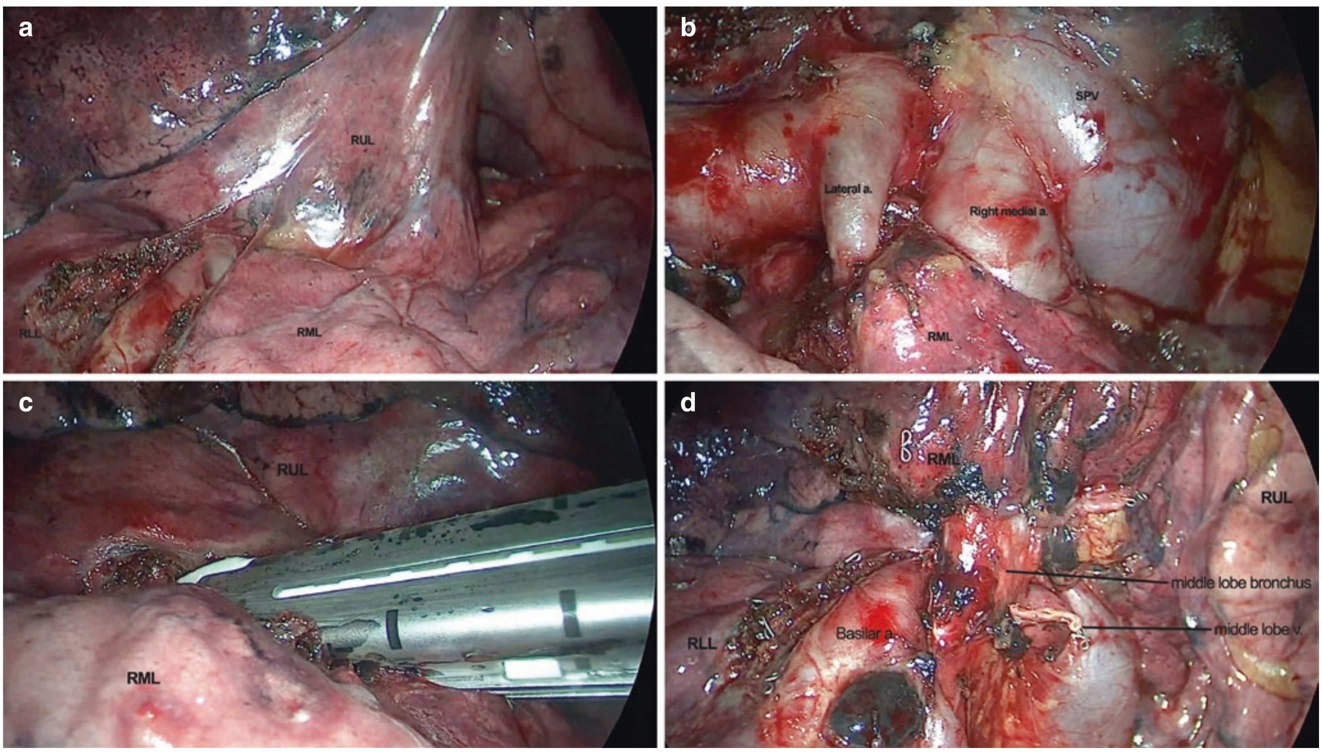

Fig. 4.12 Well differentiated fissure: (**a**) Before dissection. (**b**) After dissection of the horizontal fissure. (**c**) Ligation of the middle lobe artery. (**d**) Exposing the bronchus

4.3.1.1 Anatomical Landmarks (Fig. 4.14)

Bronchus: the right middle lobar bronchus originates from the right intermediate bronchus and separates into two branches called medial and lateral segment bronchus. The back segment bronchus is located opposite to the middle lobe, and the basal segment bronchus initiates at about 1 cm inferior to the back segment. Due to the anatomic uniqueness of the right middle lobe bronchus, the cutting edge should not be too close to the initiating part, in order not to cause obstruction in the intermediate bronchus. The bronchus should be ligated after the lower lobe is confirmed inflatable.

Artery: The right middle lobe artery originates from the remote aspect of the pulmonary artery, after or before the arising of the ascending artery. The right middle lobe artery and the ascending artery should be distinguished before ligation. The right middle lobe artery is usually divided into two branches, while sometimes they fuse into one thicker stem. Confusion between right middle lobe artery, ascending artery and back segment artery could be made when the fissure is poor differentiated.

Vein: The vein of right middle lobe and right upper lobe usually converge before finally inject into the left atrium. The right lower lobe vein is relatively distant from the right middle lobe. It is critical to dissect the intermediate tissue between middle and upper lobe vein.

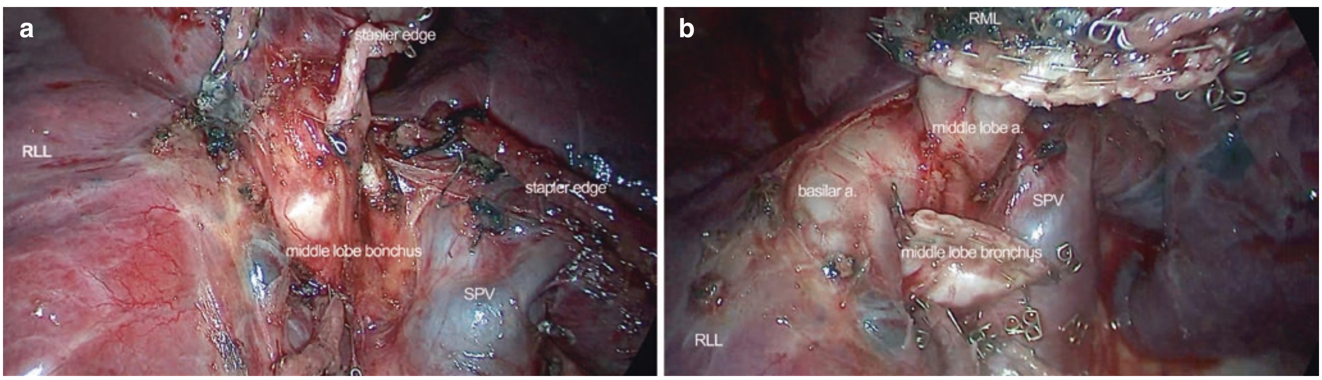

Fig. 4.13 Poor differentiated fissure: (**a**) Ligation of the bronchus. (**b**) Exposing the artery

4.3.1.2 Operating Procedure

Position and Incision

The patient is in left lateral decubitus. Incision 1 is about 1.5 cm in the eighth intercostal space in the midaxillary line. Incision 2 is about 4 cm in the fifth intercostal space in the anterior axillary line. And incision 3 is about 1.5 cm in the eighth intercostal space in the infrascapular line.

4.3.2 Procedure

1. The right lower lobeare pushed to the apex using oval forceps through the assistant incision. The pulmonary ligament is dissected to the level of inferior pulmonary vein. And the group 9 lymph nodes should be dissected.
2. The right middle lobe is stretched forward, and the posterior mediastinal pleura is fully exposed. The bronchial arteries both superior and inferior to the right main bronchus are cut off at the same time. Hem-o-lock can be used to ligate thick bronchial arteries. The pleura is further divided up to the inferior board of arch of azygos vein. The group 7 lymph nodes can be dissected either at this step or after finishing the lobectomy. A gauze ball can be left in the subcarinal space if necessary to stop bleeding.
3. The lung is pulled backward using oval forceps through the assistant incision and the anterior pulmonary hilum is exposed. A coagulator is used to dissect the mediastinal pleura in the interspace between pulmonary vein and phrenic nerve.
4. Dissection into the oblique fissure from the inferior side will reveal a group of lymph nodes that has a rather steady location between the right middle bronchus, right middle artery and basal segment artery of lower lobe. The artery and bronchus can be seen only after the node's dissection. The lymph node often appears heavy adhesion to the vascular sheath, thus the sheath should be divided. The lateral segment artery and the inferior side of the right middle lobe bronchus can be revealed after the lymph node is dissected. A staple with white cartridge is used to ligate the lateral artery (Fig. 4.14).
5. Right middle lobe lateral segment artery is exposed and ligated with a staple with white cartridge through the anterior incision.
6. The lung is pulled to the posterior side with oval forceps through the assistant incision, and the surrounding mediastinal pleura is divided. The superior edge of the middle lobe vein is revealed by separating the interspace between the upper and middle lobe vein. The revealing part can be lengthened by dividing the vascular sheath. Lift the right middle lobe with oval forceps through the assistant incision to expose the inferior edge of the middle lobe vein. An angled clamp is used to clear a path through the tissue posterior to the vein. A staple with white cartridge is used to ligate the vessel (Fig. 4.15).
7. Lift the right middle lobe to the posterior side of thoracic cavity through the assistant incision. A path posterior to the middle lobe bronchus is cleared with angled clamp. A staple with green cartridge is used to ligate the bronchus.
8. Push the right middle lobe to the superior direction with oval forceps through the assistant incision, medial segment artery is exposed. The artery sheath is divided to acquire sufficient length of middle lobe artery. An angled clamp is used to clear the path though the posterior tissue of the artery, and a staple with white cartridge is used to ligate the medial segment artery.
9. A staple with blue cartridge is used to ligate the horizontal fissure through the anterior incision.
10. An aseptic glove is used as a container of the dissected lung, and is pulled out though the anterior incision.

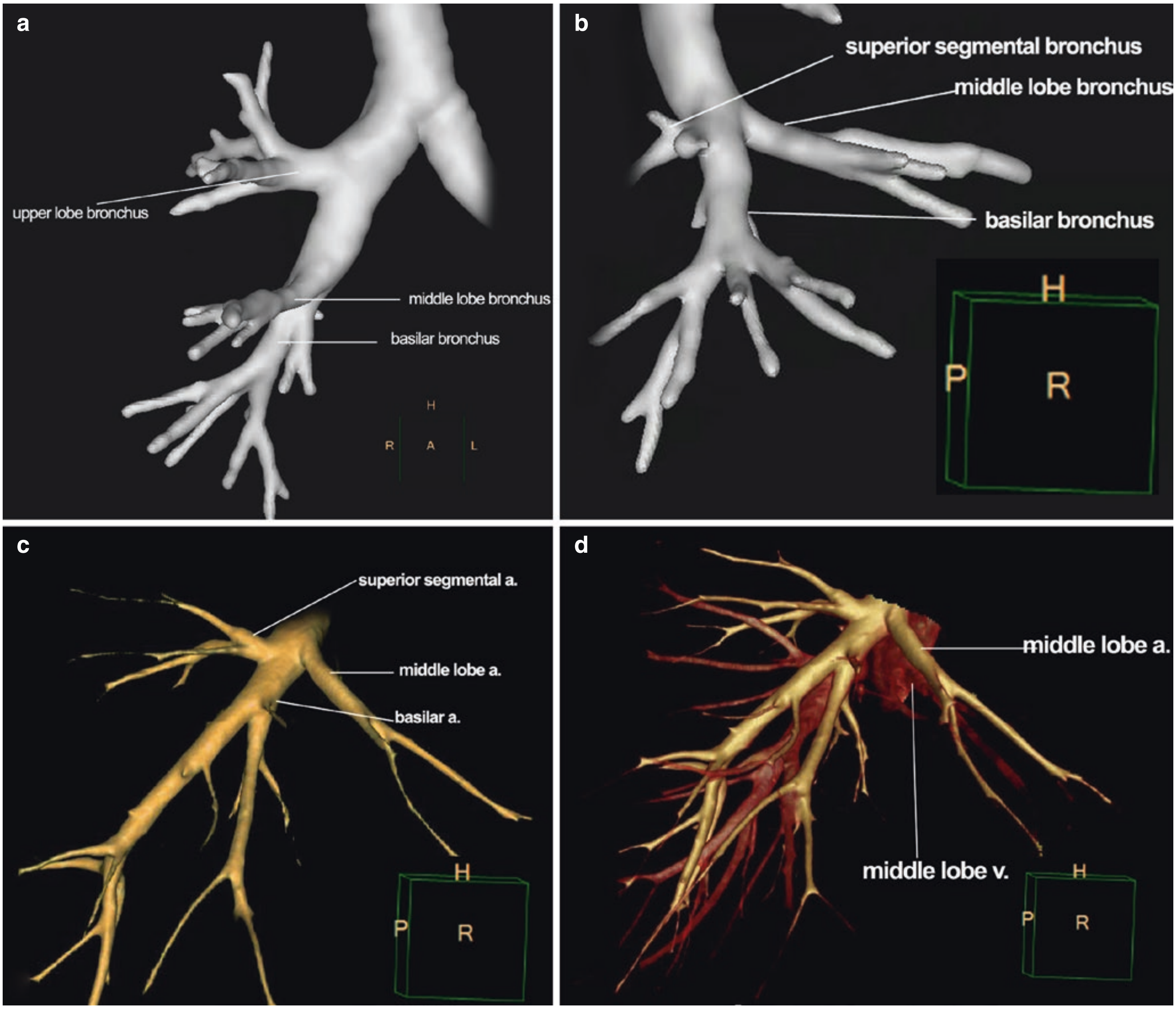

Fig. 4.14 Anatomical landmarks of right middle lobe: (**a**) Middle lobe bronchus (*anterior view*). (**b**) Middle lobe bronchus (*right lateral view*). (**c**) Middle lobe arteries (*right lateral view*). (**d**) Relationships between arteries and veins of the right middle lobe (*right lateral view*)

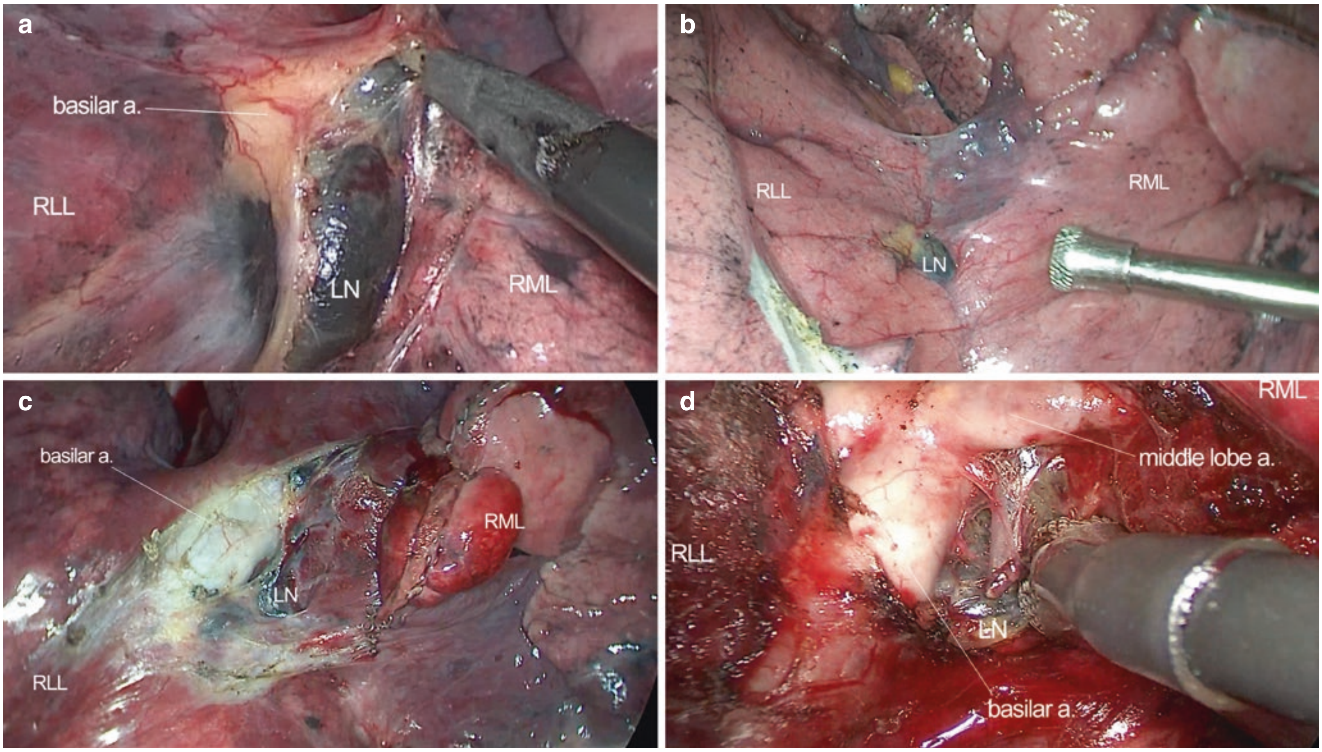

Fig. 4.15 Ligation of the vein: (**a**) An angled clamp is used to clear a path through the tissue posterior to the vein. (**b**) Ligation with a staple

4.4 Right Lower Lobe

James Huang and Tiejun Zhao

4.4.1 Technical Point

A right lower lobectomy is a slightly more complex procedure than a left lower lobectomy owing to the presence of the right middle lobe. Positive identification and exclusion of the hilar structures to the middle lobe is necessary in order to complete the lower lobectomy. Our usual practice entails division of the hilar structures in the following order: pulmonary vein, pulmonary artery, and bronchus. We routinely use a double-lumen endotracheal tube for lung isolation. Epidural catheters, arterial lines, and foleycatheters may be utilized at the surgeon's discretion as needed.

4.4.2 Anatomical Landmarks

Figure 4.16

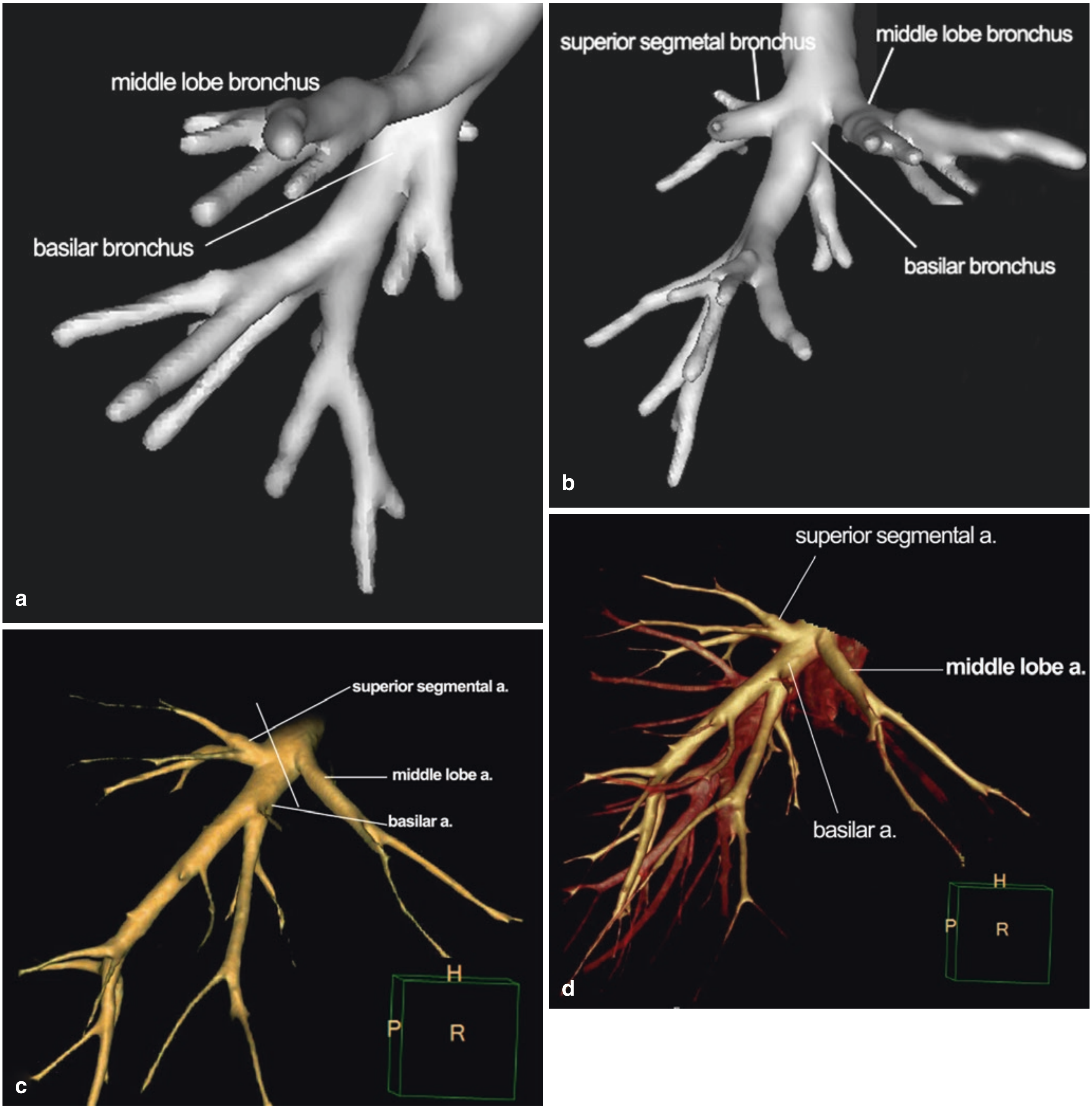

Fig. 4.16 Anatomical landmarks of right lower lobe (**a**) Lower lobe bronchus (*anterior view*). (**b**) Lower lobe bronchus (*right lateral view*). (**c**) Lower lobe arteries (*right lateral view*). (**d**) Relationships between arteries and veins of the right lower lobe (*right lateral view*)

4.4.3 Operating Procedure

4.4.3.1 Patient Positioning and Placement of Incisions

Proper patient positioning is critical to a successful operation. The patient is positioned in the lateral decubitus position, flexing the table in order to assist in spreading of the intercostal spaces. We use three incisions: one anteriorly, one posteriorly, and one inferiorly. A camera port is placed in the eighth intercostal space in the posterior axillary line, followed by an assistant's port posteriorly in the tenth intercostal space, roughly where the edge of the lung meets the diaphragm, for retraction, and then a 4 cm access incision for the surgeon in the anterior axillary line in fourth intercostal space. A disposable wound protector is extremely helpful for retraction of the wound edges at the access incision (Fig. 4.17). The operating surgeon stands anteriorly, and the assistant stands posteriorly. A second assistant is helpful in driving the camera if available, and frees the assistant to use both hands. Begin by exploring the pleural space to rule out evidence of metastatic disease, such as pleural metastases or pleural effusion. Perform a wedge resection of the lesion for frozen section for diagnosis if necessary.

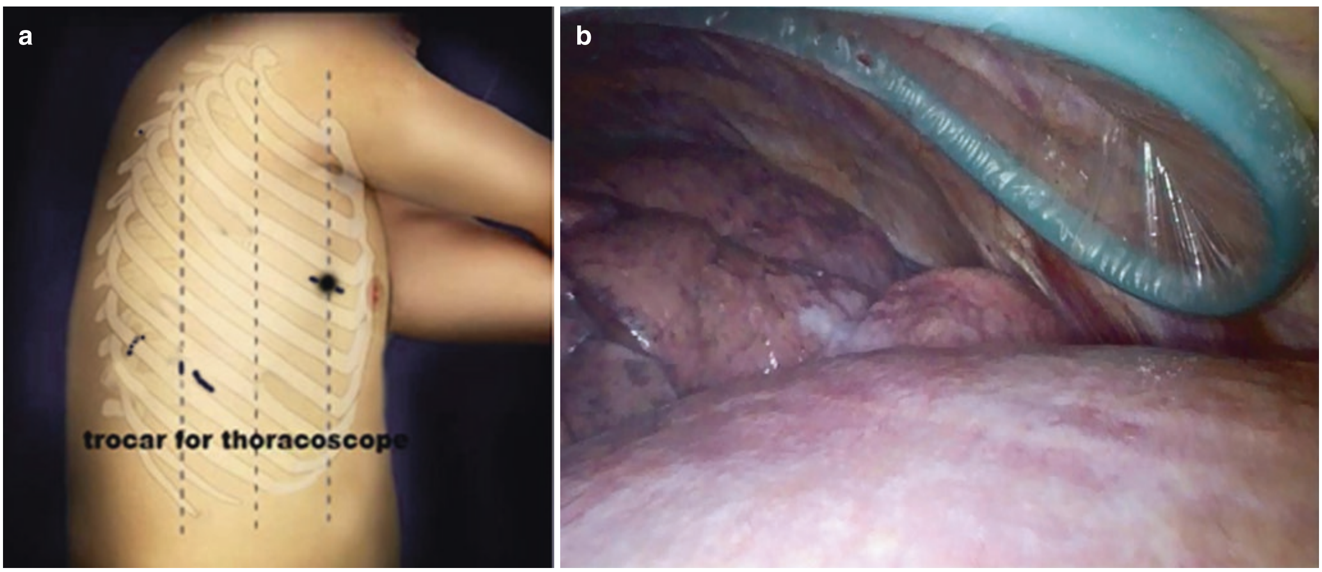

Fig. 4.17 (**a**) Three incisions: 1 anterior, 1 posterior, and 1 inferior. (**b**) Wound protector for retraction of wound edges

4.4.3.2 Confirmation of Diagnosis via Wedge Resection or Biopsy for Frozen Section, if Needed (Fig. 4.18)

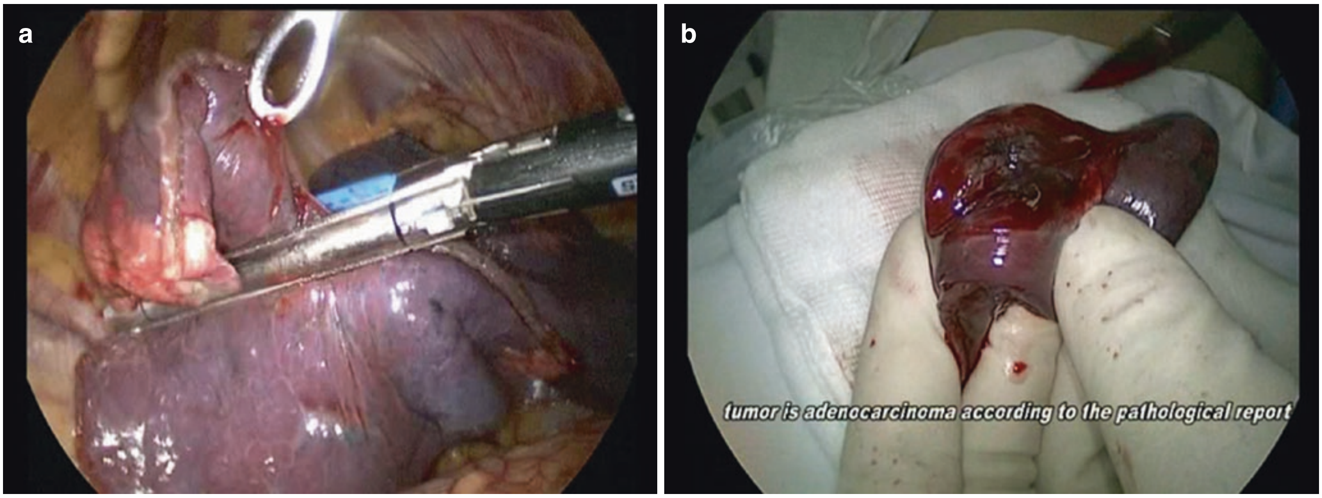

Fig. 4.18 (**a**) Wedge resection. (**b**) Frozen section demonstrated adenocarcinoma

4.4.3.3 Exploration of Pleural Space and Incision of the Hilar Pleura

Divide the inferior pulmonary ligament up to the inferior pulmonary vein and dissect the level 9 lymph nodes. Retract the lung laterally in order to put the ligament on tension. Incise the ligament sharply taking care to ensure good hemostasis from the ligament as this can be occasionally be a source of delayed and meddlesome bleeding. Extend the hilar pleural incision posteriorly up to the level of the azygos vein. Anteriorly, the hilar pleura should be incised up to the level of the superior pulmonary vein to ensure clear identification of the borders of the inferior pulmonary vein and the superior pulmonary vein (Fig. 4.19).

Tips

- The level 9 lymph nodes are adjacent to the inferior pulmonary vein. Be cognizant that once these nodes are reached during the dissection of the ligament, the pulmonary vein is in close proximity.

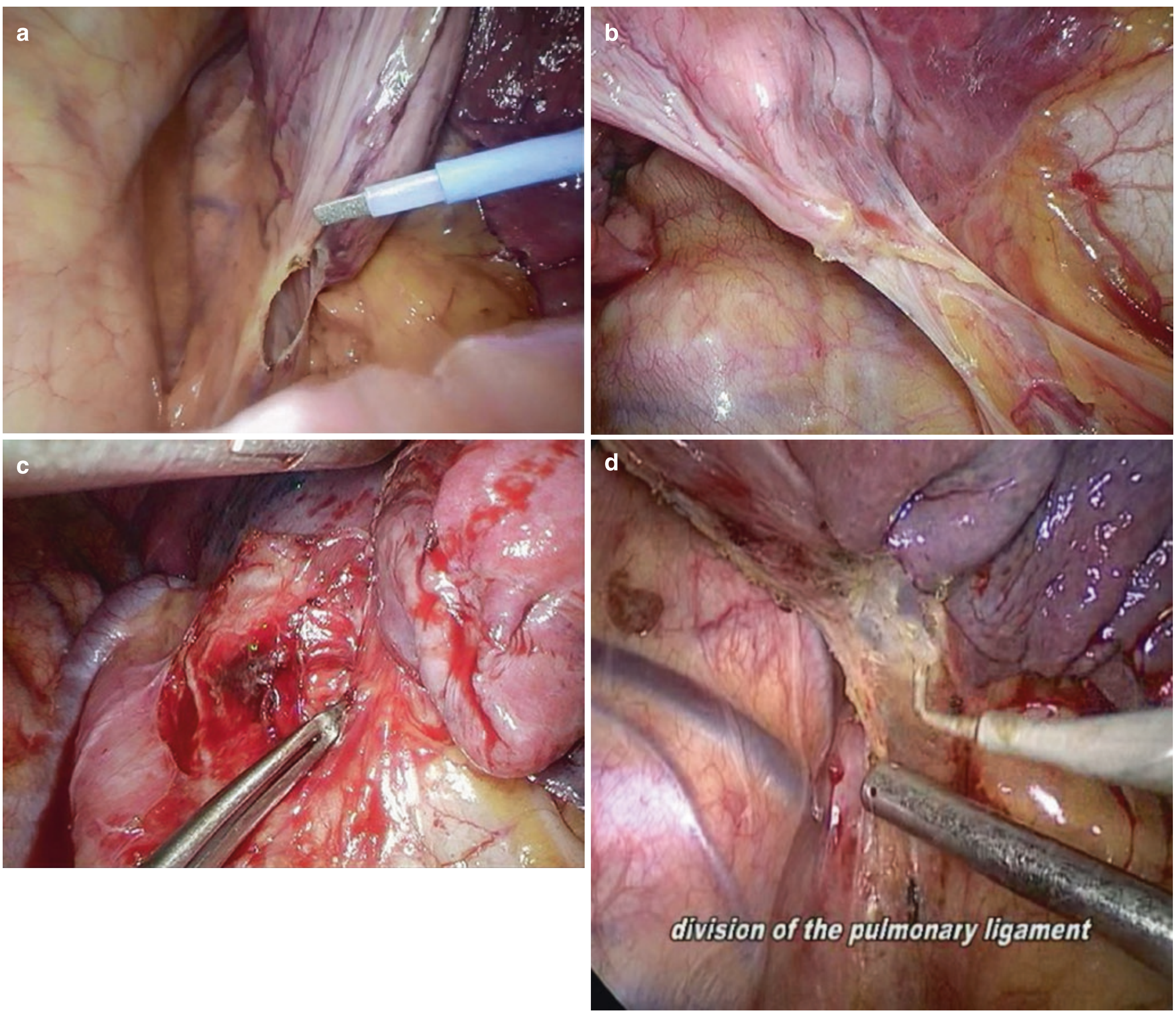

Fig. 4.19 (**a**) Retract the lung laterally to put the ligament on tension. (**b**) Incise the inferior pulmonary ligament sharply. (**c**) Extend the hilar pleural incision posteriorly up to the level of the azygos vein. (**d**) Remove the level 9 lymph nodes

4.4.3.4 Sub Carinal Lymph Node Dissection

Retract the lung anteriorly to expose the subcarinal space. Dissect the level 7 lymph node packet en-bloc, off and away from the right main stem bronchus, pericardium, inferior pulmonary vein, esophagus, carina and left main stem bronchus. A ring clamp can be used to spread and expose the subcarinal space to facilitate the node dissection. Removal of the subcarinal lymph node packet can facilitate the subsequent dissection of the inferior pulmonary vein, as well as the dissection of the bronchus. Alternatively, performing the subcarinal lymph node dissection after the division of the inferior pulmonary vein may allow for easier exposure of the subcarinal space (Fig. 4.20).

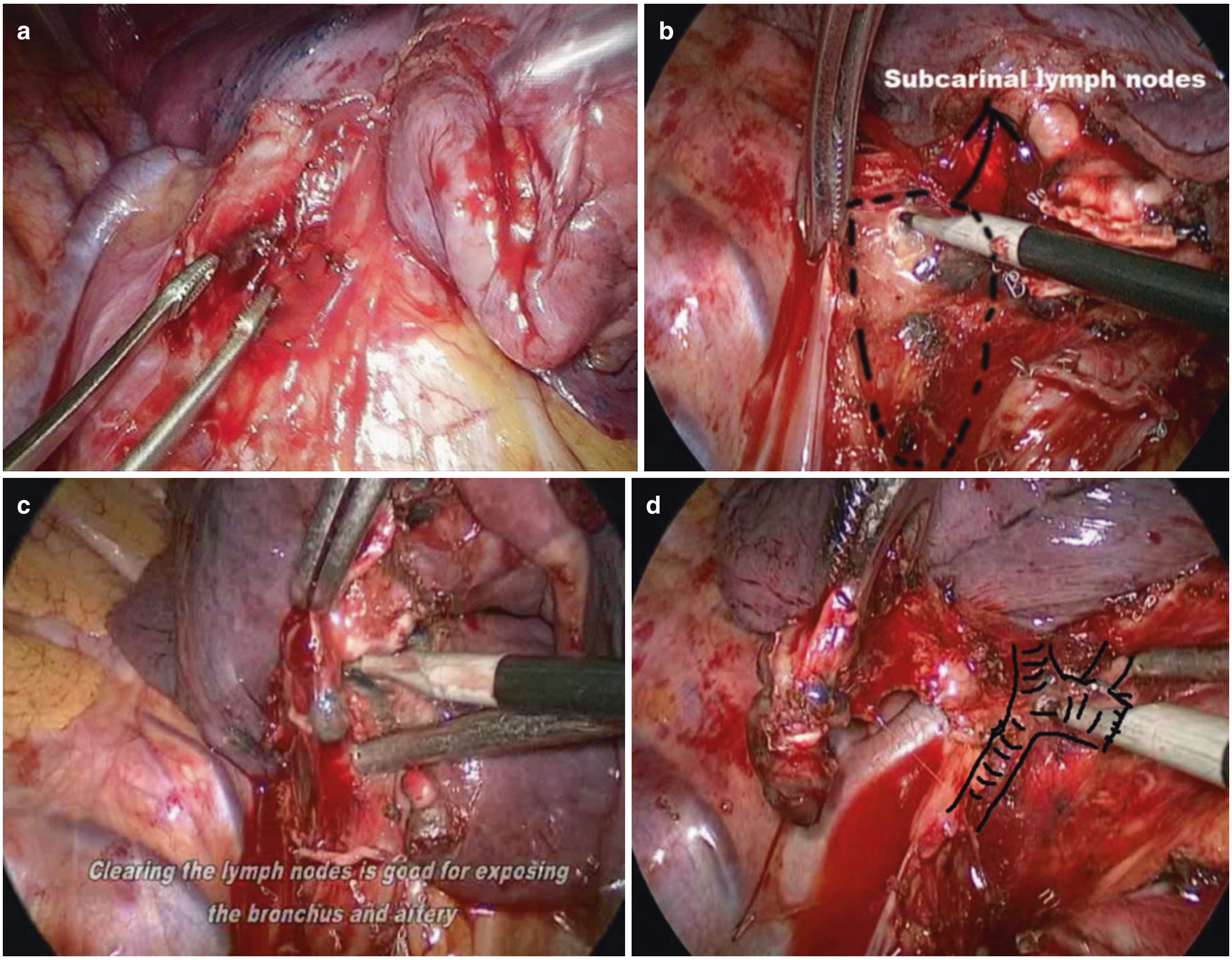

Fig. 4.20 (**a**) Exposing the subcarinal space to facilitate the node dissection. (**b**) Boundaries of the station 7 lymph nodes, including the right main stem bronchus, pericardium, esophagus, inferior pulmonary vein, carina and left main stem bronchus. (**c**) Performing the subcarinal lymph node dissection after the division of the inferior pulmonary vein. (**d**) Dissecting the level 7 lymph node packet en-bloc

4.4.3.5 Dissection of the Inferior Pulmonary Vein

The assistant retracts the lobe laterally placing the vein in a vertical orientation to facilitate dissection. Dissection can be performed with a variety of techniques, including use of scissor dissection, a hook cautery, use of a right angle clamp and electrocautery, or harmonic scalpel or other energy devices. A combination of gentle blunt and sharp dissection will permit safe isolation of the vein. A clamp can be passed around the vein from anterior to posterior, and isolating the vein with a vessel loop, or a monofilament tie can assist in retraction of the vein for subsequent passage of the stapler. Use of a stapler with an angled tip can also facilitate easy passage of the stapler. In general, passage of the anvil through the space behind the vein is safer given its lower profile, and avoids passage of the larger bulk of the staple cartridge through a tight space. The stapler is passed from the anterior access incision, but could also be passed from the posterior incision. It is important for the assistant to provide optimal retraction of the lung to orient the vein such that it facilitates passage of the stapler with ease (Fig. 4.21).

Tips

- Encircling the vein with a vessel loop or ligature can permit additional gentle retraction on the vein to facilitate easy and safe passage of the stapler.

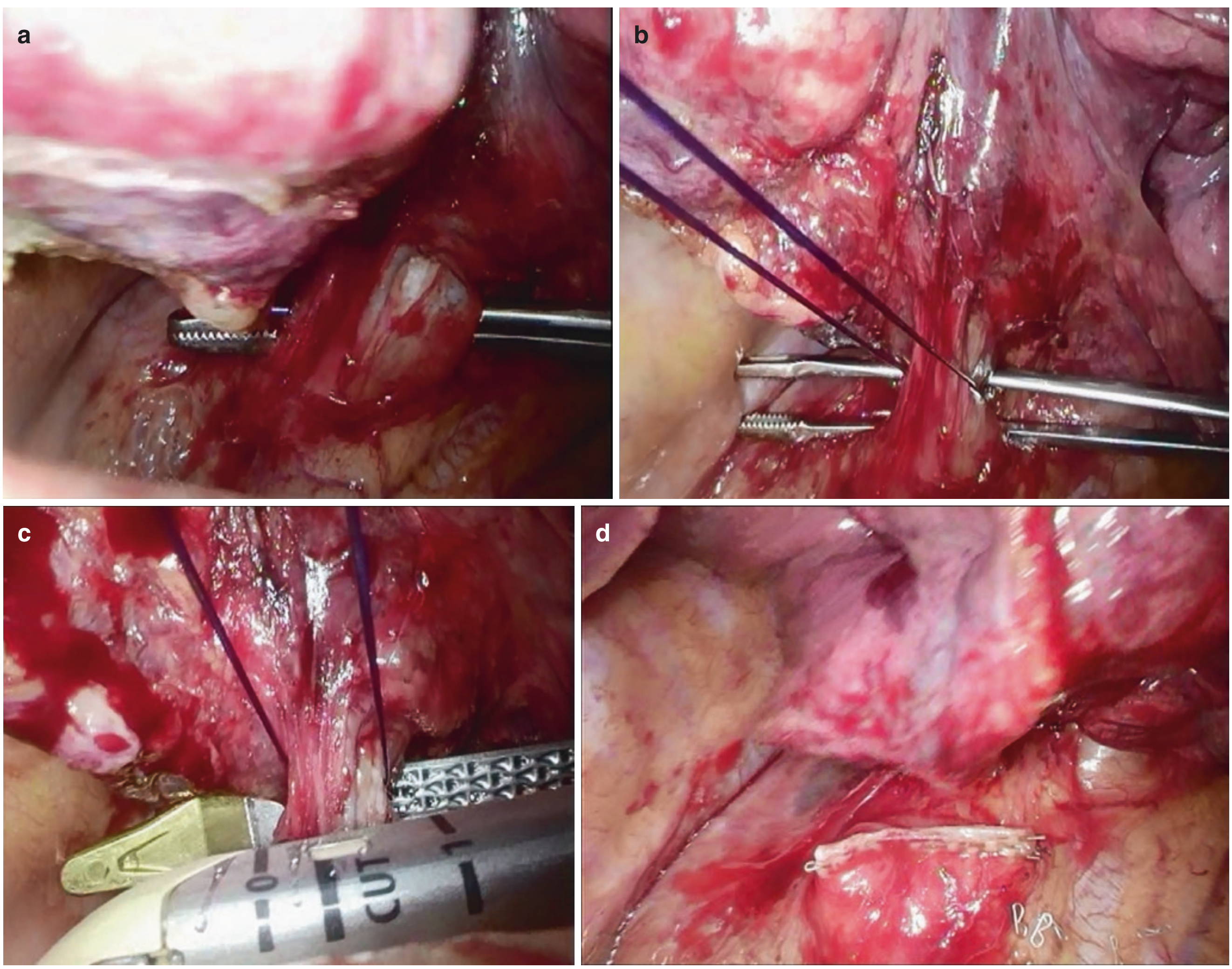

Fig. 4.21 (**a**) Dissecting the space between the vein and lower bronchus. (**b**) Encircling the vein with a ligature. (**c**) Passage of the stapler anvil behind the vein. (**d**) The stump of the vein, after division

4.4.3.6 Dissection of the Fissure

The lower lobe is retracted posteriorly and the middle lobe anteriorly to expose the major fissure between the middle and lower lobes. Division of the fissure greatly facilitates the subsequent hilar dissection. The interlobar pulmonary artery is identified and bluntly separated away from the overlying lung parenchyma of the fissure. Removal of the interlobar lymph nodes lying between the lower lobe bronchus and the middle lobe bronchus facilitates identification of the underlying pulmonary artery. The surface of the artery is carefully mobilized away from the overlying fissure, permitting the passage of a stapler to divide the overlying parenchyma of the fissure. The origin of the middle lobe artery should be clearly identified so as to begin the division of the fissure and development of the subsequent tunnel in the proper location. As the fissure is divided, care must be taken to positively identify the origins of the superior segmental artery to the lower lobe as well the posterior ascending artery to the upper lobe as a tunnel is created between the fissure and the artery. Care must be taken to avoid injury to these arterial branches during this dissection. The stapler must past between these two arterial branches to correctly complete the fissure (Fig. 4.22).

Tips

The thinnest part of the fissure is usually found centrally where the middle lobe meets the lower lobe. Beginning the dissection at this point can expedite the identification of the interlobar pulmonary artery and the subsequent division of the fissure.

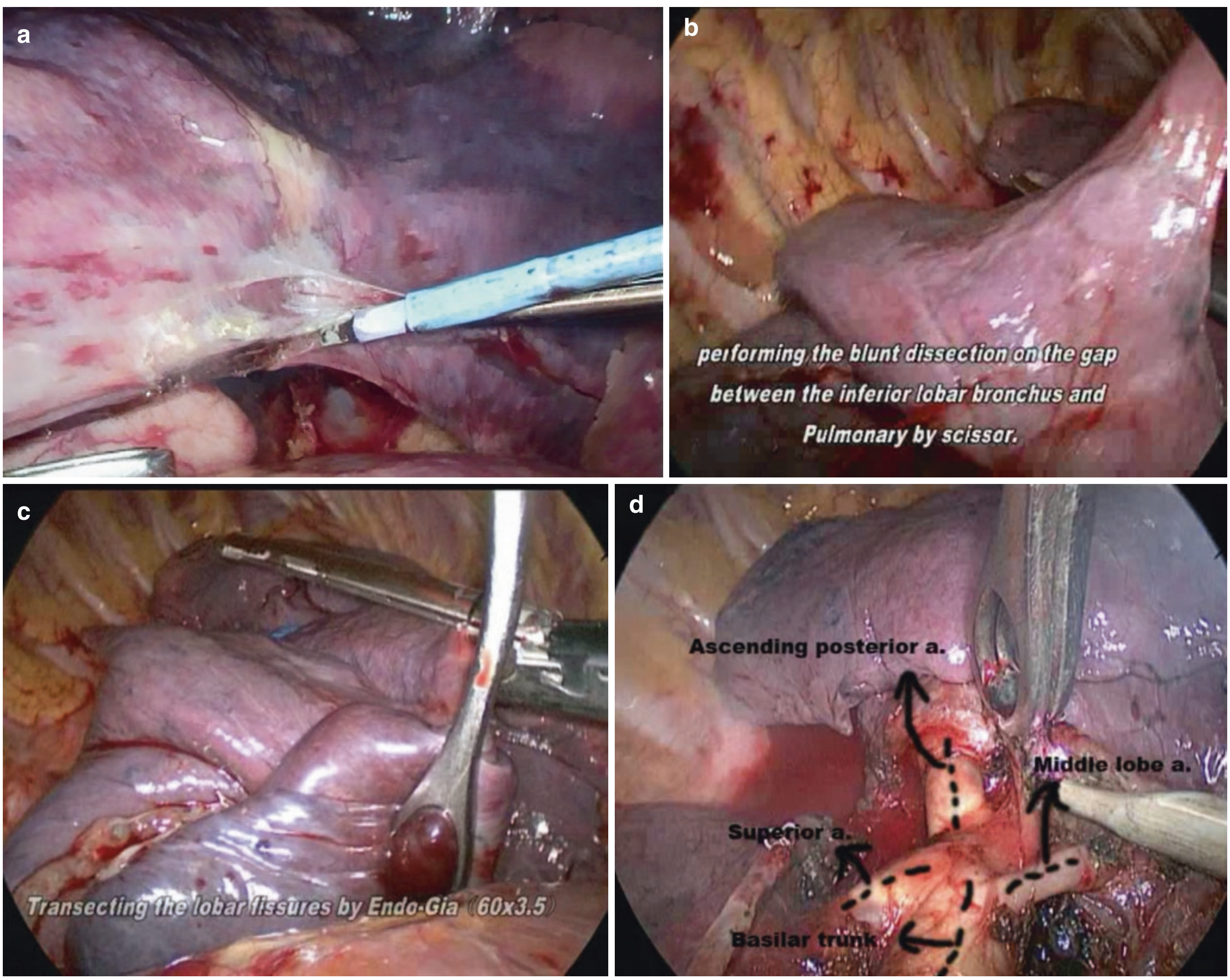

Fig. 4.22 (**a**) Initiating dissection of the fissure at its thinnest point. (**b**) Creating the tunnel. (**c**) Division of the fissure using a stapler. (**d**) Exposure of the branches of the pulmonary artery after division of the fissure

4.4.3.7 Dissection of the Pulmonary Artery

Once the fissure has been completed, dissection of the remaining artery and bronchus is straightforward. The interlobarpulmonary artery is carefully mobilized away from the underlying bronchus. A clamp is passed around the artery to encircle it, taking care to pass the tip proximal to the origin of the superior segmental artery and distal to the posterior ascending artery. As with the vein, encircling the artery with a vessel loop or suture can facilitate retraction of the artery for safer passage of the stapler. The stapler is passed from the anterior access incision, with the lower profile anvil passing between the artery and the bronchus. It is ideal to divide the interlobar pulmonary artery proximal to the origin of the superior segmental branch, however in some cases one may find themselves dividing the basilar artery separately from the superior segmental artery if needed (Fig. 4.23).

> **Tips**
> - During stapling, it is important to avoid any tension on the stapler, to avoid tearing the artery.
> - Care should be taken to avoid thermal trauma from cautery when dissecting near the artery. Scissors may be used safely as well.

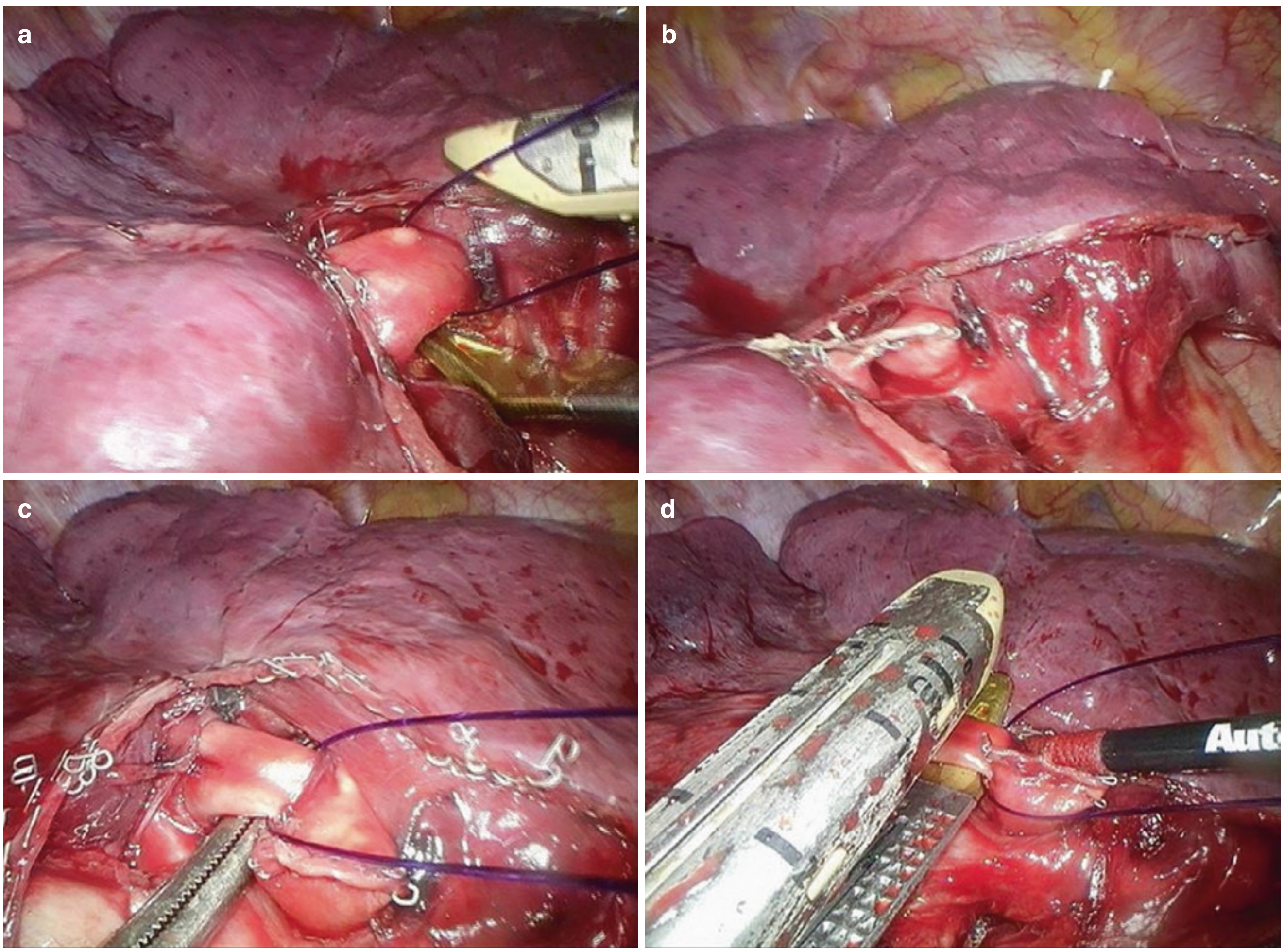

Fig. 4.23 (**a**) Isolation of the basilar artery. (**b**) After division of the basilar artery. (**c**) Isolation of the superior segmental artery. (**d**) Division of the superior segmental artery

4.4.3.8 Division of the Bronchus

After division of the artery, the surface of the bronchus is cleared of overlying lymphatic soft tissue, removing or sweeping any peribronchial lymph nodes or soft tissue to reveal the clean surface of the bronchus. Proper retraction of the lower lobe by the assistant can orient the bronchus such that the stapler will be passed around the origin of the RLL bronchus, proximal to the take-off of the superior segmental bronchus. Case must also be taken to ensure that the stapler does not compromise or narrow the origin of the middle lobe bronchus. Momentarily ventilating the right lung after closure of the stapler, but prior to firing of the stapler can ensure that the middle lobe inflates, and that there is no compromise to the middle lobe bronchus. If necessary, the basilar bronchus can be stapled and divided separately from the superior segmental bronchus (Fig. 4.24).

> **Tips**
> Proper retraction of the lower lobe by the assistant should orient the bronchus such that the stapler can be passed around the origin of the RLL bronchus, proximal to the origin of the superior segmental bronchus

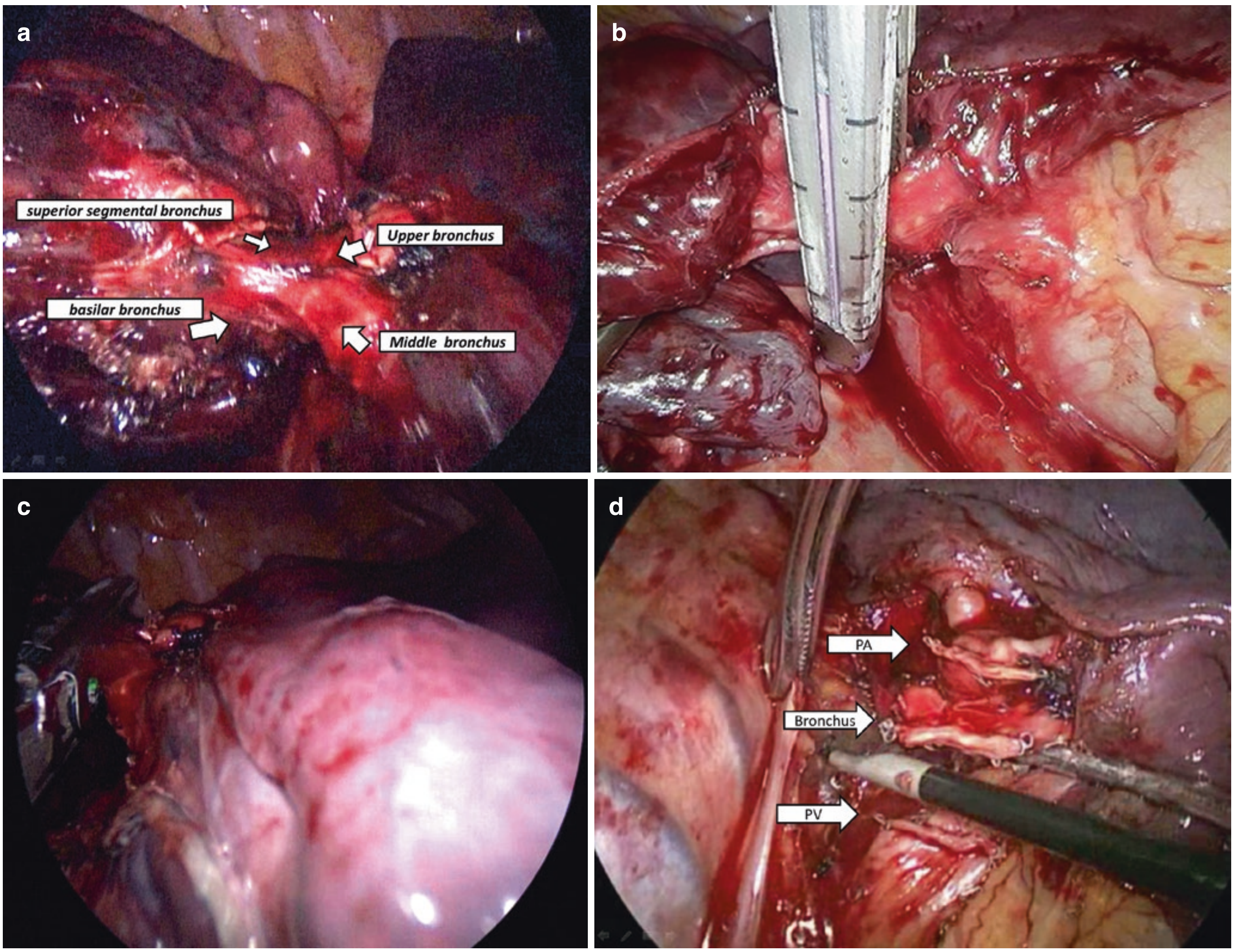

Fig. 4.24 (**a**) Identification of the branches of the bronchus. (**b**) Division of the bronchus. (**c**) Confirmation of ventilation to the middle lobe. (**d**) The stumps of the divided bronchus, artery and vein are shown

4.4.3.9 Completion of Mediastinal Lymph Node Dissection

The pleura overlying the right paratracheal space is incised from the azygos vein up towards the inlet, parallel to the superior vena cava to expose the 4R and 2R stations. Mobilization of the azygos vein away from the hilum facilitates the dissection of the lymph nodes at the tracheobronchial angle. Alternatively, the dissection can be performed from under the azygos vein, with proper retraction of the superior vena cava to provide good exposure to the paratracheal space. Although division of the azygos vein can facilitate the lymph node dissection, it is not usually necessary. The station 2R, 4R lymph nodes are dissected en-bloc, to clear all lymph node bearing tissue from the superior vena cava, the right main pulmonary artery, the trachea and the pericardium. Care should be taken to avoid injury to the phrenic nerve and the vagus nerve. Clips or energy devices should be used to seal lymphatics and help prevent the possibility of prolonged lymphatic drainage or chyle leak. One may also to choose to perform this lymph node dissection at the beginning of the procedure prior to the hilar dissection (Fig. 4.25).

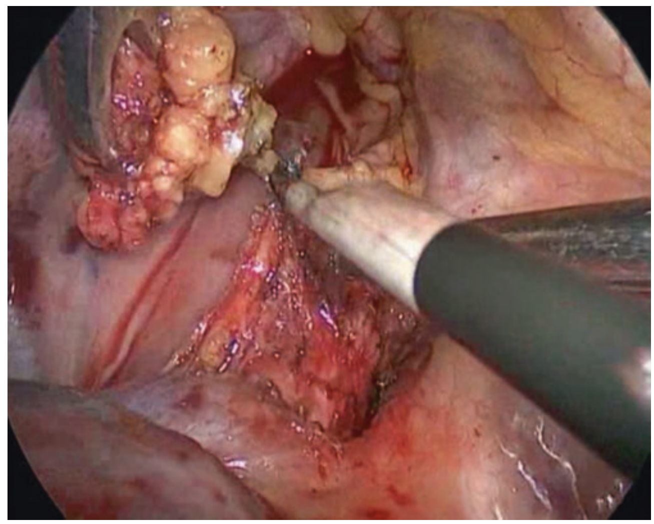

Fig. 4.25 The station 2R, 4R lymph nodes are dissected en-bloc

4.4.3.10 Closure

The pleural space is irrigated, and the bronchial stump can be tested for air leaks if desired. The chest cavity is thoroughly inspected for hemostasis, paying particular attention to the inferior pulmonary ligament, the divided hilar structures, and the lymphadenectomy beds of the subcarinal and paratracheal spaces. Intercostal nerve blocks can be placed by injecting long-acting local anesthetic in each of the intercostal spaces subpleurally adjacent to the intercostal neurovascular bundles. The lung is re-expanded. We use one 28 French chest tube introduced through the camera port incision. The incisions are closed with absorbable suture (Fig. 4.26).

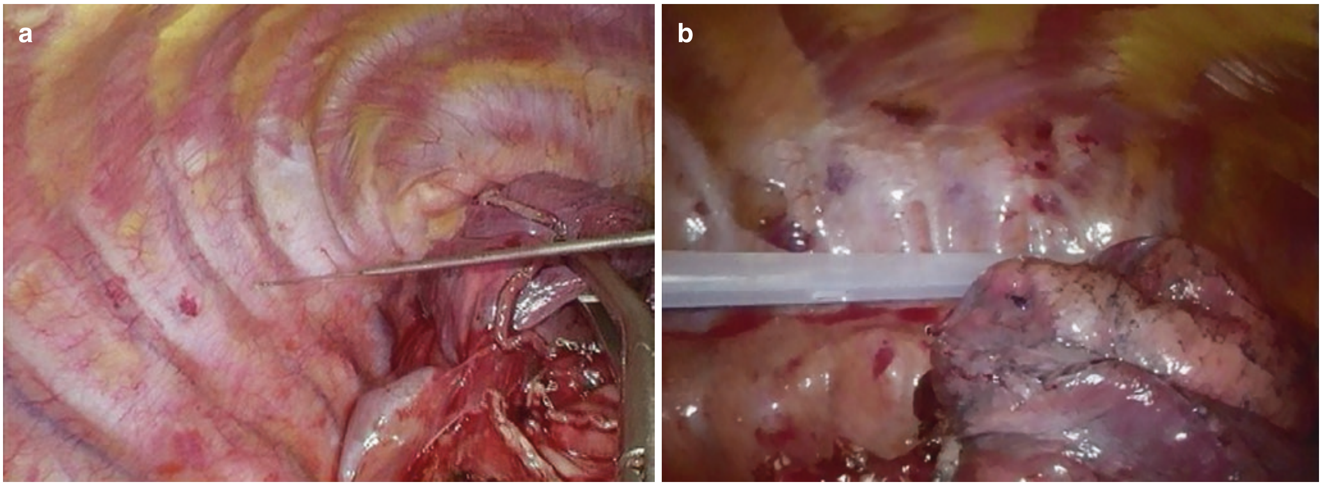

Fig. 4.26 (**a**) Intercostal nerve blocks. (**b**) *Placement of a* 28 Frchest tube

4.5 Left Upper Lobe

Zuli Zhou and Jun Wang

4.5.1 Technical Points

The left upper lobectomy is the most difficult endoscopic procedure. The following difficulties and key points may be noticed:

- It is more advisable to dissect the fused fissure and expose the pulmonary arteries first, though the fissure is frequently fused. Fissure should be divided into the vaginae vasorum of pulmonary vessels, and a "tunnel" is set up from anterior hilum to the arteries exposed or from the exposed arteries to the posterior hilum before the fissure is split by endostapler.
- If the fissure is fused, an alternative order of dissection could be: the left superior vein, the upper bronchus, the truncus anterior and the arteries to posterior and lingular segment. Then the dissection of fissure is the last step.
- There may be up to seven to nine branches of pulmonary arteries, some of which may be so tiny that the division must be careful, and the devices of energy such as LigaSure® are preferable for the dissection of vessels with short diameters.

4.5.2 Anatomical Landmarks

- **Bronchus**: The left upper lobar bronchus is between upper pulmonary vein and the left main pulmonary artery. The division of the left upper pulmonary vein gives access to the lobar bronchus then the pulmonary arteries. Lymph nodes between the upper lobe bronchus and the branches of arteries of left upper lobe (LUL) would make the dissection of arteries difficult.
- **Arteries**: The LUL arterial supply arises from three main vessels: the truncus anterior, which is the first branch originates from the main truncus, is the strongest one in all branches supplying LUL; the lingular and posterior segmental arteries, which originate within the fissure and supply the lingular and posterior segments separately. Usually they have one to three branches and should be divided separately. The truncus anterior supplies the apical/apicoposterior and anterior segments, which commonly is divided as a stem.
- **Veins**: The left superior pulmonary vein is the most anterior element just like right superior pulmonary vein. Sometimes the vein is wide and the inferior vein must be verified before any division of the three segmental veins, which can be done separately or, more often, as a stem. Sometimes it is so wide that the branches to the common upper lobe (V1+2+V3) and lingular segment (V4+S5) have to be dissected separately. There may be lymph nodes between the superior pulmonary vein and truncus main or left upper bronchus, making its dissection very difficult even dangerous, especially with calcified lymph nodes existing (Fig. 4.27).

4.5.3 Operating Procedure

3.1 The two lobes of left lung are pushed to the apex using oval forceps. The pulmonary ligament is exposed and dissected till to the inferior pulmonary vein using electric hook. The group 9 lymph nodes are resected at the same time (Fig. 4.28).

3.2 The left lower lobe is stretched forward, and the posterior mediastinal pleura is fully exposed. The pleura is divided until to the inferior board of arch of aorta. The bronchial arteries both superior and inferior to the right main bronchus are cut off at the same time. Divide the vaginae vasorum of left pulmonary arterial trunk and expose the posterior aspect of pulmonary arterial trunk (Fig. 4.29).

3.3 The left upper lobe is pulled backward. The mediastinal pleura is incised posterior to the phrenic nerve, down to the superior pulmonary vein, and the superior pulmonary vein is dissected by an electric hook. The upper lobe is pushed downward using oval forceps, and then the truncus anterior is divided (Fig. 4.30).

3.4 The left lower lobe is stretched downward, using electric hook to divide the fissure until the pulmonary arteries are exposed. Using hook to divide the branches of arteries inside the vaginae vasorum. Make an artificial "tunnel" from the gap between which the exposed posterior arteries of LLL and superior segmental artery of LLL, to the posterior hilum, and then the posterior portion of fused fissure is stapled by an endostapler (Fig. 4.31).

3.5 Divide the anterior portion of the fissure between the lingular and basal segment. Then another "tunnel" is made from anterior hilum (a gap between the superior and inferior veins) to the arteries exposed in the step 4. Then the anterior part of the fissure is split by endostapler (Fig. 4.32).

3.6 Using Long Kelly forceps to go through the gap between the lingular artery and the upper lobe bronchus, thus to make sure the endostapler can pass through the gap. Cut off the lingular artery by endostapler. Divide and cut off the branches supplying the posterior segment by endostapler or LigaSure® using the same technique (Fig. 4.33).

3.7 To draw a silk suture through the gap between the left superior pulmonary vein and the upper lobe bronchus by a right angle forceps, and cut off the pulmonary vein by endostapler through the auxiliary port (Fig. 4.34).

3.8 Divide the upper lobe bronchus. Then draw a silk suture through the space between the bronchus and the trunk of left pulmonary artery by a right angle forceps. Pulling the upper lobe bronchus forward, and then staple the bronchus by endostapler (Fig. 4.35).

3.9 Pulling the LUL upward carefully, and use endostapler to cut off the truncus anterior and all of its branches. The last step is to extract the resected lobe by a sterile glove (Fig. 4.36).

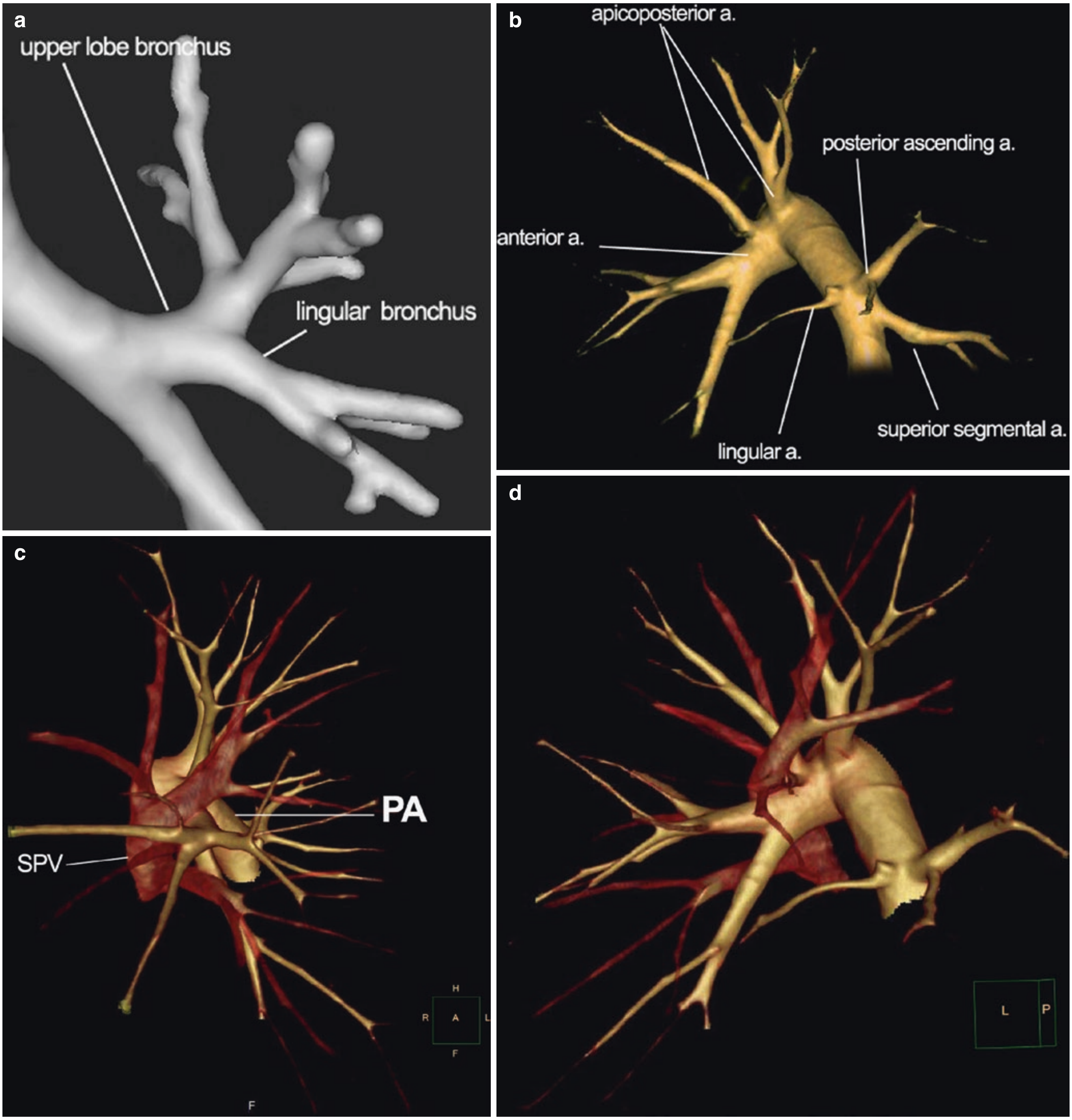

Fig. 4.27 Anatomical landmarks of left upper lobe: (**a**) Upper lobe bronchus (*anterior view*). (**b**) Upper lobe arteries (*left lateral view*). (**c**) Relationships between arteries and veins of the right lower lobe (*anterior view*). (**d**) Relationships between arteries and veins of the right lower lobe (*left lateral view*)

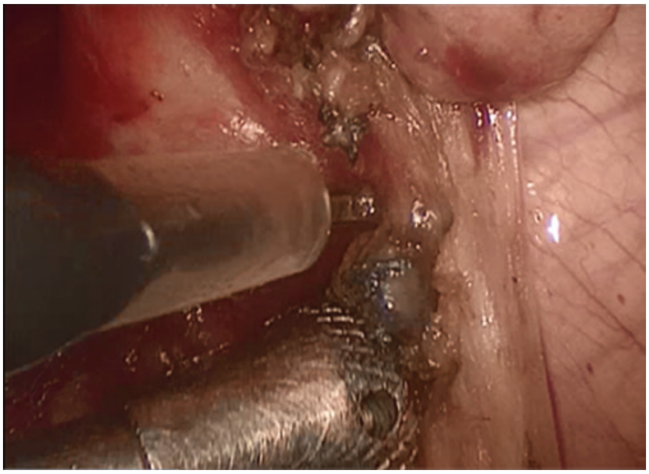

Fig. 4.28 Dissecting the pulmonary ligament, and resecting the group 9 lymph nodes

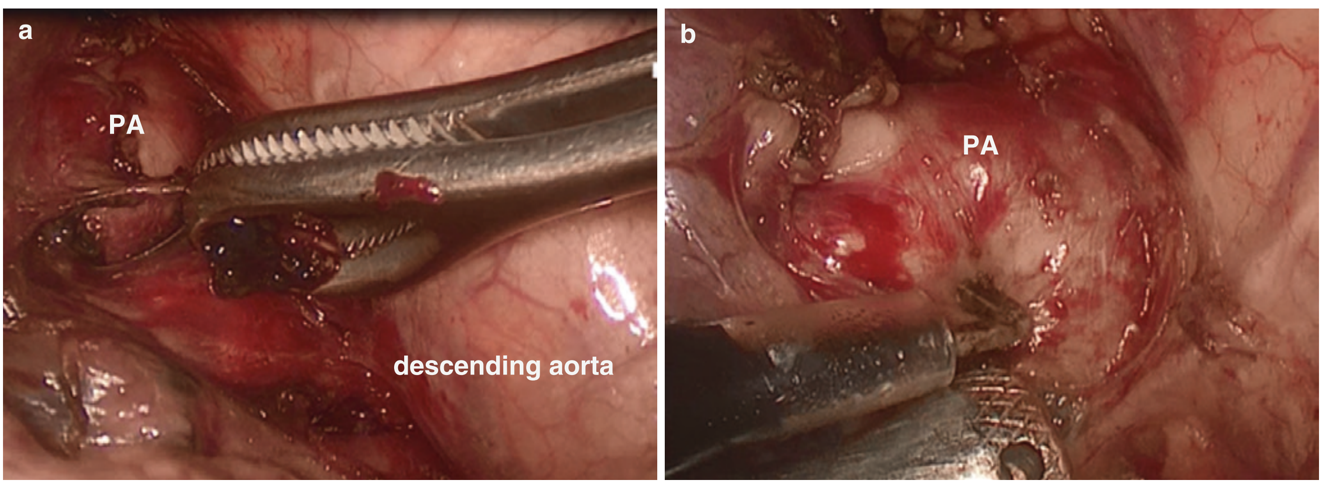

Fig. 4.29 (**a**) Dissecting the lymph nodes on the pulmonary arterial trunk. (**b**) Dividing the vagina vasorum of left pulmonary arterial trunk

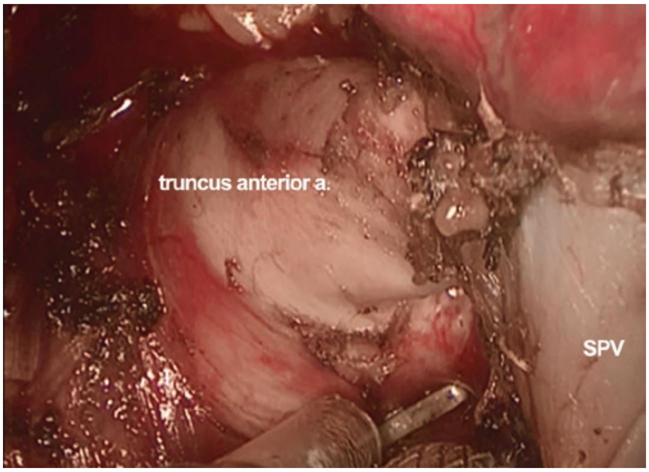

Fig. 4.30 Dividing the truncus anterior artery

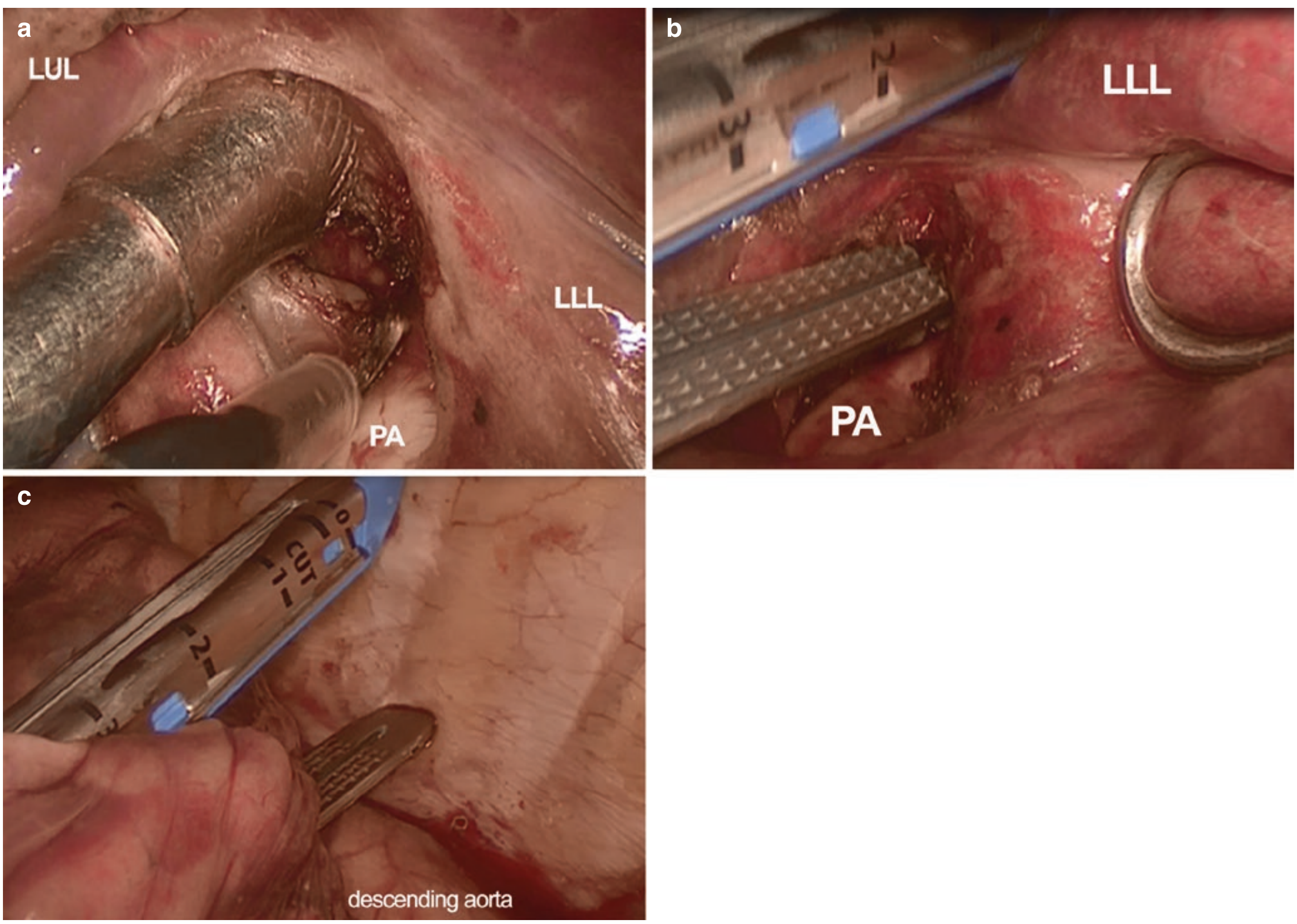

Fig. 4.31 (**a**) Dividing the fissure until the pulmonary arteries are exposed. (**b**) Making an artificial "tunnel". (**c**) Stapling the posterior portion of fused fissure

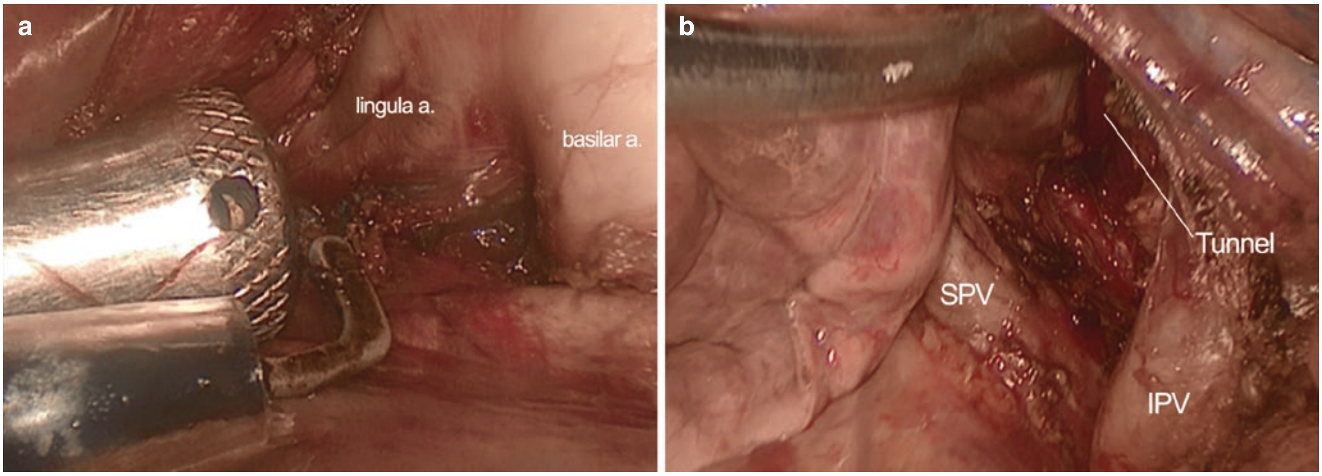

Fig. 4.32 (**a**) Anterior part of the oblique fissure, arteries exposed in last step. (**b**) Another "tunnel" made from anterior hilum

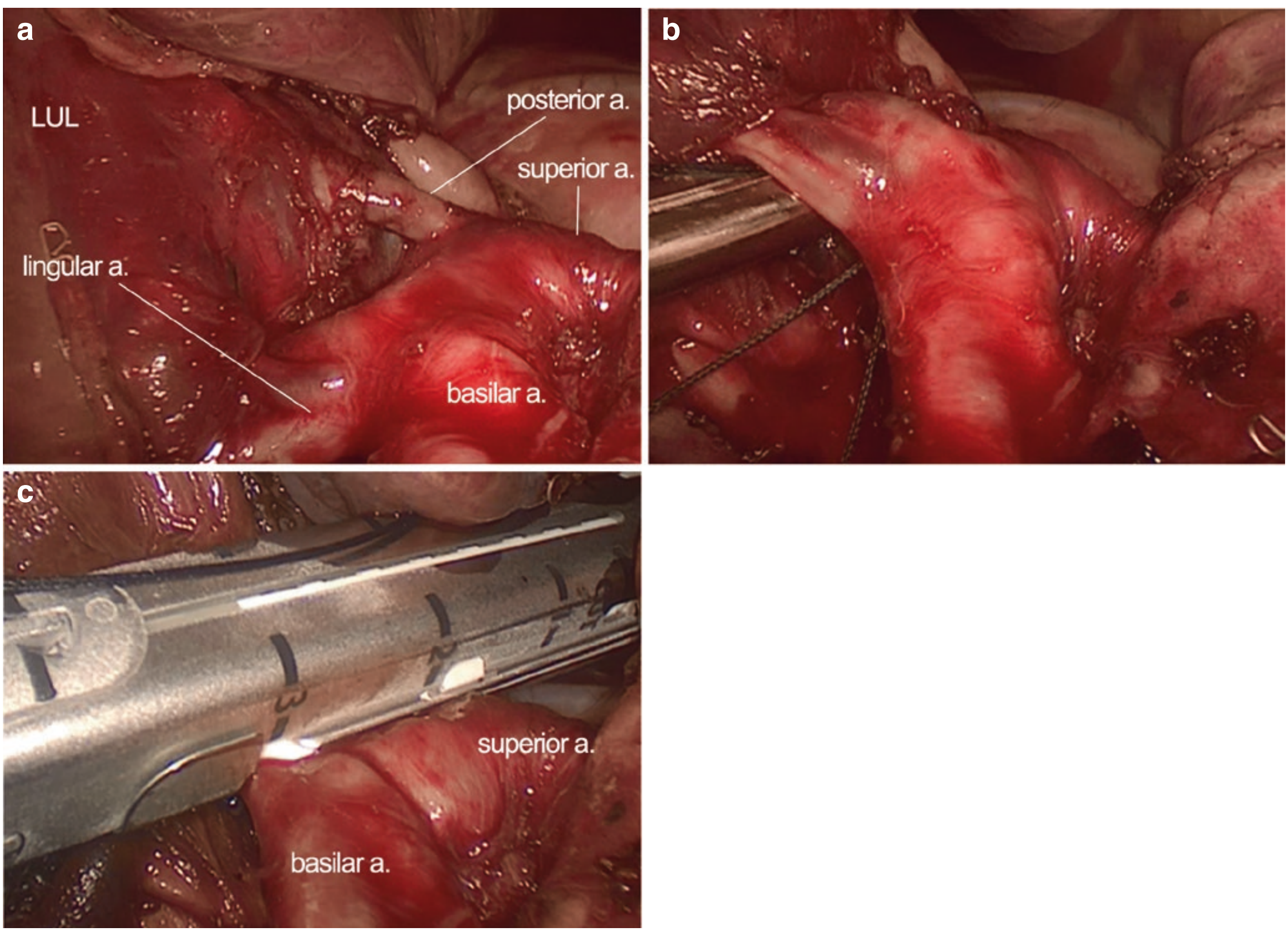

Fig. 4.33 (**a**) The well exposed pulmonary arteries. (**b**) Dividing the posterior ascending arteries. (**c**) Cutting off the posterior ascending arteries

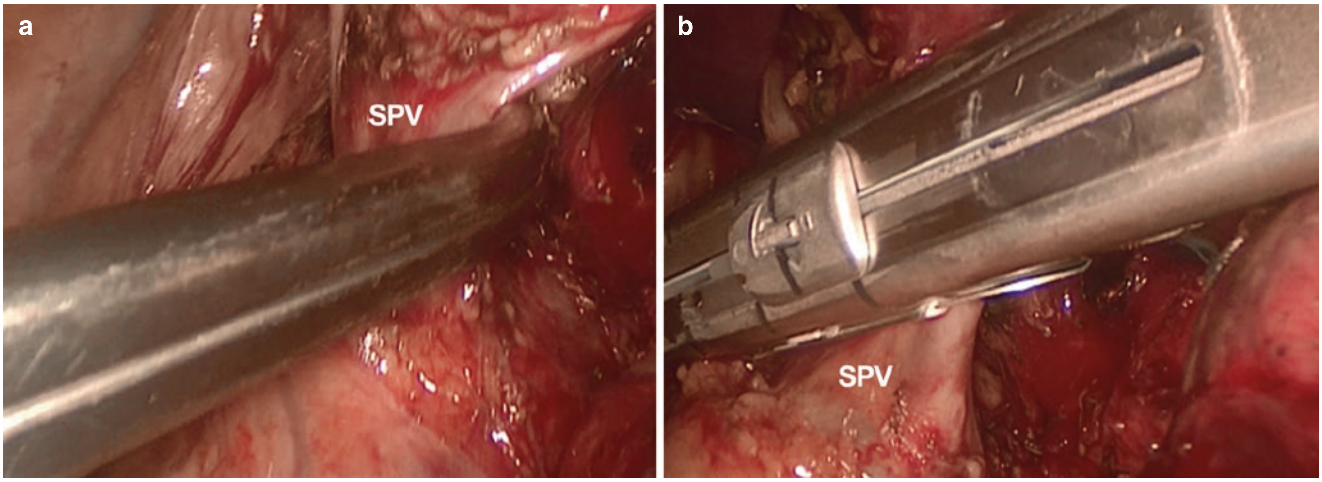

Fig. 4.34 (**a**) Dividing the superior pulmonary vein. (**b**) Cut ting off the pulmonary vein

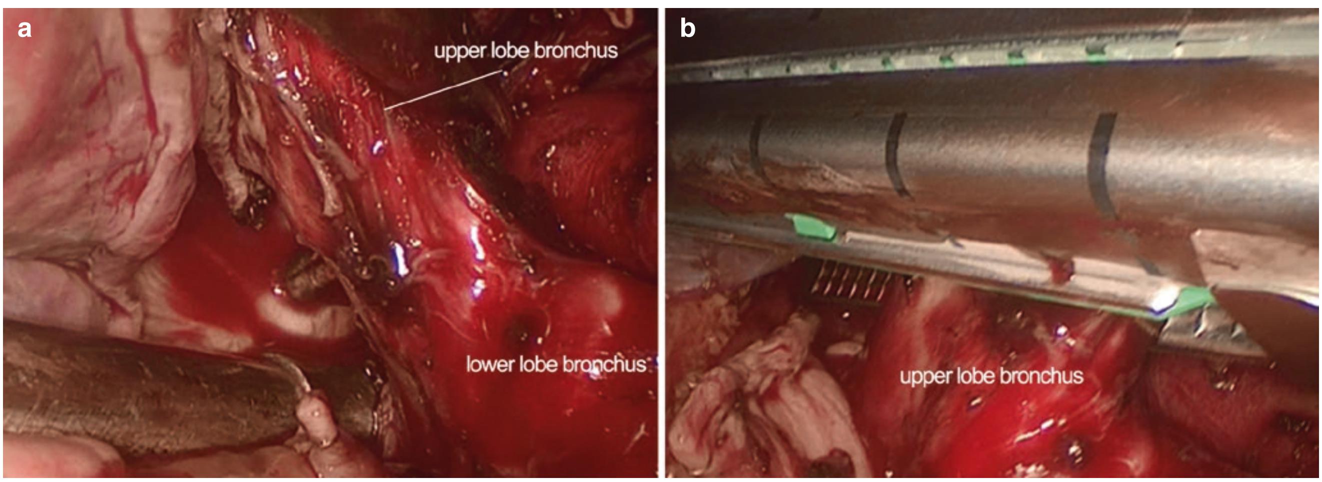

Fig. 4.35 (**a**) Dividing the upper lobe bronchus. (**b**) Cutting off the bronchus

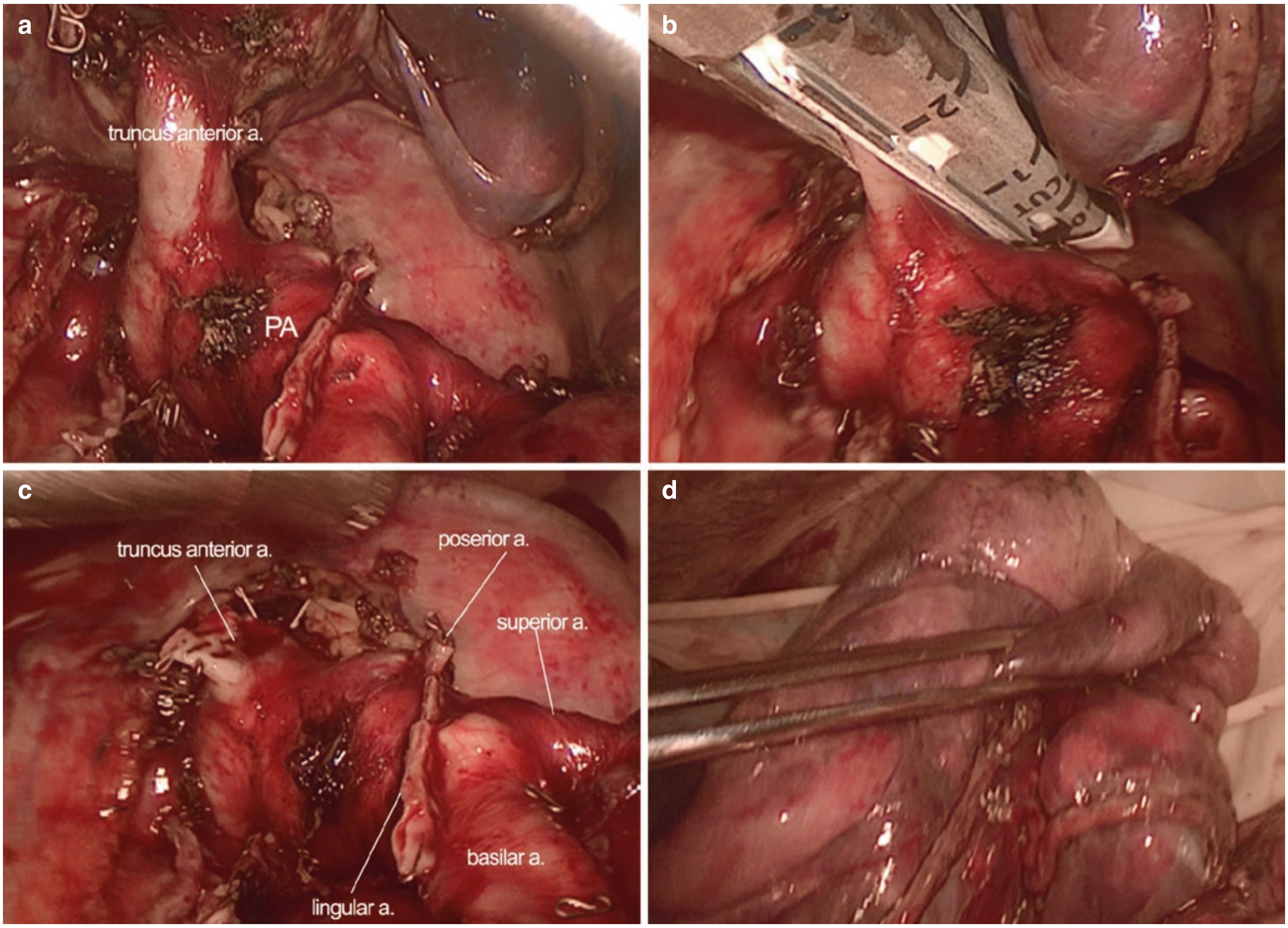

Fig. 4.36 (**a**) Dissecting the truncus anterior. (**b**) Cutting off the truncus anterior artery. (**c**) View of the arterial stumps. (**d**) Extracting the resected lobe by a sterile glove

4.6 Left Lower Lobe

Zuli Zhou and Jun Wang

4.6.1 Technical Points

- It is preferable to divide the fissure and identify the arteries first. When the fissure is almost completely fused, to dissect the inferior pulmonary vein first and to expose the lower lobe bronchus and arterial branches may be a rational alternative.
- If the dissection of subcarinal lymph nodes is necessary, it is advisable to perform the lymphadenectomy before the bronchus is dissected, for the absence of LLL makes the exposure of the subcarinal region difficult, especially for the left approach.

4.6.2 Anatomical Landmarks

- **Bronchus**: The left lower lobe (LLL) bronchus is situated under the arterial branches. The division of the pulmonary arteries or the inferior vein can both give access to the lobar bronchus.
- **Arteries**: The basal trunk and the superior segmental artery supply the LLL. Commonly they can be divided as a stem, but sometimes there are lymph nodes between above two branches, or the lingular artery locates too close to the basal trunk, thus advisably they are divided separately.
- **Veins**: The left inferior pulmonary vein is the most inferior element. Sometimes the superior and inferior converge outside the pericardium, so the inferior vein must be verified before the dissection (Fig. 4.37).

4.6.3 Operating Procedure

1. The two lobes of left lung are pushed to the apex. The pulmonary ligament is exposed and dissected till to the inferior pulmonary vein using electric hook. Divided the group 9 lymph nodes at the same time (Fig. 4.38).
2. The LLL is stretched forward, and the posterior mediastinal pleura is fully exposed. The bronchial arteries both superior and inferior to the left main bronchus are cut off (Fig. 4.39).
3. The LLL is pulled upward. The mediastinal pleura anterior to the inferior pulmonary vein is incised by an electric hook till the superior aspect of the vein is fully exposed (Fig. 4.40).
4. The LLL is stretched downward; using electric hook to divide the fissure until the pulmonary arteries are visible. Divide the vaginae vasorum of the basal trunk and superior segmental arteries are fully exposed (Fig. 4.41).
5. An artificial interlobar "tunnel" is set up from the exposed superior segmental artery to the posterior hilum, and then the posterior part of fused fissure is opened by an endostapler through the main manipulative port (Fig. 4.42).
6. Divide the anterior portion of the fissure using the hook or LigaSure® first. Then another "tunnel" is made from anterior hilum to anterior aspect of basal trunk by a right angle forceps. Then the anterior portion of the fissure is fully split by endostapler (Fig. 4.43).
7. Using Kelly forceps to divide and enlarge the space between the basal trunk and superior segmental artery and the lower lobe bronchus. Staple the basal trunk and superior segmental artery separately or together depending on the patient's anatomy (Fig. 4.44).
8. Pull the LLL toward the apex and staple the inferior pulmonary vein by endostapler (Fig. 4.45).

> **Tips**
> The group 7 lymph nodes can be dissected at this step if lymphadenectomy is necessary.

9. Divide the lower lobe bronchus by hook and "Peanut". Pulling the LLL forward, and be sure that the LUL can be reinflated before stapling the bronchus (Fig. 4.46).

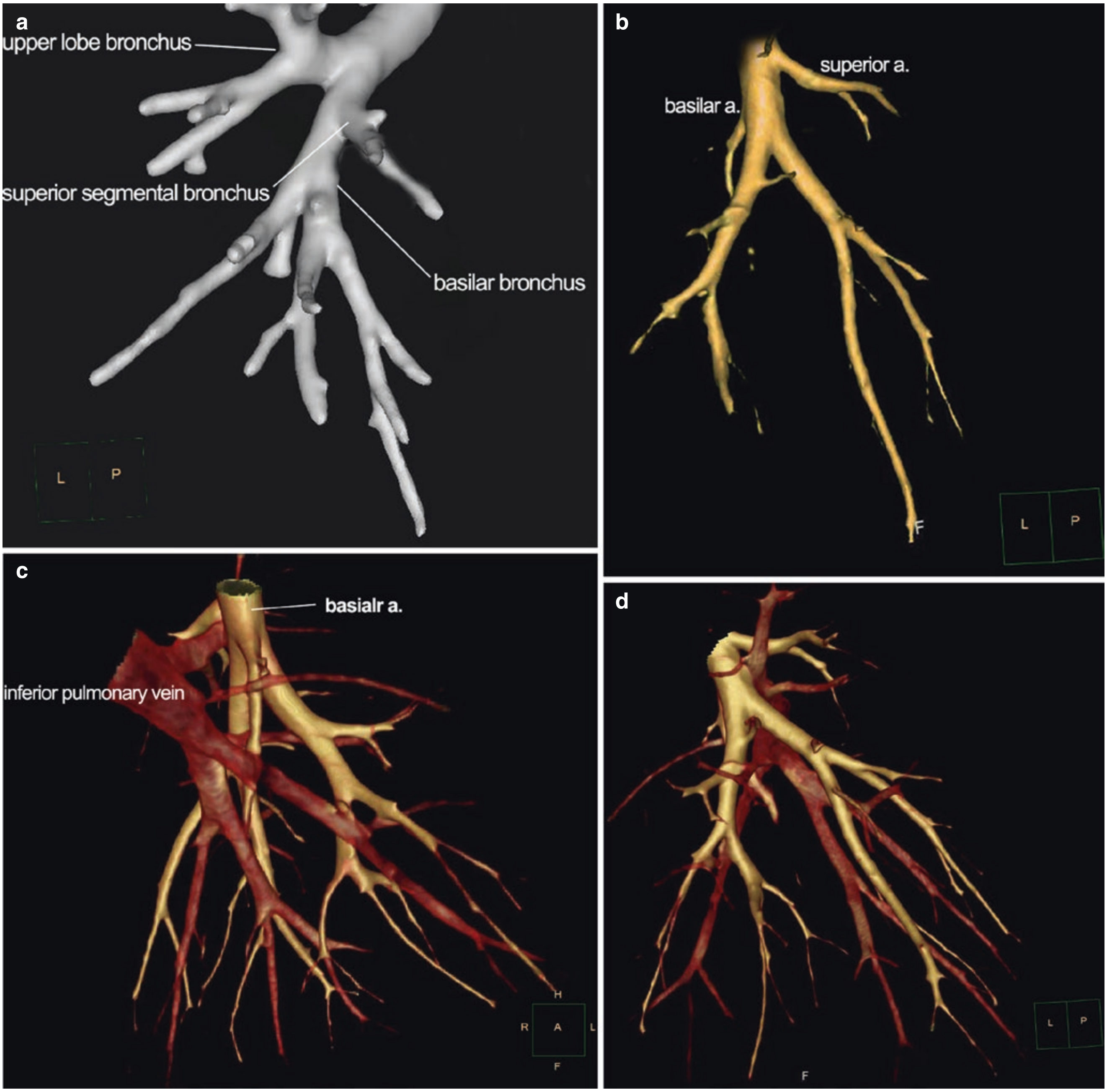

Fig. 4.37 Anatomical landmarks of left lower lobe: (**a**) Lower lobe bronchus (*left lateral view*). (**b**) Lower lobe arteries (*left lateral view*). (**c**) Relationships between arteries and veins of the right lower lobe (*anterior view*). (**d**) Relationships between arteries and veins of the right lower lobe (*left lateral view*)

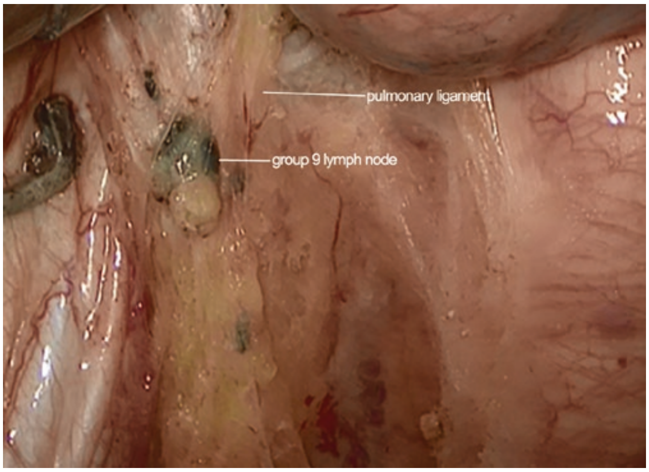

Fig. 4.38 Dissecting the pulmonary ligament, and resecting the group 9 lymph nodes

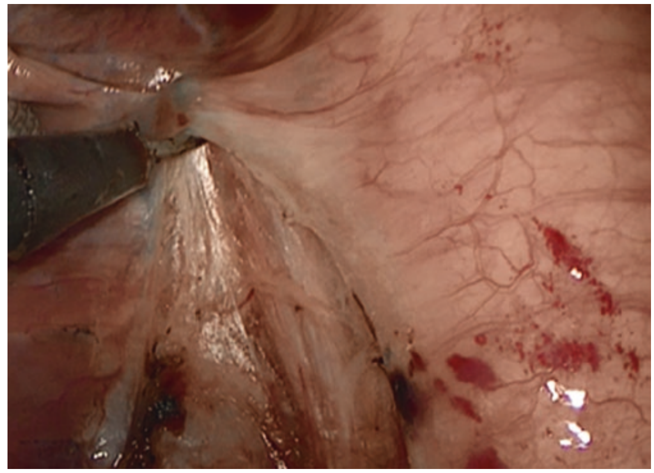

Fig. 4.39 Dissecting the posterior mediastinal pleura

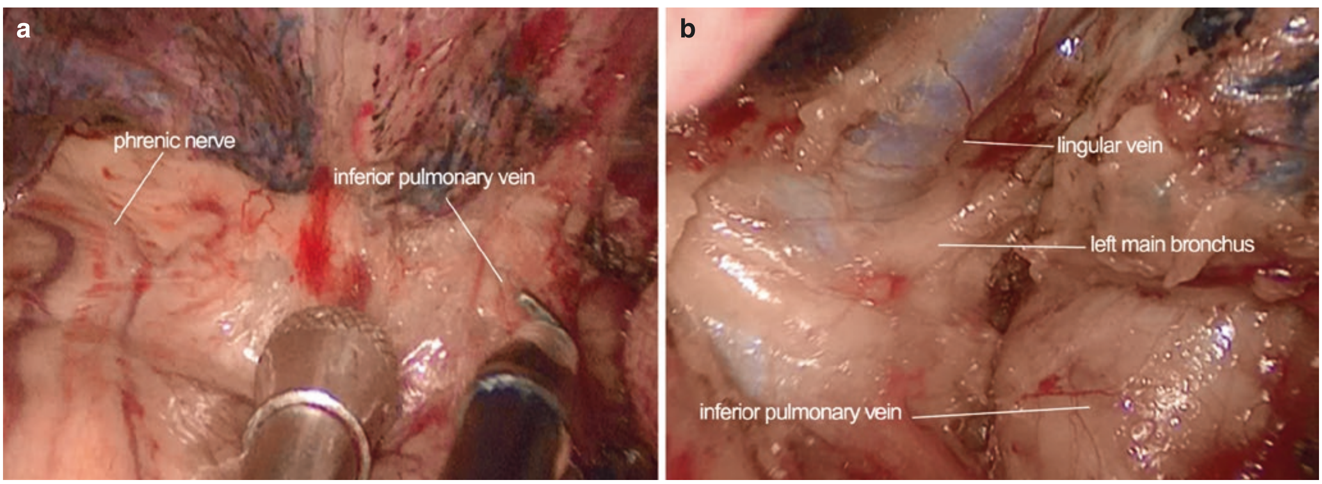

Fig. 4.40 (**a**) Dividing the anterior mediastinal pleura. (**b**) Anterior hilum between superior and inferior vein

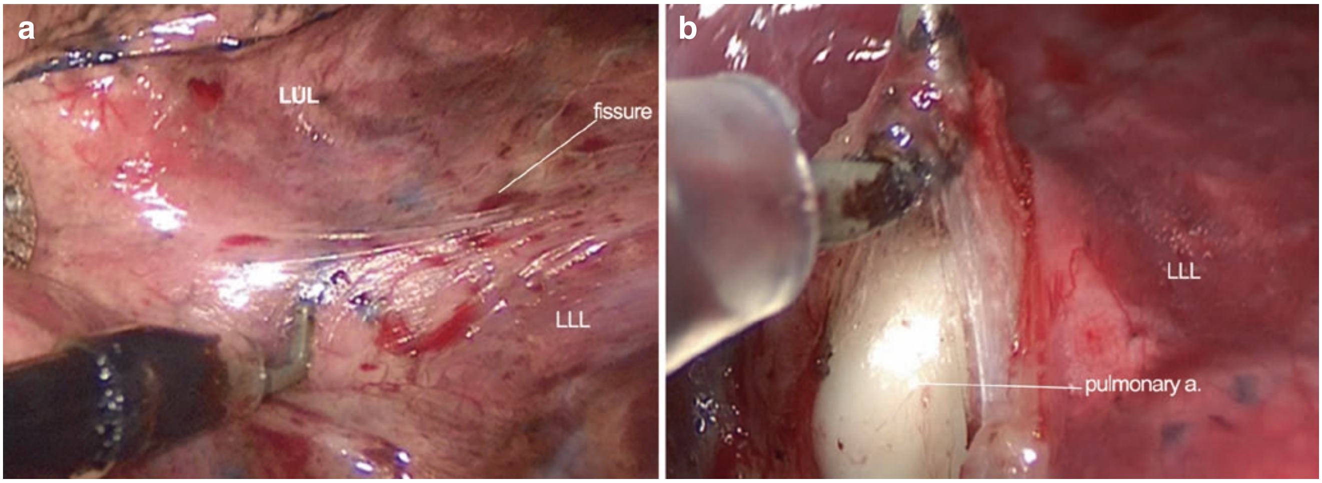

Fig. 4.41 (**a**) Dividing the fused fissure. (**b**) Exposed pulmonary artery

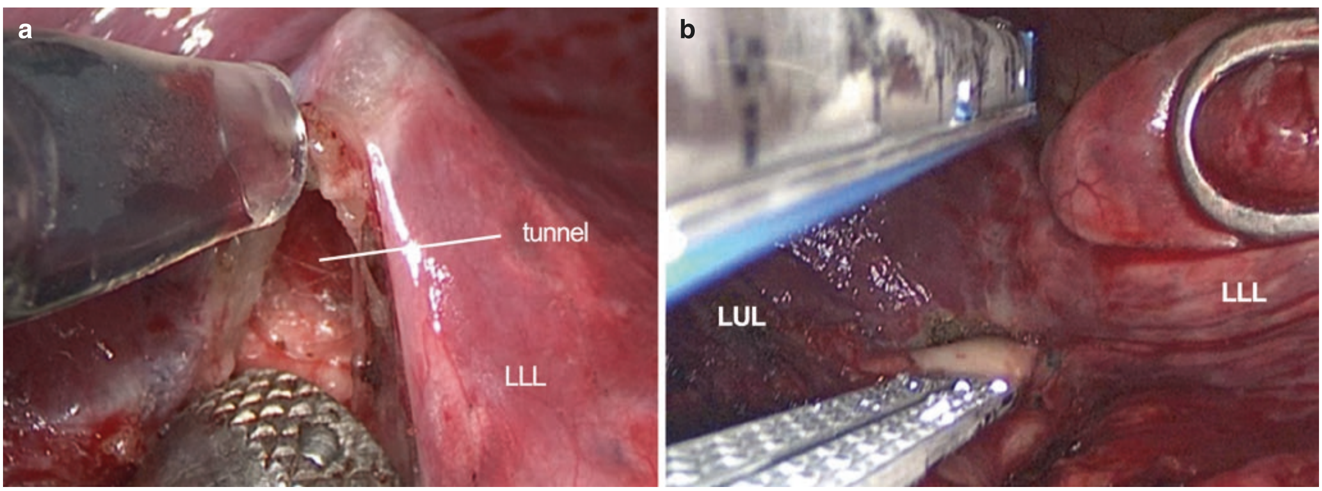

Fig. 4.42 (**a**) An artificial interlobar "tunnel" is set up. (**b**) Stapling the posterior portion of fused fissure

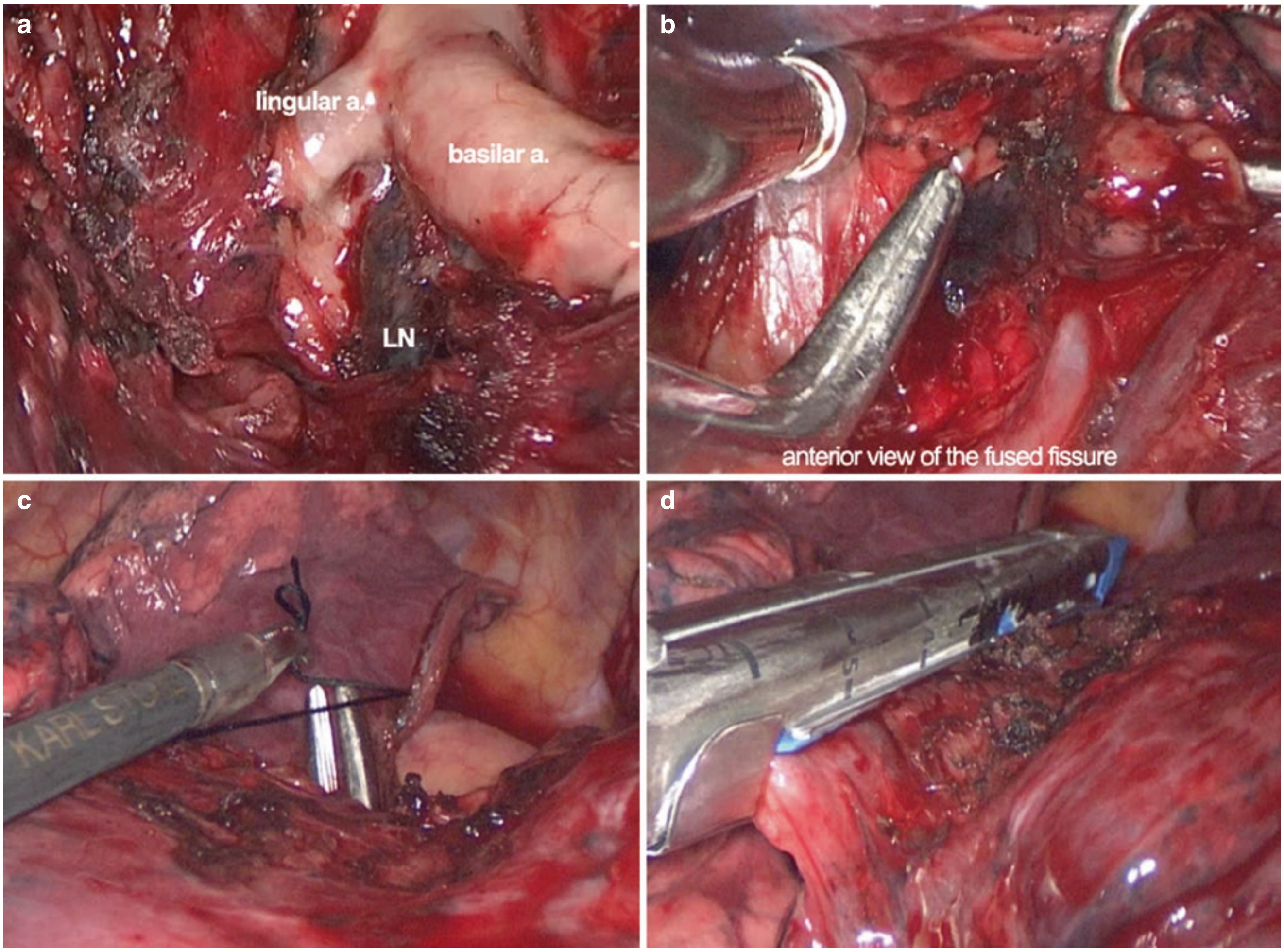

Fig. 4.43 Dividing the anterior portion of the fissure

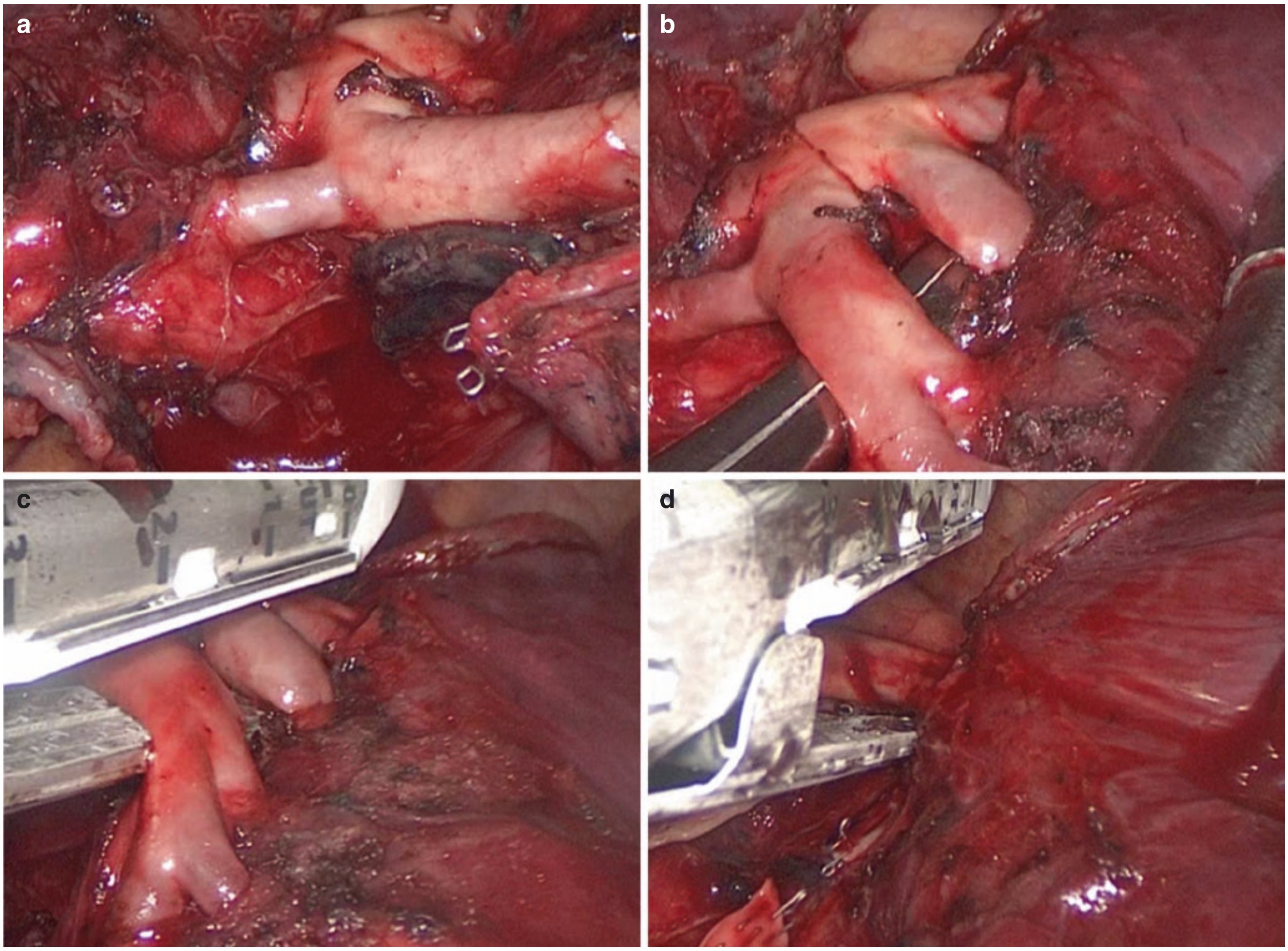

Fig. 4.44 (**a**, **b**) The well exposed pulmonary arteries. (**c**, **d**) Cutting off the basal trunk and superior segmental artery separately or together

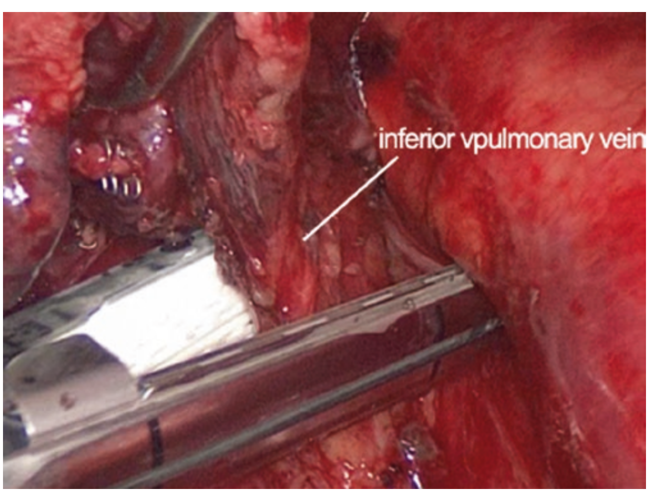

Fig. 4.45 Cut ting off the pulmonary vein

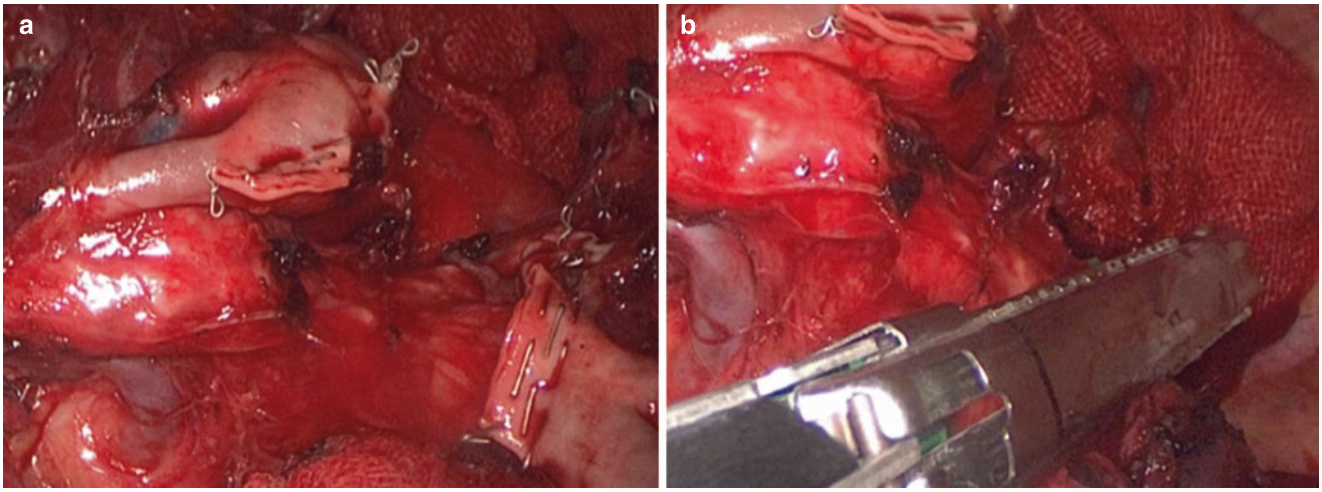

Fig. 4.46 Cut ting off the lower lobe bronchus

4.7 Results and Discussion

Pamela Samson and Traves Crabtree

One of the biggest changes to date in general thoracic surgery has been the movement from open pulmonary resection to minimally invasive techniques. For many thoracic surgeons, this shift occurred in the early 2000s to video assisted thoracoscopic surgery (VATS). This discussion of minimally invasive approaches to lobectomy will include the transition to VATS, short and long term outcomes of a VATS approach to lobectomy, and early experiences with robotic-assisted lobectomies and uniportal VATS.

4.7.1 Transition to VATS

Early adopters of VATS lobectomy were optimistic that a minimally invasive approach would lead to a shorter length of stay, decreased short-and long-term postoperative pain, decreased morbidity such as pneumonia and arrhythmias, and an increased readiness for adjuvant therapy if indicated. However, there was also concern regarding the possibility of increased intraoperative complications, given the adoption of a new technique that few were familiar with, and the ability to control bleeding quickly and effectively. Such transitions from an open to VATS practice has been described in the literature. In one such series, Seder and colleagues described the 5 year period where the percentage of VATS lobectomies increased from 16 % to 49 % over a 5-year period (2003–2008), while open lobectomy decreased from 81 % to 42 % during the same-time [50]. During this time, there was no increase in intra- or postoperative complications from the VATS approach, and a decrease in the length of inpatient stay was documented even from the 'early' adoption phase. Safe transitions to thoracoscopic practice have also been described in teaching programs where VATS was introduced to faculty and residents simultaneously [51]. Although the proportion of pulmonary resections that are performed using a VATS approach has increased steadily since the early 2000s, the majority of surgeons in the United States (approximately 60 %) continue to practice using an open approach [2].

4.7.2 Short Term Outcomes

Of immediate concern to many surgeons is the ability to perform a VATS lobectomy safely and effectively. In a review of over 11,500 clinical Stage I non-small cell lung cancer (NSCLC patients) receiving either open or VATS lobectomies or segmentectomies recorded in the Society of Thoracic Surgeons database from 2001 to 2010 demonstrated that thoracotomy patients were significantly more likely to experience pulmonary complications (including pneumonia, reintubation, and acute respiratory distress syndrome), atrial arrhythmias, and require blood transfusions [52]. In this analysis, there was no difference in thirty-day mortality (1.8 % for thoracotomy versus 1.3 % for VATS). In a study sponsored by the Alliance for Clinical Trials in Oncology (specifically, CALGB 31001), participants undergoing VATS lobectomy for stage I or II NSCLC were propensity matched on the basis of patient and tumor characteristics to individuals receiving open lobectomy [53]. In this analysis, VATS demonstrated a significantly decreased median length of stay (4 days versus 6 days), decreased proportion of patients with prolonged length of stay (defined as greater than 14 days, 6.3 % versus 8.6 %), decreased length of chest tube duration (3 days versus 4 days), decreased rate of any surgical complication (14.9 % versus 25.1 %), and an increased rate of discharge to home (93.7 % versus 90.3 %). These findings have also been confirmed in other large series in Europe [54]. In reviews among older NSCLC patients (70 or greater), similar improvements in postoperative complications and length of stay were again confirmed, along with improved in-hospital mortality [21]. Recent cost-effectiveness analyses have also demonstrated that VATS lobectomy is associated with lower 90 day costs when compared to thoracotomy, and that this improvement was largely associated with the decreased rate of prolonged length of stay [55].

Of concern to many surgeons transitioning to a VATS based practice is the conversion rate, and the factors that lead to conversion. In our experience at Washington University in St. Louis, we have noted a decrease in the VATS lobectomy conversion rate over time – from 28 % in 2004–2006 to 11 % in 2010–2012 [56]. The overall conversion rate for all VATS lobectomies was 7 %. The reasons for conversion included vascular causes/bleeding in 25 %, anatomical reasons including adhesions or tumor size in 64 %, and 8 % for difficult lymph node dissection (bulky or calcified nodes). This spectrum of complications leading to conversion is also commonly referred to as the 'VALT' classification system – vascular, anatomic, lymph node, or technical reasons. While postoperative complications were more common in the converted group than those experienced in the VATS group, there was no significant difference in the complication rate with the thoracotomy group. Of note, 23 % of our conversion cases were classified as emergent. Truly catastrophic complications during VATS lobectomy are rare – one series documents an approximately 1 % rate of such complications over 10 years, including pulmonary artery or pulmonary vein transection requiring reanastomosis, unplanned bilobectomies or pneumonectomies, and membranous airway injuries [57]. In that particular review of complications, there were no intraoperative deaths. A key and necessary measure to preventing mortality in these scenarios is being cognizant of the injury types that can occur with VATS staplers and energy devices, recognizing when adequate visualization is not obtained, and considering conversion to thoracotomy earlier rather than later, especially early in the learning curve.

4.7.3 Long Term Outcomes

Of interest to surgeons performing lobectomies is whether or not VATS offers equivalent oncologic outcomes to thoracotomy. Recent reviews have issued warnings that the rate of lymph node dissection and sampling may be inferior to that obtained during open lobectomy [31, 58]. A Danish study had documented a decreased incidence of both N1 and N2 upstaging in VATS lobectomy patients when compared to those that had received a thoracotomy [59]. In a metaanalysis of early stage NSCLC patients receiving either VATS or open lobectomy from 1990 to 2011, no significant difference in the rate of lymph node dissection or lymph node sampling was detected [60]. Furthermore, this metaanalysis also described a decreased rate of both systemic and locoregional recurrence in the VATS groups. In propensity matched groups based on patient and tumor characteristics, no significant difference in 3- or 5-year overall survival between VATS and open lobectomies was detected [61]. At this time, it is generally held that VATS lobectomy offers equivalent long-term oncologic outcomes at open resection, with improved short term outcomes. Of note, care should be taken to perform appropriate mediastinal lymph node dissections when performing a VATS lobectomy, particularly level 5/6 and 7 nodes for left-sided lesions and level 7 nodes for upper lobe resections [31].

4.7.4 Robotic Assisted Lobectomy

Select surgeons and centers have adopted a robotic-assisted approach to lobectomies. At this time, the use of robotic-assisted lobectomy versus a traditional VATS approach is a matter of surgeon preference and resources. In the largest review to date, almost 2,500 robotic assisted lobectomies were compared to approximately 40,000 VATS lobectomies in the Nationwide Inpatient Sample database [62]. In this series, when adjusting for other covariates, robotic-assisted lobectomies were associated with an increased risk of intra-operative/iatrogenic bleeding and a significantly increased cost per case. Other large database reviews have documented no difference in adverse events with robotic-assisted lobectomies, but have similarly found higher average hospital costs [63]. Of clinical concern, especially for surgeons new to robotic surgery, is the increased length of operative time that has been documented for robotic lobectomies [66, 64]. For those who do practice robotic-assisted lobectomies, it does appear that the long term overall 5-year survival is similar to that of VATS lobectomies [65].

4.7.5 Uniportal VATS

The newest minimally invasive approach to lobectomy is the ‘uniportal’ VATS approach. An early review of uniportal cases have shown no difference in postoperative pain or analgesia use, but also no difference in postoperative complications [66]. Other institutions have described their short-term experience with uniportal VATS lobectomies, and have described no difference in postoperative outcomes, thereby suggesting the relative safety of this procedure [67, 68]. At this time however, many series are too small to discern any benefit of uniportal VATS to a traditional ‘multiport’ approach, and the follow up is not long enough at this time to demonstrate oncologic equivalency. As one recent editorial stated: “raising the standards of clinical care is paramount to promoting the use of standard multiportal VATS surgery rather than trying to modify this recently achieved technique”, recognizing that a majority of surgeons in the United States and Europe are still performing open pulmonary resections [69]. At the same time, we recognize that surgical ingenuity and refinement is what creates new pathways of improved care for our patients.

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Segmentectomy

5

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5.1 Rationale for Minimally Invasive Segmentectomy

Robert J. McKenna Jr.

This chapter will describe the indications for segmentectomy, a comparison of morbidity/mortality for segmentectomy and lobectomy, and discuss the issue of open versus minimally invasive operations. Segmentectomy is a true anatomic operation that should include lymphadenectomy in cancer cases. It is not a non-anatomic wedge resection.

5.1.1 Rationale for Segmentectomy, Rather Than Lobectomy

- Goals for lung operations are to remove all disease, save as much lung tissue as possible, and not compromise survival.
- The definitive proof is a randomized, prospective study. That is underway, but not completed.
- Retrospective studies suggest that segmentectomy for proper indications is not a compromise operation.

5.1.2 Indications

- The performance of segmentectomies has significantly increased over the years. Currently, 30 % of my anatomic resections are segmentectomies. The procedures are usually performed in patients with pulmonary function good enough for the patients to undergo a lobectomy.
- Indications are listed in Table 5.1. The disease process must be anatomically located so that segmentectomy will provide good, clear anatomic margins. To accomplish that, an adjacent segment may be resected in some cases (more than one lower lobe basilar segment).
- The size of the tumor affects the choice of segmentectomy versus lobectomy. (Table 5.2) Tumors >3 cm are generally better treated with a lobectomy [1].
- In cancer cases, positive nodes would be an indication for conversion to a lobectomy.

5.1.3 Comparison of Segmentectomy and Lobectomy

- Shuchert (Table 5.3) reported comparable morbidity and mortality for Lobectomy and Segmentectomy [1].
- We compared our experience with left upper lobectomy versus left upper lobe tri-segmentectomy to evaluate the complication rates and the survival [3].
- Table 5.4 shows that the mortality rates and the length of stay were the same [3].
- Table 5.5 shows that the incidence of air leak is the same for tri-segmectomy and upper lobectomy is the same [3].
- Complication rates are slightly higher for tri-segmentectomy, but they were minor and, despite that, the length of stay was 1 day shorter for tri-segmentectomy (Table 5.5) [3].
- Survival is the most important measure of a cancer operation. Okada (Fig. 5.1) compares the survival for different sized tumors and different operative procedures [2].

We compared the long term survival of 73 patients who underwent VATS trisegmentectomy versus 266 patients who underwent VATS lobectomy [3] (Fig. 5.2).

5.1.4 Comparison of Open and Minimally Invasive (VATS) Segmentectomy

- Leshnower compared the Emory experience with thoracotomy versus VATS for segmentectomy. Video-assisted thoracoscopic surgery segmentectomy is a safe procedure which has fewer complications and a reduced hospital stay when compared with an open segmentectomy. This approach may be the ideal oncologic procedure for patients with small lung cancers (<2 cm) and (or) limited cardiopulmonary reserve and significant comorbidities [4].
- Video Assisted Thoracic Surgery (VATS) is on the increase in the management of benign and malignant processes. Large experiences have convinced the surgical community not only of the safety and possibilities of VATS surgery in early lung cancer, but of the benefits when compared to open surgery in terms of postoperative pain, length of recovery, return to activities, immune response to surgery and oncological results [5–8].
- In elderly patients, VATS segmentectomy can be safely performed among elderly patients with early stage NSCLC and is associated with equivalent postoperative and long-term oncologic outcomes [9].

5.1.5 Conclusions

- Anatomic segmentectomy is being performed with increasing frequency. In selected cases, segmentectomy appears to provide the same survival rates as a lobectomy, with the same morbidity and mortality and with greater preservation of pulmonary function. Compared to open procedures, a VATS segmentectomy can be performed without compromising the operation and with providing patients with all the benefits of a minimally invasive procedure. VATS segmentectomy should be in the armamentarium of a thoracic surgeon.

Table 5.1 Indications for segmentectomy

Adenocarcinoma in situ
Carcinoid
<2 cm tumor
Pulmonary met
Localized bronchiectasis
Tb
Perfect location in lung

Table 5.2 Five year survival for different size tumors in lobectomy, segmentectomy and wedge resection (Okada)

Procedure	<20 mm	21–30 mm	>30 mm
Lobectomy	92.40 %	87.40 %	81.30 %
Segmentectomy	96.70 %	84.60 %	62.90 %
Wedge	85.70 %	39.40 %	0 %

Table 5.3 Experience with segmentectomy and lobectomy at University of Pittsburgh (Schuchert)

VATS segmentectomy vs. VATS lobectomy			
	VATS segmentectomy	VATS lobectomy	Significance
	(n = 109)	(n = 127)	(p value)
Operative time (min)	125	219	0.001
Estimated blood loss (ml)	100	150	0.08
Length of stay (days)	5	6	0.18
Morbidity (%)	20.2	15.7	0.4
Mortality (%)	0	0	1
Recurrence (%)	15.6	15	1
Survival (%)	87.9	90.6	0.67

Table 5.4 The mortality, conversion to thoracotomy, complication rate, and med LOS (median length of stay) for segmentectomy and lobectomy (Soukiasian, McKenna)

Factor	Segment	Lobectomy
Mortality	1 %	1 %
Convert	1 %	1 %
Complications	34 %	15 %
Med LOS	4 days	5 days

Table 5.5 The rates of air leak, AF (atrial fibrillation), UTI (urinary tract infection), and readmission rate for segmentectomy and lobectomy (Soukiasian, McKenna)

Complication	Segmentectomy (%)	Lobectomy (%)
Air leak	7	6
AF	8	2
UTI	5	0.10
Readmit	3	0.60

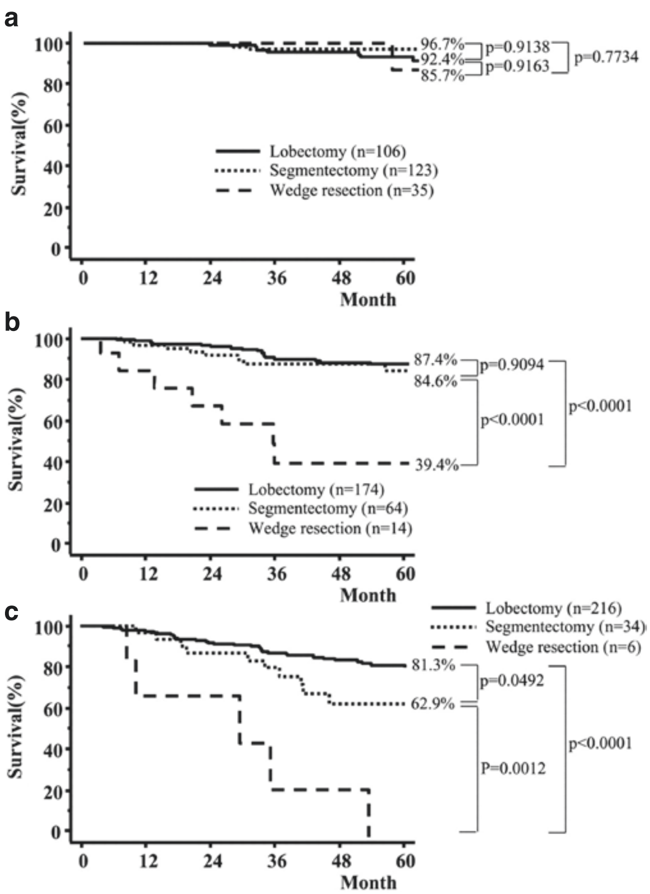

Fig. 5.1 Survival for wedge resection, segmentectomy, and lobectomy for patients with (**a**) <2 cm tumors, (**b**) 2–3 cm tumors, and (**c**) >3 cm tumors

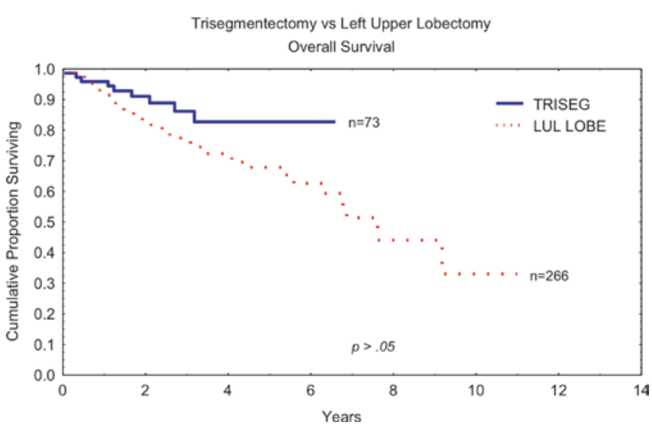

Fig. 5.2 Survival for patients after left upper lobe tri-segmentectomy versus left upper lobectomy

5.2 VATS Apical and Posterior Segmental Resections

Rodney J. Landreneau and Mark J. Crye

1. Technical Points
   - Anatomic apical and posterior segmental resections of the upper lobes can be relatively straight forward procedures. However, understanding the "three dimensional" upper lobe anatomy is required to accurately accomplish these resections.
   - When using the Video-Assisted Thoracic Surgical (VATS) approach, careful consideration of the best incisional site for the primary "intercostals access" to conduct dissection about hilar structures and to introduce endostapling device/thermo ablative/vascular fusion devices is critical.
   - During the course of the hilar bronchovascular dissection, the thoracic surgeon should maintain flexible strategy for addressing the order of vascular and bronchial ligation and division rather than persisting with a fixed order of handling these bronchovascular structures.
2. Anatomic landmarks for posterior segmentectomy (Fig. 5.3)
   - Begin dissection in the fissure at the thinnest aspect of the pleura covering the interlobar pulmonary artery to minimize possible lung parenchymal injury leading to bleeding and postoperative air leak.
   - Extend the dissection over the pulmonary artery to completely divide the oblique fissure, thus separating the posterior segment of the upper lobe from the superior segment of the lower lobe.
   - Careful blunt sucker dissection about the base of the posterior segment pulmonary parenchyma will expose the trunk of the posterior segmental artery.
   - The bronchus to the posterior segment will be anterior and beneath the posterior segmental artery.
   - The posterior segmental vein will be noted anterior and slightly inferior to the posterior segmental bronchus.
3. Operative procedure for Posterior Segmentectomy
   - A "Bi-Port" VATS approach is preferred by our team. The patient is placed in a lateral decubitus position with the ipsilateral arm held high and touching the patient's cheek. Right sided resections accomplished with use of selective ventilation with double lumen tube. The "Bi-Port" approach combines a 3–4 cm primary operative access site in the mid axillary line through the fifth or sixth intercostal space depending on the lobar location of the pulmonary pathology. Upper lobe lesions are accordingly approached through a fifth intercostal space site. Lower lobe and middle lobe lesions are approached using a sixth intercostal access site. A 5 mm intercostal access site is established two to three interspaces below the primary operative intercostal

access site in the posterior axillary line for the videoscope and subsequent tube thoracostomy tube drainage. We favor this "Bi-Port" approach to the "Uniport" approach due to our preference of videoscopic visualization from a more oblique point of view, reduction in instrument crowding during dissection, and our aversion to establishing a tube thoracostomy drainage of the chest through the operative incision (Fig. 5.4).

- After inspection of the pulmonary hilum for important adenopathy and to accomplish nodal staging, attention is directed to the interlobar fissure. The thinnest area of the fissure is chosen to begin dissection within the fissure. Complete fissures are rarely noted. The most consistent location for obvious parenchymal separation and direct pulmonary arterial trunk visualization in the fissure is in its mid hilar location.
- Right lung anatomy usually has this parenchymal separation will most commonly be just beyond the take of the middle lobe pulmonary artery and before the take offs of the posterior segmental artery of the upper lobe and the superior segmental artery of the lower lobe.
- When fissure is totally fused/incomplete oblique fissure could be divided via endoscopic stapler. The parenchymal division is carried superiorly to completely expose the interlobar artery and thus completely separate the lung parenchyma of the upper and lower lobes in this oblique interlobarfissure plane.
- Once the interlobar pulmonary artrery is exposed, further blunt dissection is carried out along the upper aspect of the artery on the upper lobe side of the fissure to expose the posterior segmental arterial trunk. It is not uncommon to encounter lymph nodes about the base of the posterior segmental artery – also associated with the deeper posterior segmental bronchus. Blunt and sharp dissection will be required to free the tissue about posterior segmental arterial trunk (Fig. 5.5a–c).
- It is common the posterior segmental vein runs over the posterior segmental artery, which makes it difficult to dissect the posterior segmental artery freely. So divide the horizontal fissure and expose the posterior segmental vein, then ligate and divide the vein before cutting off the artery is usually needed (Fig. 5.6a–c).
- The endostapler with a vascular staple load or the ligasure vessel fusion device is introduced through the "Biport" access incision, brought around the posterior segmental arterial trunk to ligate and divide the vessel (Fig. 5.7a–d).
- Blunt and sharp dissection with scissors and harmonic scalpel is then performed about the posterior segmental bronchus. Clearance of associated lymph nodes is commonly required.
- The endostapler with longer length bronchial staples is introduced through the access incision and placed about the posterior segmental bronchus which is then ligated and divided (Fig. 5.8a–d).
- The posterior segmental parenchyma is then elevated to anticipate the line of parenchymal resection along the base of the transected bronchovascular pedicle. The use of a non-crushing "Masher" forceps (PillingWeck, USA) applied across the proposed line of resection assists in proper alignment of the stapler across the tissue and segmental pedicle. Assessment of parenchymal thickness and "compression" of the parenchyma at the proposed staple line is also facilitated with the Masher forceps. The endostapler is then introduced through the access incision and applied across the pulmonary parenchyma (Fig. 5.9a).
- The masher is then reapplied across the proposed line of parenchymal resection to further insure the complete resection of the base of the posterior segment along with the lung parenchyma. Once passed this bronchovascular base of the posterior segment, the endostapler resection proceeds with care to insure a proper parenchymal margin of resection of the lung lesion (Fig. 5.9b–d).
- The specimen is retrieved in a protective bag and inspected on the operative field. Adequate surgical margins are assured (Fig. 5.10).

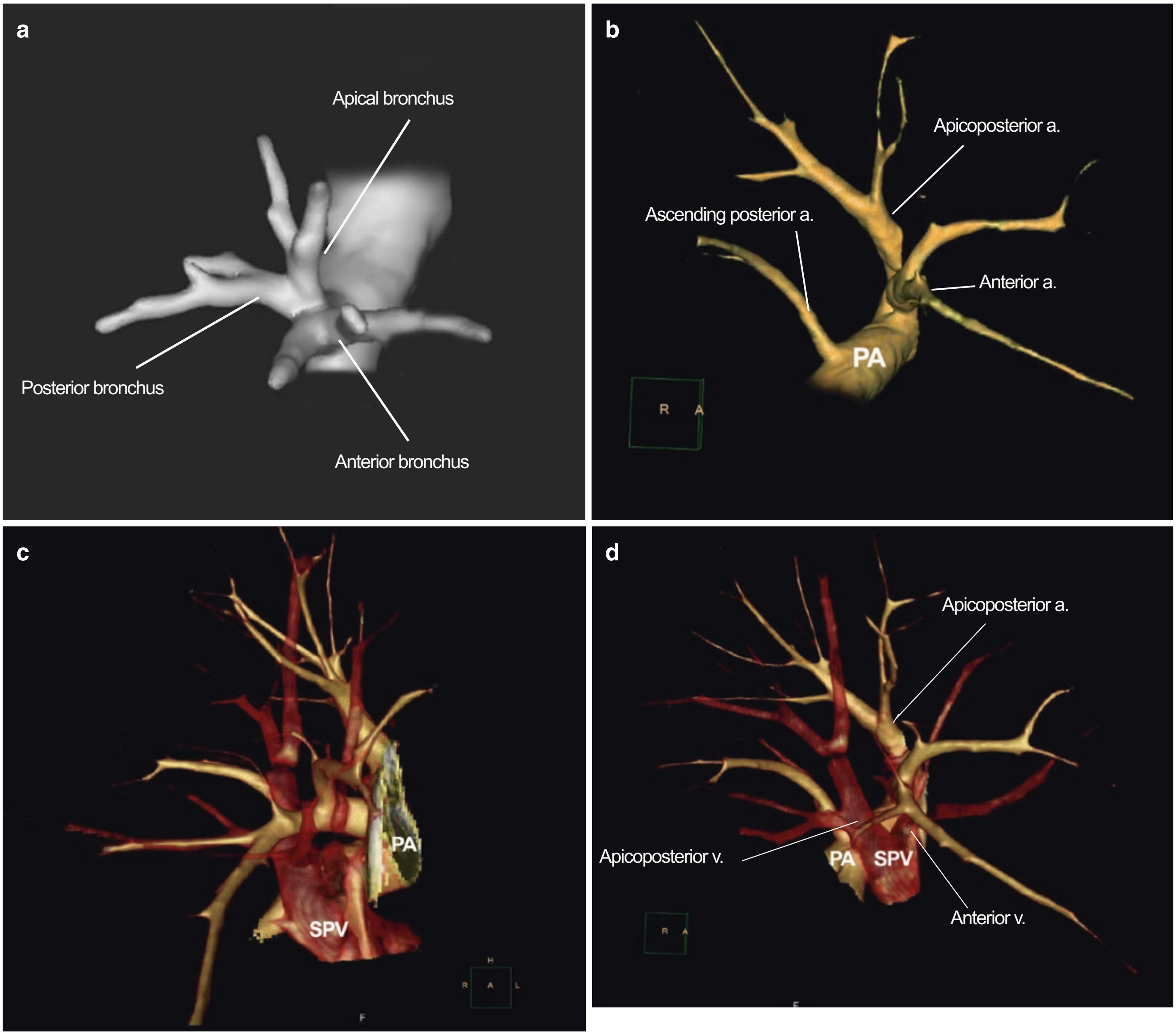

Fig. 5.3 Anatomic landmarks of right upper lobe posterior segment. (**a**) Posterior bronchus (*right lateral view*). (**b**) Posterior artery (*right lateral view*). (**c**) Relationships between arteries and veins of the posterior segment (*anterior view*). (**d**) Relationships between arteries and veins of the superior segment (*right lateral view*)

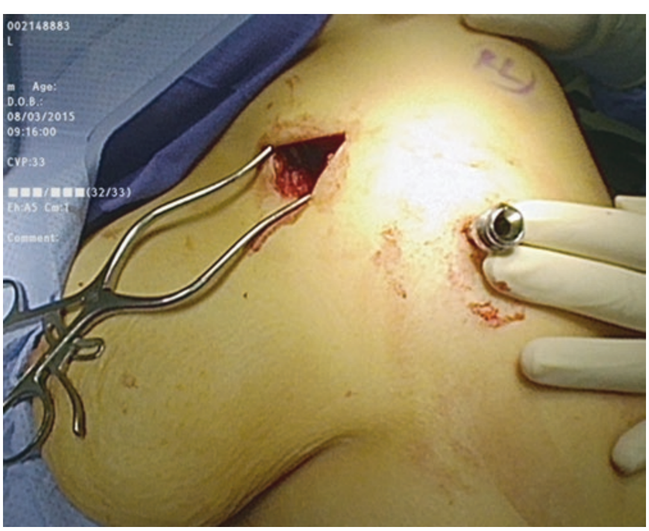

Fig. 5.4 Biport incision for left side procedures

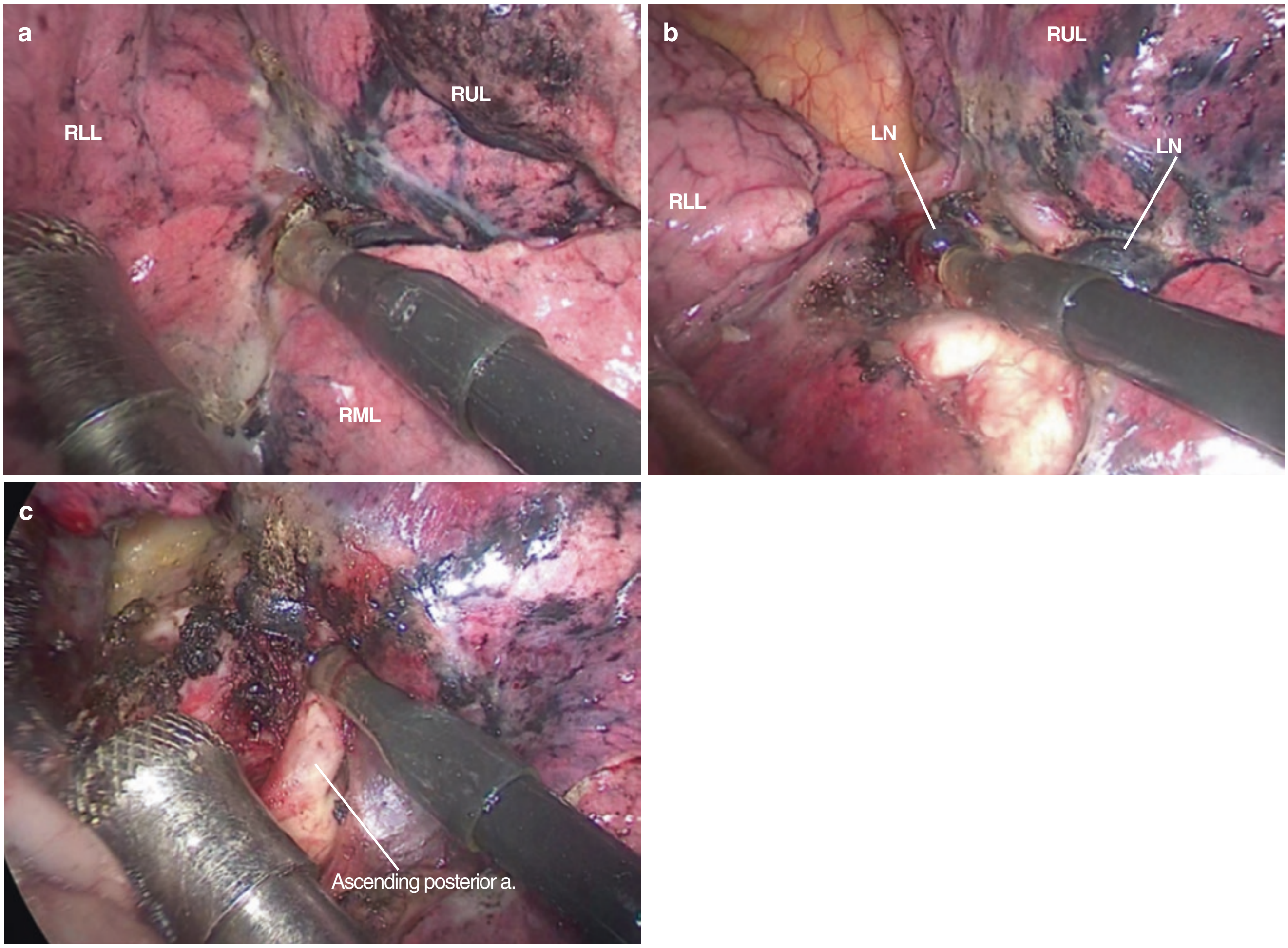

Fig. 5.5 (**a**) Dividing the incomplete oblique fissure. (**b**) Lymph nodes about the base of the posterior segmental artery (**c**) Exposing the posterior segmental artery

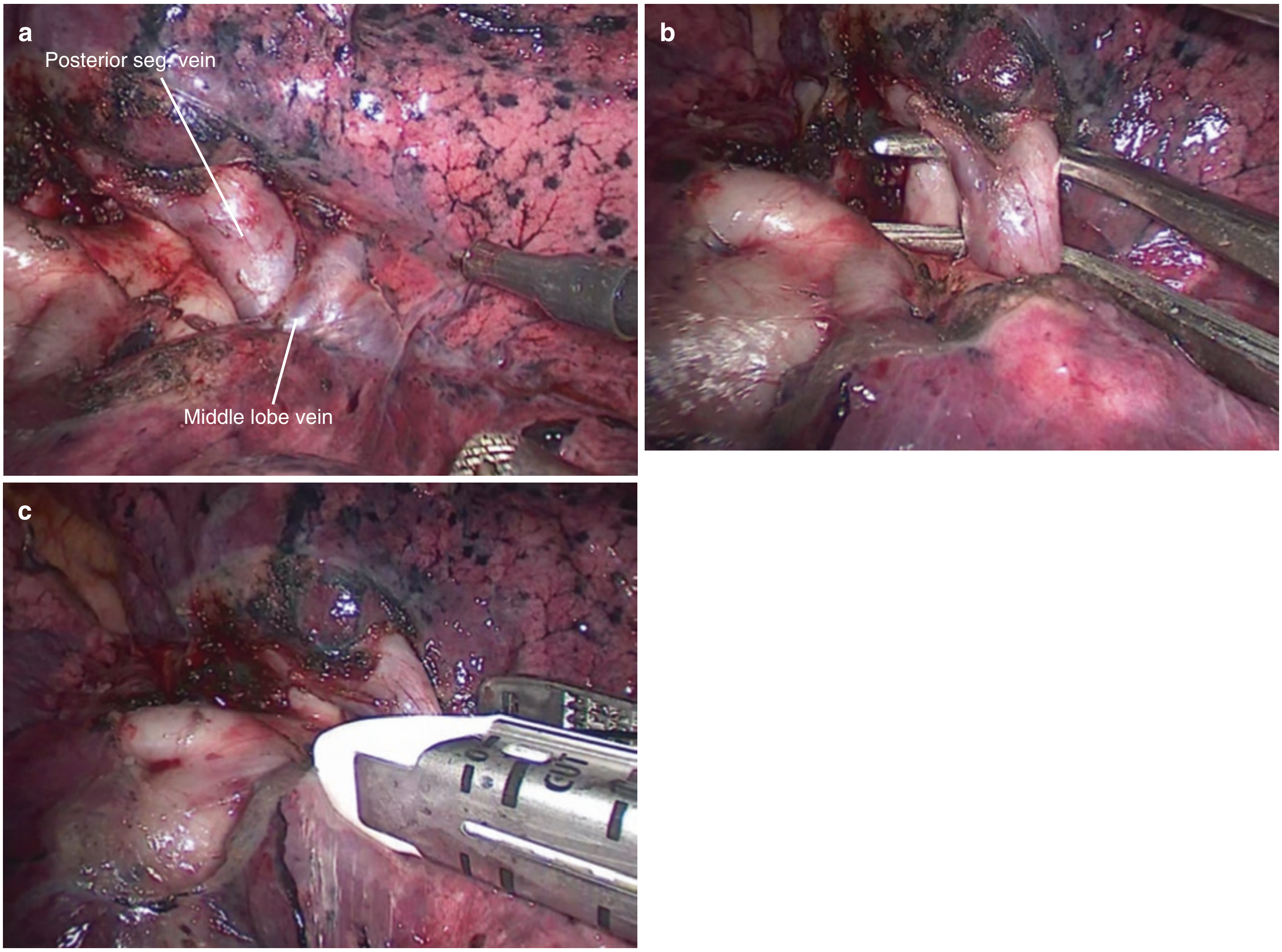

Fig. 5.6 Dividing and ligating the posterior segmental vein

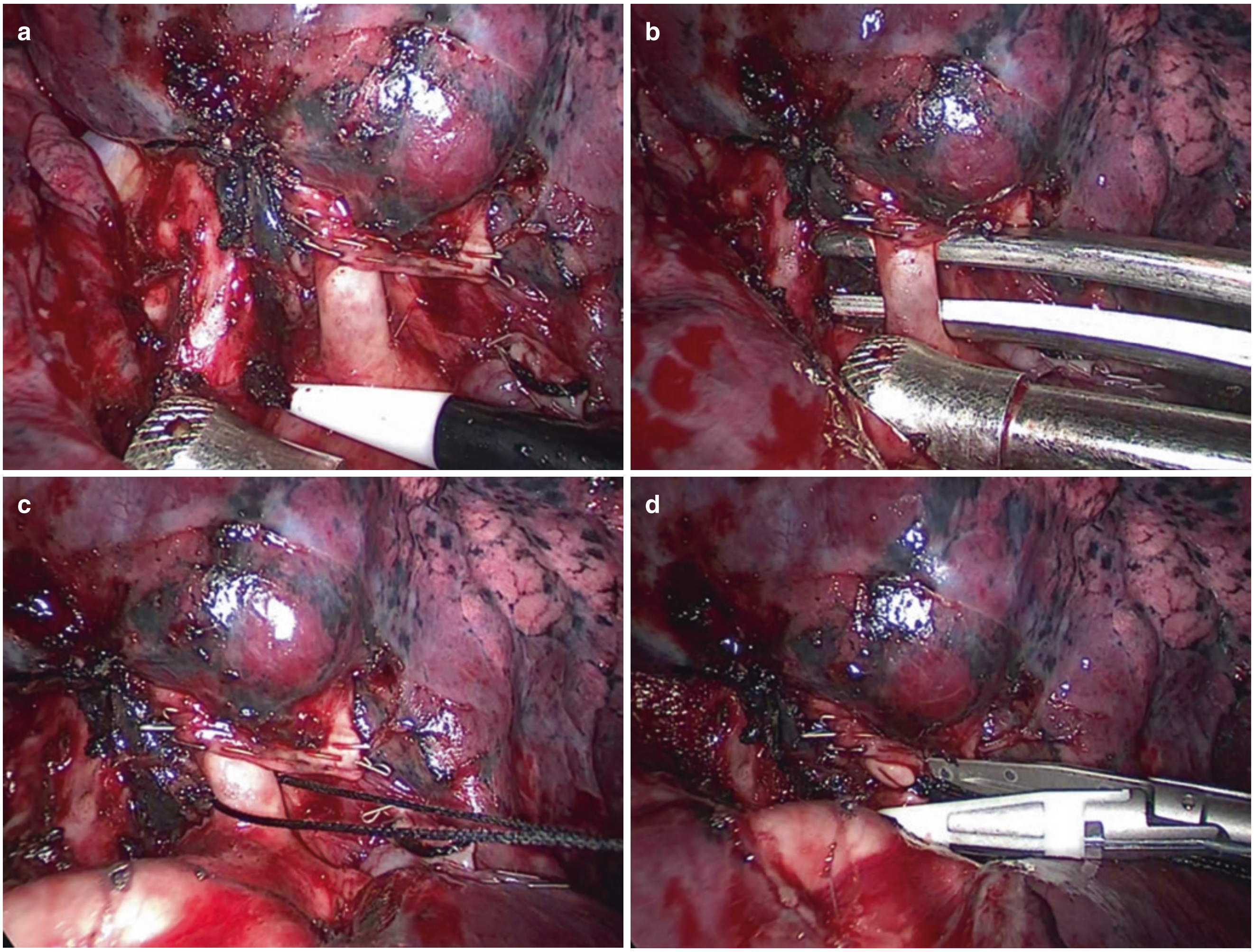

Fig. 5.7 Dividing and ligating the posterior segmental artery

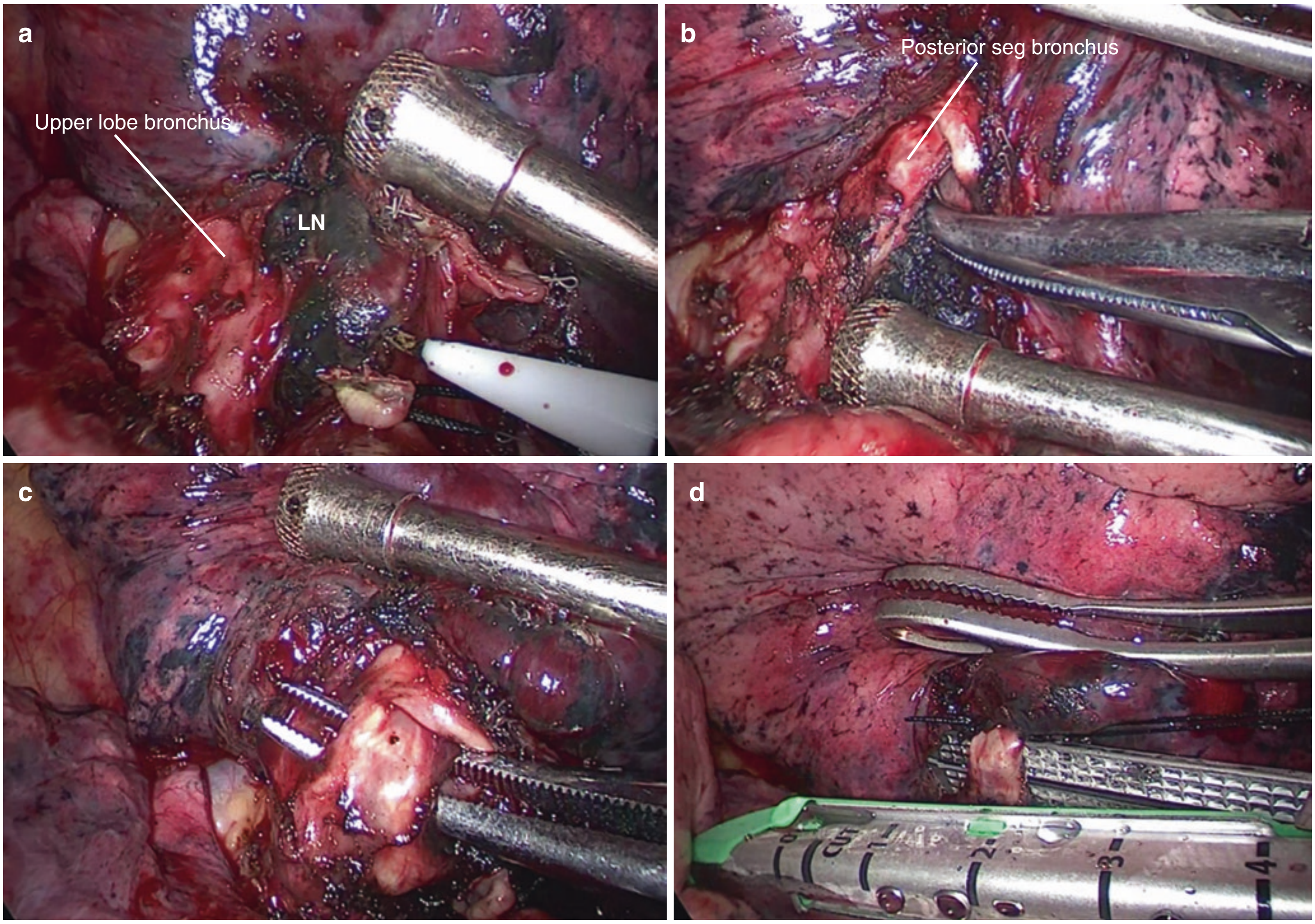

Fig. 5.8 Dividing and ligating the posterior segmental bronchus

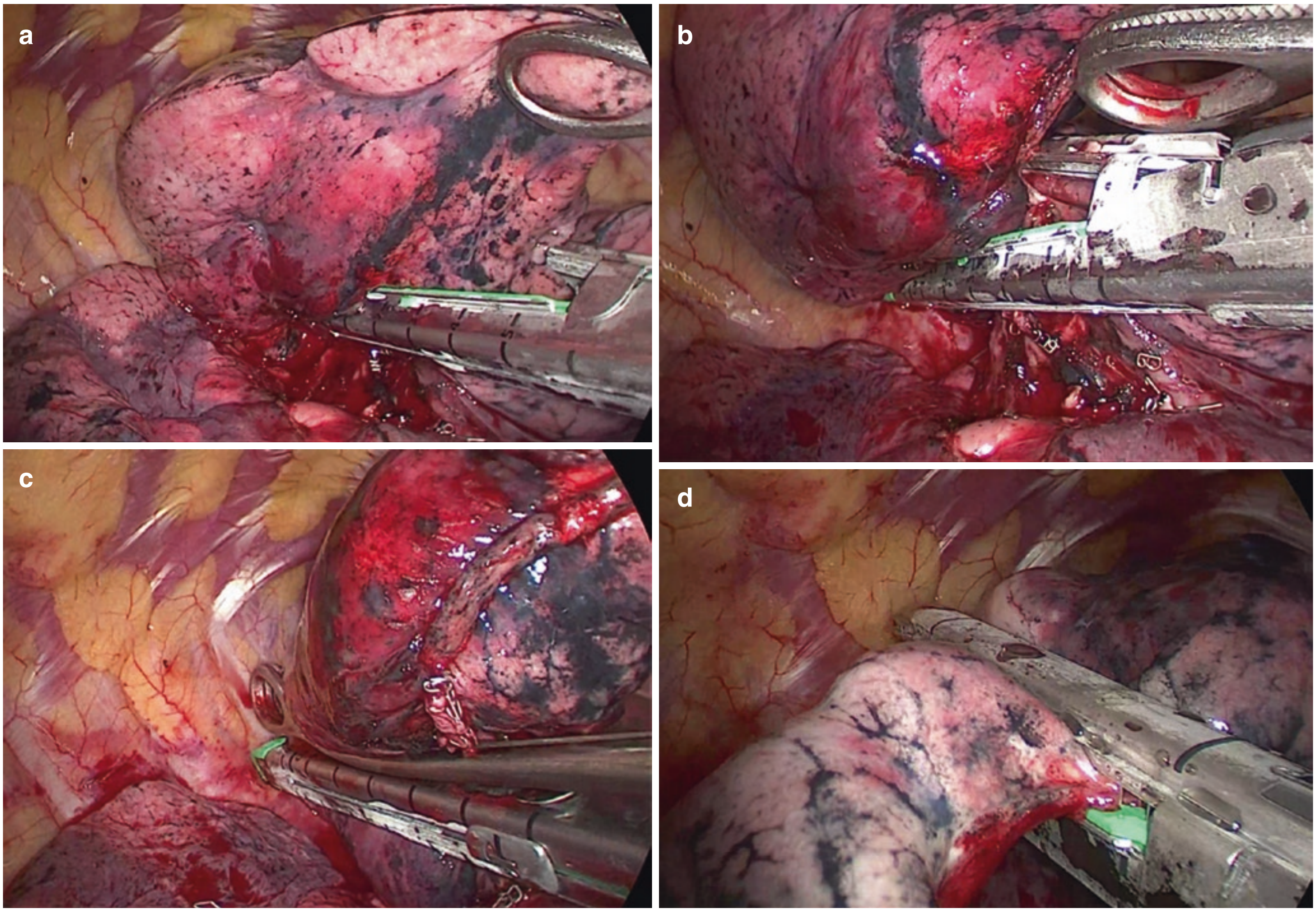

Fig. 5.9 The endostapler is introduced through the access incision and applied across the pulmonary parenchyma

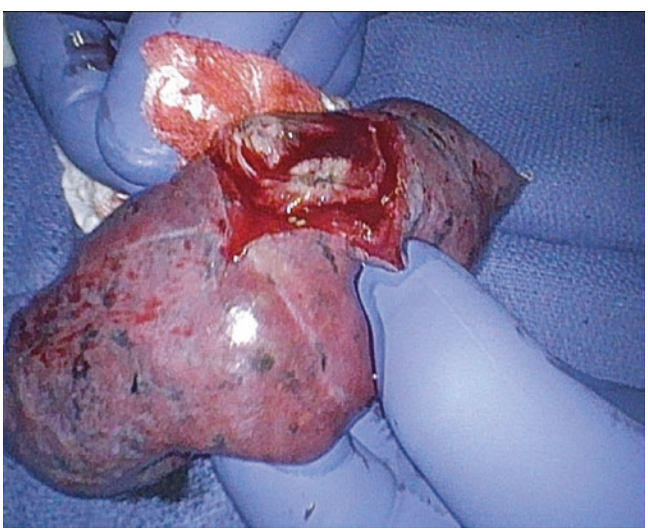

Fig. 5.10 Inspecting the specimen on the operative field

5.3 VATS Resection of the Right Lower Lobe Superior Segment

Juan A. Munoz and Hiran C. Fernando

5.3.1 Technical Point

The technique for a VATS resection of the right lower lobe superior segment is described in this chapter. The patient is in a lateral decubitus position, with the bed flexed at the hips. The surgeon will stand in front of the patient and one assistant will stand posterior to the patient. A monitor is placed at the head of the bed on either side, for the surgeon and assistant respectively. We use the same 4-port technique for anatomical resections of the lung as previously described by McKenna [18] (Fig. 5.11). These are as follows:

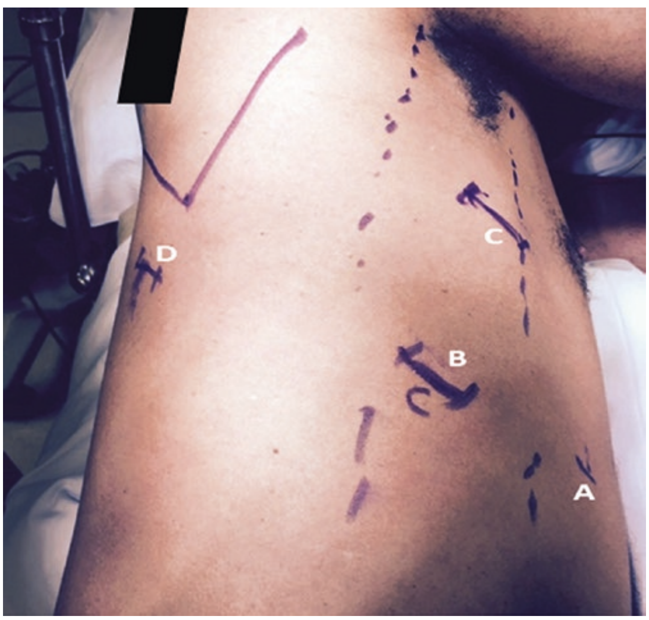

Fig. 5.11 Standard port placement. (**a**) Anterior incision. (**b**) Camera incision. (**c**) Access incision. (**d**) Posterior incision

1. A 1 cm incision is made as far anteriorly and inferiorly as possible (usually the sixth intercostal space in the mid-clavicular line).
2. A 1 cm incision is made in the eighth intercostal space in the mid-axillary line for the cameral port. Generally we use a 10 mm, 30-degree camera.
3. A 4 cm access incision is made starting at the anterior border of the latissimus dorsi muscle and extends anteriorly. The incision is made one interspace below the superior pulmonary vein. We use a soft tissue retractor (Alexis®, Applied Medical, Rancho Santa Margarita, CA 92688), which is especially useful in obese patients to help with visualization and placement of instruments.
4. A 1 cm incision is made posterior and inferior to the tip of the scapula.

5.3.2 Instrumentation

We do not use standard open instruments, as these will be difficult to open and close through the 1 cm port incisions with the hinge-point usually close to the chest wall. We prefer VATS scissors, right angles, and lung graspers such as those produced by Thoramet® (Rutherford, NJ, 07070, USA) or Scanlan International Inc.® (Saint Paul, Minnesota, 55107, USA) (Fig. 5.12). The exception to this will be the use of standard ring forceps (to grab and retract the lung), peanut dissectors, and electrocautery (with an extended insulated flat tip). We will occasionally use a harmonic scalpel, especially when adhesions are present, or in obese or tall patients where reach may be an issue with standard electrocautery.

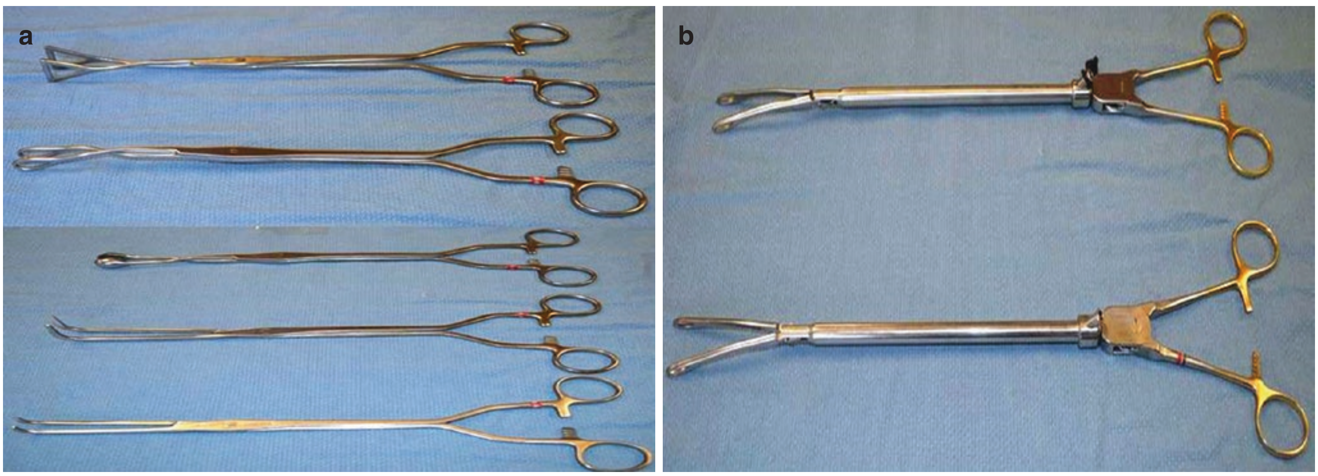

Fig. 5.12 (**a**) Thoramet VATS instruments. (**b**) Landreneau masher grasping forceps (Pilling Surgical®, Horsham, PA, 19044, USA)

5.3.3 Operative Steps

Anatomical landmarks are shown in Fig. 5.13 to be better understanding the procedures.

1. The inferior pulmonary ligament is taken down using electrocautery or harmonic scalpel dissection (Fig. 5.14). Level 8 and 9 lymph nodes are removed as this is done. The inferior pulmonary vein and its superior segmental branch are identified (Fig. 5.15).
2. The dissection then continues superiorly, opening the mediastinal pleura above the inferior pulmonary vein. This allows identification and removal of the subcarinal lymph nodes. The right main bronchus is then identified. As the lung is retracted forward, peanut dissection on the bronchus is performed to expose the bifurcation between the bronchus intermedius and right upper lobe bronchi. The level 11 node at this bifurcation can be removed.
3. The arterial dissection and division is then performed. If the fissure is complete this will be easily identified and dissected at this point. If the fissure is incomplete (Fig. 5.16), attention is turned anteriorly to the fissure between the middle lobe and lower lobe bronchus. The lower pulmonary artery is usually easily identified in this area. Once the artery is identified dissection along the anterior aspect of the artery is performed from an inferior to superior direction, so exposing the arterial branches to the middle lobe and the lower lobes. The superior segmental artery is then encircled and divided using a vascular load endostapler (Fig. 5.17). Our preference is to use the curve-tip staple loads for vascular structures. The superior segmental artery is usually more easily divided from the anterior incision.
4. The superior segmental branch of the inferior pulmonary vein is then divided in a similar fashion to the artery. This is usually divided from the anterior incision (Fig. 5.18).
5. The superior segmental bronchus is usually easily exposed at this point. This is then encircled and divided. Our preference is to use the curve-tip purple-load stapler (Fig. 5.19).
6. A standard (non-curved-tip) stapler is then used to separate the superior segment from the basilar segments (Fig. 5.20). Upwards traction on the divided superior segmental stump will facilitate this (Fig. 5.21).
7. The specimen is placed into an endo-bag and removed from the access incision.
8. Usually one chest-tube is used. We do not use an epidural catheter. An intercostal block and extrapleural catheter (with continuous lidocaine infusion) are used for post-operative analgesia [19].

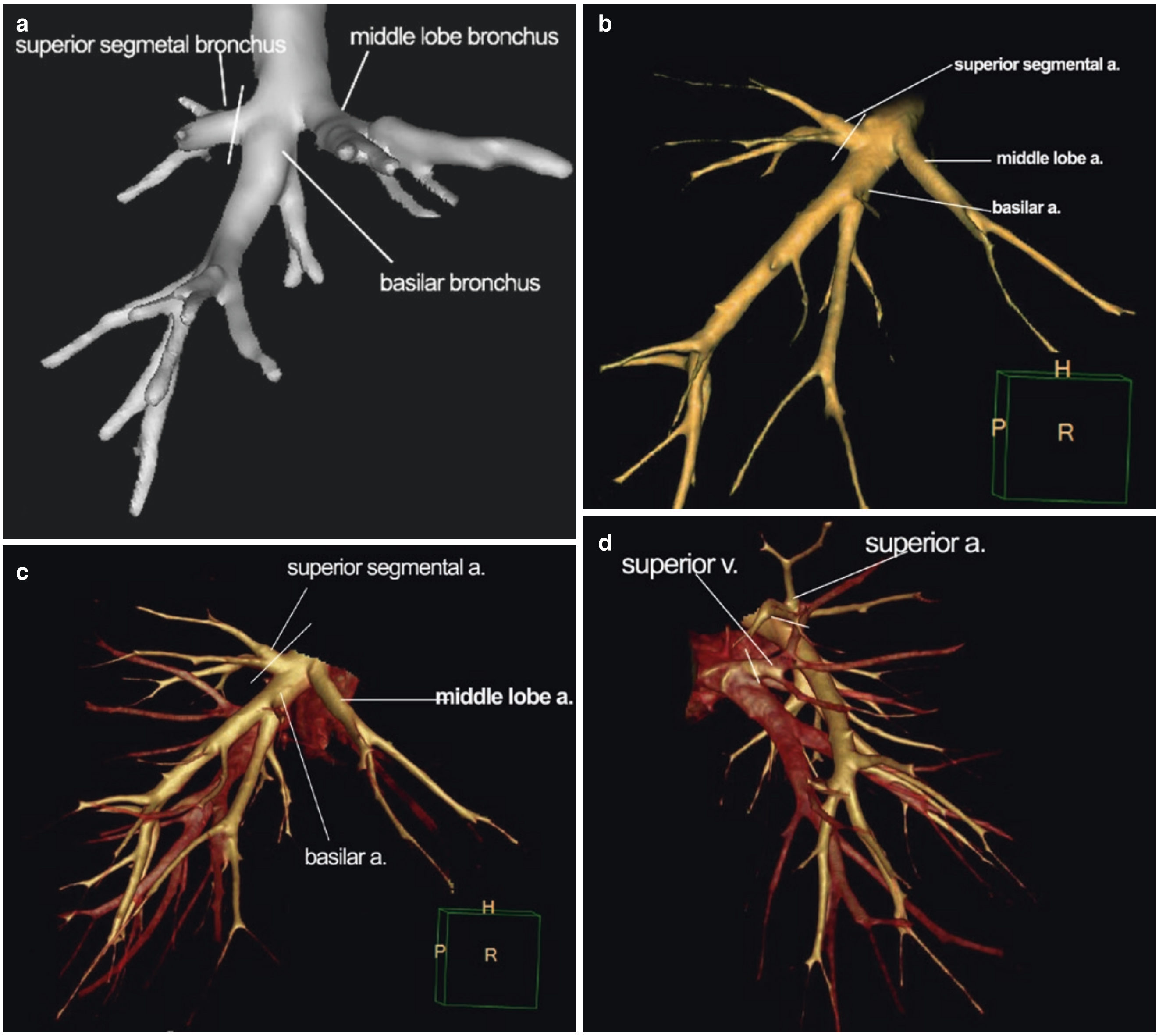

Fig. 5.13 Anatomical landmarks for right lower lobe superior segment

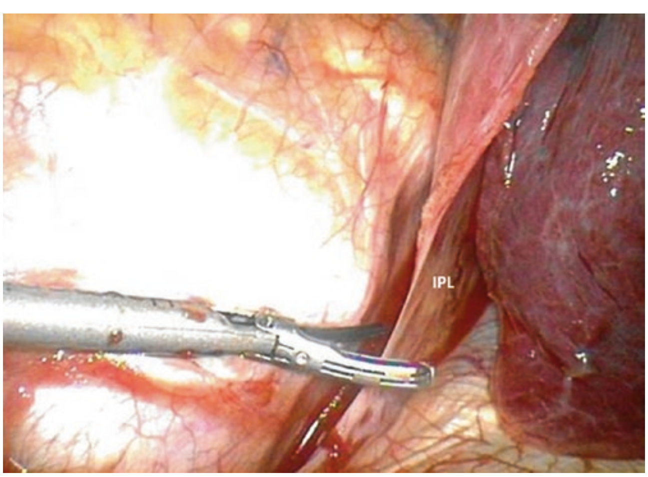

Fig. 5.14 Division of the right inferior pulmonary ligament (IPL)

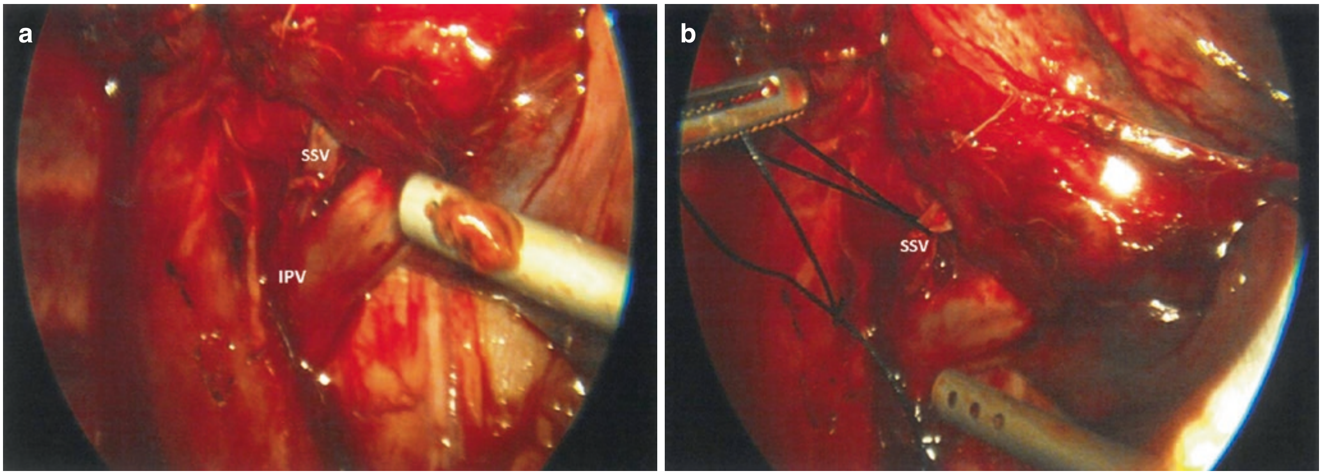

Fig. 5.15 (**a**) Inferior pulmonary vein (IPV) and superior segmental vein (SSV). (**b**) Isolation of the superior segmental branch

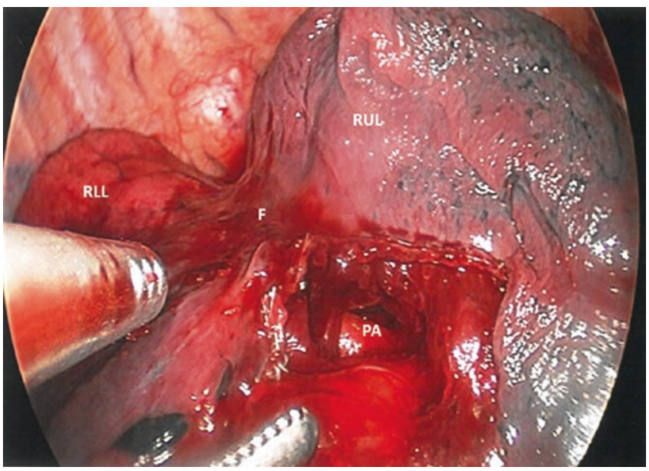

Fig. 5.16 Incomplete fissure (F) has been developed with stapler exposing PA

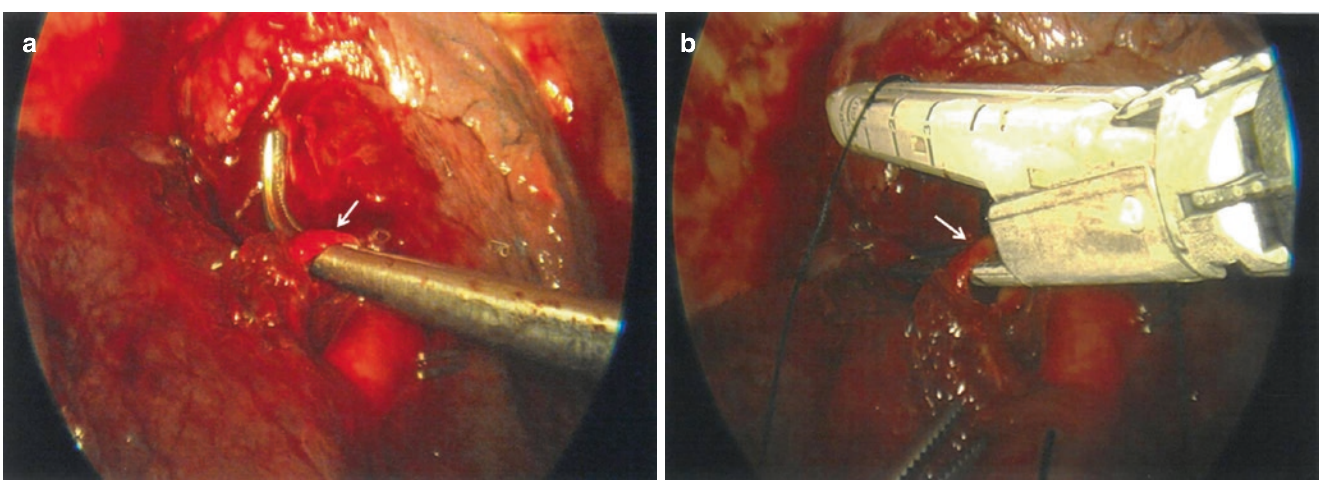

Fig. 5.17 Superior segmental artery (*arrow*). (**a**) Dissection and (**b**) Ligation with curve-tip vascular stapler

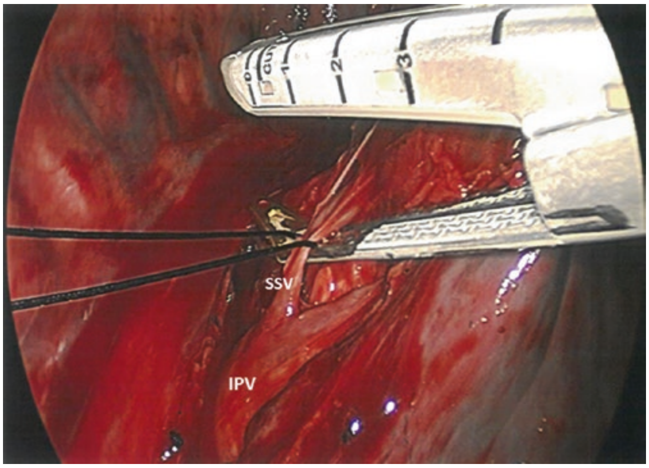

Fig. 5.18 Division of the superior segmental vein (SSV) branch of the inferior pulmonary vein (IPV)

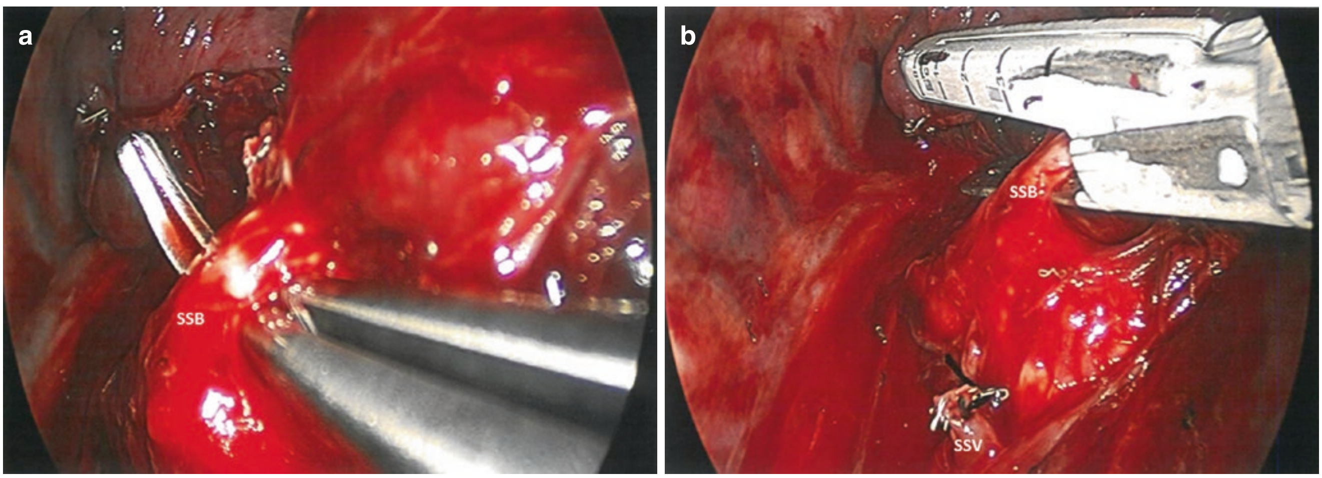

Fig. 5.19 Superior segmental bronchus. (**a**) Isolation and (**b**) Division. (*SSV* divided superior segmental vein)

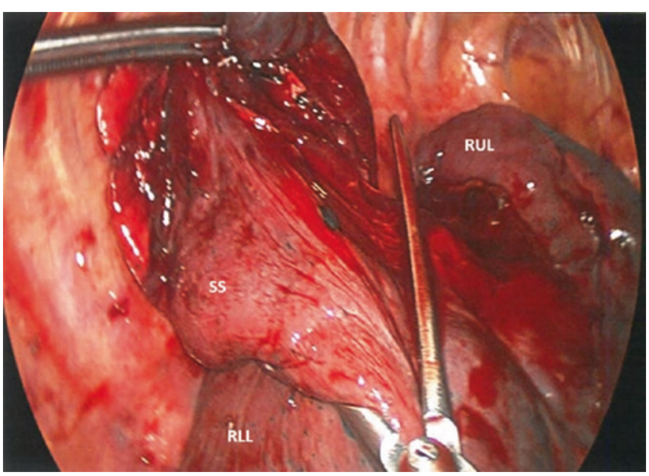

Fig. 5.20 Lung clamp is applied to delineate staple line for division of superior segment from basilar segments

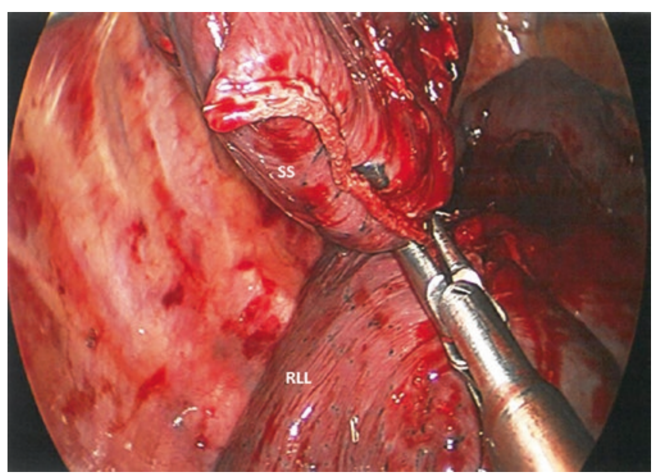

Fig. 5.21 Stapling and resection of the right lower lobe superior segment

5.4 Left Upper Lobe: Trisegments

Simon R. Turner and Brian E. Louie

5.4.1 Technical Tips

VATS left upper lobe trisegmentectomy, also known lingula-sparing left upper lobectomy, is a potentially challenging thoracoscopic procedure. It requires a thorough understanding of the relational anatomy, particularly the juxtaposition of the anterior and apicoposterior segments of the pulmonary artery, the bronchus of the upper lobe proper and the pulmonary veins [20–27]. Although we describe our preferred VATS approach, we use the same approach when conducting a robotic trisegmentectomy. The following key points should be kept in mind:

- The left upper lobe has more direct branches originating off the main pulmonary artery than any other lobe, which creates more potential for injury during dissection of these vessels.
- The surgeon must be prepared to approach the relevant arterial anatomy from a variety of different ports and potentially with several methods to secure the vessels including clips, energy sealing and endo-stapling.
- The upper lobe bronchus can be approached from posterior after division of the apicoposterior artery branches or from anterior after division of the upper lobe vein branches
- Identification of the most proximal lingular branch of the pulmonary artery is required before parenchymal division to avoid division of an aberrant lingular artery arising proximally and running deep to the pulmonary vein.

5.4.2 Anatomical Landmarks (Fig. 5.22a–d)

- **Veins**: The left superior pulmonary vein is the most anterior structure in the left hilum, lying just inferior to the first upper lobe arterial branches and just anterior to the left upper lobe bronchus. The first division of this vein is into the apical branch, superiorly, which drains the anterior and apicoposterior segments, and the lingular branch, inferiorly.
- **Arteries**: The anterior trunks of the left pulmonary artery can generally be found at, or just superior to, the upper border of the left superior pulmonary vein. These branches may be short, wide and multiple. The upper division of the lobe is also supplied by a variable number of apicoposterior branches. These are most easily identified by a posterior approach to the hilum at the level of the fissure. When identified, these are preferentially divided first to improve access to the truncal branch, which can be divided from the either a posterior or anterior approach.
- The lingular arteries, which are preserved during trisegmentectomy, are most often found distally and superficially within the anterior aspect of the fissure. However, an important anatomic variant to be aware of is a proximal origin of the lingular artery, arising near the anterior branches and running deep to the superior pulmonary vein. This anomalous branch is at risk for injury during dissection of the vein or may be inappropriately divided, eliminating the possibility of sparing the lingula. Thorough review of the pre-operative CT scan can help to avoid such complications.
- **Bronchus**: The left upper lobe bronchus is largely surrounded by vascular structures. The superior pulmonary vein overlies the bronchus, while the anterior and apicoposterior arterial branches are adjacent to the superior and posterior surfaces of the bronchus, respectively. These structures, with the possible exception of the apicoposterior arterial branches, must be divided prior to fully dissecting the branches of the bronchus. The first major division of the upper lobe bronchus is into the upper division superiorly and the lingular division inferiorly.

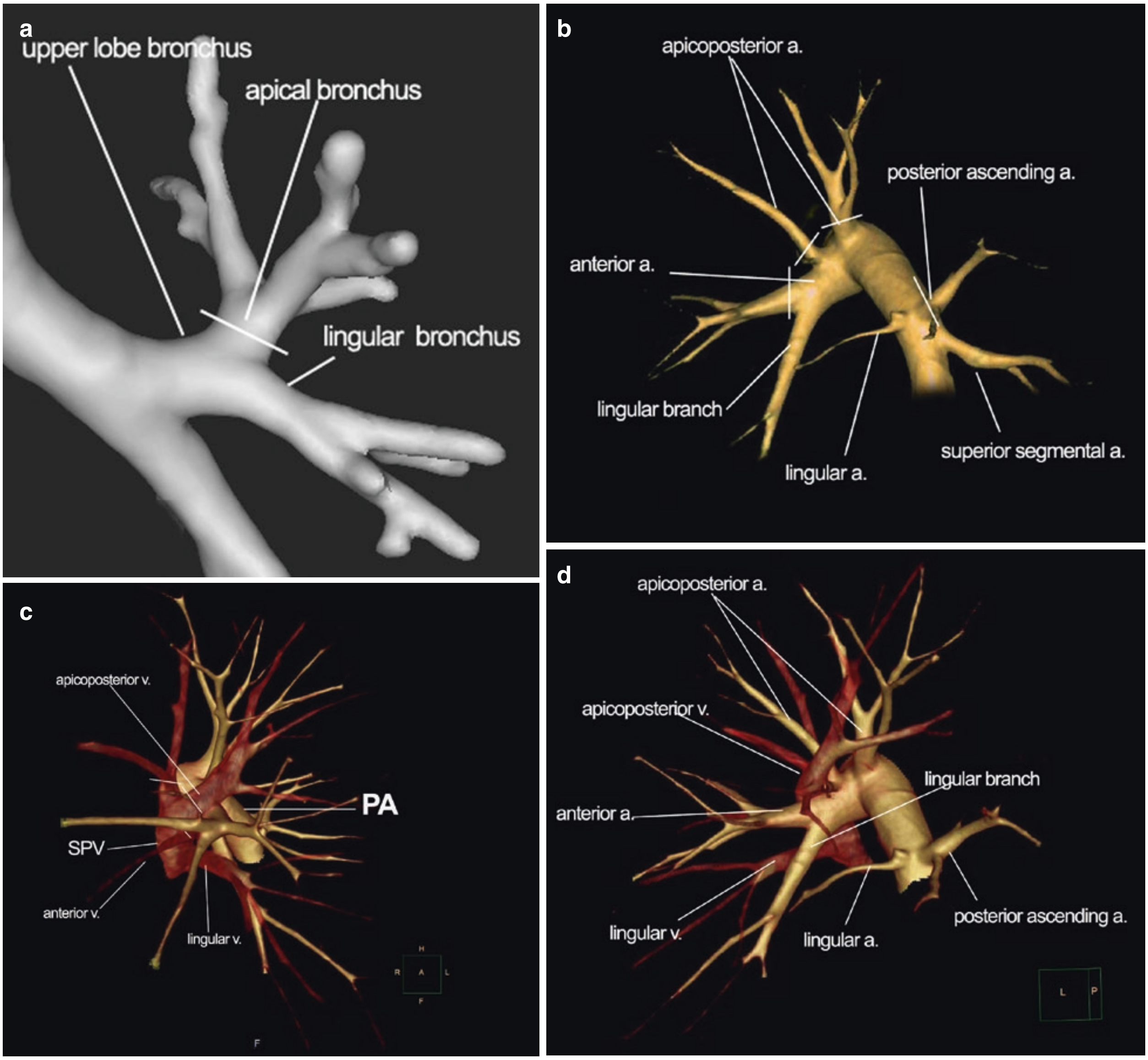

Fig. 5.22 Anatomical landmarks for left upper lober trisegments

5.4.3 Operating Procedure

1. The patient positioned in right lateral decubitus with the bed flexed to ensure the hip is level with the chest wall. Ports are placed as follows: (A) 10 mm in the seventh intercostal space, posterior axillary line; (B) 5 or 10 mm in the line of the scapular tip, at the level of the dome of diaphragm, which approximates the ninth interspace, for the 5 or 10 mm, 30° camera; (C) 10 mm placed inferior and slightly posterior to the scapula, lining up one rib space below the tip of the superior segment; and, (D) 10 mm in the posterior axillary line in the fourth intercostal space, directed at the superior pulmonary vein (Fig. 5.23). It is not necessary to create a large working incision, as the entire procedure can usually be conducted through these small ports. The specimen is extracted by enlarging port B to 5 cm.
2. The lower lobe is pushed to the apex of the thoracic cavity with ring forceps and held via port D. The inferior pulmonary ligament is divided using the L hook to the inferior base of the hilum and the station 9 lymph node packet removed (Fig. 5.24).
3. The lower lobe is then retracted anteriorly to expose the pleural reflection and aorta. The pleura is then divided from the inferior vein to the top of the pulmonary hilum with the L hook to expose the main bronchus, pulmonary artery and vagus nerve (Figs. 5.25 and 5.26).
4. Using cotton tipped dissectors and the L hook, the tissue between the superior aspect of the inferior vein and the inferior aspect of the main bronchus is opened to expose station 7. Commonly, a bronchial artery can be identified as station 7 is exposed (Fig. 5.27). All lymph nodes in the area are then removed and the area packed with hemostatic, absorbable gauze.

Tips

When performing mediastinoscopy at the same stage of a planned lung resection, leave hemostatic, absorbable gauze in the location of the nodes that were biopsied, especially 4L and 7. At the time of subsequent thoracoscopic mediastinal lymph node dissection, this will serve as a landmark to ensure you have identified the correct location of these nodal stations.

5. Station 4L can be accessed just superior to the edge of the bronchus and the posterior aspect of the pulmonary artery. If a mediastinoscopy is performed pre-operatively with biopsy of station 4L, this remaining node dissection is greatly facilitated (Fig. 5.28).

Tips

Performing mediastinal lymph node sampling at the beginning of the operation allows time for pathologic analysis and facilitates dissection of vascular structures.

6. The lung is then retracted posteriorly and inferiorly to expose the aortopulmonary window. The vagus is visualized passing vertically over the arch of the aorta, providing the posterior landmark for the recurrent laryngeal nerve, which must be avoided. Similarly, the phrenic nerve is identified anteriorly. Dissecting between these structures stations 5 and 6 nodal stations are exposed and removed (Fig. 5.29).

   Removing these lymph nodes at this point completes the mediastinal staging and also facilitates later exposure of the anterior arterial branches.
7. Retracting the upper lobe anteriorly and away from the hilum, the posterior aspect of pulmonary artery is identified. Gentle blunt dissection and careful use of the L hook will expose the main artery and its apicoposterior and superior segmental branches (Fig. 5.30). At times, a small portion of the fissure may require division to access these vessels.
8. The apicoposterior branches to the upper lobe are then divided. Care is taken to identify and preserve the superior segmental artery of the lower lobe, which arises in close proximity to the posterior upper lobe branches (Fig. 5.31).
9. After division of the arterial branches, the next steps depend on the completeness of the fissure and/or ability to identify the interlobar pulmonary artery:
   A. If the fissure is complete, it is opened with the L hook, though recently, we have found bipolar energy shears to be helpful here. The dissection is carried onward until the lingular branches are identified and confirmed by gentle forward traction on the lingular segment.
   B. If the fissure is partially complete but the pulmonary artery is visible, the pleura will be opened atop of the artery. Once in the correct plane, the artery will be pushed away from the lung creating a tunnel toward the superior aspect of the fissure (Fig. 5.32). The fissure can then be completed with a stapler to expose the interlobar artery and the origin of the most proximal lingular branch (Fig. 5.33).
   C. If the fissure is incomplete and the interlobar artery not visible, the anterior hilar dissection is begun by dividing the pleural reflection from the inferior vein to the area of the superior hilar dissection. The superior pulmonary vein is visualized and defined through a combination of gentle blunt dissection with the suction and sharp dissection with cautery to expose the borders of the vein and its division into the apical branches superiorly and the lingular branches inferiorly. Removal of the lymph nodes between the superior and inferior veins anteriorly often opens up the space needed to identify the interlobar pulmonary artery and the distal lingular branch. From this space, completion of the fissure can be performed if necessary to identify these branches.

10. Gentle traction on the lingula helps to delineate the lingular vein(s) clearly to preserve them (Fig. 5.34). The vascular stapler then divides the apical vein branch(es), further exposing the anterior arterial branches and the bronchus.
11. The lymph node overlying the origin of the anterior arterial branches from the main pulmonary artery is identified. Removal this node facilitates subsequent dissection of the anterior arteries (Fig. 5.35).

Tips
Removal of lymph nodes found at the branch points of arteries and bronchi helps to facilitate dissection and allows for intra-operative pathologic analysis. Positive nodes warrant completion lobectomy in patients who will tolerate it.

12. Dissection of the truncus anterior is potentially the most hazardous step of the operation. This branch or sometimes branches may often be short, wide and multiple, and injury can be fatal. Also beware an aberrant lingular artery with an origin in this location and running deep to the vein. Injury to this artery can also be difficult to control and inadvertent division mandates an upper lobectomy. Because the branch is often intimately associated with the apical bronchus, it is viewed from anteriorly and then posteriorly. Where access is easiest, gentle dissection with a right angle clamp or Harkin 1 is performed to delineate each branch. Division with a vascular stapler can be accomplished via port A or port C (Fig. 5.36).

Tips
The utmost care must be taken when dissecting the anterior arterial branches. Pre-operative review of the CT scan will help to identify normal and variant anatomy [21]. A thin layer of surgical lubricant along the stapler anvil and cartridge prevents excess staples from falling into the chest.

13. At this point, the bronchus is evaluated again anteriorly and posteriorly and will be the most superior structure remaining in the hilum. With the lung retracted anteriorly, the tissue on the bronchus can be gently pushed distal with a cotton-tipped dissector. This will expose the carina between the upper and lingular bronchus (Fig. 5.37).
    Alternatively, retracting the lung again posteriorly will identify the bronchus just past the divided superior vein. Gentle blunt dissection sweeping the tissue onto the bronchus will identify the segmental carina. Placing outward traction on the upper lobe helps to lengthen the bronchus and makes dissection easier. Segmental nodes are found at the division of the bronchus into the apical and lingular bronchi. These nodes are removed and also sent for intra-operative pathology.
14. The apical bronchus is encircled with a clamp or the jaws of the stapler and closed. The lingula is then inflated gently. This delineates the parenchymal division between the apical segments and the lingula (Fig. 5.38). The apical bronchus can then be safely divided with the stapler.
15. The entire upper lobe is then oriented in its normal anatomic position. The stapler is advanced from port C and the line between inflated and deflated lung is followed (Fig. 5.39). Lifting the distal end of the divided bronchus via port D can help to navigate the lung into the jaws of the stapler while avoiding the remaining intact hilar structures and ensuring the segmental bronchus is included in the specimen [22].

Tips
To clearly mark the intersegmental plane on the lung parenchyma, ask the anesthesiologist to inflate the lung after the upper division bronchus is divided. This will guide the parenchymal stapling quickly and accurately.

16. Once completely separated, the specimen is placed into a retrieval bag. An extraction port is created from the camera port anteriorly along the ninth rib, which has a wide interspace, which we feel causes less pain.
17. Finally a thorough check for hemostasis is performed, including all staple lines, nodal stations and incisions. The chest is irrigated with warm water and the lung is partially inflated to check for air leaks, especially at the bronchial staple line. A single straight chest tube is placed via port A and directed along the lateral chest wall to the apex. Intercostal blocks are placed using long acting local anesthetic. The lung is fully re-inflated under thoracoscopic vision and incisions closed.

5.4.4 Conclusion

Although technically challenging, VATS trisegmentectomy is an important tool for thoracic surgeons to have in their arsenal. As the trend towards earlier detection of smaller lung tumors and the push to operate on patients with marginal pulmonary reserve continues, there will be a continued need for this, and other parenchyma-preserving procedures, to be performed. With a thorough knowledge of the relevant anatomy and the steps outlined above, VATS trisegementectomy can be performed safely, efficiently and in an oncologically effective manner.

5.4.5 Acknowledgements

The authors would like to acknowledge Drs. Ralph Aye and Eric Vallières for lending their expertise and experience for the content of this chapter.

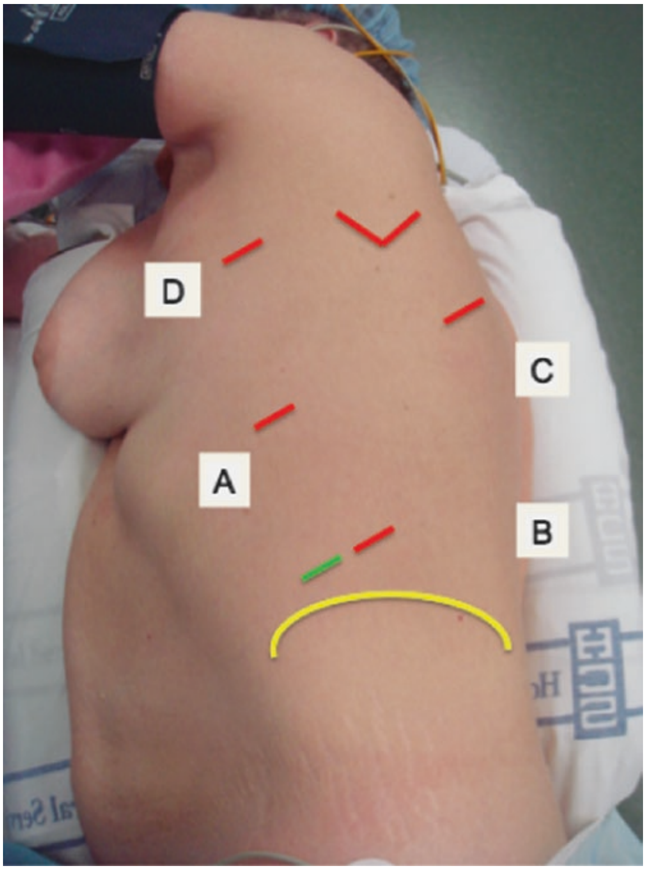

Fig. 5.23 Positioning and port placement

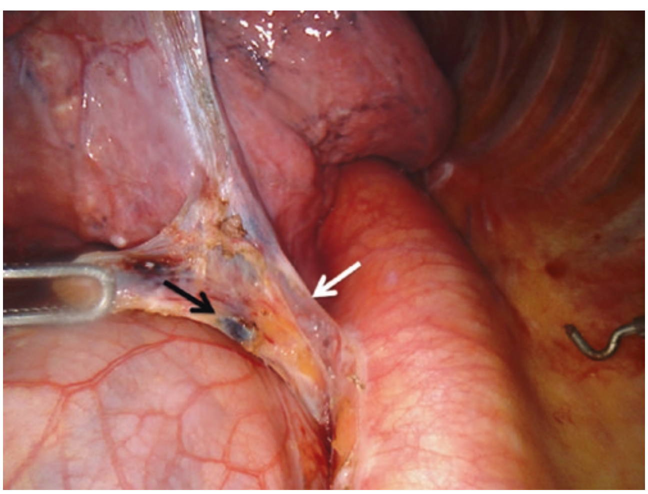

Fig. 5.24 Division of the inferior pulmonary ligament (*white arrow*), exposing station 9 nodes (*black arrow*)

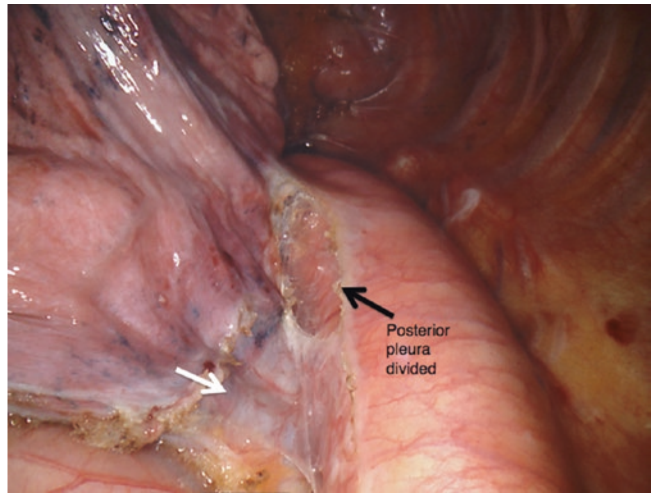

Fig. 5.25 Division of the posterior hilar pleura (*black arrow*) to expose the pulmonary artery. The inferior pulmonary vein is visible (*white arrow*)

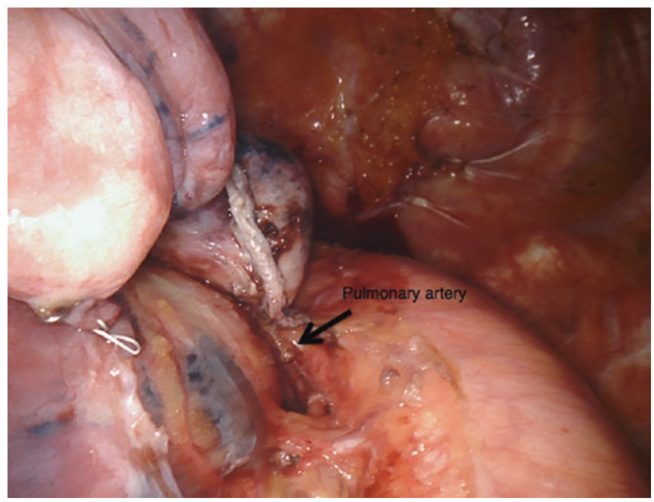

Fig. 5.26 The pulmonary artery (*black arrow*) is visible posteriorly once the pleura is completely divided

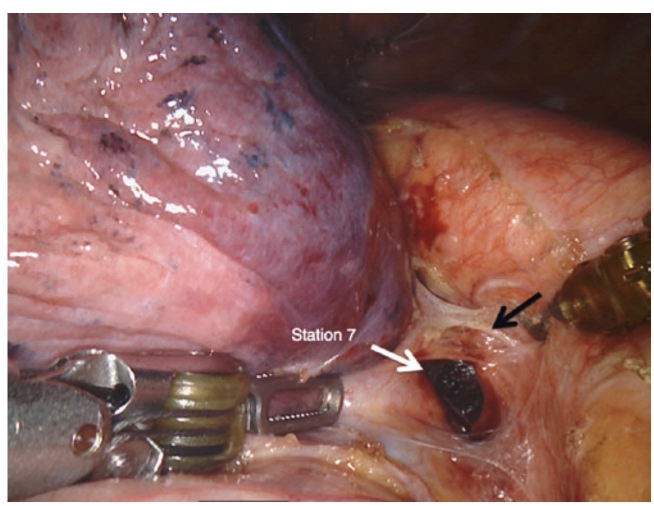

Fig. 5.27 Exposure of station 7 with visualization of a bronchial artery (*black arrow*) and hemostatic gauze (*white arrow*) placed previously during mediastinoscopy

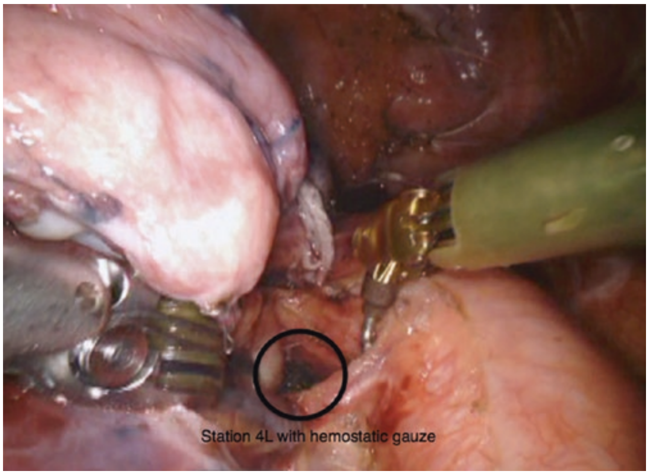

Fig. 5.28 Exposure of station 4L (*circle*) with visualization of hemostatic gauze placed previously during mediastinoscopy

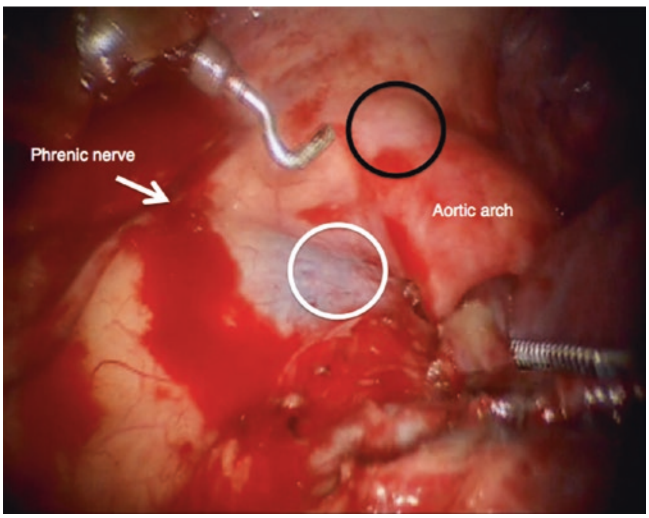

Fig. 5.29 Exposure of the AP window to expose stations 5 (*white circle*) and 6 *black* (*circle*). The phrenic nerve is preserved (*white arrow*)

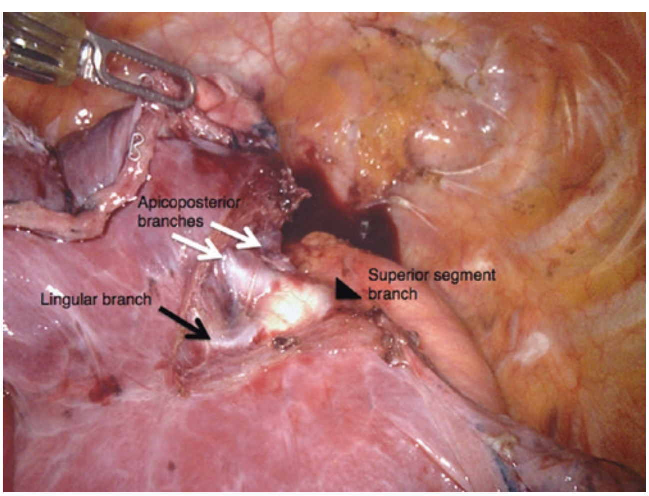

Fig. 5.30 Partial division of the fissure may be necessary to expose the apicoposterior (*white arrows*) lingular (*black arrow*) and superior segment (*arrowhead*) branches of the pulmonary artery, visualized posteriorly

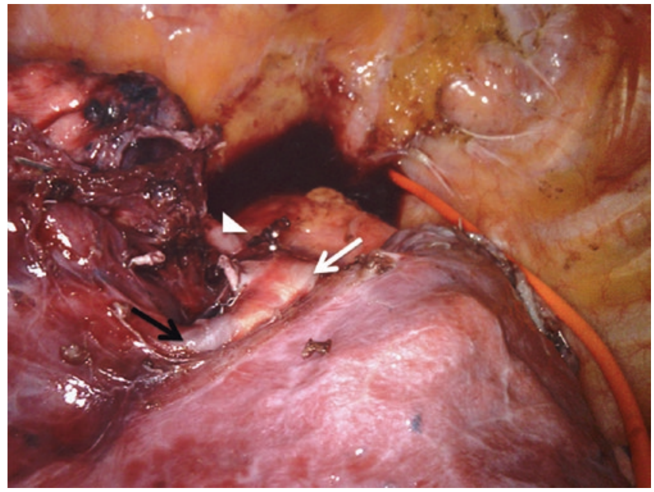

Fig. 5.31 After division of an apicoposterior branch, a lingular branch (*black arrow*), superior segment branch (*white arrow*) and an additional apicoposterior branch (*arrowhead*) are visible

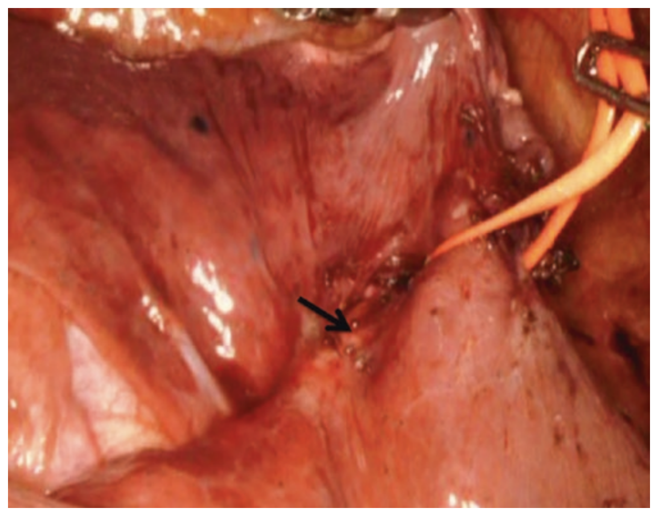

Fig. 5.32 Creation of a tunnel over the interlobar pulmonary artery (*black arrow*) in order to divide an incomplete fissure

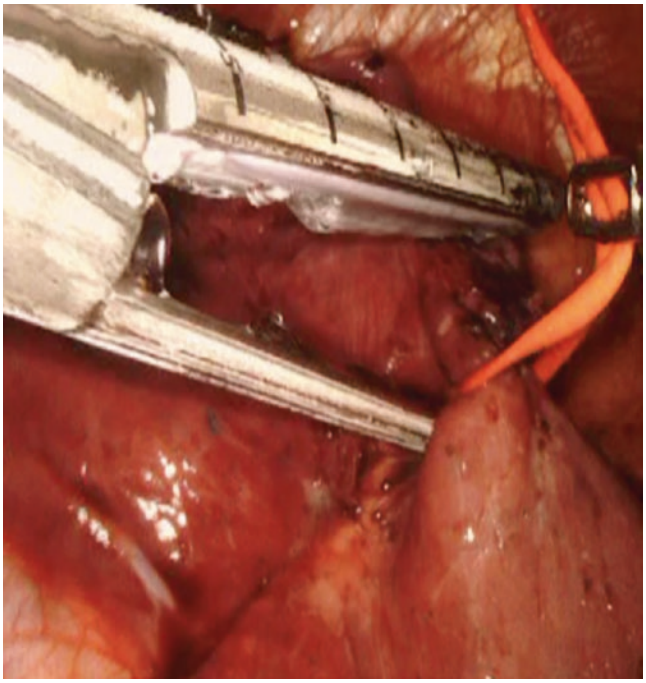

Fig. 5.33 Division of an incomplete fissure using a stapler

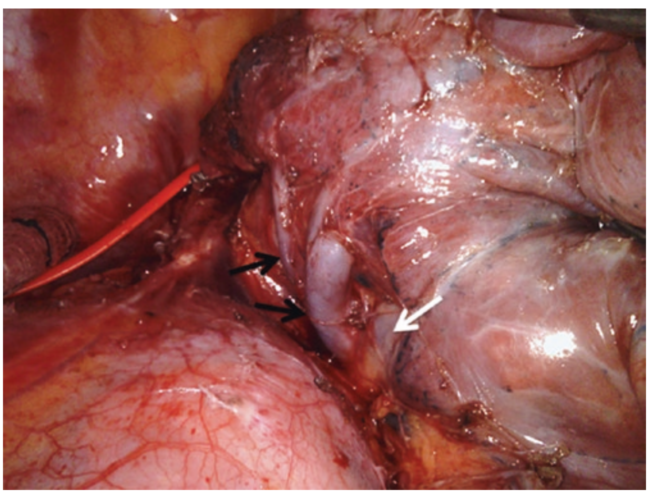

Fig. 5.34 Superior (*black arrows*) and inferior/lingular (*white arrow*) divisions of the superior pulmonary vein

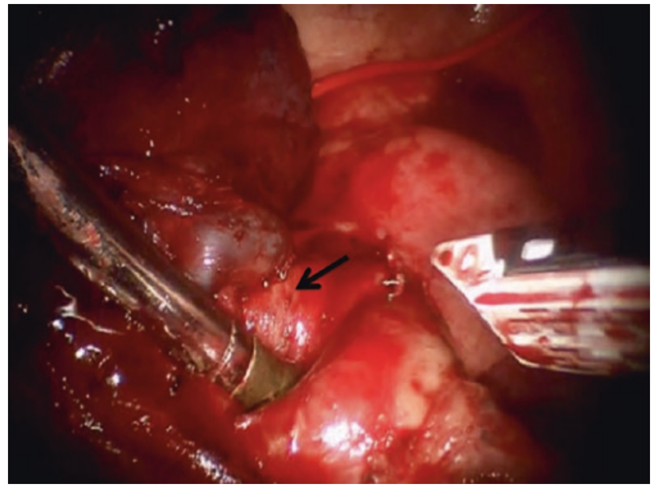

Fig. 5.35 Posterior view of the truncus anterior artery (*black arrow*) with nodes removed

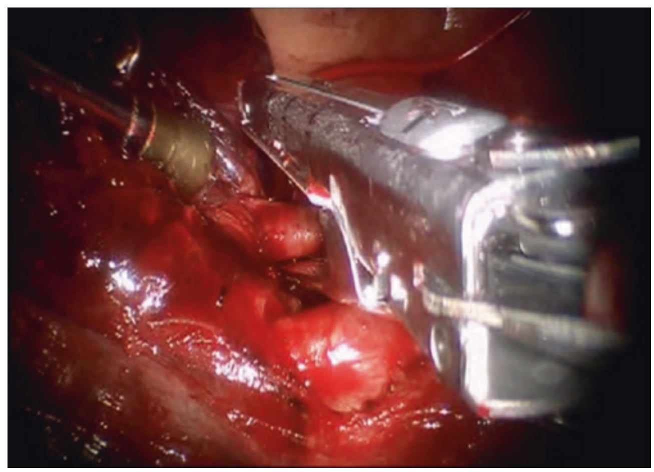

Fig. 5.36 Division of the truncus anterior artery using a stapler via port C

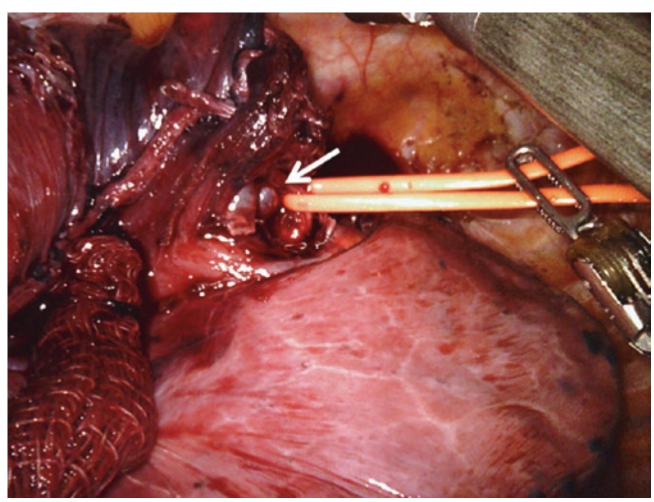

Fig. 5.37 With the lung retracted anteriorly, the superior division (*white arrow*) of the upper lobe bronchus is dissected out

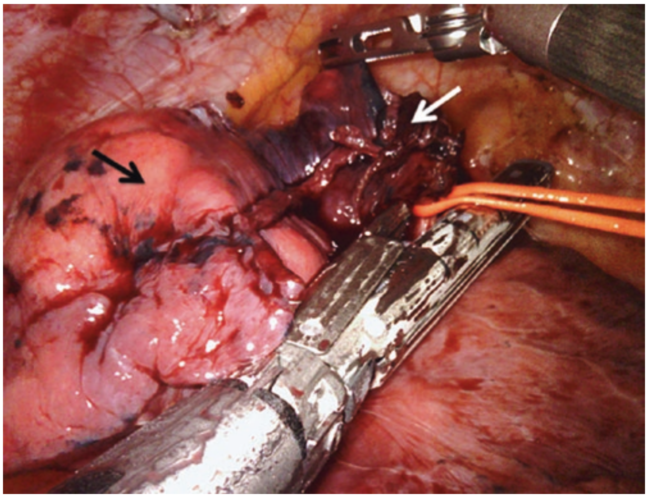

Fig. 5.38 Bronchial division with inflated lingula (*black arrow*) and collapsed apical segments (*white arrow*). In this case a wedge resection has been previously performed to confirm the diagnosis of malignancy

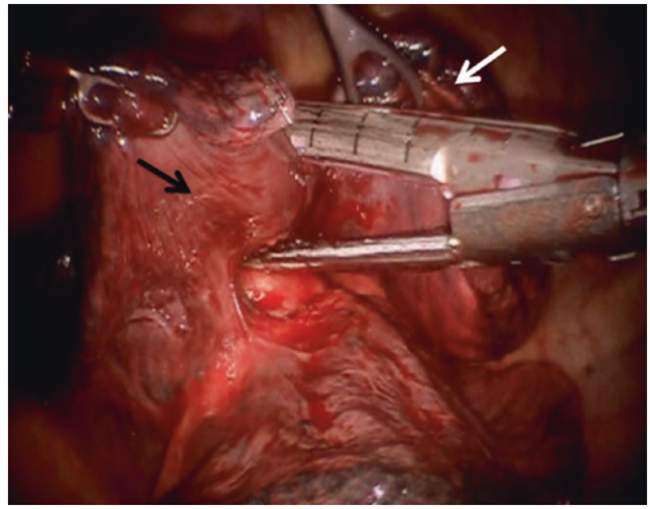

Fig. 5.39 Parenchymal division to resect the apical segments (*white arrow*), preserving the lingula (*black arrow*)

5.5 Left Upper Lobe: Lingular Segment

Jennifer L. Wilson and Michael S. Kent

5.5.1 Technical Points

VATS lingulectomy (segments 53 and 54) is usually a straightforward segmentectomy, however one should be mindful of aberrant anatomy as with any pulmonary resection. The lingula is approached in an anterior to posterior direction. The posterior fissure does not need to be dissected therefore minimizing risk of air leak postoperatively.

Formal lymphadenectomy or sampling should be performed with any cancer operation. During this procedure it is our routine to sample mediastinal stations 5, 6, and 7 as well as hilar nodes. Node sampling will not be described in this chapter.

5.5.2 Anatomic Landmarks (Fig. 5.40)

- Bronchus: The lingular bronchus is the inferior-most branch of the upper lobe bronchus. It is often helpful to clamp the lingular bronchus and inflate the lung prior to dividing it to confirm inflation and therefore preservation of the upper division bronchus. This maneuver also helps the surgeon identify the parenchymal transection plane between the upper division and the lingula.
- Artery: The lingular artery may be single or multiple. It is encountered first when dissecting in an anterior-posterior direction in the fissure. A second artery may be present arising from the truncus.
- Vein: The lingular vein is the most inferior branch of the superior pulmonary vein which commonly branches into the apicoposterior, anterior and lingular veins. However, if more than 3 branches are present, one may divide the vein last to ensure correct identification of the lingular vein.

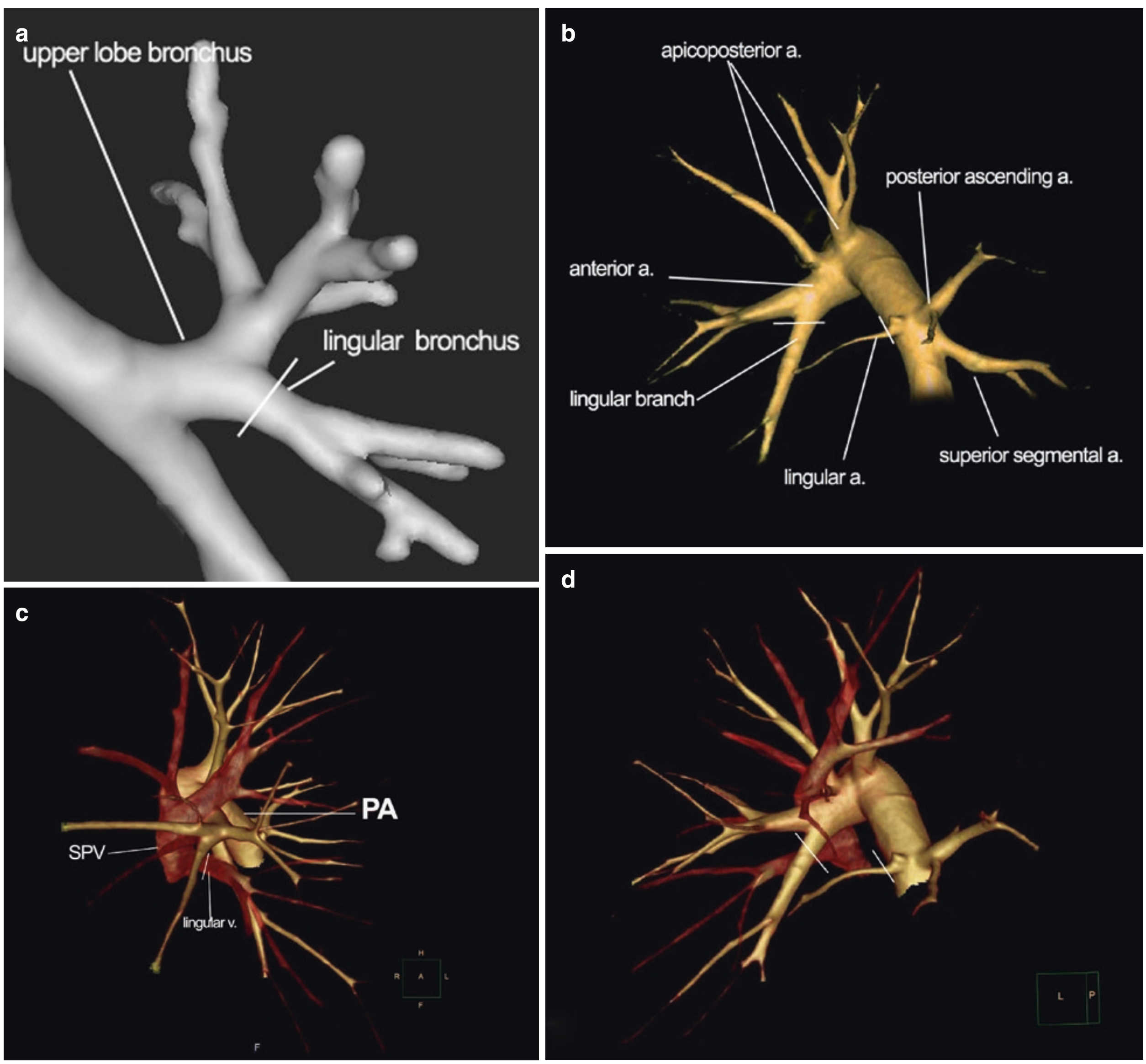

Fig. 5.40 3D reconstruction of anatomic landmarks

5.5.3 Operating Procedure

1. Port placement:
   - Five millimeter camera port sixth intercostal space mid axillary line
   - Twelve millimeter utility port fourth intercostal space anterior axillary line
   - Ten millimeter seventh intercostal space anterior axillary line
   - Ten millimeter sixth intercostal space posterior axillary line
2. First, the lingular artery is identified in the fissure (Fig. 5.41). A combination of electrocautery and sharp dissection facilitates entry into the avascular plane overlying the artery. There may be 1 or 2 lingular artery branches. The artery is then isolated and divided using a vascular stapler (2.5 mm staple height) with care to avoid any tension on the artery with the stapler.
3. The lingular bronchus is then identified and isolated in the anterior hilum (Fig. 5.42). Removal of the hilar lymph nodes that surround the bronchus facilitates staging and isolation of the bronchus. Once the lingular bronchus is isolated, it is clamped using the endoscopic stapler (3.5 mm staple height) and the lung is ventilated to confirm preservation of the upper division bronchus. Once proper identification of the lingular bronchus is confirmed, the bronchus is divided (Fig. 5.43).
4. Retracting the lung posteriorly and dissecting anterior hilar attachments exposes the lingular vein which is the lower-most tributary of the superior pulmonary vein (Fig. 5.44). The lingular vein is isolated and divided using a vascularendoscopic stapler (2.5 mm staple height).
5. The parenchyma is then divided between the upper division and lingula using multiple endoscopic staplefirings (3.5 mm staple height). It can be helpful grasp the divided specimen side of the lingular bronchus while advancing the parenchyma onto the stapler. Also, it is wise to confirm preservation of the upper division structures by visualizing them anteriorly prior to firing the stapler (Fig. 5.45). The parenchyma can subsequently be divided safely (Fig. 5.46).
6. The specimen is removed using a laparoscopic extraction bag through the utility incision.

Tips
Do not divide the anterior fissure without identifying the lingular artery first.

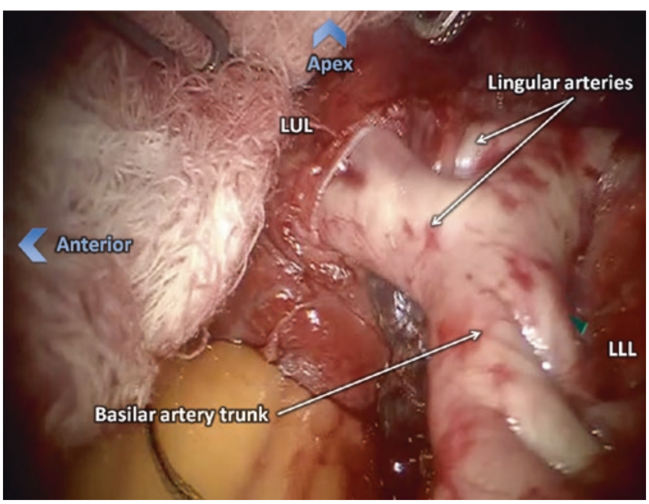

Fig. 5.41 The anterior fissure is dissected exposing the lingular artery

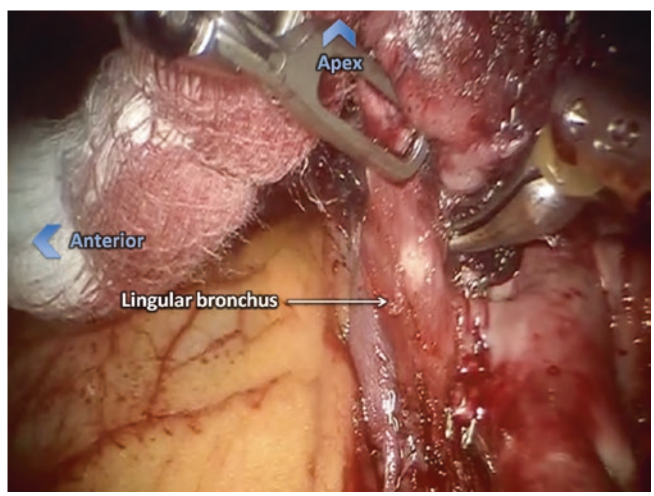

Fig. 5.42 The lingular bronchus is identified and isolated

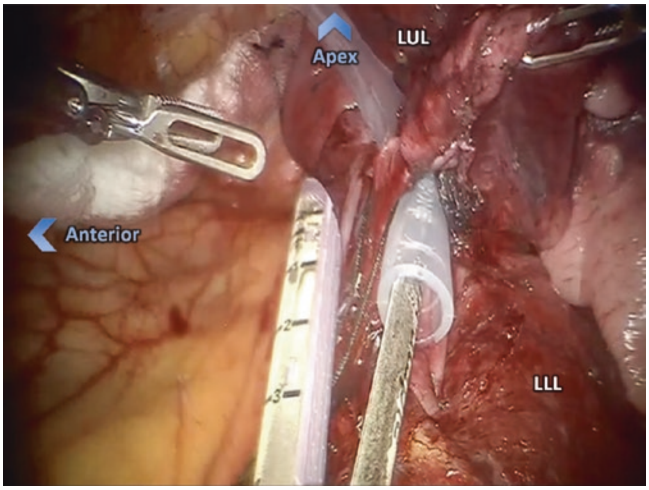

Fig. 5.43 The lingular bronchus is divided using an endoleader (Modified foley catheter used as endo-leader)

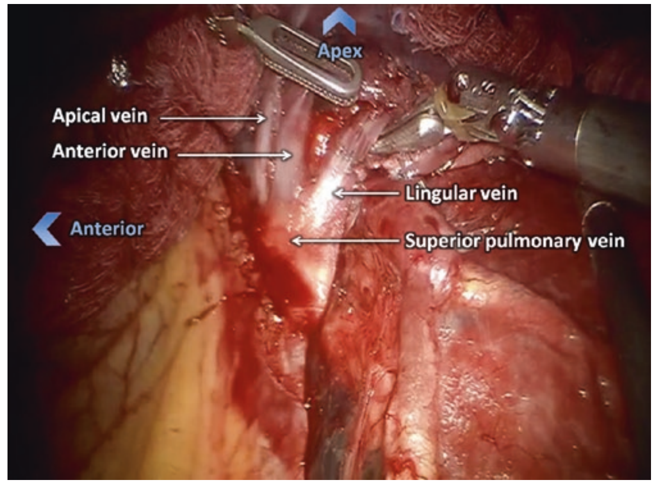

Fig. 5.44 Identification of the lingular vein as the inferior-most branch of the superior pulmonary vein

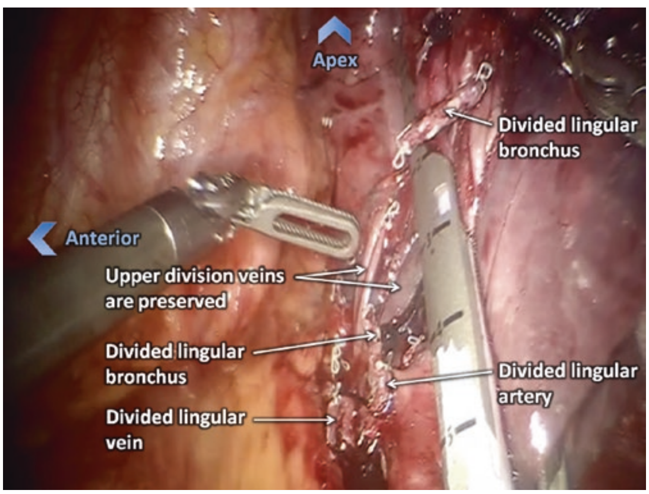

Fig. 5.45 Incisions for a left lower lobe superior segmentectomy

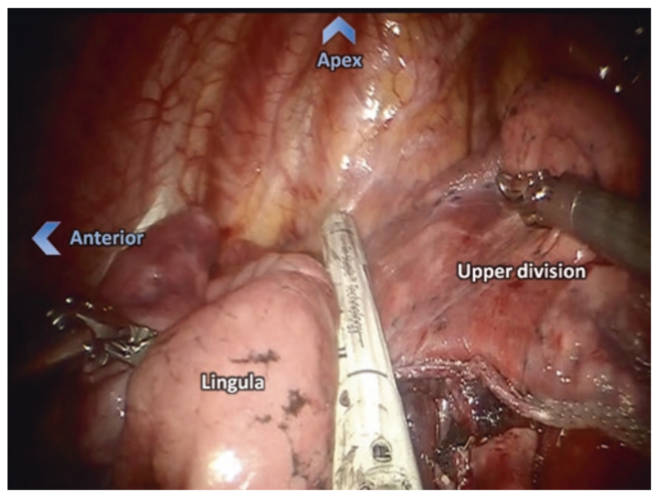

Fig. 5.46 Tunnel from fissure to posterior mediastinum

5.6 Left Lower Lobe Superior Segmentectomy

Robert J. McKenna Jr.

5.6.1 Technical Points

Resection of the Superior Segment of the Left Lower lobe can be approached from anteriorly or posteriorly. Key issues include defining the anatomy and determining the separation between the superior segment and the basilar segments:

- With an anterior approach, the order of events is complete the posterior aspect of the fissure, transect the segmental artery, segmental bronchus, segmental vein, and finally the fissure to separate the basilar segments.
- For the anterior approach, if the fissure is nearly complete, to complete the fissure between the superior segment and the posterior segment of the left upper lobe clearly define the artery to the superior segment so that the procedure can proceed easily.
- With a posterior approach, the order of events is staple the vein, transect the segmental bronchus, segmental artery, segmental vein, and finally the fissure to separate the superior segment.
- For the posterior approach, resection of the subcarinal nodes helps to identify the pulmonary artery and the vein from posteriorly.

5.6.2 Anatomical Landmarks for Artery, Vein, and Bronchus of the Superior Segment (Fig. 5.47a–d)

- **Artery**: The lower lobe, superior segmental artery is most anterior of the three structures. It is the first artery from the left pulmonary artery to supply the lower lobe. The next arterial branch usually goes to the lingula, and finally, the last two branches go to the basilar segments.
- **Bronchus**: The superior segmental bronchus runs parallel to the artery. It is located posteriorly and often minimally superiorly to the artery. Lymph nodes are normally between arteries and bronchi at the origin of a bronchus, such as the superior segmental bronchus.
- **Veins**: The vein from the superior segment is posterior to the artery of the superior segment and inferior to the bronchus. It angles obliquely from the bronchus and does not course parallel to the bronchus. It is usually small.

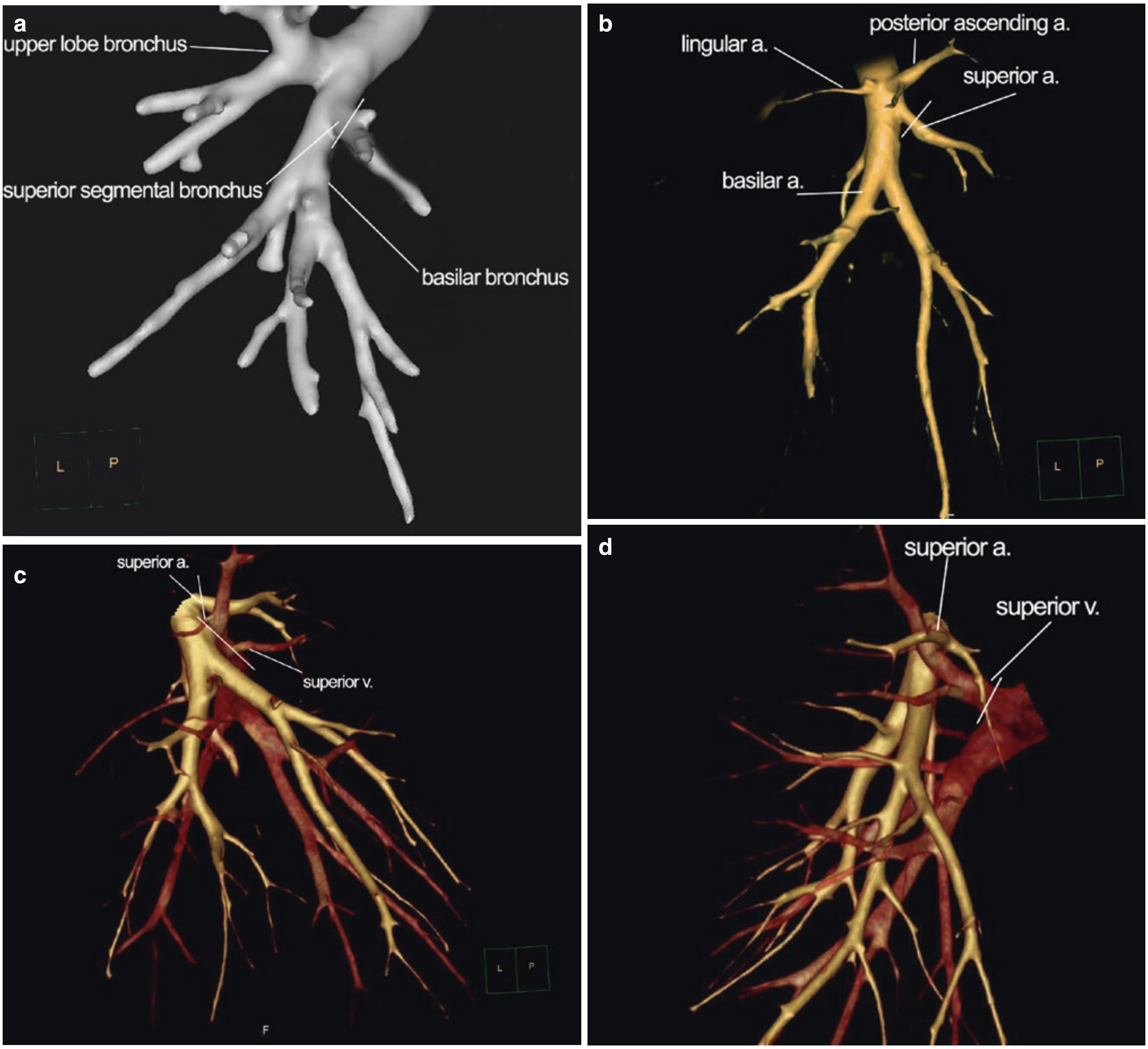

Fig. 5.47 Anatomical landmarks. (**a**) Superior segmental bronchus (*left lateral view*). (**b**) Superior segmental artery (*left lateral view*). (**c**) Relationships between arteries and veins of superior segment (*left lateral view*). (**d**) Relationships between arteries and veins of the trisegments (*posterior view*)

5.6.3 Operating Procedure

1. Incisions: The standard incisions for a superior segmentectomy are seen in Fig. 5.48. Incision 1 is in about the eighth intercostal space in the posterior axillary line. Incision 2 is as far inferiorly and medially as possible. It is usually one space below the breast crease. Incision 3 is directly up from the superior pulmonary vein. It extends about 3 cm from the anterior border of the latissimus muscle.
2. The fissure between the posterior segment of the left upper lobe and the superior segment of the left lower lobe is opened so the artery for the superior segment is fully exposed. If the fissure is quite complete, the pleura over the artery is divided with cautery or energy to expose the artery from just proximal to the origin of the basilar arteries to the superior extent of the fissure. If the fissure is more incomplete, dissection on the artery creates a tunnel to facilitate completing the fissure. The stapler passes through incision 2; and the anvil of the stapler is placed in the tunnel so the stapler can be fired to complete the fissure.
3. Alternatively, if the fissure in quite incomplete, the entire fissure can be opened with staples to minimize the air leak created by completing the fissure with electrocautery or energy. Completing the entire fissure with staples provides excellent exposure for the artery. This is accomplished by exposing the artery anteriorly. First, a stapler begins completion of the fissure between the lingula and the lower lobe. The tissue in the fissure is then lifted to expose the lower lobe bronchus which travels perpendicularly to the veins and is just posterior to the veins (Fig. 5.49). Metzenbaum scissors dissect on the surface of the artery to create a tunnel. The anvil of the stapler in placed in the tunnel and is fired several times to complete the fissure. When the dissection has progressed to expose the superior segmental artery, exposure of the rest of the artery is improved if separate ring forceps lift up and pull anteriorly the posterior segment of the upper lobe and the superior segment of the lower lobe. Thus, continued dissection of the surface of the artery extends the tunnel to the descending aorta so the stapler can finalize completion of the fissure.
4. The right angle clamp mobilizes the artery to the superior segment (Fig. 5.50). Through incision 2, the stapler passes to transect the artery.
5. Just posterior to the artery is the superior segmental bronchus. Lymph nodes between the artery and the bronchus hide the bronchus. Remove the nodes for oncologic reasons and for exposure of the bronchus. The right angle mobilizes the bronchus so the stapler can pass through incision 2 to transect the bronchus. The superior segmental vein runs obliquely and inferiorly from the bronchus to the inferior pulmonary vein. The vein is small so it can be clipped, stapled or transected with energy (Fig. 5.51a–d).
6. Finally, staples separate the superior segment from the basilar segments. The placement of the staples depend upon the location of the tumor and the actual margin of the superior segment. Look for a segmental fissure because occasionally, there is a fissure that defines the superior segment. Otherwise, from incision 2, pass the stapler. The anvil should be placed just above the artery to the lower lobe. Feel for the tumor to make sure there is an adequate margin. If the tumor is too close to the staple margin, then pull basilar segmental lung parenchyma through the stapler to get a wider margin.

Tips

- To find the separation between the superior segment and the basilar segments, have the anesthesiologist ventilate the lung while the stapler compresses the superior segmental bronchus. Do not over-ventilate; just enough to confirm that the correct bronchus is compressed and to define the border of the superior segment and the basilar segments.
- Alternately, when the superior segmental bronchus is compressed, inflate air into only the superior segment through a needle into the bronchus distal to the compression so that only the superior segment is expanded. That avoids over-expansion of the left lung and having to decompress it with suction.

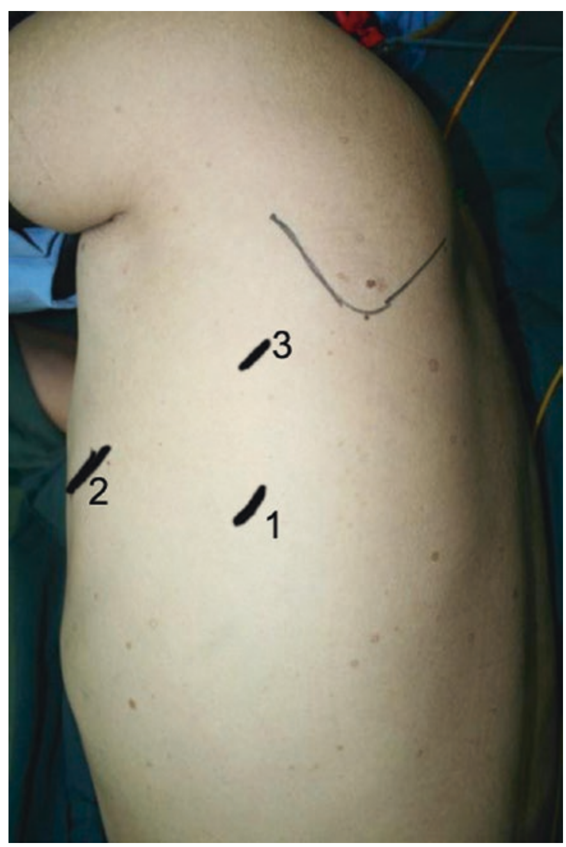

Fig. 5.48 Incisions for a left lower lobe superior segmentectomy

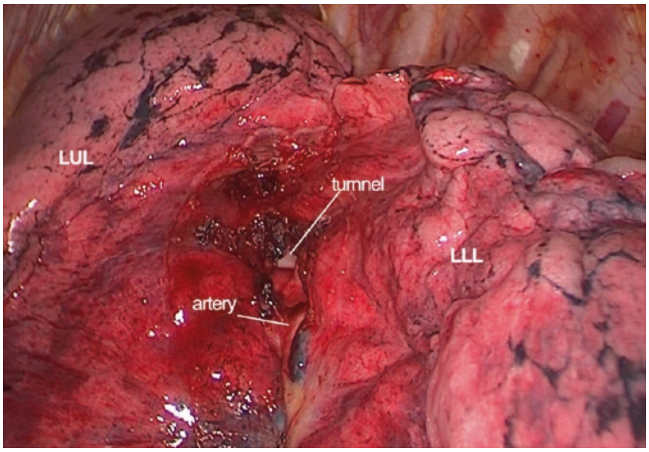

Fig. 5.49 Tunnel from fissure to posterior mediastinum

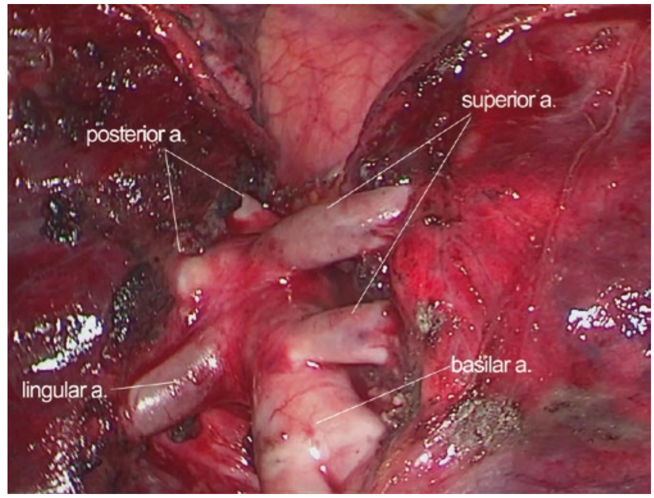

Fig. 5.50 Mobilized artery to the superior segment

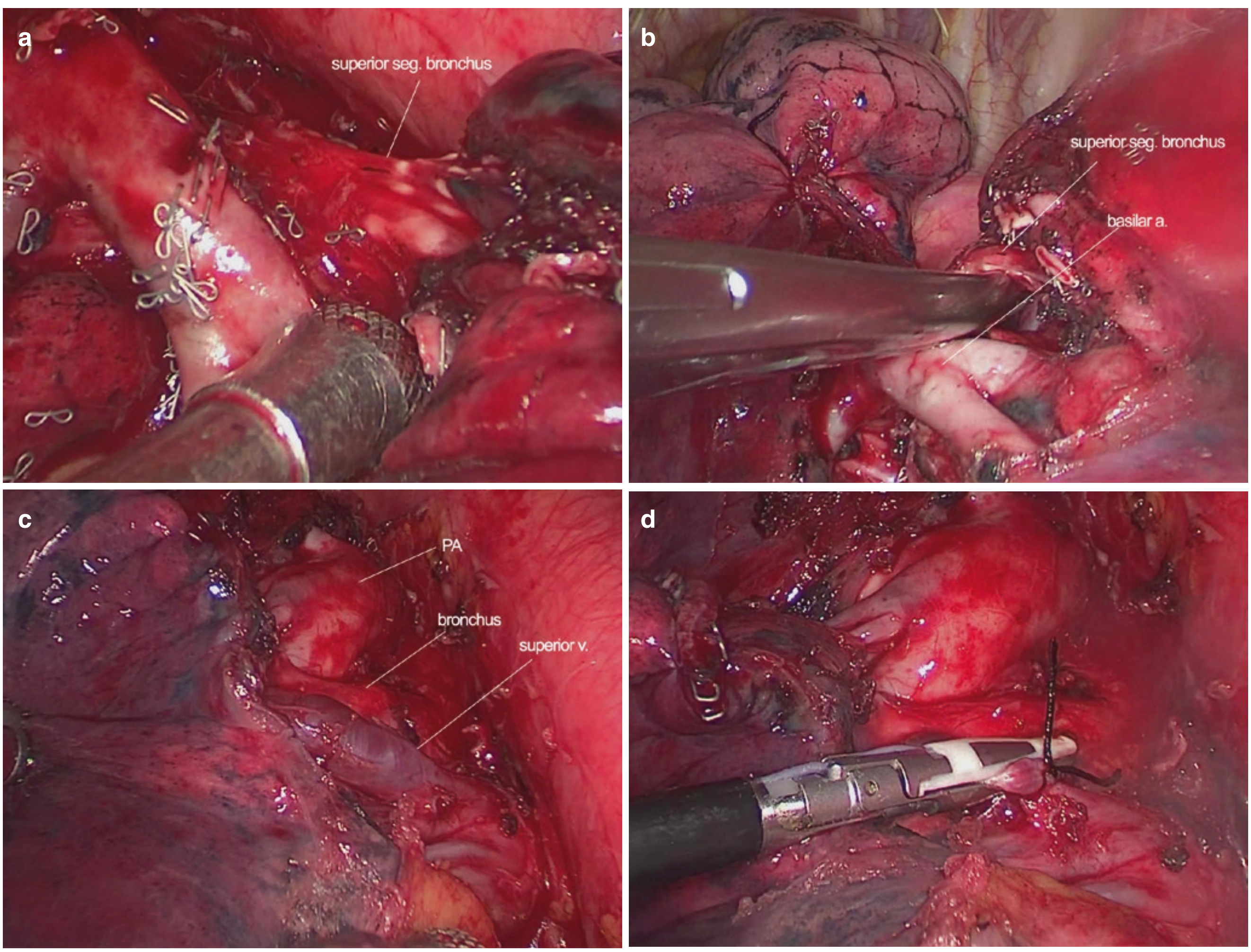

Fig. 5.51 Mobilizing superior segmental bronchus and vein. (**a**, **b**) Superior segmental bronchus just posterior to the artery. (**c**) Superior segmental vein. (**d**) Transecting the vein with energy

5.7 Left Lower Lobe: Basal Segments

Alper Toker and Erkan Kaba

Although many have discussed oncologic perspectives and refinements in the field of thoracoscopic segmentectomy, few offer technical advice in their experiences. In addition, most experiences are limited to easily excised segments, such as the lingular, superior, and basilar segments. In the resection of such segments, it is easy to simultaneously staple the lung from both the hilum of the lobe and the periphery by using staplers without dissecting the parenchyma along the intersegmental veins. However, this technique could not be considered as an oncological procedure because separate segmental hilus and intralobar lymph node dissections are not performed. Also, this technique cannot be employed for the excision of other segments. By assessing the intersegmental veins, the thoracoscopic removal of other segments may be possible.

One of the most important parts of the VATS segmentectomy operation is the anatomic localization of the lesion. The surgeon should decide the anatomic availability of the lesion for a segmental resection. Pathologists should examine lymph nodes obtained from the hilum and mediastinum during an extended segmentectomy operation. In the presence of any lymph node positivity, the operation should be modified [32, 33].

5.7.1 Technical Advice

The left lower lobe basilar segmentectomy operation is one of the easiest endoscopic segmentectomy procedures. Most often it is called a common basal segmentectomy operation. There are three segments in the lower lobe basilar segment (S7-8, 9, and 10) and segmentectomy operation on each of them separately is difficult. The operative field is very small and complex. This area is like the network of vessels and bronchus (Fig. 5.52). Extensive experience in surgical techniques and endoscopy are required to perform segmentectomy operations separately on the segments of the basilar segment [34, 35]. The authors will describe mainly the common basal segmentectomy operation, and the other segmentectomy operations of the lower lobe basilar segments rarely performed.

- The fissure may be fused in left lower lobe common basal segmentectomy operation. At least, the lingular segment fuses with some parts of the anteromedial basal segment.
- Pulmonary arterial anatomy may show variations. Generally, this occurs at the level of the division of the common basal artery.
- First of all, the arterial distribution must be understood. Owing to their intersegmental positions, the identification of detailed anatomy of the venous structures in the lower lobe is difficult. The venous anatomy should be carefully described and understood during the surgery as any surgical misinterpretations may cause lethal or highly morbid complications. Venous anomalies are more common on the left side. The vein of the superior segment of the lower lobe should be preserved during the common basal segmentectomy operation.
- The union of the superior segment vein with the common basal segment vein may be distally located, which may cause a complete division of the lower lobe vein during a common basal segmentectomy operation. Obligatory lobectomy should be performed.
- The superior segment vein is just behind the common basal segmental bronchus. Dissection of the common basal segment bronchus maybe difficult. Division of the common basal segmental vein before the bronchus may provide better exposure of the superior segmental vein and the common basal segmental bronchus.
- Lymph nodes are often found at the level of the common basal segmental bronchus during an operation performed for bronchiectasis. Thus, this condition can cause burdensome hemorrhage during dissection.

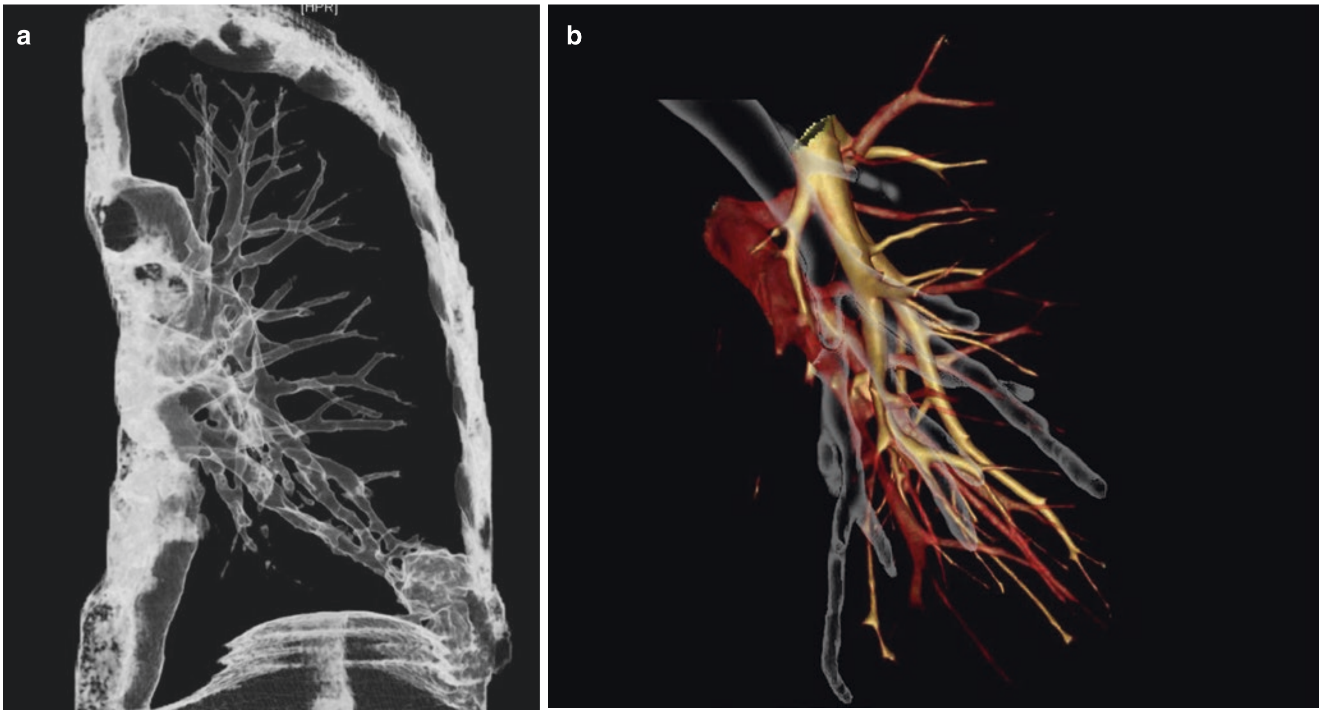

Fig. 5.52 The operative field is very small and complex. This area is like a network of vessels and bronchi. In reconstructed images specific vessels and bronchus to the mass can be seen

5.7.2 Anatomical Landmarks

Bronchus: The basal segment bronchus continues approximately 1.5 cm as after giving off the superior segmental bronchus (Fig. 5.53). Division of bronchus (B) is not the same as that of the right lower lobe. Instead of the anteriobasal and mediobasal segments of the right lower lobe, there is anteromedial basal segment (B7- 8) in the left lower lobe. B7 may be an independent bronchus in only 4 % of specimens. The bronchus then divides into two branches named an anteromedial basal segmental bronchus and a common stem bronchus. Then, the latter gives off the lateral basal (B9) and posterior basal (B10) segments. Often, B7-8, B9, and B10 do not arise at the same level. Often there is a common trunk named B9-10 for B9 and B10. These three segment bronchi are remarkably constant in shape, but B9 is often smaller. B9 may be considered a subsegmental bronchus rather than an independent bronchus, and it may be absent in 8 % of specimens. At CT, it may not be demonstrated.

Pulmonary artery: Arterial anatomy is variable in number and topography. This theory may explain the possibility of several normal vascular shadows around B8, B9, and B10 on chest CT. On CT, these segmental arteries lie in a half-ring laterally around B7-8, and in a half-ring posteriorly around B9, 10 (Fig. 5.54). Separation of basilar segment arteries (A) shows variability. After the origin of lingular vessels, the common basal trunk mostly divides into two. The more anteriorly situated branch supplies the anteromedial basal segment, and the posterior branch feeds both the lateral basal and posterior basal segments. Single or multiple vessels arise from the common basal stem or more frequently from the posterior basal branch, to supply the subsuperior segmental region (Fig. 5.55).

Pulmonary veins: The veins (V) of the lower lobe give rise to the inferior pulmonary vein with two main tributaries, V6 draining the superior segment and the common basal vein draining the basal segments. The basal segmental veins lie mostly central to the bronchi, V7-8 and V9 are behind B8 and B9, respectively, and V10 is anterior to B10 (Fig. 5.56).

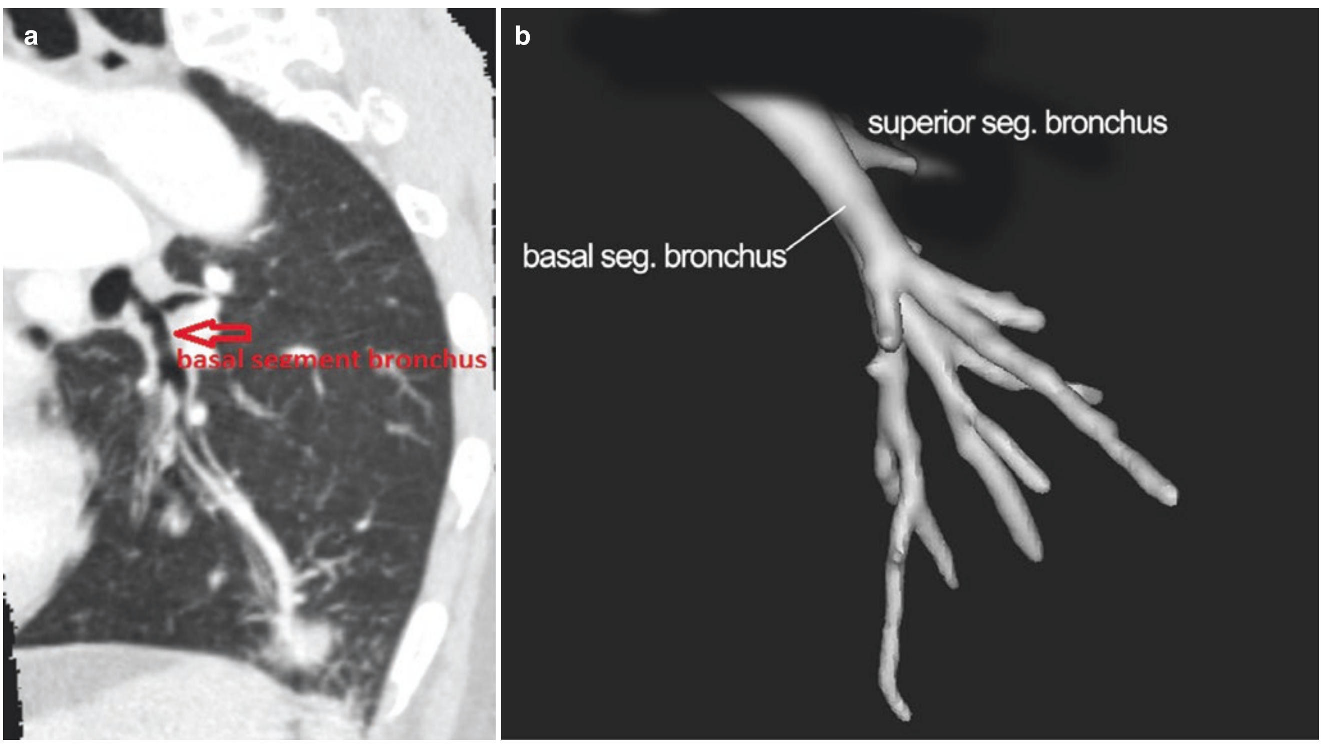

Fig. 5.53 After giving off the superior segmental branch, the basal segment continues for an average distance of 1.5 cm as a single trunk

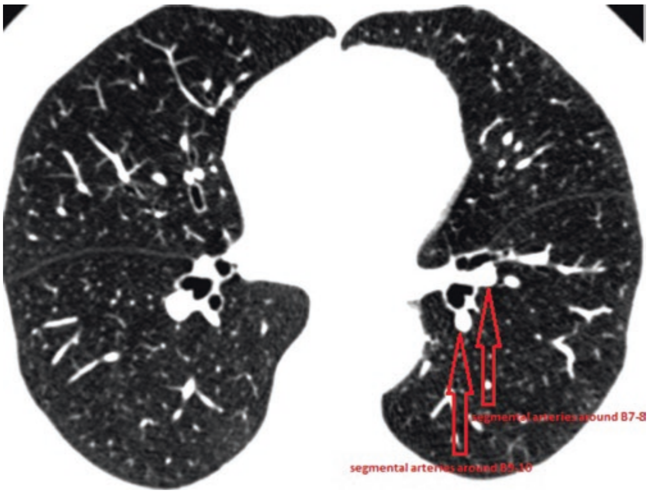

Fig. 5.54 On CT, segmental pulmonary arteries lie in a half-ring laterally around B7-8, and in a half-ring posteriorly around B9, 10. Knowledge of anatomy prior to the operation eases the dissection

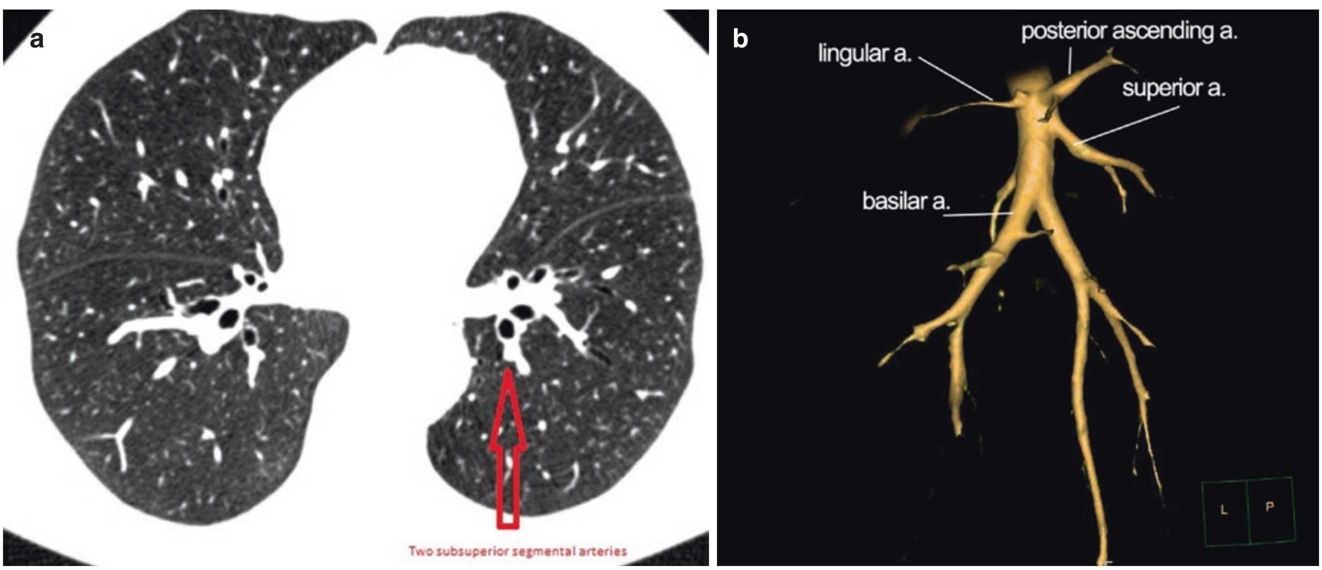

Fig. 5.55 Branches to the subsuperior segmental region are often found arising as single or multiple vessels from the common basal stem or more frequently from the posterior basal branch

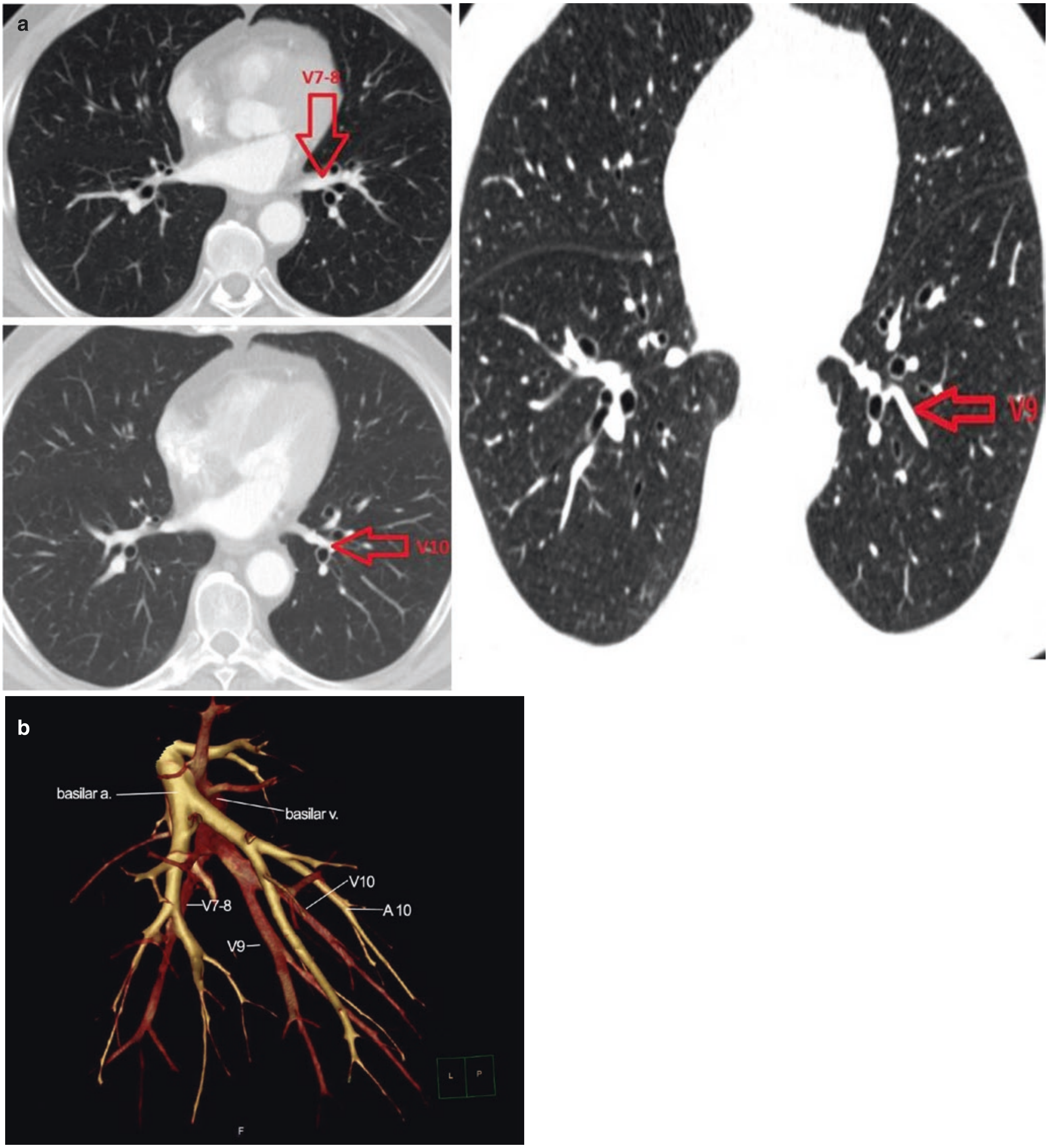

Fig. 5.56 The basal segmental veins lie mostly central to the bronchi: V7-8 and V9 are behind B8 and B9, respectively, and V10 is anterior to B10

5.7.3 Operating Procedure

We operate on patients via the two ports technique. The camera is placed at the seventh intercostal space at the midaxillary line, and the anterior port is placed at the fissure line on the chest wall after confirmation from the inside of the chest with a camera. A mini soft tissue retractor is placed.

1. The lower lobe is pushed postero-inferiorly and the upper lobe is pushed towards apex by grasping the lingula using oval forceps from the anterior port. The lingual and the lower lobe are separated from each other by cautery or energy devices. The pulmonary ligament is exposed and dissected up to the inferior pulmonary vein using cautery by retracting the lower lobe towards apex (Fig. 5.57). Group 7, 8 and 9 lymph nodes are resected at the same time. The posterior mediastinal pleura is fully exposed by pulling the lower lobe anteriorly and superiorly and the pleura is divided up to the inferior border of main bronchus.
2. The left upper lobe is stretched towards the apex, and the lymph nodes located at the interlobar fissure are resected and sent for frozen section analyses. After removing the stage 11 lymph nodes, the interlobar pulmonary artery is exposed (Fig. 5.58a–c). The lingular, superior and common basal segmental arteries are identified. A lymph node is always present between the common basal and superior segmental arteries. This node should be dissected carefully and analyzed via frozen section. During the dissection of the common basal segmental artery, it is extremely important to verify that the surgeon is dissecting superior to the level of bifurcation or trifurcation of the common basal trunk. Otherwise, an injury may result. A vascular stapler is used to divide the common basal trunk (Fig. 5.59).
3. The lymph nodes are dissected off the common segmental bronchus and then sent for pathological evaluation. Common basal segmental bronchus is dissected free from the superior segmental vein and stapled (Fig. 5.60).
4. The vein is dissected free with a peanut or an aspiration cannula. It is extremely important to visualize and preserve the superior segmental vein, which is located just under the common basal segmental bronchus (Fig. 5.61). When the common basal segmental and superior segmental veins are dissected, a vascular stapler is used to divide the common basal segmental vein.
5. The surgeon then dissects or staples the parenchyma along the intersegmental plane. The CT images may help to define both the venous branches which would be divided, and the intersegmental veins that have to be protected. The intersegmental vein is taken as a guide in the dissection of the parenchyma by using an electrocautery and staplers. The inflation and the deflation of the lung may help the visualization of the intersegmental plane. This maneuver is also useful to ensure the dissection along the anatomical plane [36, 37].
6. The detection of the intersegmental plane is variable depending on the surgeon's preferences. After complete dissection of the segmental bronchus, the affected lobe is transiently inflated (Fig. 5.62). The distal part of this bronchus is tied which keeps the air inside the segment, and the proximal bronchus is left open after being divided by scissor or knife. Thus, the segments supposed to be preserved are collapsed. The intersegmental plane is indicated by the line between the inflated lung and the collapsed lung. Another possible strategy is just the opposite. After stapling the bronchus, the distal side is cut, the targeted segment is deflated, and the remnant lobe is inflated. The bronchus is stapled using an endostapler while the whole lung is deflated, and the distal side of the resected bronchus is inflated with 0.5 L of O_2 via a butterfly needle. Also, 3D images are used to identify the lesion and its relation to the vessels and the bronchus.
7. At the end of the operation, the surgeon should visualize the superior segmental vein, the common basal bronchus, and the common basal artery stump (Fig. 5.63).

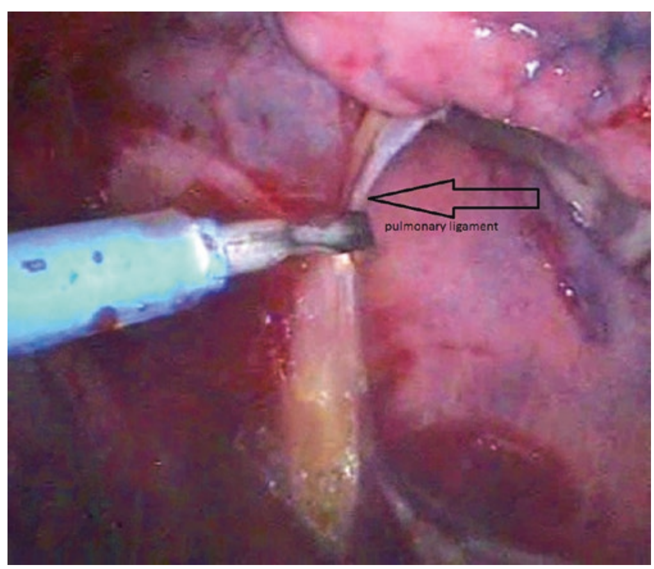

Fig. 5.57 The pulmonary ligament is exposed and dissected up to the inferior pulmonary vein using cautery by retracting the lower lobe towards the apex. The division of the inferior pulmonary ligament may also be performed bluntly with a suction cannula and/or energy devices

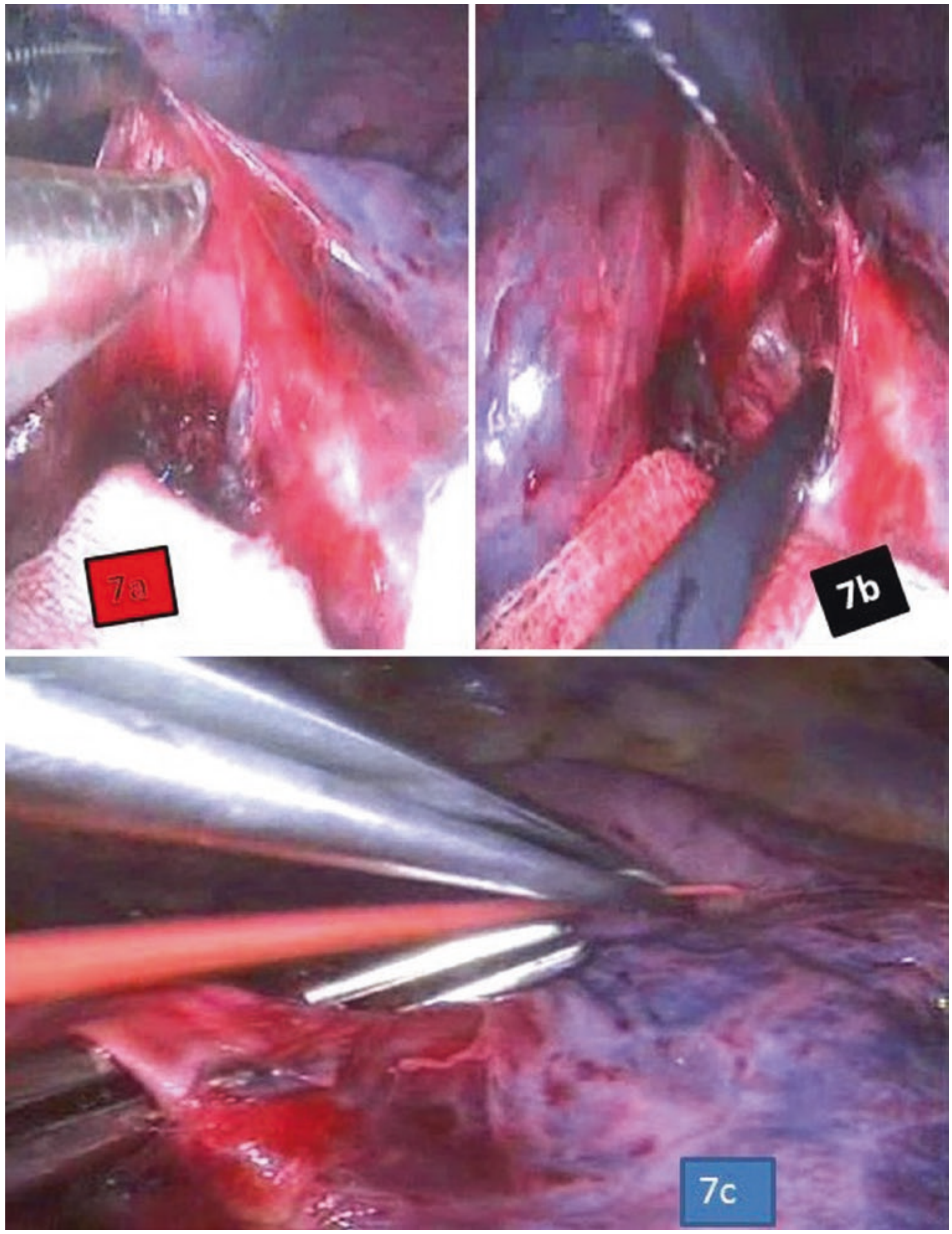

Fig. 5.58 (**a**) The left upper lobe is stretched towards the apex. After removing the stage 11 lymph nodes, the interlobar pulmonary artery is exposed. (**b**) The sheath of the artery is opened with scissors or an energy device. The inferior part of the vessel is retracted with an endo-peanut and the dissection can be performed with a peanut or suction cannula. (**c**) A vessel loop is generally used before stapling the pulmonary artery

Fig. 5.59 A vascular stapler is used to divide the common basal trunk. The authors use both sides of the stapler (either anvil or cartridge side) while placing the stapler, depending on the location and the size of the area under the vessel

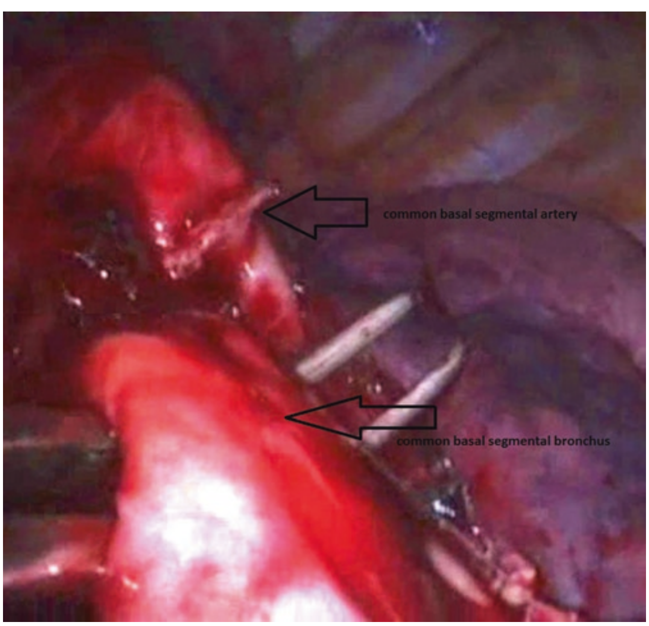

Fig. 5.60 The common basal segmental bronchus is dissected free from the superior segmental vein and stapled. This part of the operation is most accident-prone part of the procedure

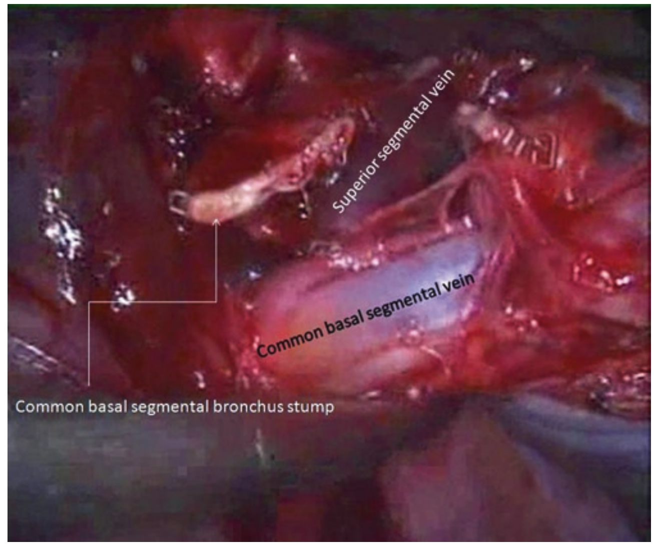

Fig. 5.61 It is extremely important to visualize and preserve the superior segmental vein, which is located just under the common basal segmental bronchus. Before and after the completion of the procedure, the surgeon should visualize this vessel

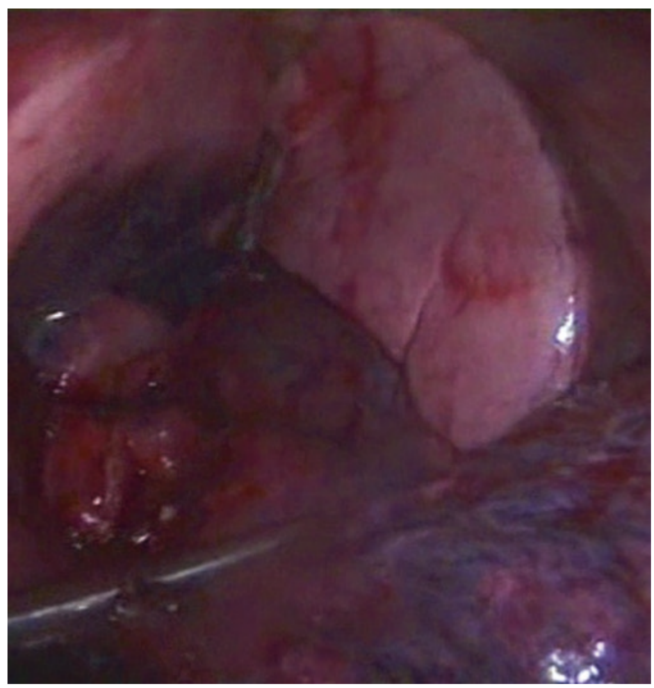

Fig. 5.62 After the isolation and division of the segmental bronchus, the affected lobe is temporarily inflated. The superior segment is expanded while the common basal segments are atelectatic

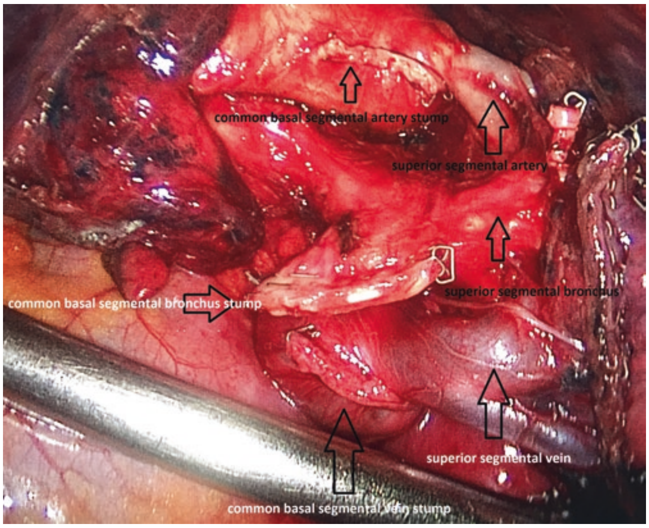

Fig. 5.63 At the end of the operation, the surgeon should visualize the superior segmental vein, the superior segmental artery, the superior segmental bronchus, the common basal segment bronchus, and the common basal segment artery stumps

Separate Segmentectomy of the Common Basal Segments

Surgeons' experience on segmentectomy of S7-8

1. For the resection of S7-8 or anteromedial basal segment, A7-8 should be prepared (Fig. 5.64) and divided. This artery maybe visualized after completing the fissure between lingular and anteromedial basal segments. Under the artery, B7-8 can be visualized. Again, the superior part of this anteromedial basal segmental bronchus and the vein of the superior segment are present, requiring a careful dissection.
2. There is not a unique vein to be dissected. By retracting the segment from the divided distal bronchus, intersegmental veins are localized. The rest of the intersegmental plane is stapled.
3. The most important part of this operation is the preservation of the remnant lobar vein.

Surgeons' experience on segmentectomy of the S10:

1. This segment is generally resected with S6, either en-bloc or separately due to a suspicion of marginal positivity.
2. After the resection of S6, A10 is divided (Fig. 5.65). Right under this artery, there is B10. It is also divided by stapling (Fig. 5.66). By pulling the distal side of the resected bronchus, the vein of this segment may be found. This vein can be divided with hem-o-lok (Teleflex Medical, Research Triangle Park, NC) clips.

5.7.4 Conclusions

Recently published studies demonstrated that the outcomes of segmentectomies for small-sized stage I lung cancers were similar to those of lobectomies, even in non-compromised patients [38, 39].

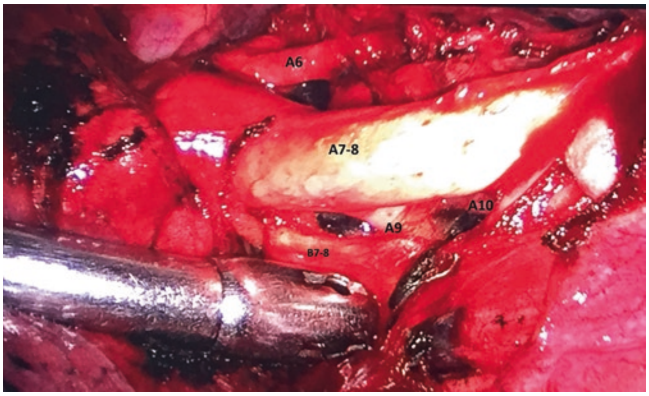

Fig. 5.64 For the resection of S7-8 or anteromedial basal segments, A7-8 should be prepared. This artery can be visualized after completing the fissure between the lingular and anteromedial basal segments. In the dissection towards the parencyhma of the common basal segments artery, B7-8 can be visualized

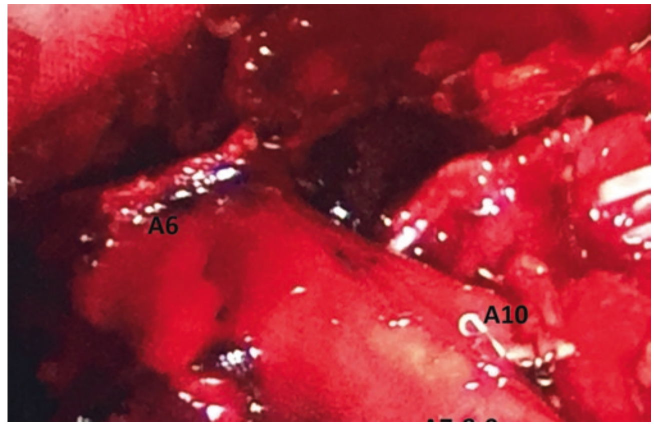

Fig. 5.66 After the division of the posterior basal segmental bronchus with a stapler, the vein draining this segment can be seen. The authors use vascular staplers for the division of the subsegmental bronchus of the lower lobe common basal segments

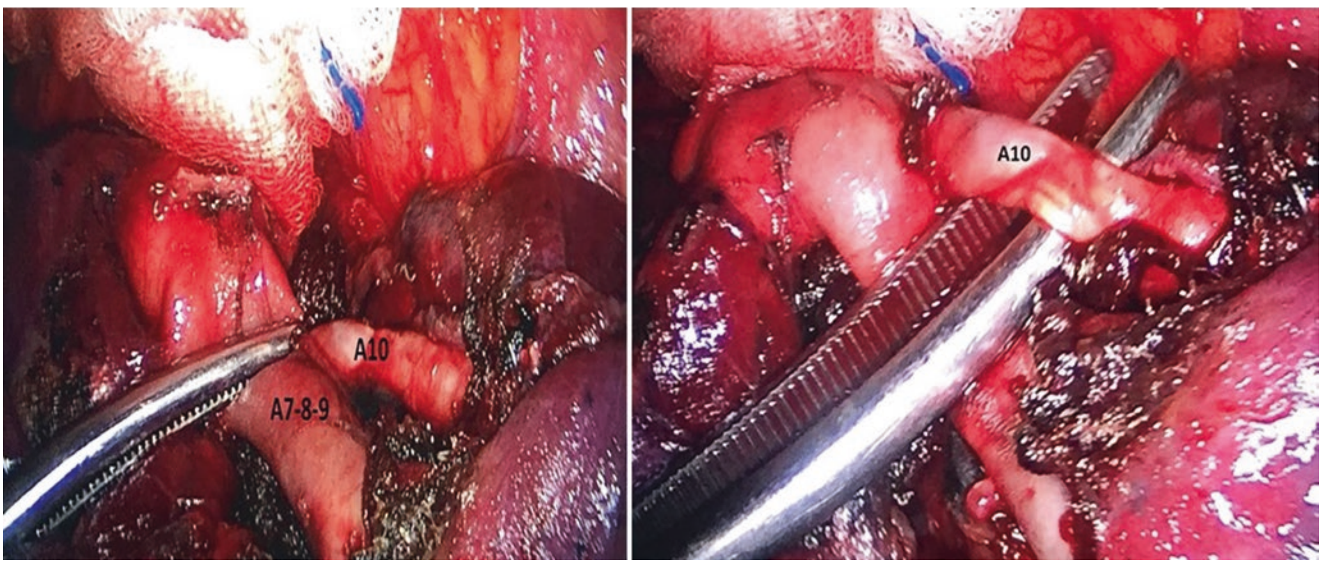

Fig. 5.65 After the resection of the superior segment of the left lower lobe, the artery to segment 10 is identified by dissecting the artery more distally. The posterior basal segmental artery is dissected free. After the division of artery 10, the brochus of the posterior basal segment will be seen

5.8 Results and Discussion

Mark F. Berry

5.8.1 Introduction

Being able to perform a minimally invasive segmentectomy is a very valuable skill to have in the armamentarium of a thoracic surgeon. Although an anatomic surgical lobectomy is the recommended treatment for patients diagnosed with early stage non-small cell lung cancer (NSCLC), a lesser resection via segmentectomy may be an appropriate treatment choice for some specific clinical situations of patients with small clinical stage IA NSCLC tumors or increased risk of morbidity after lobectomy. Minimally invasive resection via video-assisted thoracoscopic surgery (VATS) has well documented short-term benefits of reduced peri-operative morbidity over thoracotomy without compromise of oncologic outcomes for lobectomy for NSCLC, and these short-term benefits have also been observed when segmentectomy is performed.

5.8.2 Segmentectomy Oncologic Outcomes

A randomized trial by the Lung Cancer Study Group established that a sublobar resection of clinical stage IA NSCLC was associated with an increased chance of recurrence compared to lobectomy, and guidelines therefore recommend lobectomy as treatment for patients diagnosed with early stage non-small cell lung cancer (NSCLC) [40, 41]. However, resection via lobectomy may not be necessary to optimize survival for all patients presenting with NSCLC, most notably subsets of patients with Stage IA tumors [42–45]. Several single-institution and multi-institution studies have suggested that sublobar resection may have similar survival benefits to lobectomy for patients with smaller tumors and older patients [46–53].

Comparison with Lobectomy for Small Tumors

The Lung Cancer Study Group randomized trial that compared lobectomy with more limited resection for T1N0 NSCLC involved 276 patients who had surgery between 1982 and 1988 and demonstrated that limited resection was associated with nearly double rates of local recurrence and trends toward worse disease-specific and overall survival [41]. However, both diagnostic and staging modalities have clearly changed since this randomized trial was performed. The increased use of radiologic studies in general and particularly screening with computerized tomography (CT) scans are likely leading to the identification of a higher proportion of tumors with smaller sizes than what was typically seen in the 1980s.

Prognosis for T1 tumors is related to tumor size, with survival appearing to be significantly better in patients whose tumors are less than 2 cm [54–58]. Less extensive resection than lobectomy has been hypothesized as being adequate treatment for smaller tumors, and a prospective, randomized, multi-institutional phase III trial (Cancer and Lymphoma Group B [CALGB] 140503) that compares survival after lobectomy and intentional sublobar resection for peripheral tumors less than or equal to 2 cm in size is currently being conducted [59]. Another prospective, randomized, multi-institutional study is being conducted in Japan (the Japan Clinical Oncology Group 0802/West Japan Oncology Group 4607L trial) and intends to compare the prognosis and postoperative pulmonary function between patients with NSCLC 2 cm or less in diameter who are undergoing either lobectomy or segmentectomy [60]. The results of these trials will likely provide Level 1 evidence to guide clinical practice in the future, but the results are probably not going to be available for several years.

However, several retrospective studies have found no significant differences in survival between patients treated with a sublobar resection versus an anatomic lobectomy for stage IA NSCLC tumors [46–48]. The findings from several of the larger studies are summarized in Table 5.6. Although all are retrospective, similar findings that sublobar resection may not compromise survival compared to lobectomy in appropriately selected patients have been demonstrated by single-institution, multicenter, and population database analyses. Although a higher level of evidence will not become available until after the completion of the prospective randomized trials described above, the available evidence does support that surgeons can consider segmentectomy for patients with clinical stage IA tumors that do not require lobectomy to achieve resection with adequate margin, particularly when tumors are less than 2 cm in size.

Advantages of Segmentectomy Over Wedge Resection

Despite the findings across the studies described above that sublobar resection may be an adequate oncologic therapy for patients with early-stage NSCLC, surgeons must consider several issues when considering sublobar resection for clinical stage I NSCLC. First and foremost, sublobar resection is only appropriate for patients who are technically amenable to sublobar resection with achievement of adequate margins. In addition, some degree of lymph node harvest is mandatory, as several studies have demonstrated the importance of lymph node evaluation at the time of sublobar resection [46, 61]. It is also very important to note that the randomized CALGB 14053 trial restricted to tumors less than or equal to 2 cm requires pathologic lymph node assessment prior to treatment randomization [58]. Being able to pathologically assess margins and confirm complete resection as well as

Table 5.6 Series of oncologic outcomes comparing segmentectomy/sublobar resection and lobectomy

	Patient population	Outcome comparison
Landreneau et al. [49]	Single institution study of propensity matched patients who underwent anatomic segmentectomy (n = 312) or lobectomy (n = 312) for clinical stage I lung cancer, with mean tumor size of 2.2 cm	No differences in 5 year freedom from recurrence (70 % vs 71 %, p = 0.47) or 5 year survival (54 % vs 60 %, p = 0.26) between segmentectomy and lobectomy
Wisnivesky et al. [58]	SEER-Medicare database study of patients who underwent sublobar resection (n = 196) or lobectomy (n = 969) for stage I lung cancer with tumors ≤2 cm	Patients undergoing limited resection did not have an increased risk of all cause mortality or lung cancer-specific death compared to patients who had lobectomy in multivariable analysis
Altorki et al. [42]	Patients in the International Early Lung Cancer Action Program who underwent lobectomy (n = 294) or sublobar resection (n = 53) for clinical stage I lung cancer with tumors ≤3 cm	10-year Kaplan–Meier for 53 patients treated by sublobar resection compared with 294 patients treated by lobectomy was 85 % (95 % confidence interval, 80–91) versus 86 % (confidence interval, 75–96) (p = 0.86)
Okada et al. [56]	Single institution review of 1,272 patients who underwent complete resection of non-small cell lung cancer	5-year cancer-specific survival for pathologic stage I disease with tumors ≤2 cm was 92.4 % after lobectomy, 96.7 % after segmentectomy, and 85.7 % after wedge resection
Wolf et al. [61]	Single institution study of patients who underwent sublobar resection (n = 154) or lobectomy (n = 84) for stage I lung cancer with tumors ≤2 cm	Lobectomy was associated with improved overall survival and recurrence free survival overall, but advantage did not persist when sublobar resection included lymph node sampling

SEER Surveillance, Epidemiology, and End Results, *OS* overall survival, *RFS* recurrence free survival

pathologically confirm nodal status is a primary advantage of sublobar resection over a non-surgical ablative technique such as stereotactic radiotherapy.

For these reasons, segmentectomy if technically feasible should be strongly favored over wedge resection if considering sublobar therapy for NSCLC. One potential reason that anatomic resection with lobectomy was observed to have better locoregional control in the original randomized trial may have been due to resection of unsuspected intralobar tumor spread, which could be therapeutic in itself or also help direct adjuvant treatment, especially considering that in one study 23 % of patients with clinical IA NSCLC were found to have pathologic lymph node involvement or intrapulmonary metastases [62]. Wedge resection in one trial was associated with a smaller parenchymal margin, and a lower yield of lymph nodes and rate of nodal upstaging when compared with segmentectomy [63]. A potential advantage of segmental resection over wedge resection is that anatomic dissection of segmental bronchial and vascular structures is likely to lead to more retrieval of interlobar, lobar, segmental, and subsegmental lymph nodes than a wedge resection. While it is possible that lymph node resection may be therapeutic, this lymph node removal more importantly provides pathologic nodal staging data, whether to select patients who should have a more formal anatomic lobectomy at the time of surgery, or to help guide appropriate postoperative therapy.

Other Situations Where Segmenectomy Is Indicated

A segmentectomy may be an appropriate alternative to lobectomy in other clinical scenarios, beyond those described above where oncologic outcomes may be equivalent. Probably most importantly, segmentectomy may be the optimal resection extent in patients who have impaired pulmonary function. In some cases, a patient's pulmonary function may preclude their ability to tolerate the removal of an entire lobe and a less extensive resection may be all that is feasible. Segmentectomy is associated with significant preservation of pulmonary function compared with lobectomy and may be the best resection option that balances the risk and benefits of anatomic resection in patients with poor lung function [64–66]. In addition, other studies have suggested that the survival benefit of lobectomy over sublobar resection diminishes with age or with co-morbid conditions, likely secondary to the higher perioperative mortality in these patients as well as the competing risk of mortality from other comorbidities [47, 67]. Segmentectomy if technically feasible may be a good resection option in these higher risk patients. Finally, other situations where a less extensive resection than lobectomy may be appropriate include when multiple lesions are present and utilizing a lobectomy to achieve resection of all lesions is not physiologically feasible.

Table 5.7 Results from series of minimally invasive segmentectomy

	Study years	Use of VATS approach	VATS mortality	VATS morbidity
Atkins et al. [70]	2000–2006	62 % (48 of 77 patients)	0 % (2.6 % overall)	Atrial arrhythmia 15 %
				Pulmonary 10 %
				Air leak 10 %
Leshnower et al. [76]	2002–2009	37 % (15 of 41 patients)	0 % (4.8 % overall)	None reported
Schuchert et al. [69]	2002–2010	60 % (468 of 785 patients)	Not specifically reported (1.1 % overall)	Not specifically reported.
				Overall morbidity was:
				Atrial arrhythmia 6.5 %
				Respiratory failure 5.5 %
				Pneumonia 4.5 %
				Air leak 3.8 %

5.8.3 Use of Minimally Invasive Approach

Pulmonary segmentectomies can be performed safely with acceptable morbidity and mortality [68]. Thirty-day mortality, overall morbidity, and major morbidity rates have been reported as 1.1–2.6 %, 35 %, and 9 %, respectively [69, 70]. Several series have reported the performance of all common segmentectomies (superior segmentectomy, basilar segmentectomy, lingulectomy, and lingular-sparing left upper lobectomy) as well as individual segmental resections of the right upper and right middle lobes. Complications most often reported after segmentectomy include atrial arrhythmia, pulmonary complications, and prolonged air leak.

A minimally invasive approach should be considered if segmentectomy for early-stage NSCLC is planned [68]. Multiple reports have shown that, compared to thoracotomy, minimally invasive lobectomy for NSCLC via video-assisted thoracoscopic surgery (VATS) reduces peri-operative morbidity without compromising oncologic outcomes [71–75]. Performing segmentectomy via VATS has also been shown to have less short-term morbidity than thoracotomy [68]. VATS segmentectomy is safe with fewer complications and a reduced hospital stay than an open procedure, and can be used for all potential segmental resections [69, 70, 76]. Conversion to thoracotomy due to inadequate exposure, hilar fibrosis, or bleeding has been reported to occur in 0–6.4 % of attempted VATS segementectomies [69, 70]. Table 5.7 shows the VATS segmentectomy experience reported by several centers [67, 70, 76]. The peri-operative mortality in these published studies have all been very low (Table 5.7).

5.8.4 Conclusions

Lobectomy is currently the recommended resection for early-stage lung cancer, though evidence is increasing that a lesser resection may be adequate oncologic treatment for small stage IA NSCLC tumors. Considering that prospective trials evaluating the role of sublobar resection are currently being conducted but have not yet provided level 1 evidence supporting sublobar resection, surgeons should generally be cautious when utilizing a sublobar resection for clinical stage IA NSCLC, but the therapy may be appropriate in select patients, particularly those with significant comorbidities or poor lung function. Segmentectomy is likely the ideal sublobar treatment, as it likely leads to better lymph node assessment and wider margins than a non-anatomic wedge resection. Minimally invasive resection via VATS has been shown to be feasible with very low peri-operative mortality.

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Sleeve Lobectomy

6

Yun Li, Xun Wang, Jun Wang, and Yanguo Liu

Contents

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6.1 General Considerations of VATS Sleeve Lobectomy on Treating Lung Cancer

Yun Li, Xun Wang, and Jun Wang

6.1.1 Overview of Sleeve Lobectomy

In 1947, Price Thomas performed the first sleeve lobectomy for a patient diagnosed as pulmonary carcinoid of right main stem bronchus. And the first successful right upper lobe sleeve lobectomy was performed by Allison, and this was the first time to perform sleeve lobectomy for patient with lung cancer.

The sleeve lobectomy for lung cancer used to be thought of as a compromised operation, because some patients could not permit pneumonectomy for a low pulmonary function. Many studies have conformed that sleeve lobectomy could reduce the postoperative risks and loss of pulmonary function. With the development of surgical technique, sleeve lobectomy should be considered firstly for centrally located lesions of non-small cell lung cancer. The sleeve lobectomy consists of the resection of lobe with tumor and circumferential segment of the adjacent main stem bronchus, and then anastomosis of the proximal and distal bronchial resection edges, with or without resection of pulmonary parenchyma and vascular structures. It is a parenchyma-sparing surgical strategy of resection, and widely adopted with the double aim of ensuring the completeness of tumor resection and preserving lung function.

When the tumor involved the main or lobar bronchus, the sleeve lobectomy could be considered as a treatment plan. Non-small cell lung cancer is the most common indications for sleeve lobectomy when dealing with tumors which involved bronchus. Sleeve lobectomy can be performed in any lobe, but the right upper lobe sleeve lobectomy is the most common surgery. There are two explanations for this situation: the first is that the long bronchus intermedius makes it easier to anastomose the bronchial stump. Another is that the low incidence rate of lymphatic metastasis around the middle lobe bronchus. The sleeve lobectomy of left upper lobe is the second most common site. As a challenging

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surgery, it is very important to protect of the aorta and left recurrent nerve during this operation. When the pulmonary artery is involved, the vascular sleeve resection should be performed.

The common types of sleeve lobectomy including: (a) Tumor involving the right upper lobe orifice with or without hilar lymph node metastasis requiring bronchial sleeve resection of the right upper lobe; (b) Tumor involving the left upper lobe orifice with or without hilar lymph node metastasis requiring bronchial sleeve resection of the left upper lobe; (c) Tumor involving the left lower lobe orifice with or without hilar lymph node metastasis requiring bronchial sleeve resection of the left lower lobe; (d) Peripherally located tumor in the right upper lobe or left upper lobe with hilar lymph node metastasis; (e) Involvement pulmonary artery or vein with one of the situations mentioned above which needs partial or circumferential vascular resection and reconstruction. Involvement of the pleura, superior vena cava, atria, or transverse aortic arch is the contraindication of sleeve lobectomy. R0 resection for sleeve lobectomy is important for low incidence of local recurrence (Figs. 6.1 and 6.2).

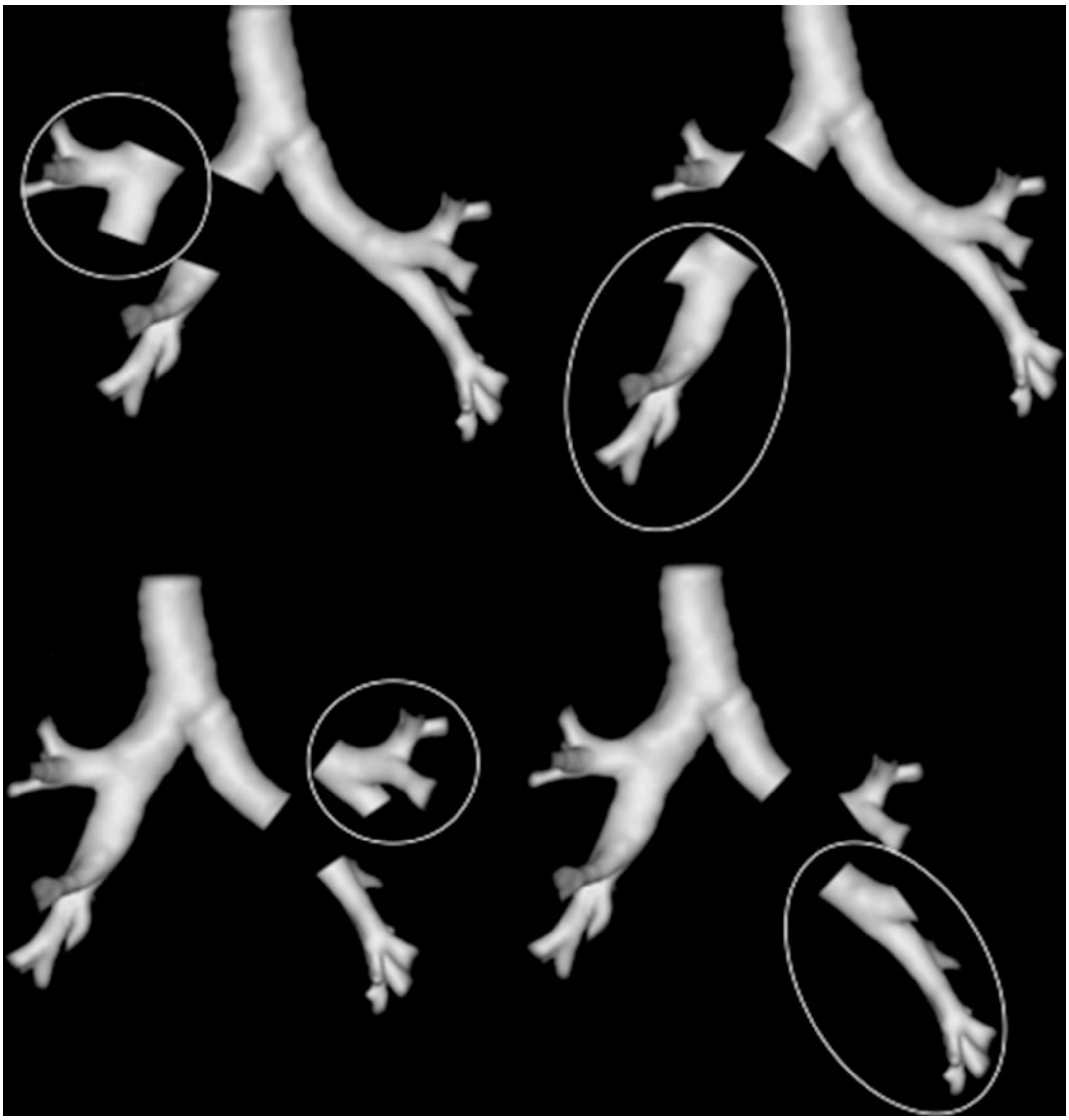

Fig. 6.1 Illustration of the most common types of sleeve resections

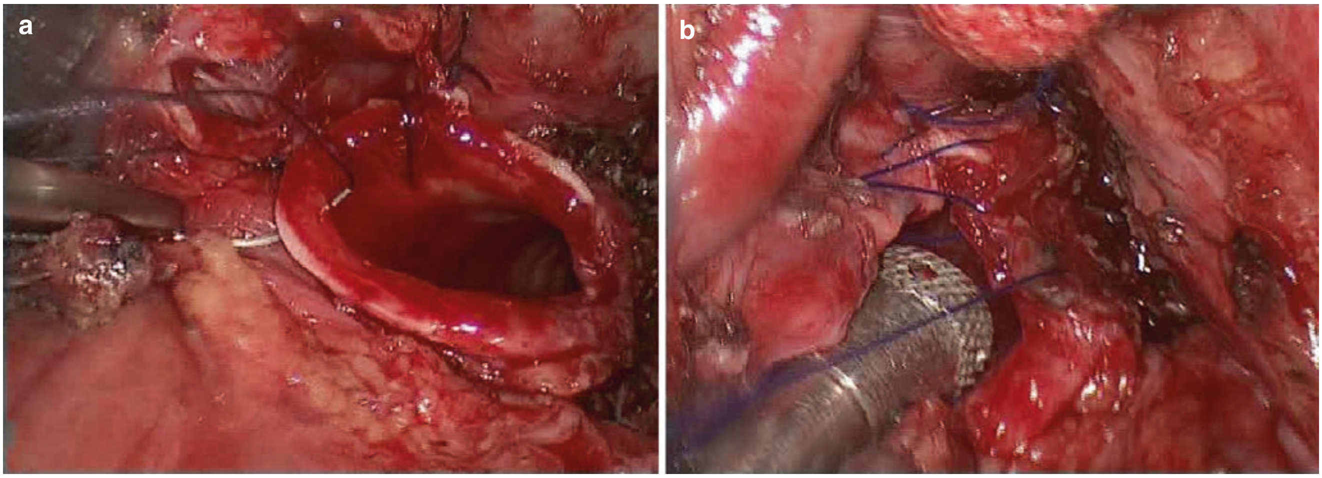

Fig. 6.2 (**a**) Illustration of sleeve lobectomy by VATS (simple interrupted suturing of the posterior bronchial wall). (**b**) Illustration of sleeve lobectomy by VATS (simple continuous suturing of the membranous portion of the bronchial membrane)

6.1.2 Overview of VATS Sleeve Lobectomy

Video-assisted thoracoscopic surgery (VATS) lobectomy has been proven as a minimally invasive, safe, and feasible surgical approach for early-stage non-small cell lung cancer. However, the VATS have been usually thought not suitable for patients requiring sleeve resection for the operation difficulty. In 2002, Santambrogio and colleagues performed the first VATS sleeve lobectomy of left lower lobe for a 15-year-old female patients with low-grade mucoepidermoid carcinoma. In 2008, Mahtabifard and colleagues first reported a series study of VATS sleeve lobectomy.

In recent years, VATS sleeve lobectomy developed for lung cancer in selected patients is proven technically feasible and safe. The distinguishing feature of VATS sleeve lobectomy is bronchial anastomosis after the resection of the lobe with tumor, However, VATS sleeve lobectomy should be performed in comparatively experienced centers.

6.1.2.1 Preoperative Examinations

The most important preoperative examinations for potential candidates of sleeve lobectomy is flexible bronchoscopy, because the flexible bronchoscopy could demonstrate the endobronchial tumor extension and define the boundary of the sleeve resection. Meanwhile, the biopsies could be performed during the bronchoscopy examination to confirmed malignant tumor. Radiographic examinations should be also performed in potential patients to evaluate the situation of the tumor and the mediastinal lymph nodes. The preoperative staging examinations should be taken in all candidate patients to exclude local advanced lesions or distant metastasis (e.g. chest CT, brain magnetic resonance imaging, abdominal ultrasound or CT scan, bone scintigraphy, or PET-CT). We should ensure the pulmonary function testing could tolerate a pneumonectomy.

6.1.2.2 Anesthesia and Airway Management

The sleeve lobectomy surgery was performed under general anesthesia. The proximity of the tumor to the carina should be taken into consideration for the choice of endotracheal tube. The most common way of airway management is the using of double-lumen endotracheal tube to conform the single-lung ventilation. When the bronchial anastomosis is performed close to the carina, high-frequency positive pressure ventilation or jet ventilation should be taken into consideration. Intraoperative bronchoscopy performed by the anesthetist is helpful to inspect the anastomosis so that the surgeon could rectify the suture in time.

6.1.2.3 Surgical Technique

At the beginning of the operation, the exploration of the lesions by VATS should performed to conform the feasibility of the sleeve resection. Extensive nodal or bronchial wall involvement should be excluded. The proximal of the pulmonary artery and vein should be controlled firstly during the sleeve lobectomy. And then, division of the lobar artery and vein, and the mediastinal lymph nodes were dissected. As a routine for oncological surgery, the right side VATS sleeve lobectomy should include lymph node stations 2R, 2L, 4R, 4L, 7, 8, 9, 10L, 10R, 11, 12; and 4L, 5, 6, 7, 8, 9, 10R, 10L, 11, 12 for the left side. The resection of involved bronchus and removal of the lobe was followed the main stem bronchus was divided first, and then the bronchus intermedius was divided using endoscopic scissors.

The anastomosis of the bronchus should be performed with tension-free reconstruction. Frozen sections of the incisal margins must be confirmed negative before suture. If the tumor invades the pulmonary artery, resection and reconstruction of the pulmonary artery should also be performed. As reported in literatures, the patients who received sleeve lobectomy by VATS had less operation time, less chest tube time, less hospitalization time and less postoperative pain.

6.2 Right Upper Sleeve Lobectomy by Complete Video-Assisted Thoracic Surgery

Yun Li, Xun Wang, and Jun Wang

6.2.1 Abstract

The sleeve lobectomy with bronchial or pulmonary vascular reconstruction was once one of the relatively contraindication in VATS. The surgical technical advances and the experience gained make it possible to perform the sleeve lobectomy by VATS in some experienced centers. The bronchial anastomosis is the core technology of VATS sleeve lobectomy. The bronchial anastomosis was performed by simple continuous suturing for the membranous portions of the bronchus and by simple interrupted suturing for the cartilaginous portions of the bronchus, respectively. The bronchial anastomosis began with the suturing of the posterior wall and a knot was tied to minimize anastomotic tension between the proximal and distal bronchial stumps. The right upper lobe is the most

common location for sleeve lobectomy. If the patients meet the inclusion criteria of sleeve lobectomy, they may gain from all the advantages of minimally invasive techniques.

6.2.2 Anesthesia and Preoperative Preparation

6.2.2.1 Anesthesia and Airway Management

Surgery was performed under general anesthesia with single lung ventilation. The patient should be intubated with a left double-lumen endotracheal tube during the surgery. High-frequency positive pressure ventilation was used whenever bronchial anastomosis is performed close to the carina.

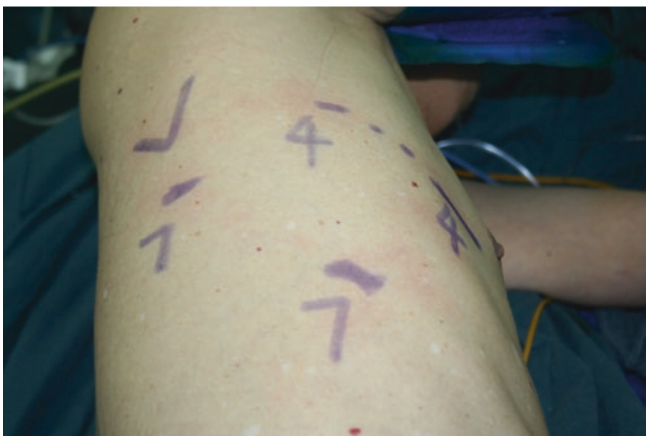

Fig. 6.3 Schematic diagram for patient position and incision location for right upper sleeve lobectomy of VATS: camera port at the seventh intercostal space, median axillary line; utility incision at the fourth intercostal space, anterior axillary line; additional operative port at the seventh intercostal space, ubscapularis line

6.2.2.2 Patient Position

The patient should be set in the lateral position with arm hanging down. Surgeon stood at the abdominal side of the patient.

6.2.2.3 Trocar Position

After single lung ventilation, three trocars were inserted. The observation port was located in the seventh inter-costal space in right median axillary line. The incision made at the level of the fourth inter-costal space in the anterior axillary line was the main operation port. The additional operative port was in the level of the seventh inter-costal space in the subscapularis line (Fig. 6.3).

6.2.3 Surgical Procedures

6.2.3.1 Mobilization and Dissection of the Mediastinal Pleura

Once the thoracoscopy has been placed in the thoracic cavity, the thoracic exploration should be performed to conformed the sleeve lobectomy could be done with R0 resection. At first, the right lower lobe was pulled in a cephalad direction by the ring forceps and then the inferior pulmonary ligament was divided.

The lung was retracted laterally and anteriorly and the posterior mediastinal pleura were incised up to the azygos vein level, meanwhile the bronchial artery was dissected carefully (Fig. 6.4).

And then we pulled the parenchyma into the posterior thoracic cavity by the ring forceps which placed from the auxiliary operation port.

The anterior mediastinum pleura was dissected by electrotome between the pulmonary vein and the phrenic nerve. The azygos vein could be preserved if the tumor or the metastatic lymph nodes did not affect the operation (Fig. 6.5).

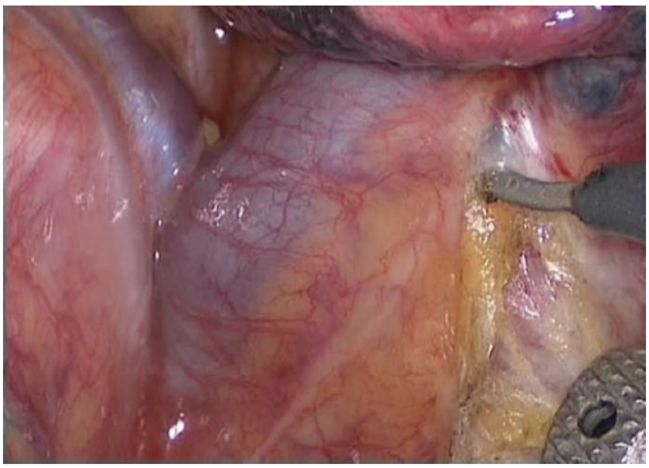

Fig. 6.4 Schematic diagram for sleeve lobectomy of the right upper lobe: the posterior mediastinal pleura was incised up to the azygos vein level

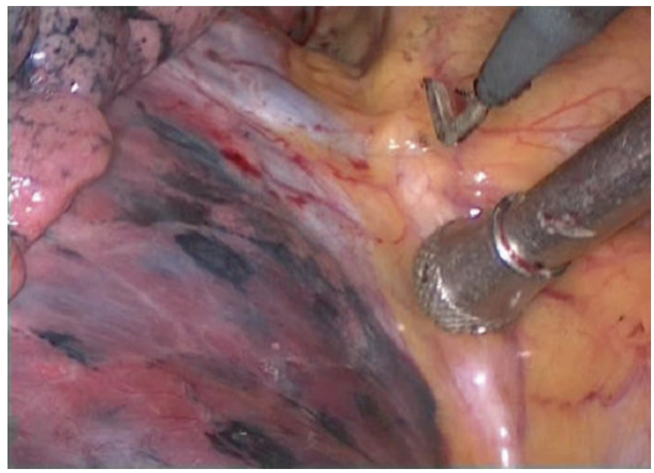

Fig. 6.5 Schematic diagram for sleeve lobectomy of the right upper lobe: the mediastinal pleura between the pulmonary vein and the phrenic nerve were incised

6.2.3.2 Lobectomy of the Right Upper Lobe

We exposed the right superior pulmonary vein and divided them by the staplers. A ring forceps was placed holding the right upper lobe for a cephalad traction, electrocautery was used to dissect the border between the horizontal fissure and the oblique fissure (Fig. 6.6).

Then the mid-segment of the pulmonary artery adventitia was dissected in the incised fissure. We build an artificial tunnel in the lung fissure and then the minor fissure was divided by the staplers through the seventh inter-costal space of the right mid-axillary line. And then, the posterior ascending branch arising from the superior segmental artery of the right lower lobe was dissected by the using of 4-0 sutures. The apico-anterior artery and the posterior oblique fissure were divided by the staplers (Figs. 6.7, 6.8, and 6.9).

The surrounding connective tissue of the right main bronchus and the intermedius bronchi was removed. Stations 2, 4, 7, 8, 9, 10 and 11 lymph nodes were dissected before dissection of bronchus. It is beneficial for the anastomosis without tension. The specimen was packed into a surgical glove and then extracted through the fourth inter-costal space incision in the anterior axillary line. Then the right main stem bronchus and the bronchus intermedius were divided using scissors and a scalpel. Frozen sections of the margin of the right main bronchus and the bronchus intermedius were negative of tumor infiltration as confirmed pathologically during surgery (Fig. 6.7, 6.8, 6.9, 6.10, 6.11, and 6.12).

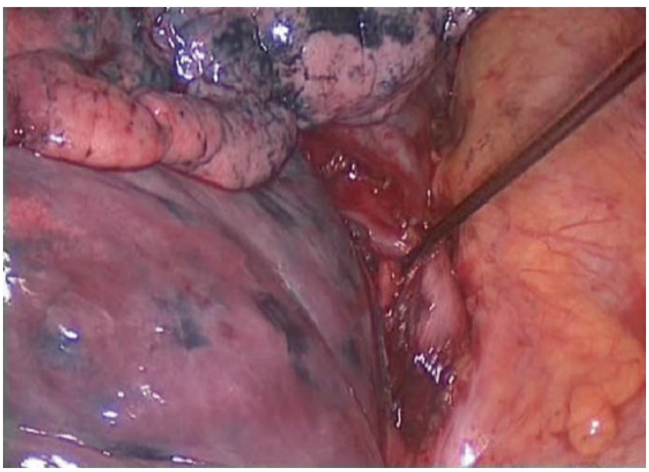

Fig. 6.6 The right superior pulmonary vein was divided

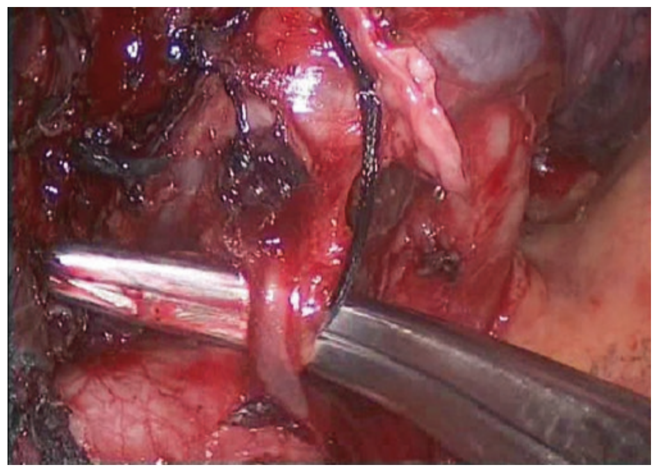

Fig. 6.8 Dissection of the posterior ascending branch artery

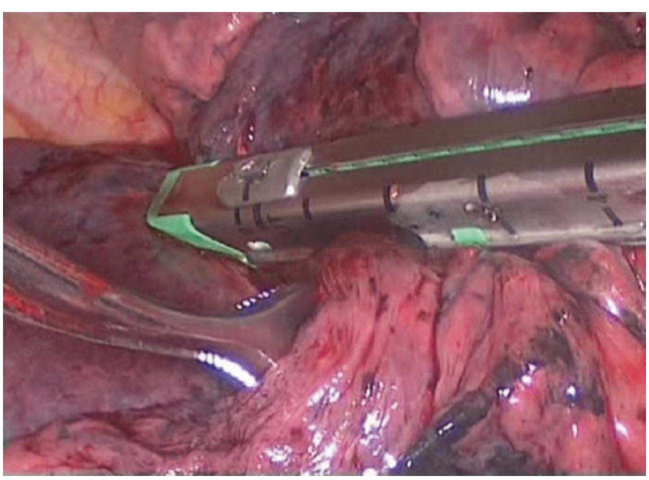

Fig. 6.7 The minor fissure was divided by the staplers

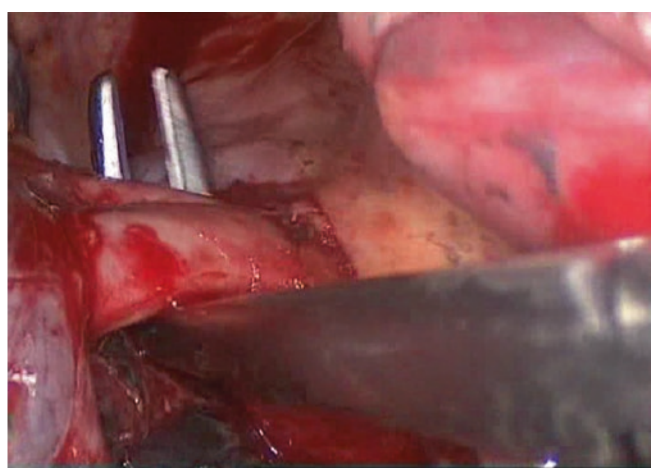

Fig. 6.9 Dissection of the apico-anterior artery

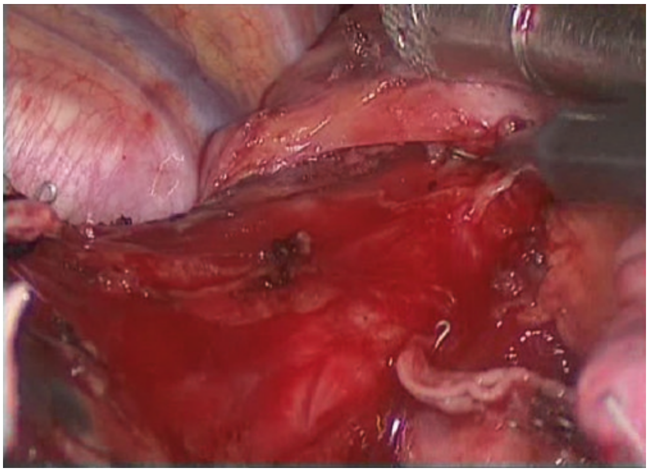

Fig. 6.10 Dissection of surrounding connective tissue of the right main bronchus

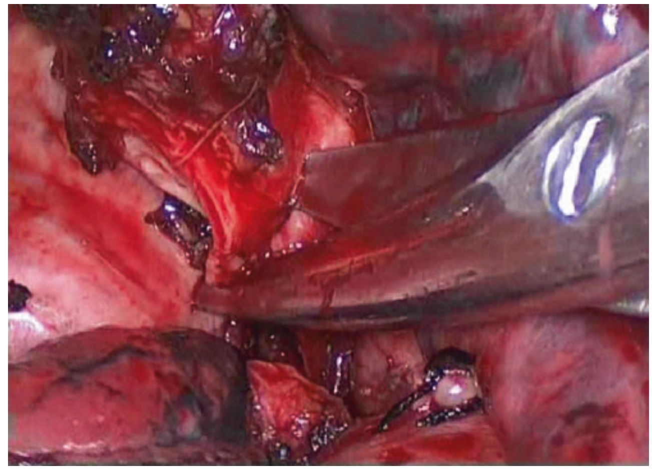

Fig. 6.12 The right main stem bronchus was divided by using the scissors

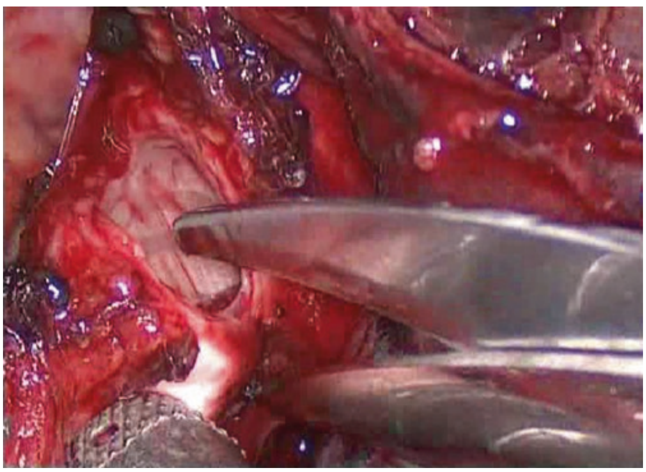

Fig. 6.11 The right bronchus intermedius was divided by using scissors

6.2.3.3 Anastomosis of the Bronchus Ends

The end-to-end bronchial anastomosis was then performed. When we deal with the membranous portions of the bronchus, the simple continuous suturing should be used. And for the cartilaginous portions of the bronchus, the simple interrupted suturing was recommended (Fig. 6.13).

The first step was to suture the posterior wall of bronchus, the simple interrupted suturing with 3-0 absorbable sutures was used in the process of the anastomosis, and a knot was tied to minimize the tension of the anastomotic bronchus (Fig. 6.14).

Then we should anastomose the membranous portion of the bronchus and the simple continuous 4-0 non-absorbable sutures were used for this process. The anastomosis was from the deepest portion of the posterior bronchial wall to mid-point of the anterior bronchial wall, which was tagged without making a knot (Fig. 6.15).

The simple interrupted suturing with 3-0 absorbable sutures was used when dealing with the remaining bronchus. The suturing began from the tension line to the mid-point of the anterior bronchial wall, where it converged with the continuous suture line. The anastomosis was finished when the knot was tied between the last simple interrupted suture and the continuous suture (Fig. 6.16).

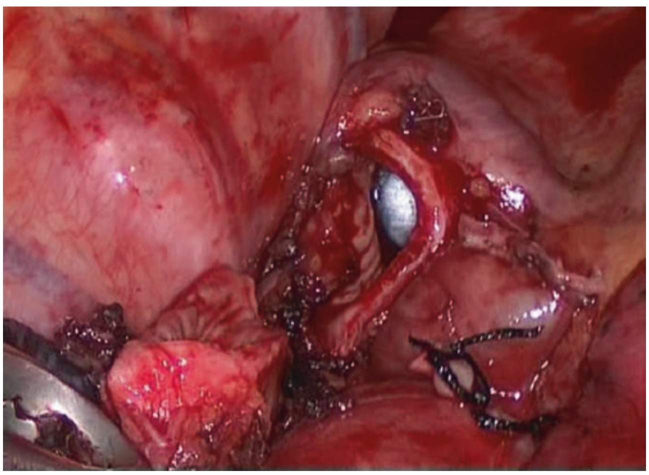

Fig. 6.13 Bronchial stump of the right middle segmental bronchus and right main bronchus

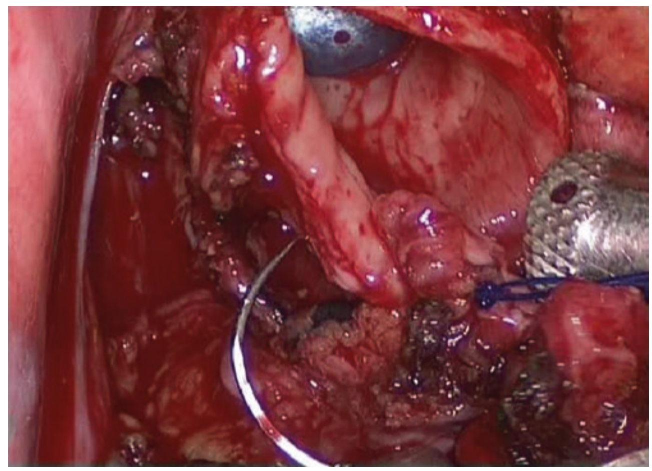

Fig. 6.15 Simple continuous 4-0 nonabsorbable suturing of the membranous portion of the bronchial membrane

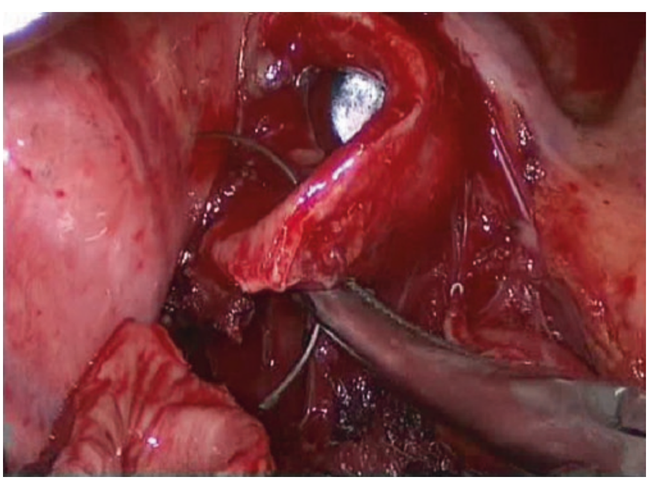

Fig. 6.14 Posterior bronchial wall, with anastomosis of simple interrupted 3-0 absorbable sutures

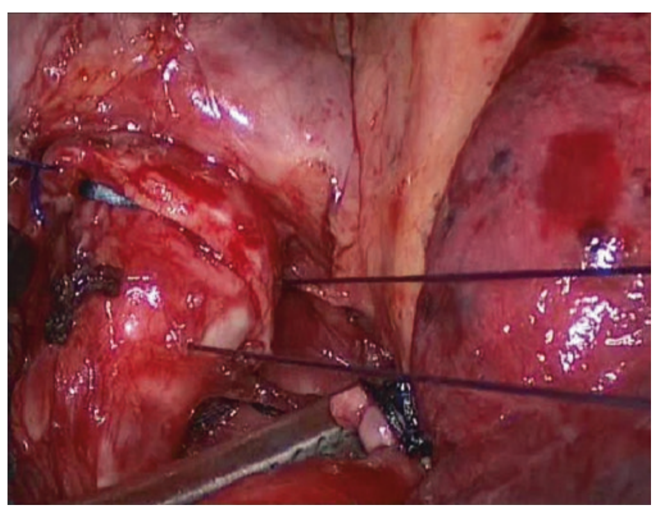

Fig. 6.16 Simple interrupted 3-0 absorbable suturing of the anterior bronchial wall

6.2.4 Postoperative Care

The sleeve resection of the bronchus disrupts the normal mucociliary clearance and the mucosal barrier which lead to secretion retention in the bronchus. Adequate coughing and sufficient pain control should be considered for patients who underwent the sleeve lobectomy, these measures could minimize these morbidities. When the inadequate sputum clearance takes place, bed-side bronchoscopy is recommended, but the bronchoscopy should be operated carefully to avoid potential trauma of the anastomosis.

6.3 Left Lower Sleeve Lobectomy

Yanguo Liu and Jun Wang

6.3.1 Summary of Basic Operation Procedures

After entry into the chest, complete exploration is carried out. Incise the inferior pulmonary ligament, followed by the mediastinal pleural around the hilum pulmonis, then dissect and divide the bronchial arteries. Dissect the fissure in a regular lobectomy manner, mobilize the branches of left lower lobe artery in the fissure and divide them with the endo-cutter-stapler. Completely dissect the subcarinal lymph nodes, then mobilize the left main bronchus and the origin of the left upper lobe bronchus. Divide the left main bronchus and the upper lobe bronchus separately 0.5-cm to the bifurcation and the left lower lobectomy is completed. The specimen is removed in protective specimen bag. Finally the end-to-end anastomosis of the two bronchial stumps is performed with 3-0 absorbable suture.

6.3.2 Technical Points

6.3.2.1 Incision Placement Points

The placement of the incision is crucial for a thoracoscopic sleeve procedure.

The operating port is placed in the left anterior axillary line in the fifth intercostal space. This access makes it possible for the direction of needle holder to be parallel with the hilum pulmonis. And it is right facing the anastomosis, which is very convenient and consistent with suture fashion of the open procedure. The placed sutures can be pulled out via the assisting port prior to tying, so it has no influence on the following procedures.

6.3.2.2 Anastomosis Points

We used both running and interrupted suture techniques for the membranous and cartilaginous portions of the bronchus, respectively.

The suturing starts from the posterior wall. Initially an interrupted suture is placed in the deepest part (the most difficult part of anastomosis). Appose both stumps of the bronchi with the suture then tie.

A running suture is placed from cartilaginous-membranous junction, along the membranous portion of the bronchus, and then pull out the end of the suture without tying.

Continue with suture of the cartilaginous portion in interrupted manner, till cartilaginous-membranous junction and join with the running suture. A knot was formed between the last simple interrupted suture and the membranous continuous suture.

The left lower sleeve lobectomy is technically difficult because of the presence of the pulmonary artery.

Buttress of the anastomosis is not essential.

6.3.3 Operation Procedure

1. The lung is retracted cranially using the ring forceps introduced from the assisting port, and divide the inferior pulmonary ligament by blunt dissection combined with electrocoagulation. Then the lung is retracted forward, and divide the mediastinal pleural posterior of the hilum pulmonis (Figs. 6.17, 6.18, and 6.19)
2. The lung is retracted backward and the mediastinal pleura anterior of the hilum pulmonis is divided with an electrocoagulation. Then the left inferior pulmonary vein is identified and mobilized (Figs. 6.20 and 6.21).
3. Introduce the ring forceps from the assisting port to retract the left lower lobe downward, dissect the oblique fissure with the electrocoagulation, and reveal the branches of the left inferior pulmonary artery (Figs. 6.22 and 6.23).
4. Introduce the long curved clamp via the operating port to mobilize the dorsal artery. Then the linear endo-cutter-stapler to divide the dorsal artery, follow the same procedure to dissect and divide the basilar artery (Figs. 6.24, 6.25, 6.26, and 6.27).
5. Retract the lower lobe cranially, introduce the linear-cutter-stapler and divide the inferior pulmonary vein (Figs. 6.28 and 6.29).
6. Dissect the subcarinal lymph nodes: Firstly mobilize the subcarinal lymph nodes along the esophagus and divide the supplying arteries at the same time. Then the nodes are dissected starting from the inferior pulmonary vein, moving forward from behind the pericardium, and all the way up to below the carinal (Figs. 6.30 and 6.31).
7. Reveal the bifurcation of the left main bronchus in the fissure. Mobilize the bronchus by blunt dissection, and the tumor is seen to originate from the opening of the left lower lobe bronchus and invade the bifurcation. Dissect the left main bronchus and the origin of the left upper lobe bronchus, and then transect the main bronchus and the

upper lobe bronchus 0.5-cm to the bifurcation respectively. The left lower lobectomy is completed (Figs. 6.32, 6.33, 6.34, 6.35, 6.36, and 6.37).

8. End-to-end anastomosis of the left upper lobe bronchus and the left main bronchus is constructed. The suture starts from the posterior wall and initially an interrupted suture is placed in the deepest part. Appose both stumps of the bronchi with the suture, then tie and cut the suture. A running suture is placed from this stitch along the membranous portion of the bronchus to cartilaginous-membranous junction, and then pull out the end of the suture without tying. Again starting from the initial suture interrupted sutures are placed forward on the remaining bronchial edge till cartilaginous-membranous junction and join with the running suture. Knot is formed with the last interrupted suture and the running suture. And then the circumferential anastomosis of the bronchi is completed (Figs. 6.38, 6.39, 6.40, 6.41, 6.42, 6.43, 6.44, 6.45, 6.46, 6.47, 6.48, 6.49, and 6.50).

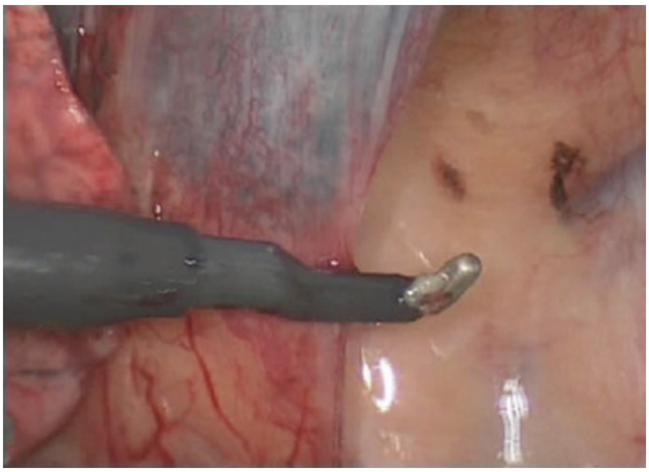

Fig. 6.17 Retract the lung cranially

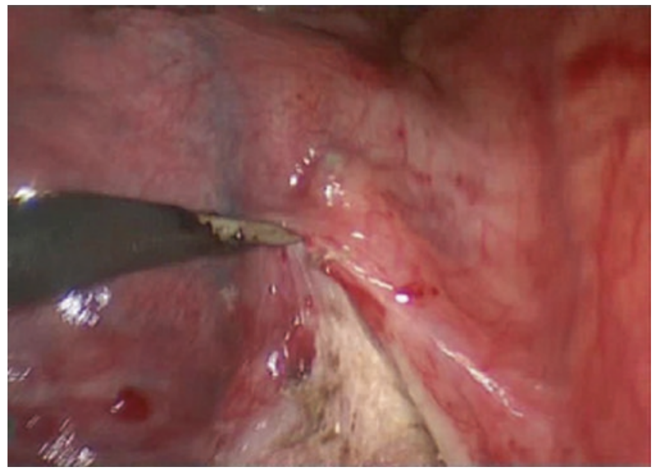

Fig. 6.19 Divide the pleura posterior of the hilum pulmonis

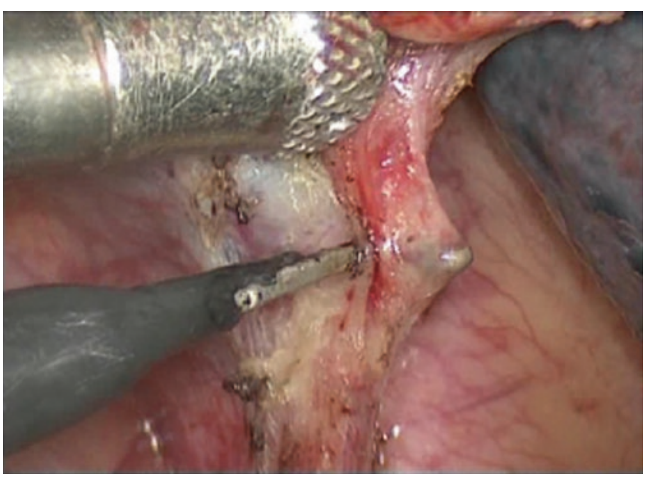

Fig. 6.18 Divide the inferior pulmonary ligament

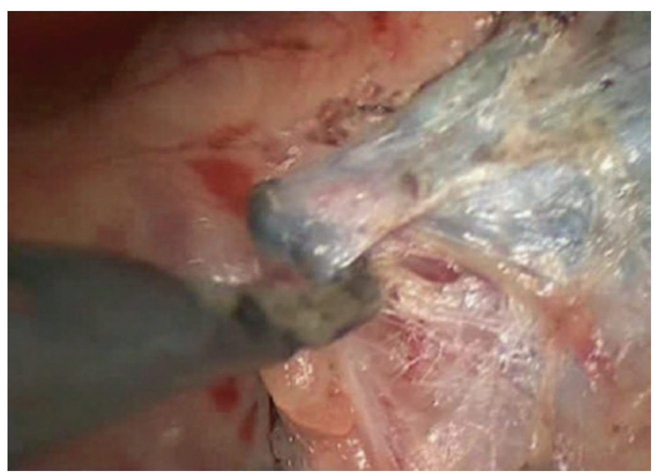

Fig. 6.20 Divide the pleura anterior of the hilum pulmonis

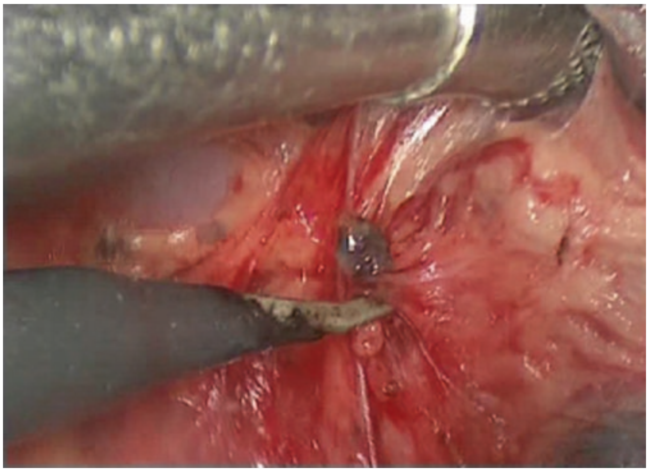

Fig. 6.21 Dissect the plane between the superior and inferior pulmonary veins

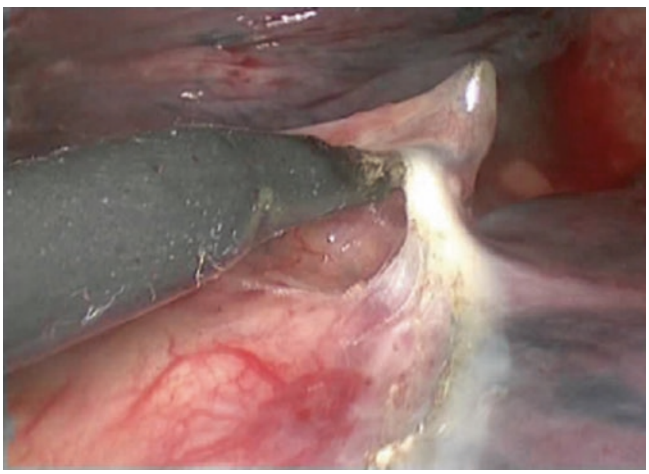

Fig. 6.22 Dissect the oblique fissure with electrocoagulation

Fig. 6.23 Divide and expose the inferior pulmonary artery

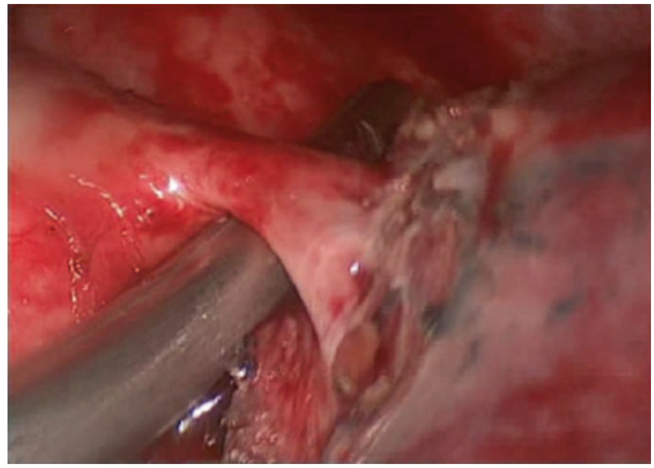

Fig. 6.24 Dissect the lower lobe dorsal artery

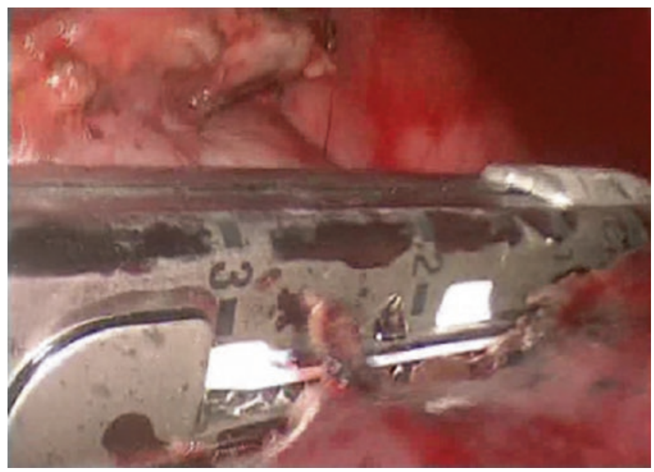

Fig. 6.25 Divide the dorsal segment artery with stapler

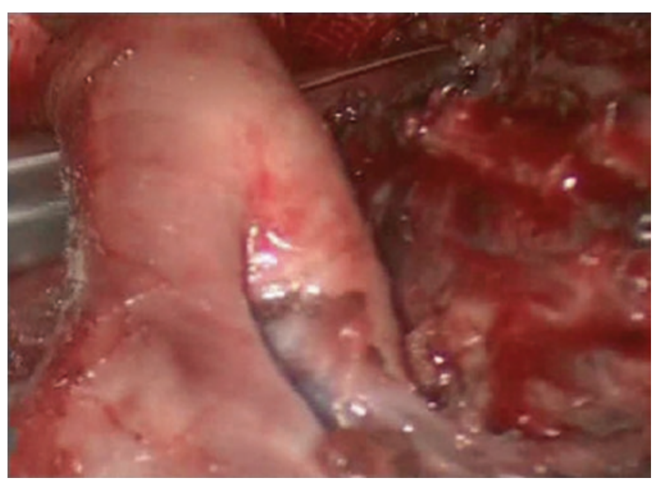

Fig. 6.26 Dissect the basilar segment artery

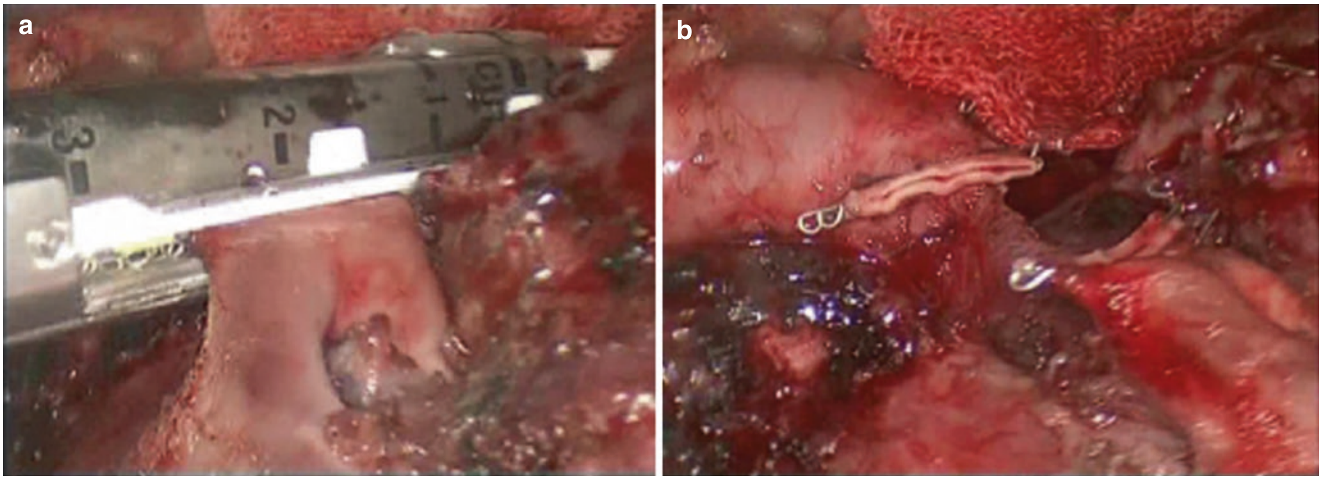

Fig. 6.27 Divide the basilar segment artery with stapler

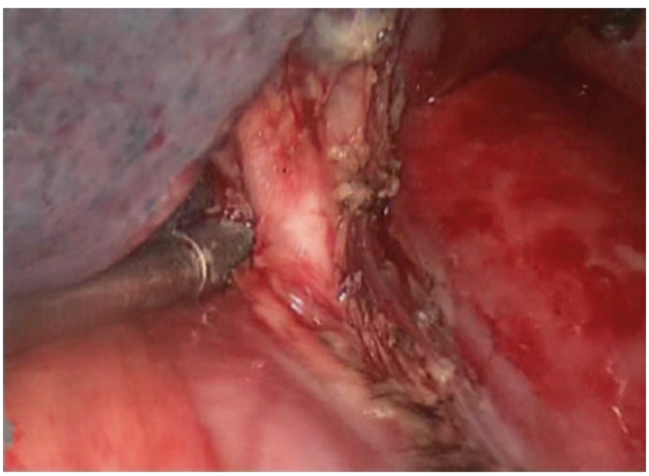

Fig. 6.28 Retract the lower lobe cranially

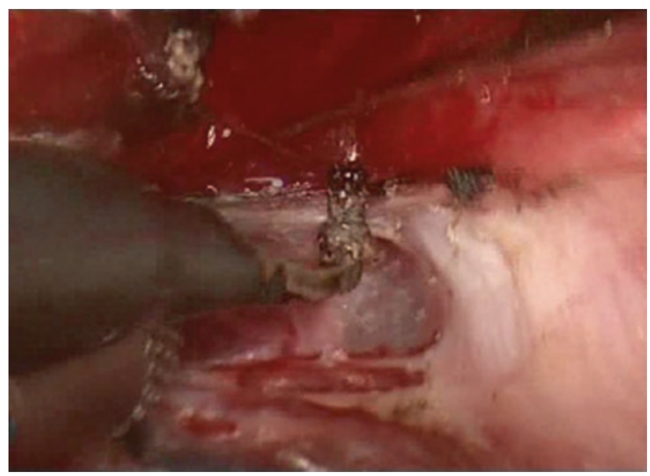

Fig. 6.30 Dissect the posterior side of the subcarinal lymph nodes

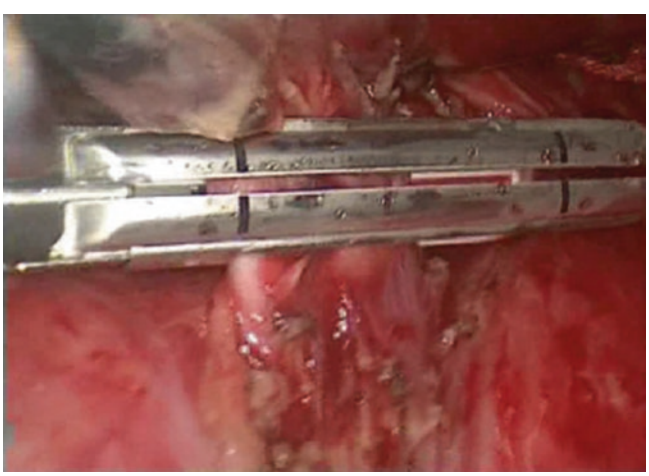

Fig. 6.29 Divide the inferior pulmonary vein with stapler

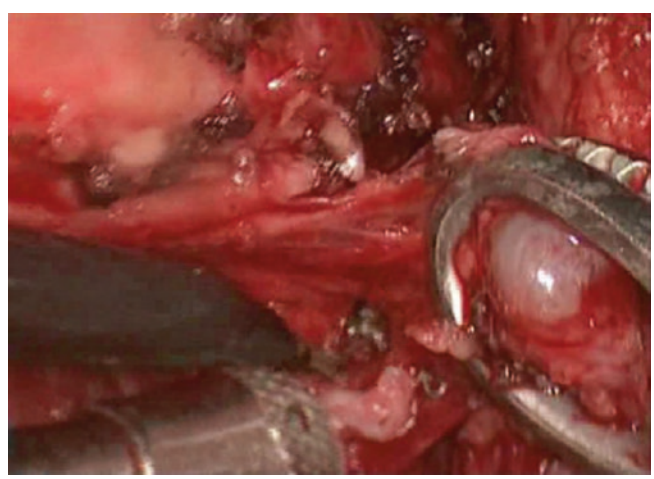

Fig. 6.31 Dissect the anterior side of the subcarinal lymph nodes

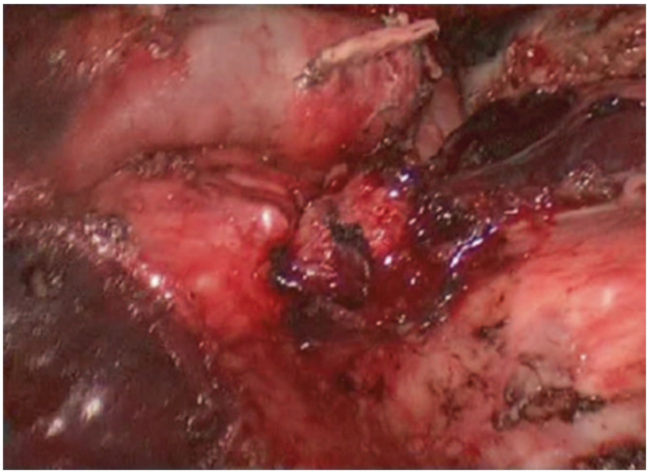

Fig. 6.32 Reveal the bifurcation of the left main bronchus in the fissure

Fig. 6.33 *Encircle* the left upper bronchus using the right-angled clamp

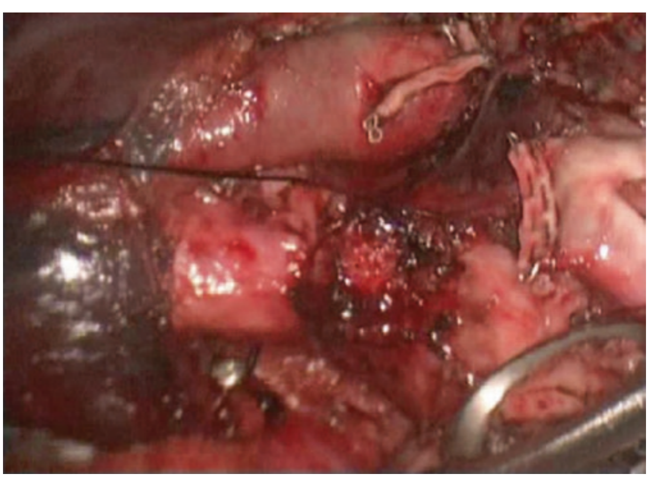

Fig. 6.34 Retract the upper bronchus with silk suture. (**a**) Left upper bronchus, (**b**) pulmonary artery, (**c**) left lower bronchus, (**d**) stump of left lower artery

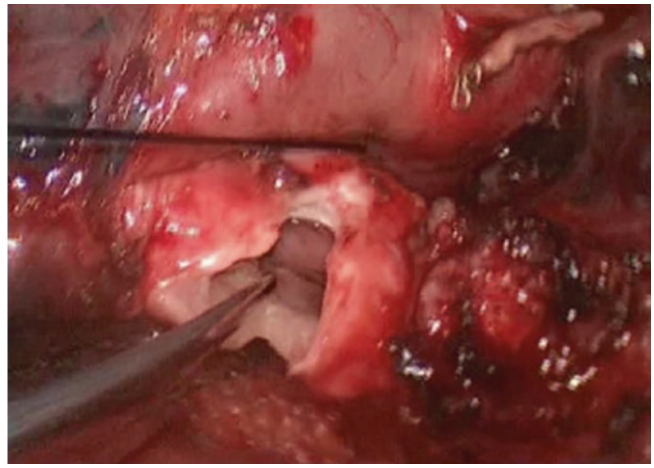

Fig. 6.35 Transect the left upper bronchus 0.5 cm distal to the bifurcation

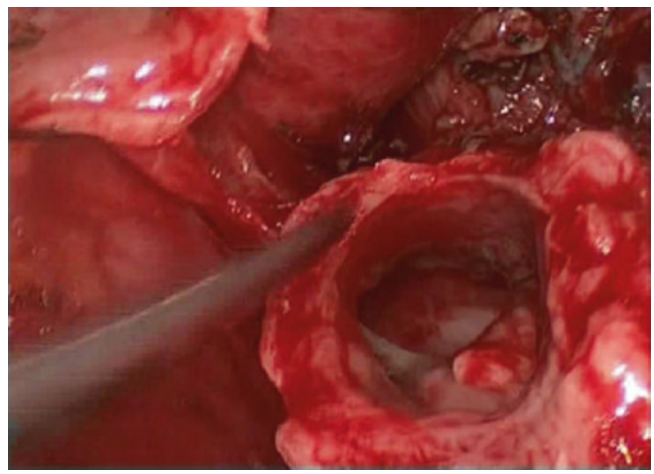

Fig. 6.36 Transect the left main bronchus 0.5 cm proximal to the bifurcation

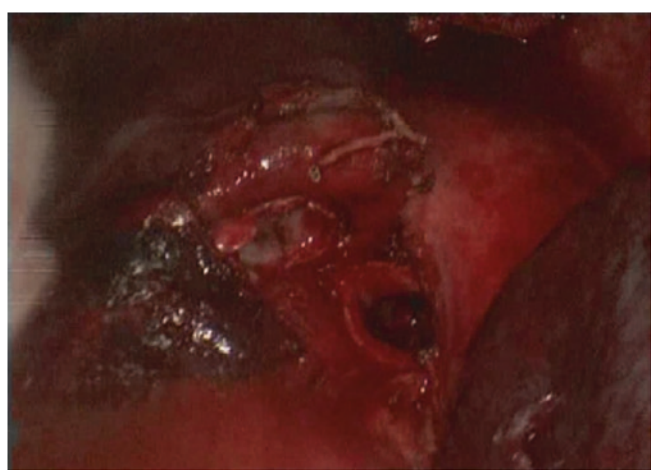

Fig. 6.37 Remove the left lower lobe. (**a**) Left pulmonary artery, (**b**) the stump of the left upper bronchus, (**c**) the stump of the left main bronchus

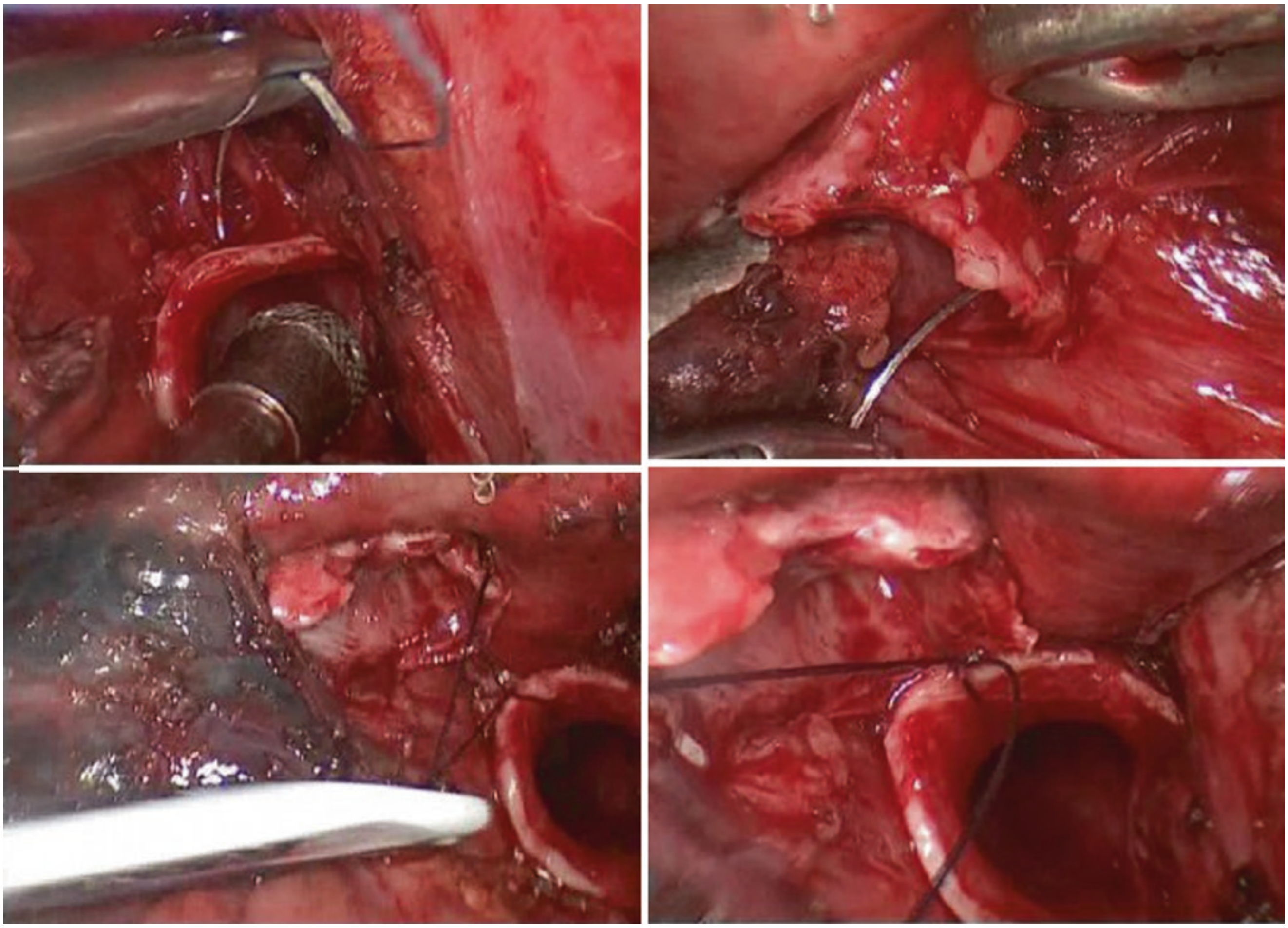

Fig. 6.38 The first suture of the posterior wall: the needle is pulled in at the midpoint of the posterior wall of the left main bronchial stump, and pulled out at the midpoint of the posterior wall of the left upper lobe bronchial stump. Appose the two branchial stumps and tie. (**a**) Left upper lobe bronchus, (b) left main bronchus

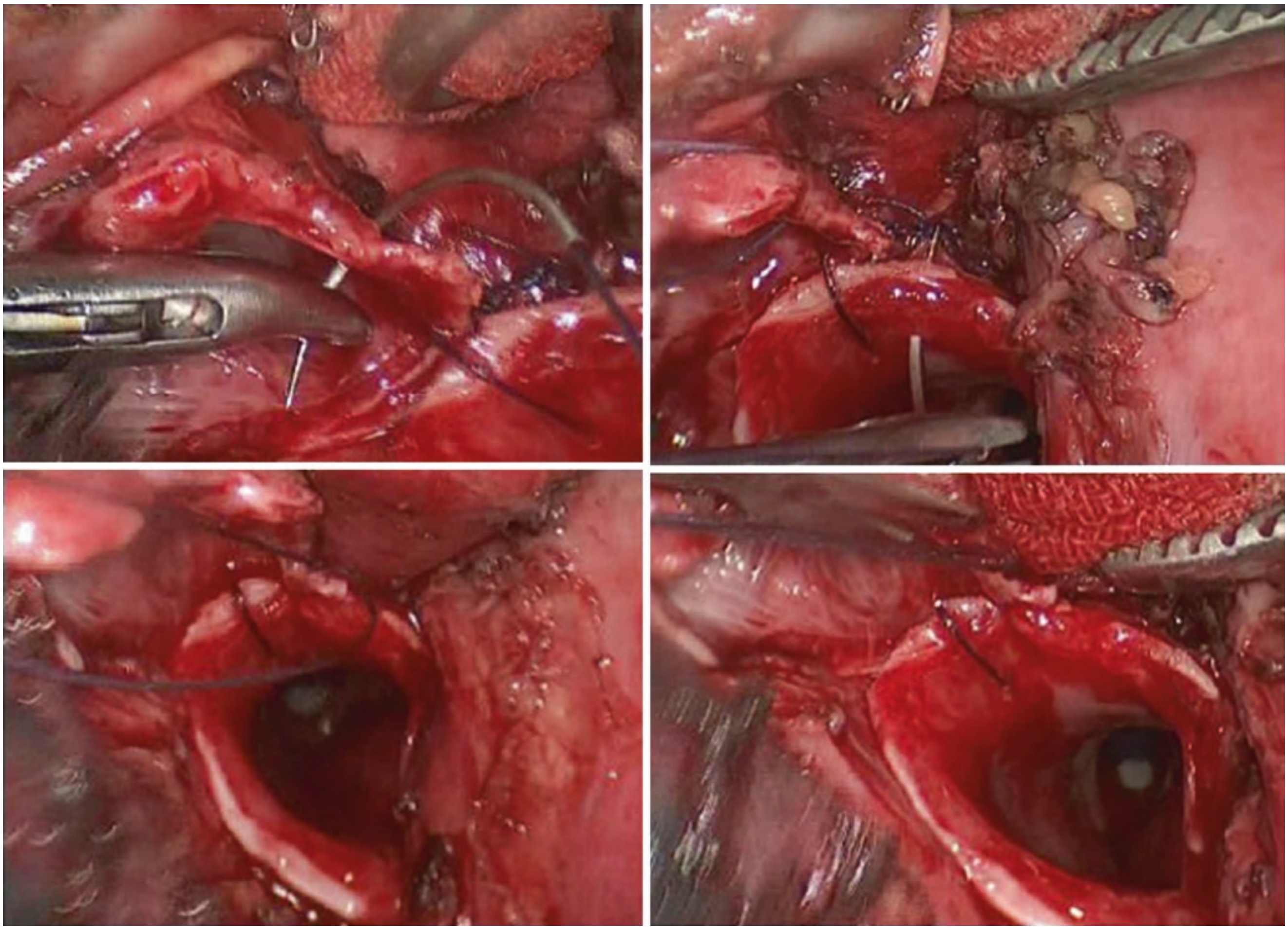

Fig. 6.39 The second suture of the cartilaginous portion of the posterior wall in interrupted manner

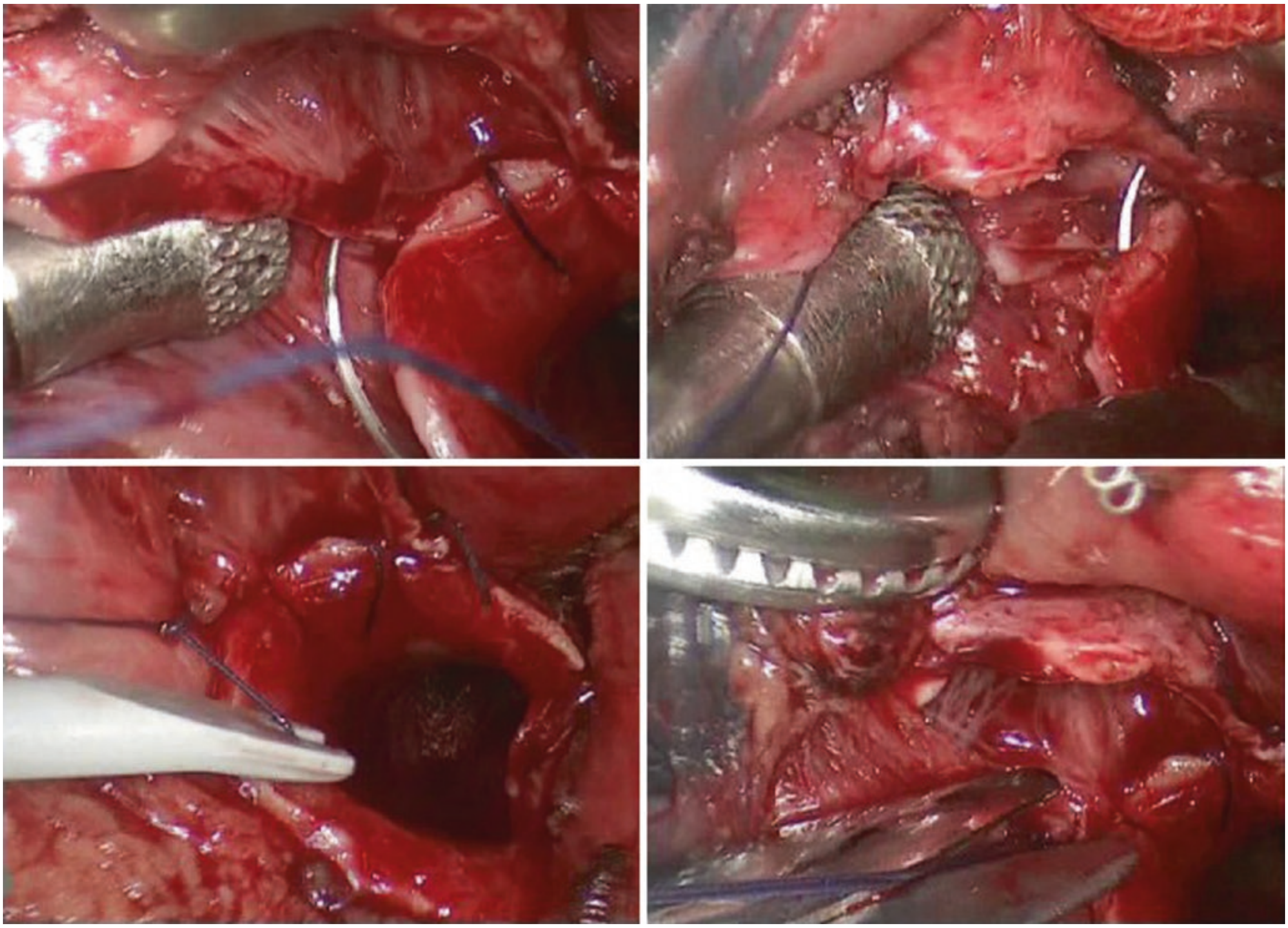

Fig. 6.40 The third suture of the cartilaginous portion of the posterior wall in interrupted manner

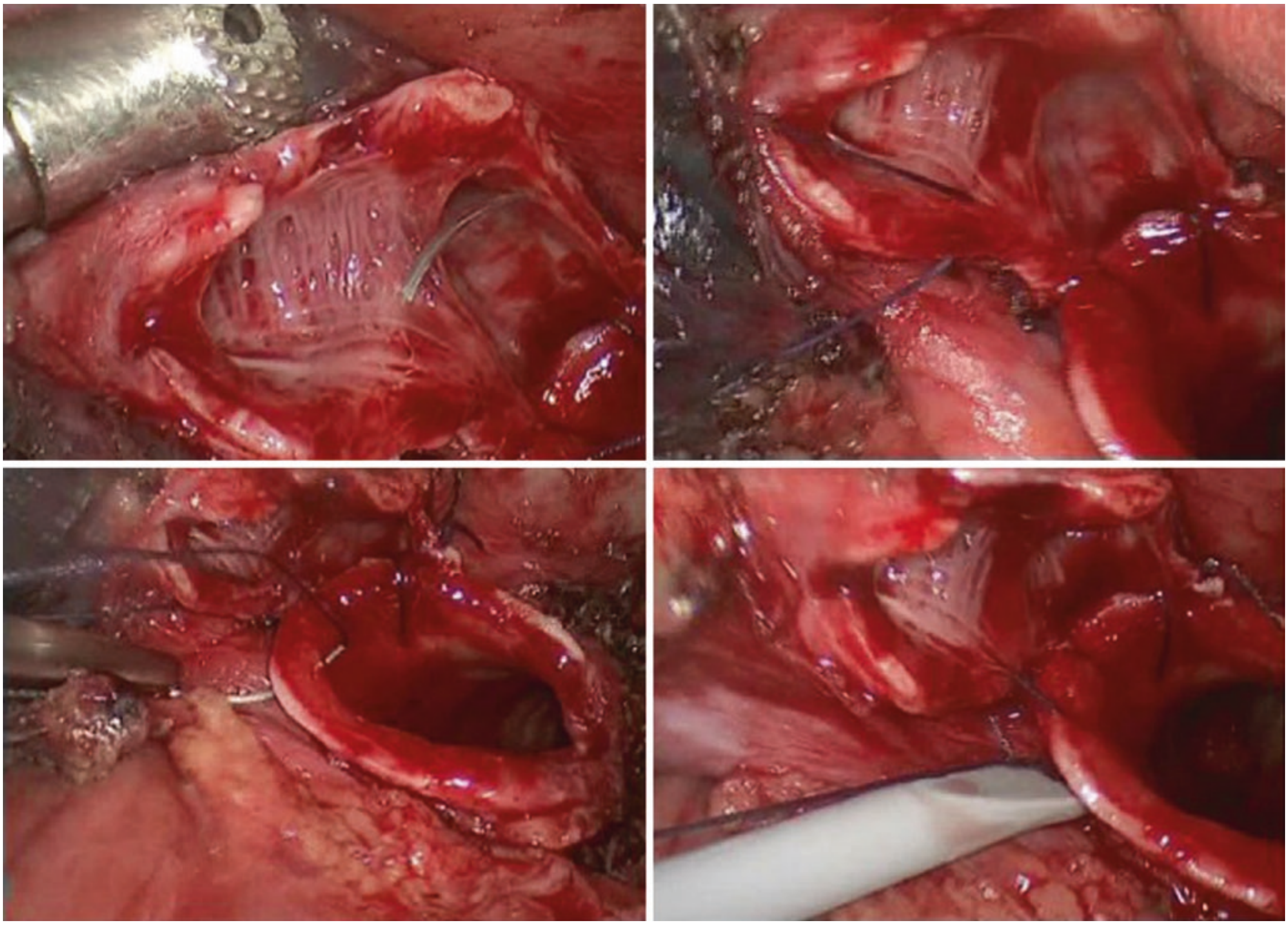

Fig. 6.41 Continue to suture the posterior wall in interrupted manner *1* left upper lobe bronchus, *2* left main bronchus

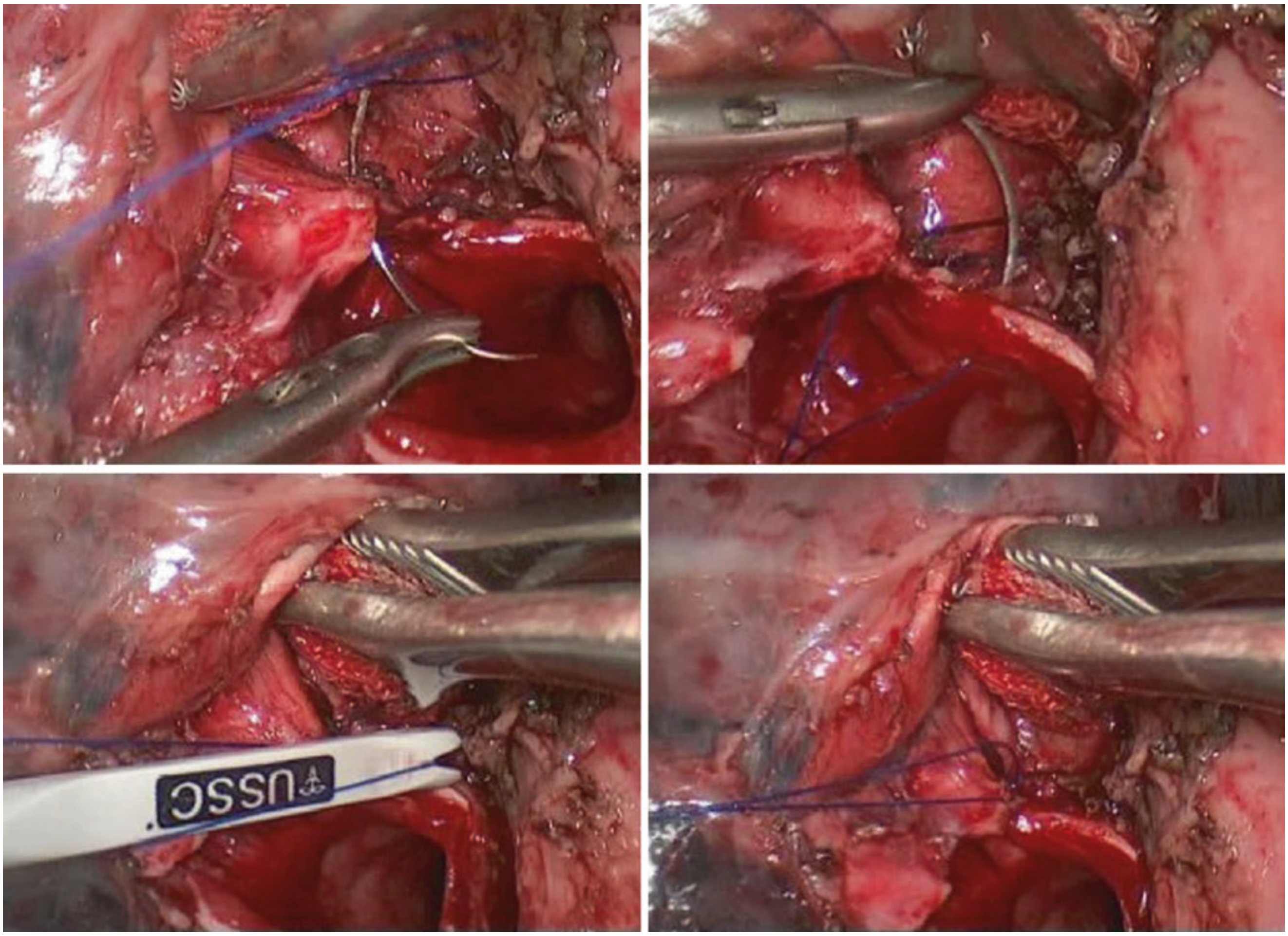

Fig. 6.42 Suture the membranous portion with nonabsorbable 3–0 polypropylene in the running manner. Start from the last stitch of the interrupted suture of the posterior wall at the membranous-cartilaginous junction. Knot the first stitch of the running suture outside the bronchus

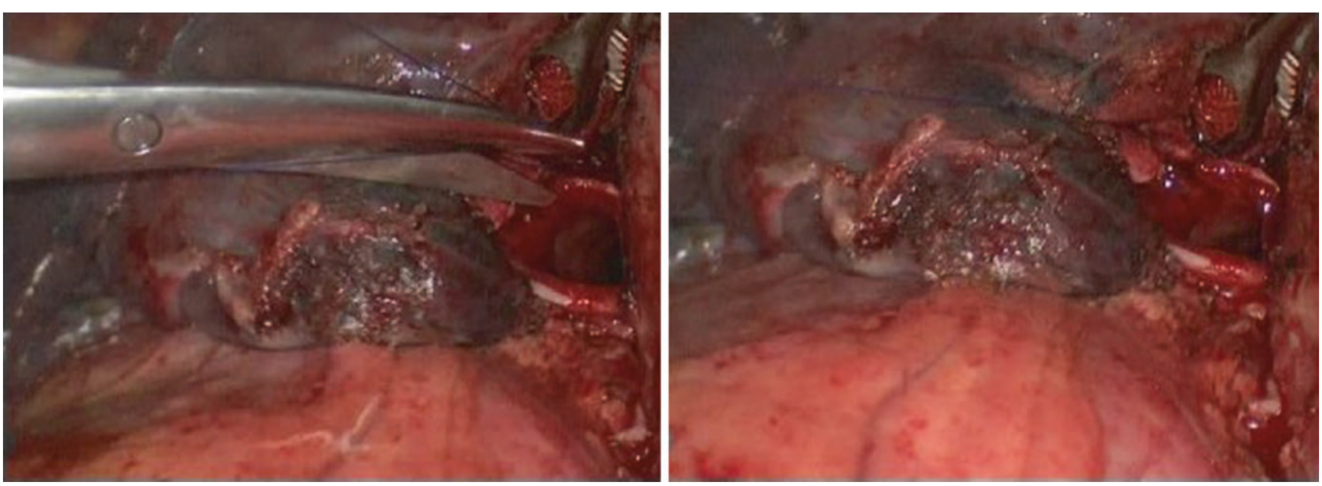

Fig. 6.43 Cut one end of the suture after tying and continue to suture in the running manner with the remaining end

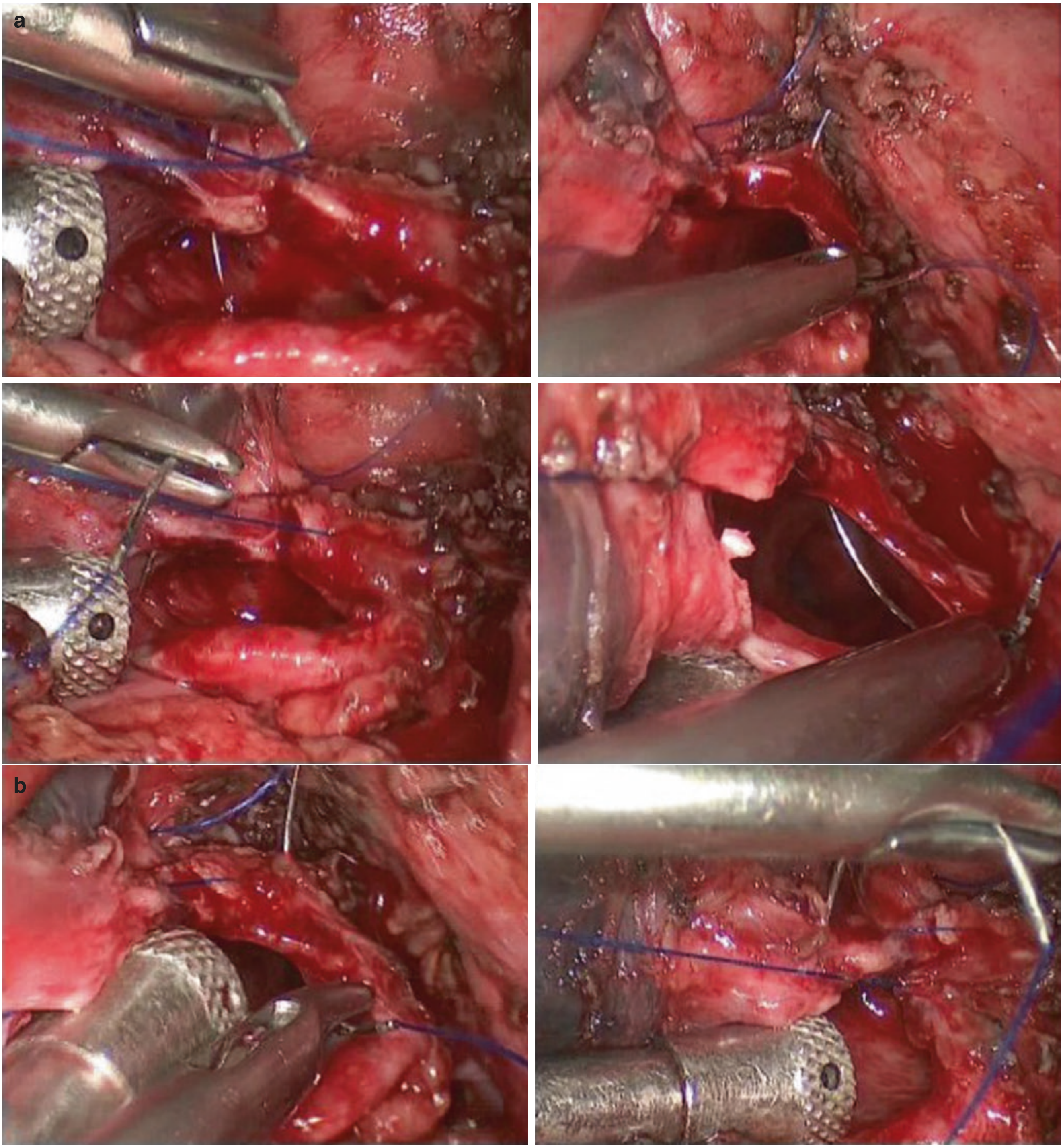

Fig. 6.44 Suture the membranous portion of the posterior wall in running manner. After the last stitch, tension the suture

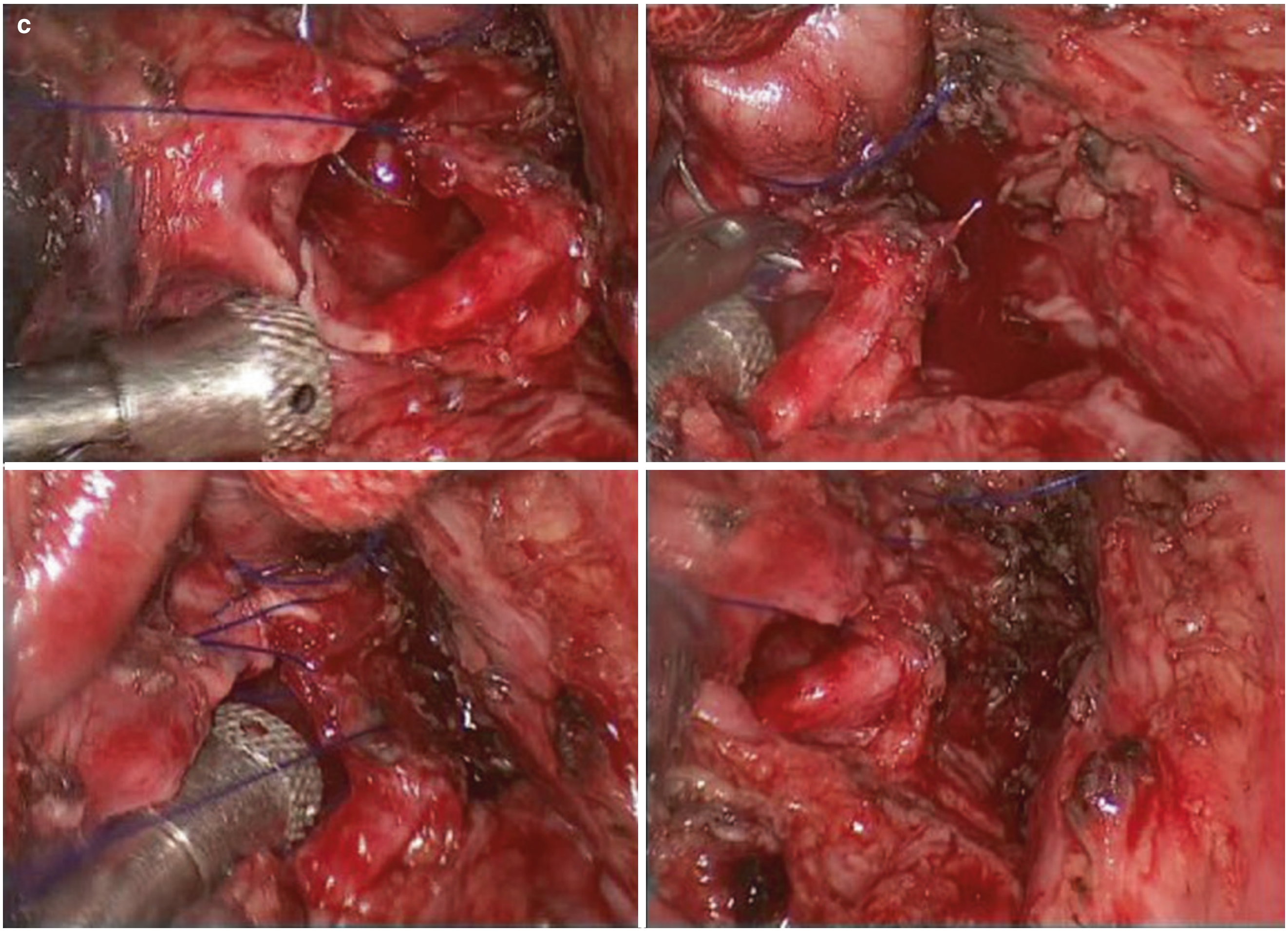

Fig. 6.44 (continued)

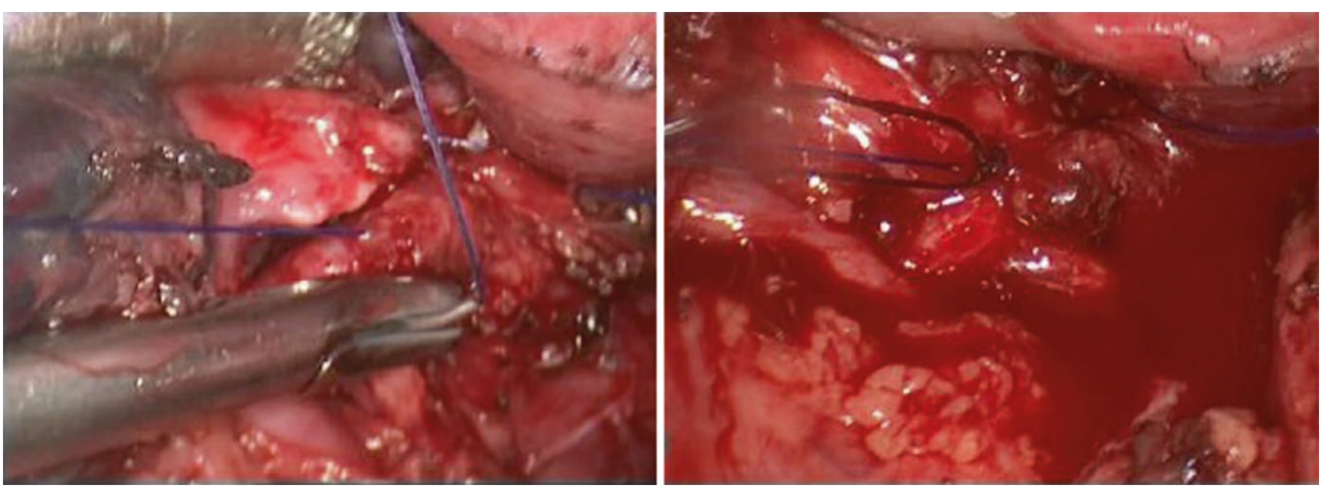

Fig. 6.45 Start an interrupted suture with absorbable suture 2-mm apart from the last stitch of the running suture and tie the suture

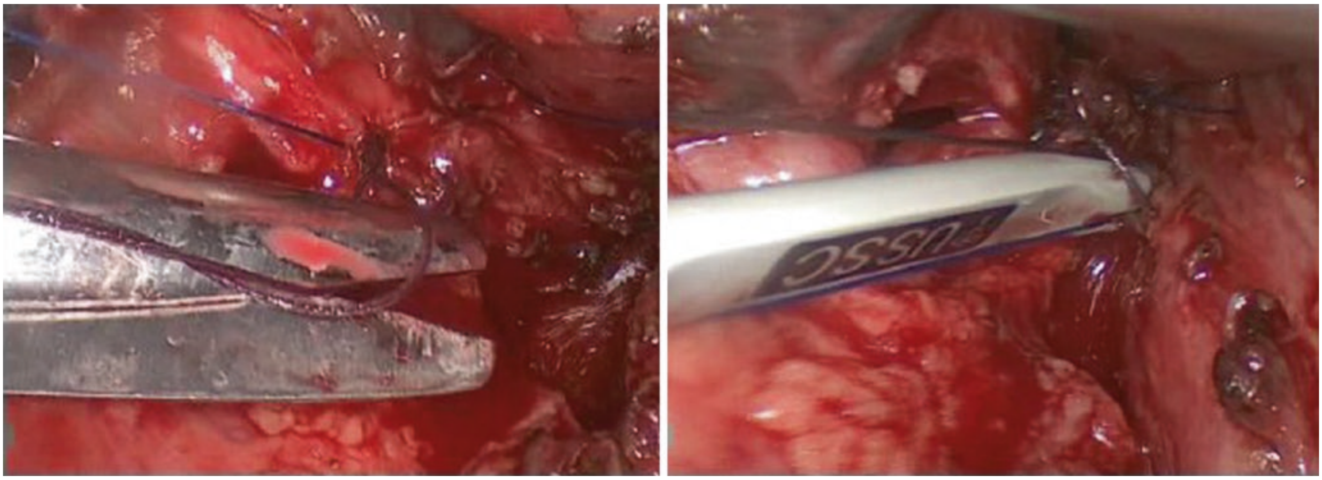

Fig. 6.46 Cut one end of the suture after tying, and the remaining end of the suture ties with the suture used in the running manner

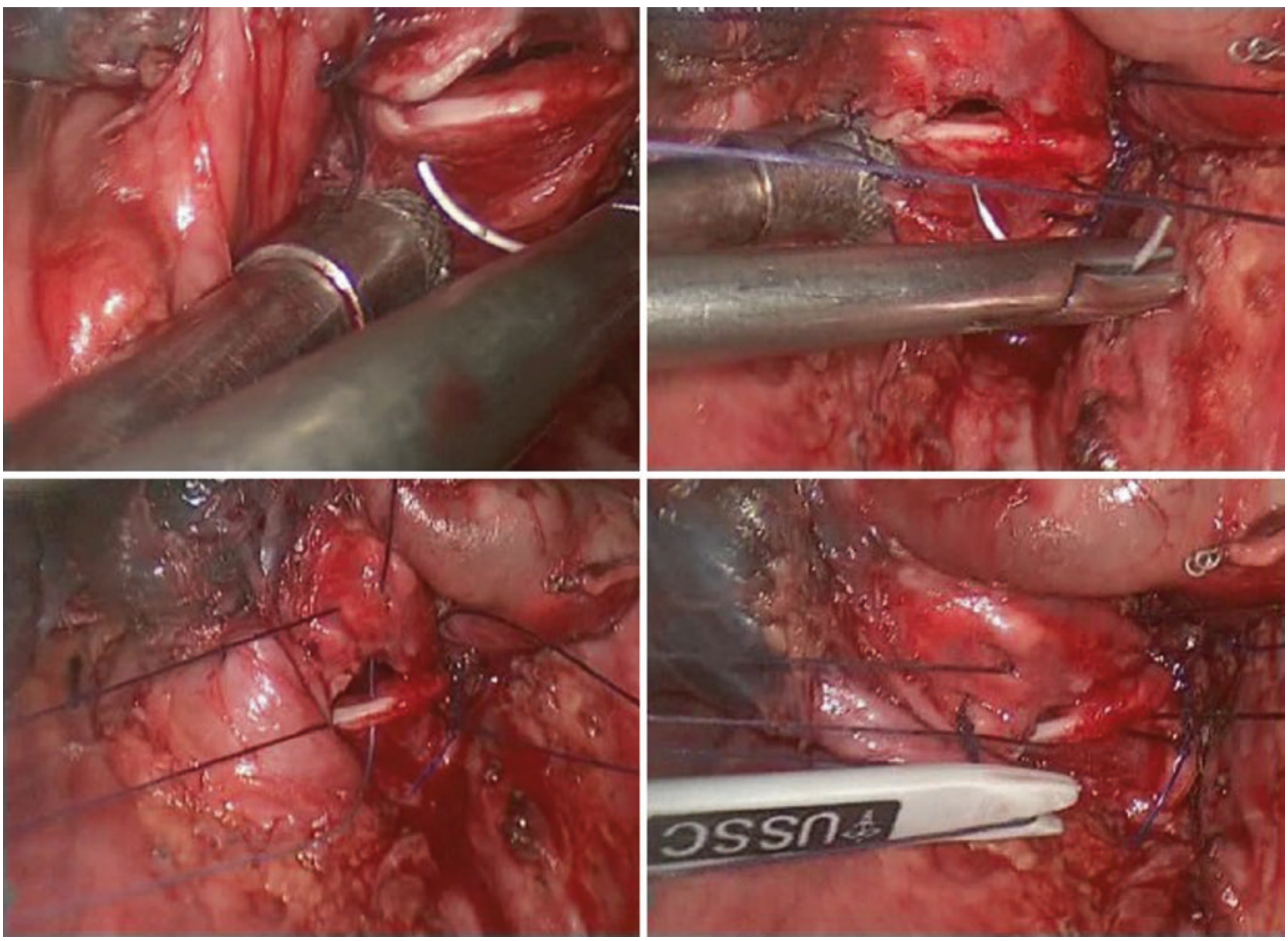

Fig. 6.47 Suture the remaining cartilaginous portion of the anterior wall with absorbable suture in interrupted manner

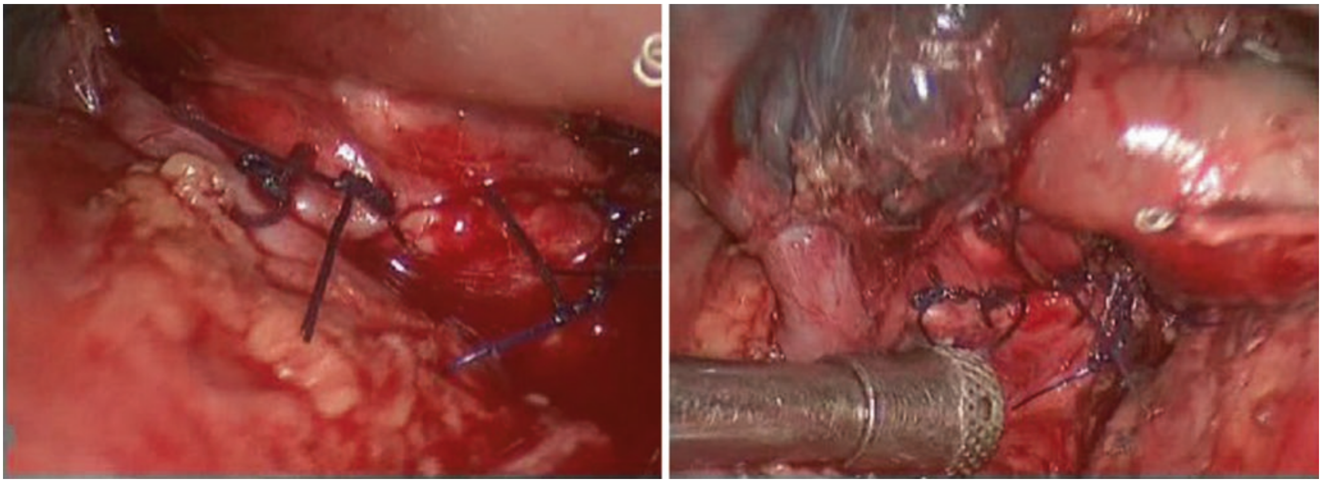

Fig. 6.48 The completed anastomosis

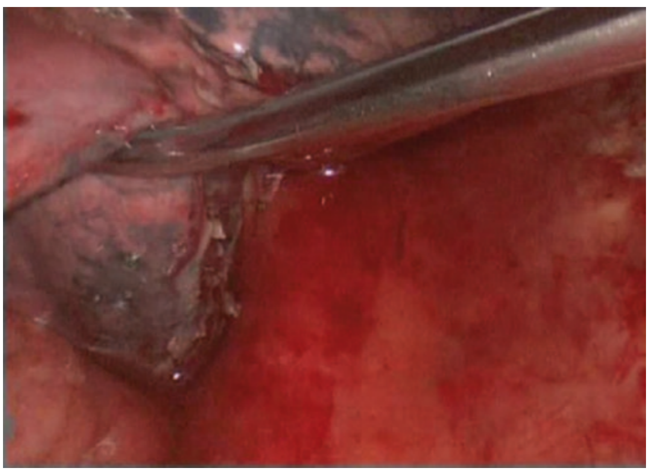

Fig. 6.49 The anastomosis is checked for air leak under water

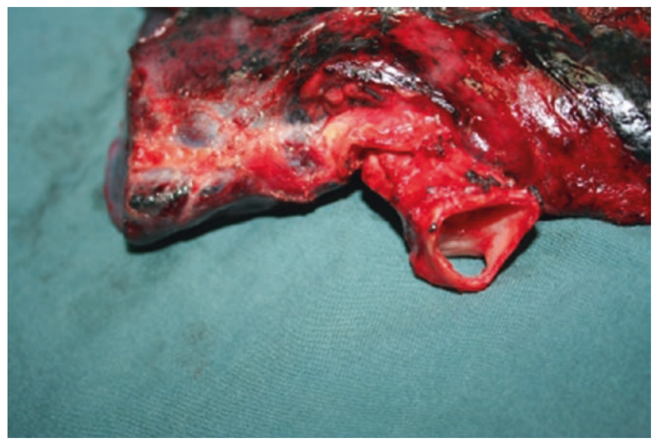

Fig. 6.50 The specimen

6.4 Left Upper Sleeve Lobectomy

Yanguo Liu and Jun Wang

6.4.1 Summary of Basic Operation Procedures

The process of left upper lobectomy is same as common VATS lobectomy. Carefully exploration first is essential to eliminate occult metastasis and confirm the feasibility of the surgery. The mediastinal pleura surrounding the hilar should be dissected first, and station 7, 8, 9, 10 lymph nodes are dissected at the same time. Then free superior pulmonary vein, open the inter-lobar fissure, and dissect the branches of the superior pulmonary artery. Tiny branches can be cut off by Ligasure instead of an endo-stapler. After the vein, fissure and artery are all dissected, then comes to the mobilization of the bronchus. Left main bronchus at 5 mm proximal to the superior border of left upper bronchus, and the left lower bronchus at 5 mm distal to the inferior border of left upper bronchus are cut off. The incisal margin should be sent to the pathologist for frozen section to eliminate tumor residual before the anastomosis is carried out. Both running and interrupted suture can be used when doing the anastomosis.

6.4.2 Technical Points

- The most difficult point of left upper lobe resection is handling with the apical-anterior branch of the pulmonary artery. Careless operation may cause disastrous bleeding by tearing the artery.
- Central type of lung cancer which needs sleeve lobectomy is usually with heavy adhesion around the bronchus. So special attention should be paid when doing the dissection of the posterior wall of the left main bronchus in case of pulmonary artery injury.
- If the apical-anterior branch of the pulmonary artery is cut off after the bronchus cut off, attention should be paid after cutting off the bronchus. As the artery branch is easy to be torn.
- Anastomosis of the bronchus when doing left upper sleeve lobectomy is somewhat easier than left lower sleeve lobectomy.
- When doing anastomosis, it is necessary to pay attention to the precise adjust of the upper and lower ends of bronchus to avoid bronchus distortion, and to ensure the quality of the anastomosis.

Embedding of the anastomosis part is necessary. But tress of the anastomosis is not essential.

6.4.3 Operation Procedures

1. The lung is retracted cranially using the ring forceps introduced from the assisting port, and divide the inferior pulmonary ligament by blunt dissection combined with electrocoagulation (Fig. 6.51). Then the lung is retracted forward, and divide the mediastinal pleural posterior of the hilum pulmonis (Fig. 6.52).
2. The lung is retracted backward and the mediastinal pleura anterior of the hilum pulmonis is divided with an electrocoagulation. The superior pulmonary vein is dissected then (Fig. 6.53).
3. The inter-lobar fissure is dissected and the lingular branch of pulmonary artery is mobilized. The tiny the lingular branch can be cut off with a Ligasure instead of an endo-stapler. Then free posterior ascending artery is freed, and cut off with an endo-stapler (Fig. 6.54).
4. The superior pulmonary vein is mobilized, and cut off with an endo-stapler (Fig. 6.55).
5. A rubber band is used to circle the pulmonary artery stem, and the blood vessel is retracted lateral posteriorly to expose the left main bronchus (Fig. 6.56).
6. Left main bronchus at 5 mm proximal to the superior border of left upper bronchus, and the left lower bronchus at 5 mm distal to the inferior border of left upper bronchus are cut off (Fig. 6.57).
7. The apical-anterior branch of the pulmonary artery is mobilized and cut off by an endo-stapler (Fig. 6.58).
8. An interrupted suture is used for the anastomosis (Figs. 6.59, 6.60, 6.61, and 6.62).
9. Station 5 and 6 lymph nodes are dissected at last (Fig. 6.63).

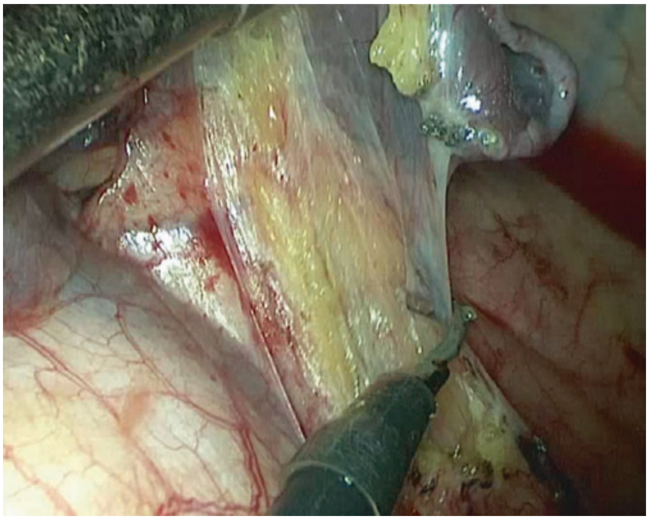

Fig. 6.51 Divide the inferior pulmonary ligament

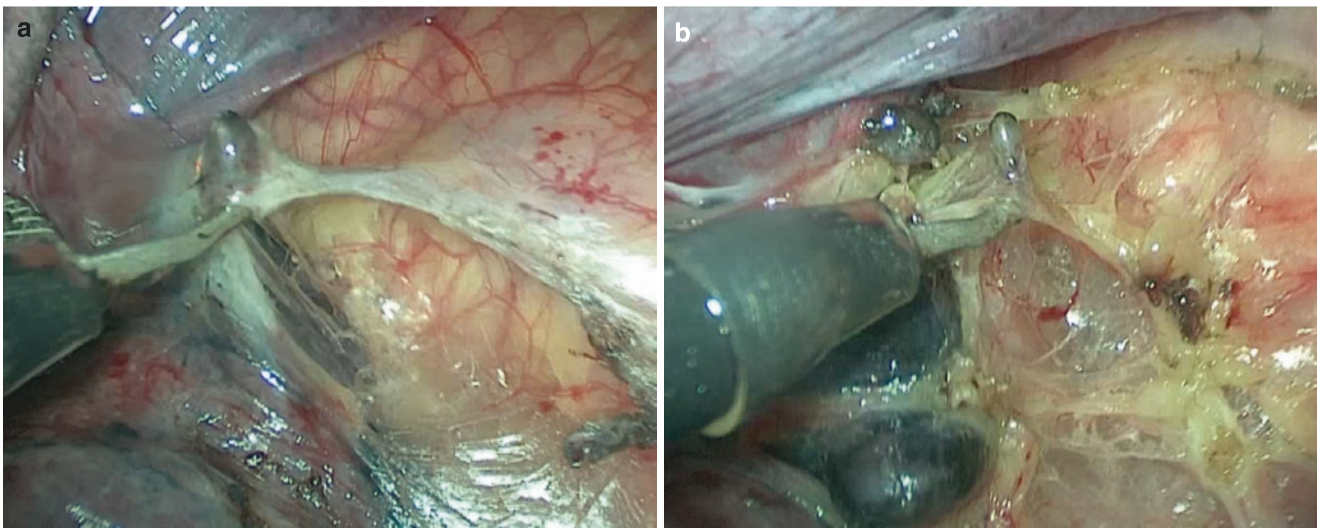

Fig. 6.52 Divide the pleura posterior of the hilum pulmonis, and dissect the posterior hilar and subcarinal lymph nodes at the same time

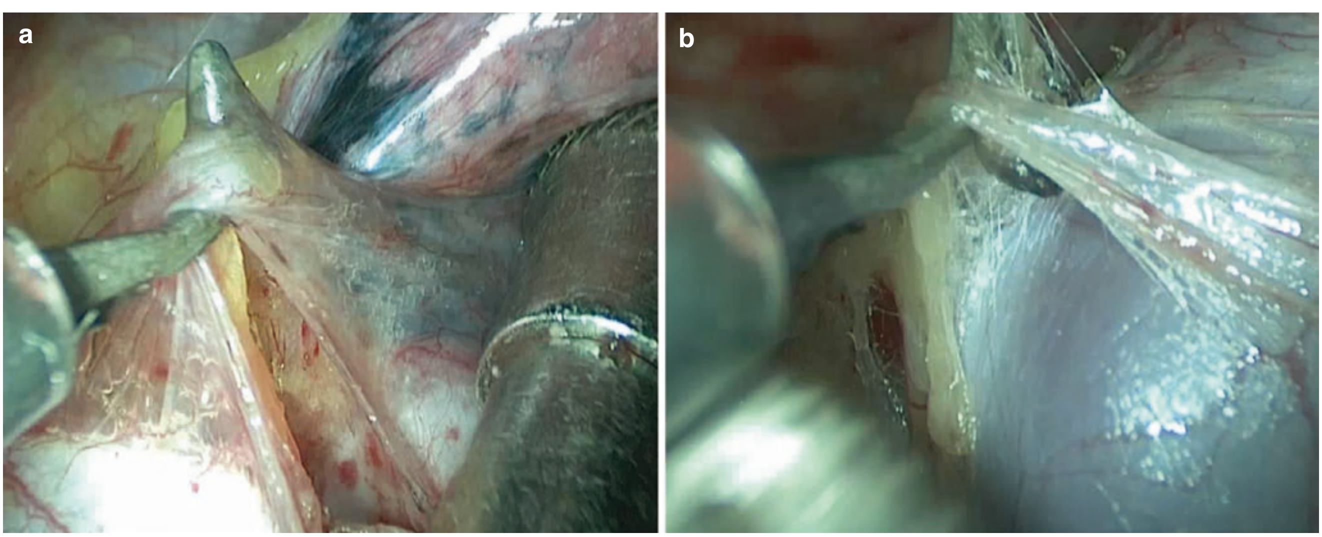

Fig. 6.53 Divide the pleura anterior of the hilum pulmonis, and dissect the superior pulmonary vein

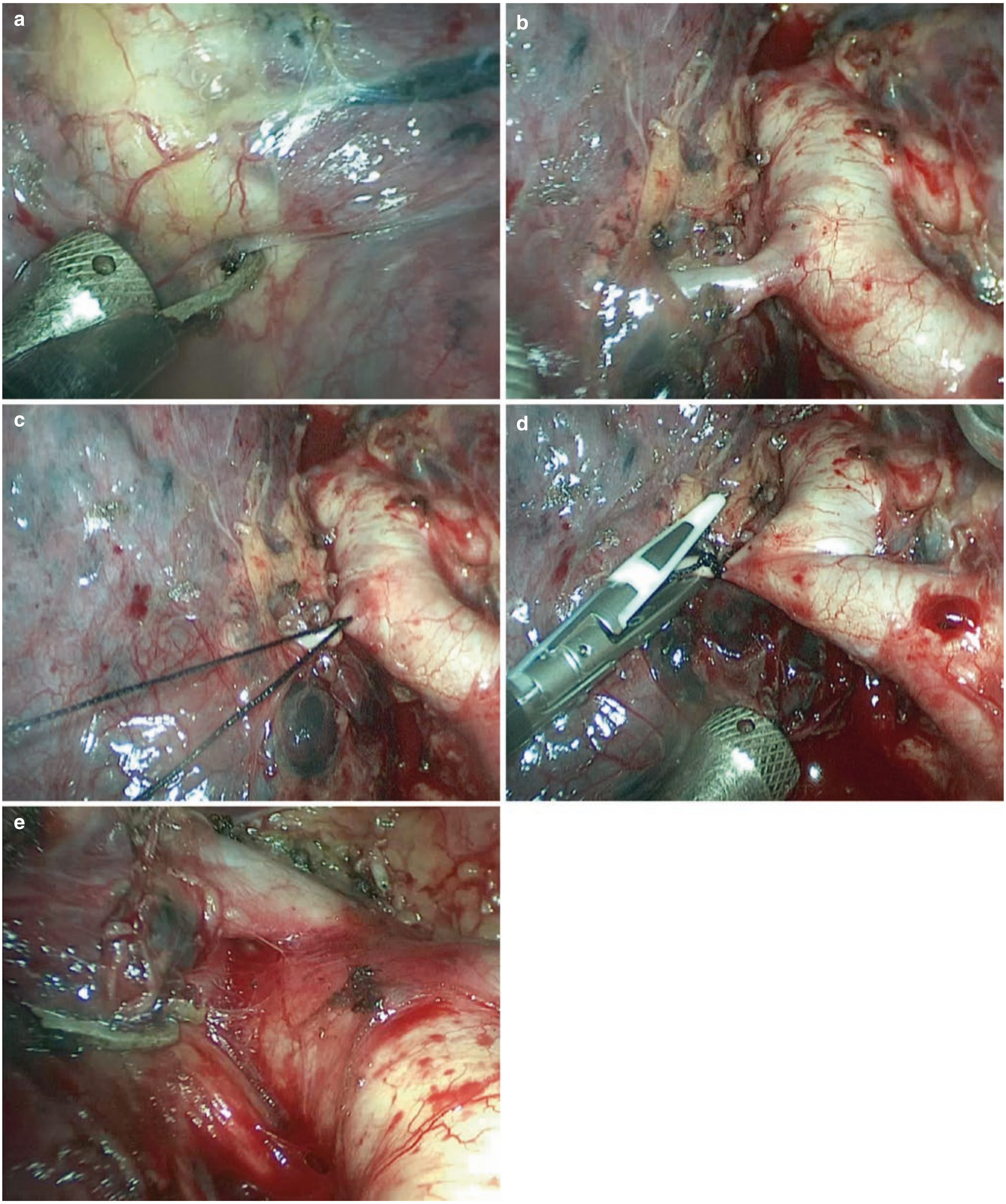

Fig. 6.54 (**a**) Dissect the inter-lobar fissure with an electrocoagulate hook. (**b**) The lingular branch artery is tiny. (**c**) Ligate the tiny artery with a silk suture. (**d**) Cut off the artery with a Ligasure device. (**e**) posterior ascending artery

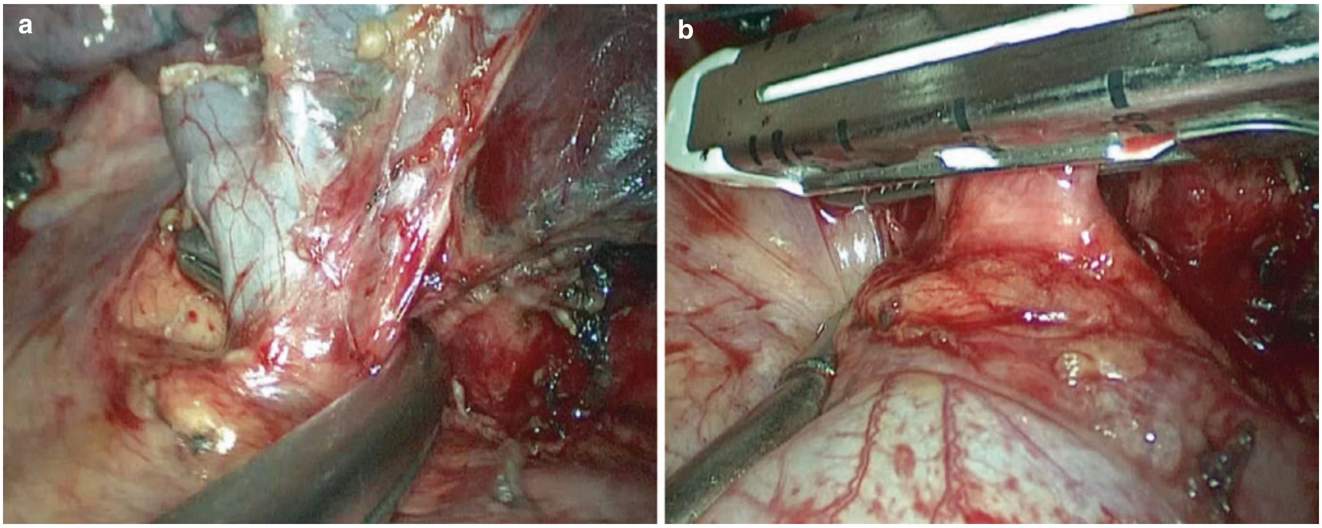

Fig. 6.55 (**a**) Mobilize the superior pulmonary vein (**b**) cut off with an endo-stapler

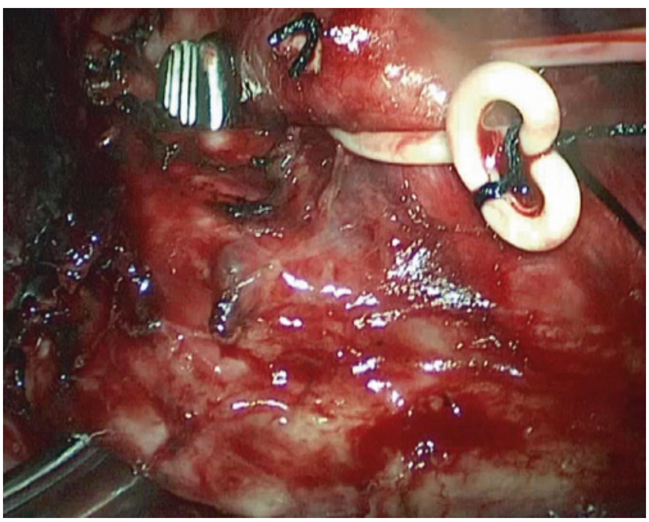

Fig. 6.56 A Rubber band is used to retract blood vessel

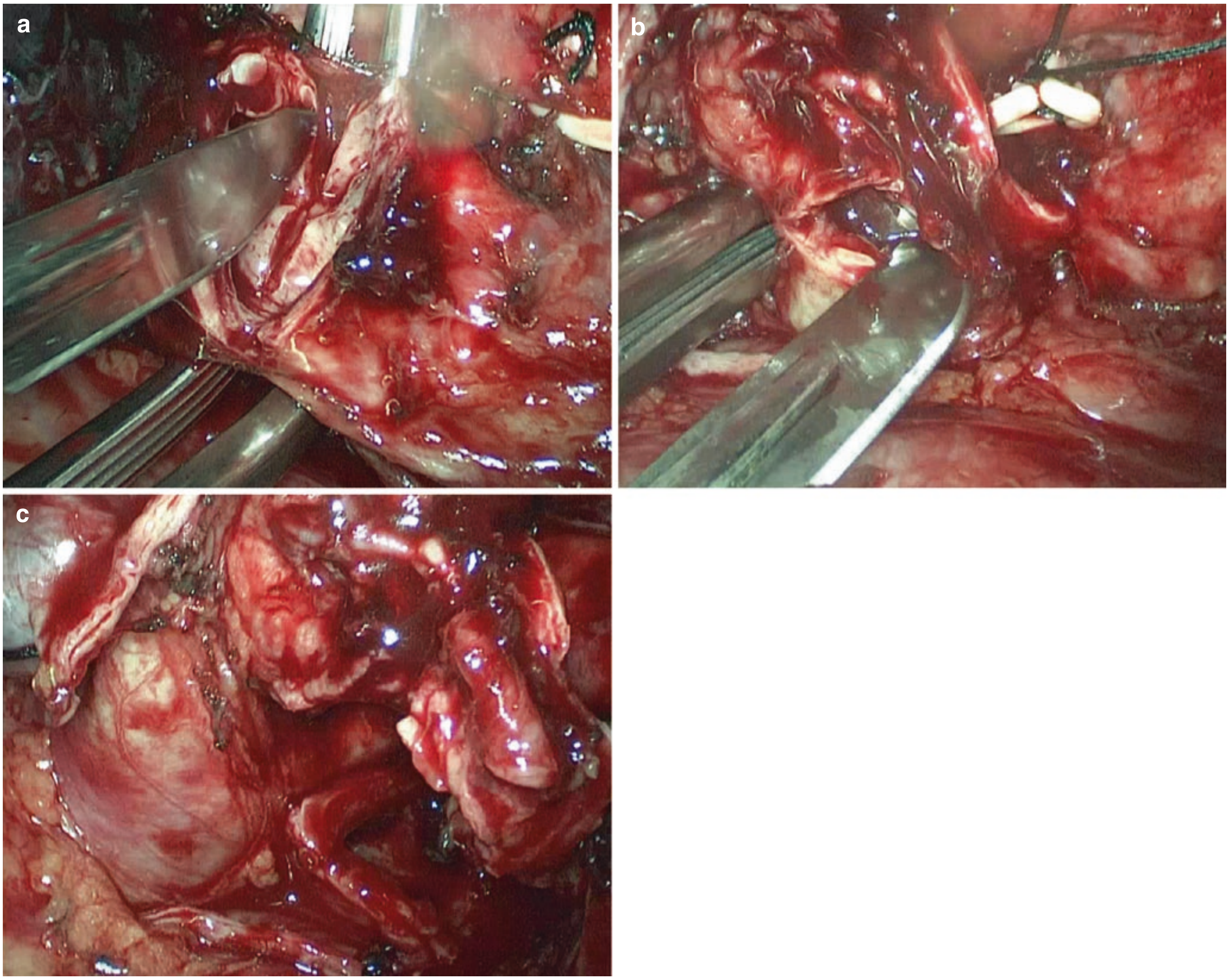

Fig. 6.57 (**a**) Cutting off the left main bronchus (**b**) cutting off the left lower bronchus (**c**) the bronchus stumps after cutting off

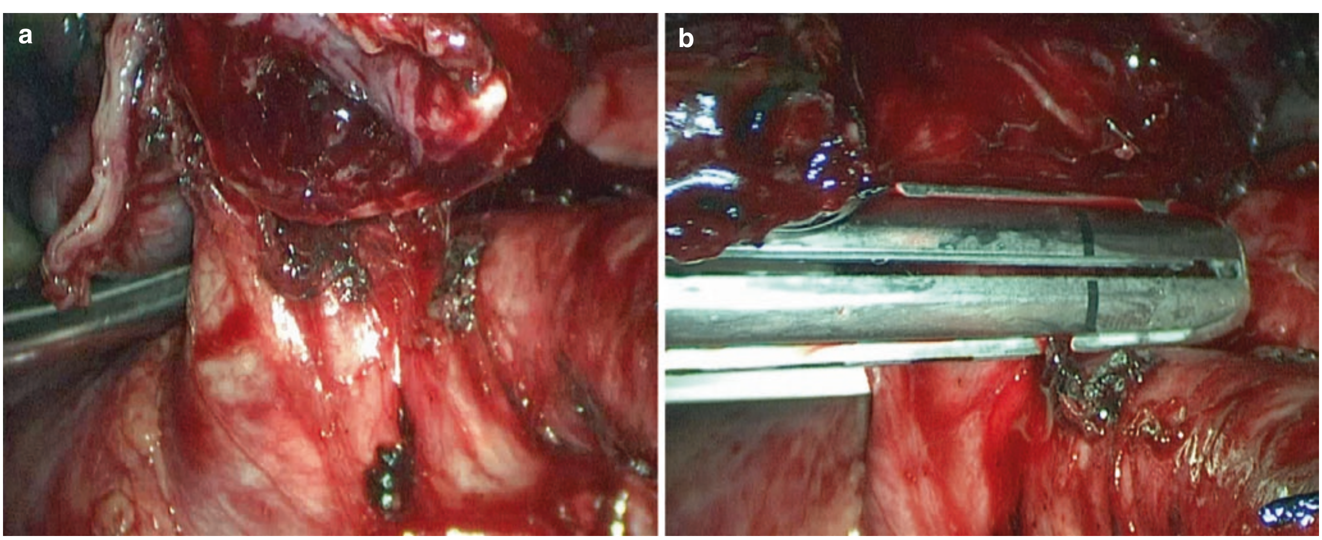

Fig. 6.58 Mobilize and cut off the apical-anterior branch

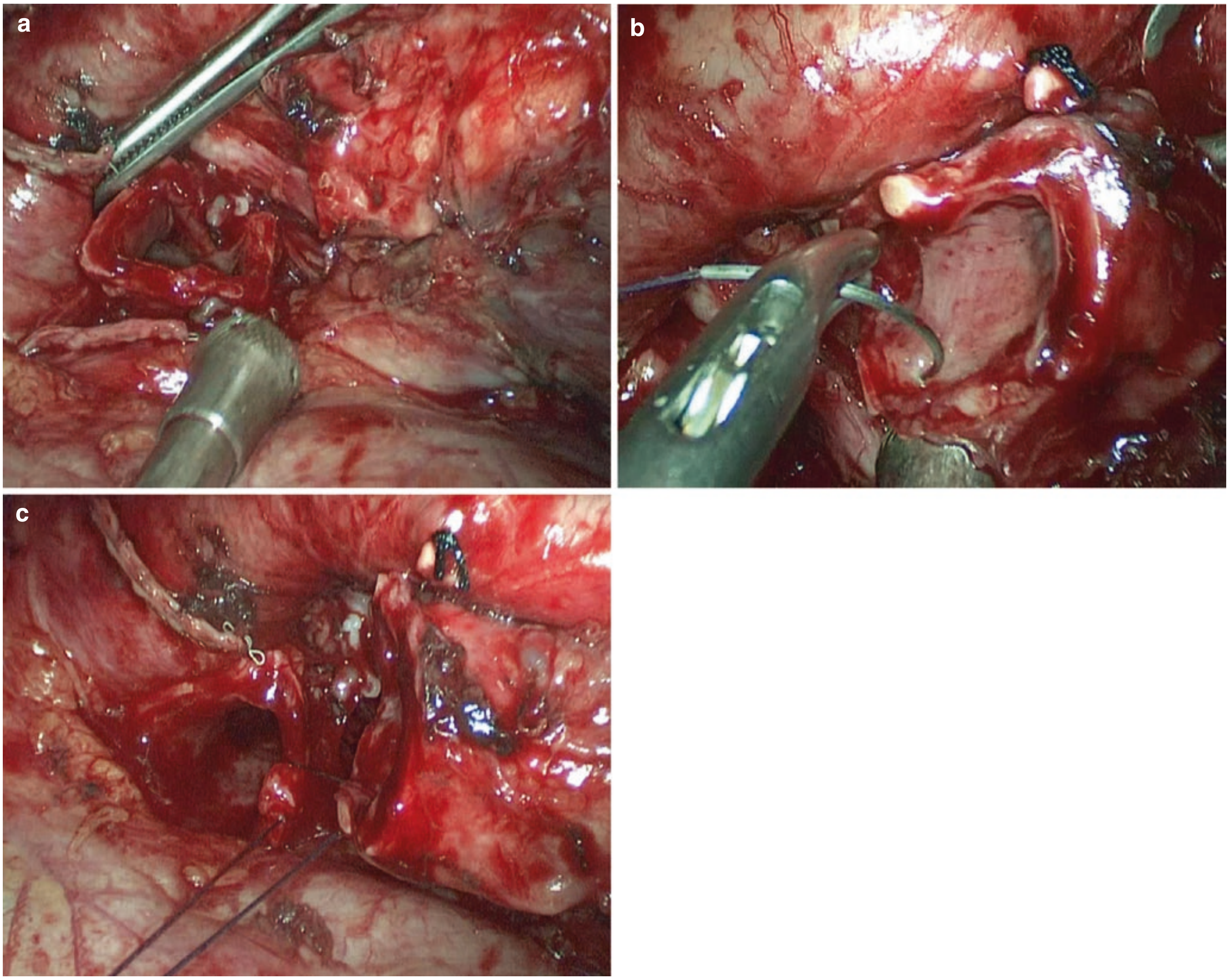

Fig. 6.59 (**a**) The bronchus stumps before anastomosis. (**b**, **c**) The first suture of the posterior wall of the bronchus

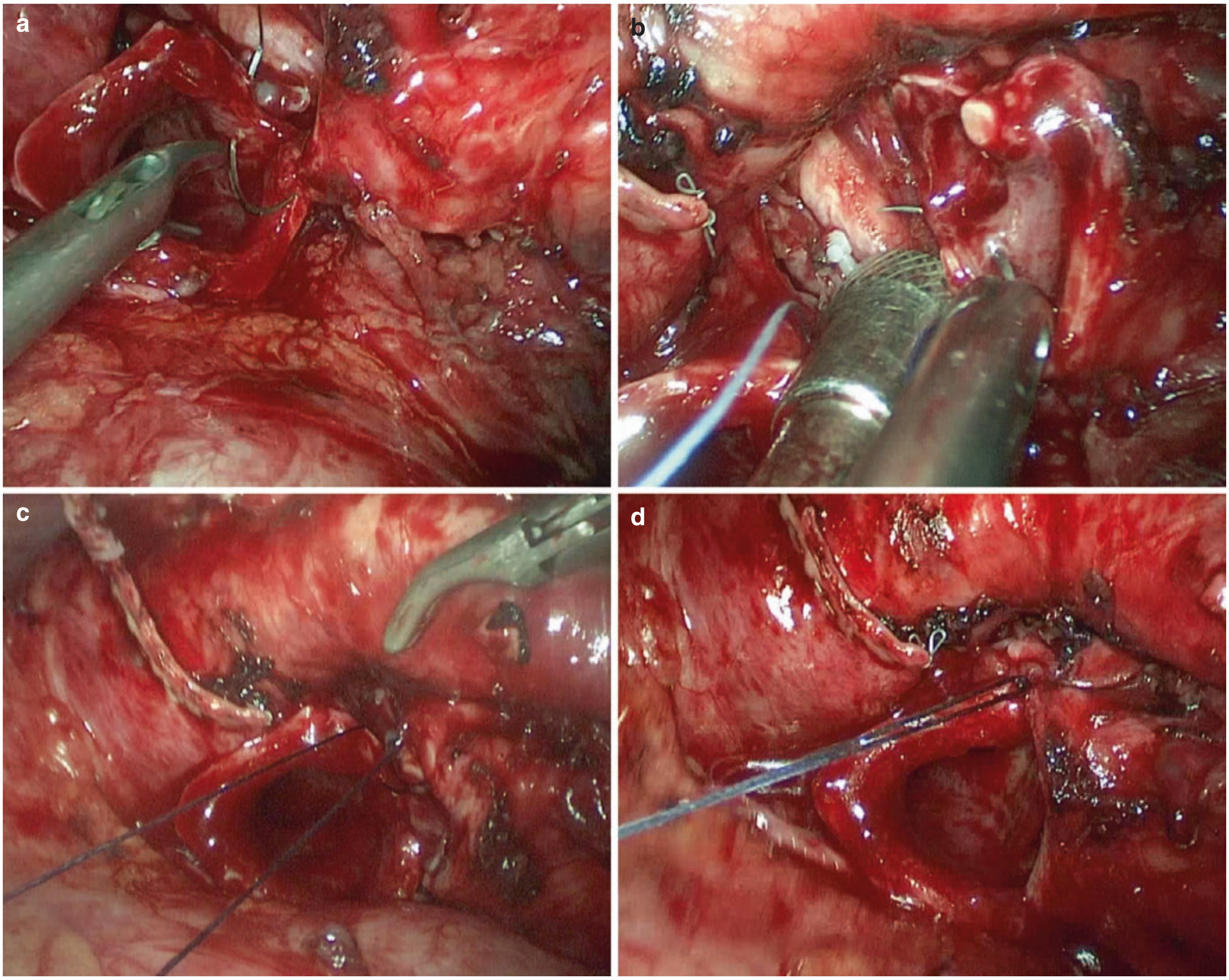

Fig. 6.60 (**a**–**d**) The second suture of the posterior wall of the bronchus

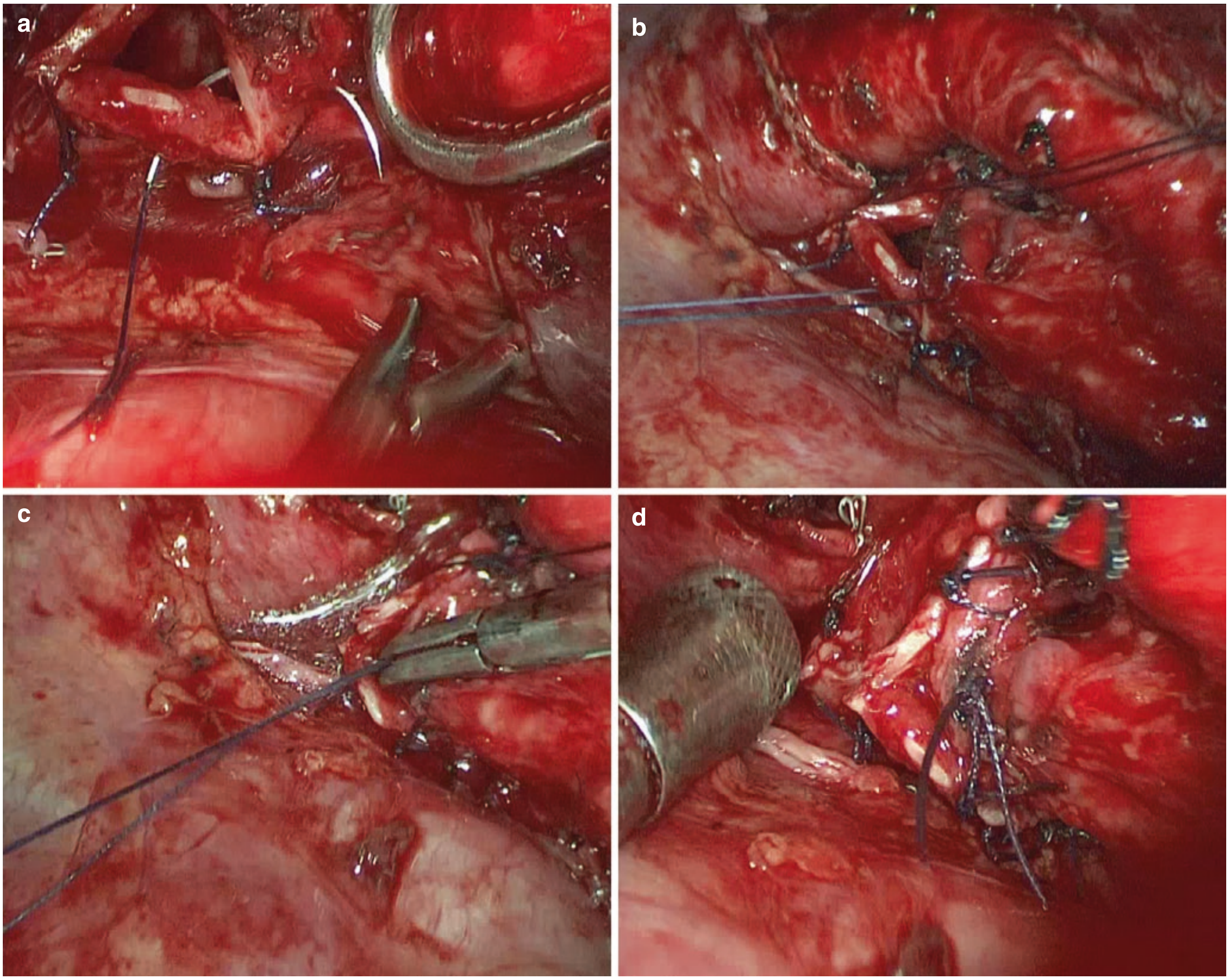

Fig. 6.61 (**a**–**c**) Interrupted suture of the anterior wall of the bronchus. (**d**) Overview of the anastomosis part

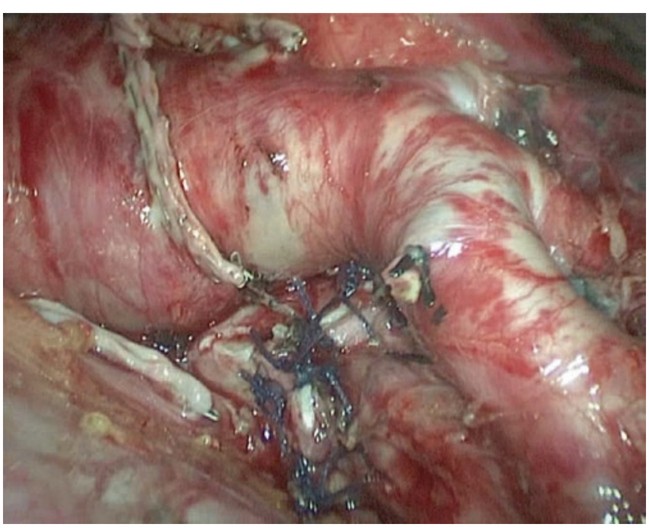

Fig. 6.62 Overview of the stumps of the blood vessels and anastomotic bronchus

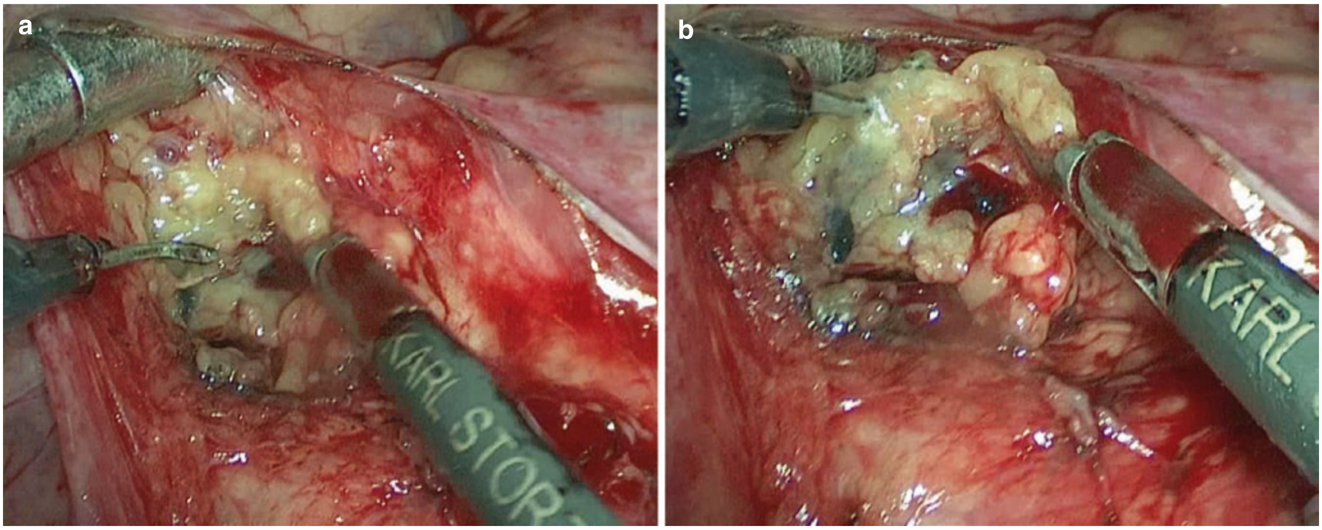

Fig. 6.63 Station 5 and 6 lymph nodes

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Pneumonectomy

7

Ying Tai Chen, Guanchao Jiang, Jun Wang, Fengwei Li, and Teng Mu

Contents

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7.1 General Considerations on VATS Pneumonectomy for Lung Cancer

Ying Tai Chen and Fengwei Li

In 1933 Graham and Singer successfully performed the first pneumonectomy for a patient with lung cancer who survived for 33 years after the operation. Since then, pneumonectomy has gradually become one of the important thoracic surgical procedures. In recent years, 20–25 % of thoracic surgical procedures performed for lung cancer were pneumonectomy. However, as more and more lung cancer was detected in early stage and thoracic surgical skills improved, the proportion of pneumonectomy had been declining year by year. There were studies suggesting that pneumonectomy proportion was linked to postoperative complications and mortality (the complications rate was 11–49 %, and the mortality rate was 2.9–12 %), but this surgical procedure didn't reduce the long-term survival rate of lung cancer. However, for patients with cancer indications, pneumonectomy is irreplaceable. With the constant development of thoracoscopic technology and instrument, pneumonectomy has been operated by video-assisted thoracoscope, which can reduce the surgical trauma while achieve the same therapeutic effect as compared with traditional procedures. Although video-assisted thoracoscopic pneumonectomy is rather difficult, as long as the operator is able to expertly processed pulmonary vessels and bronchi under thoracoscope, and properly handles the intraoperative severe tissue adhesion, special anatomical variation, and excessive bleeding, video-assisted thoracoscopic pneumonectomy is still worthy of promotion.

7.1.1 Operation Indication

Pneumonectomy has a greater influence on the circulation and respiratory function, so we need strictly comply with the operation indication, which can mainly be considered from the following two aspects:

J. Wang, M.K. Ferguson (eds.), *Atlas of Minimally Invasive Surgery for Lung and Esophageal Cancer*,
DOI 10.1007/978-94-024-0835-5_7

7.1.1.1 Scope of Lesion

1. The tumor locates in lobar bronchus and infiltrates to the plane of adjacent lobar bronchus.
2. The tumor is limited within the lobe and metastasis lymph node encroaches to adjacent lobar bronchus wall.
3. The tumor is located in hilus of lung and we can't dissect fissurae interlobaris.
4. Peripheral lung cancer has infiltrated to the whole lung.

7.1.1.2 Cardio-pulmonary Function

Routine examinations include pulmonary function test, blood gas analysis before and after exercise, and pulmonary perfusion imaging for patients prepared to receive pneumonectomy. The results are used to comprehensively evaluate the pulmonary function. It is generally believed that pulmonary function should satisfy the following conditions: forced expiratory volume in 1 s (FEV1) is greater than 2.0 L and forced expiratory volume in 1 s/forced vital capacity (FEV1/VC) is greater than 50 %. Pulmonary perfusion imaging should be used to predict postoperative residual pulmonary function, and the predicted value of FEV1 needs to be greater than 0.8 L. In addition, blocking the pulmonary artery trunk can determine the tolerance of pneumonectomy in the condition of one lung ventilation. If the fluctuation of systolic pressure is within 2.9 kPa and the heart rate change is within 20 times per minute after blocking the pulmonary artery trunk, patients should generally tolerate pneumonectomy. Meanwhile, it should be kept in mind that satisfactory cardiac function is also a major contributing factor to a safe and successful pneumonectomy.

7.1.2 The Preoperative Preparation

The preoperative preparation is almost similar to an ordinary thoracic surgery, but some aspects need special attention.

7.1.2.1 Chest CT Examination

Chest CT is very important for the safety assessment of video-assisted thoracoscopic pneumonectomy: First, the chest CT scan can help us understand the mediastinum, especially detect if there are calcifications in hilar lymph node. Generally, calcified lymph nodes indicate that pneumonectomy surgery is very troublesome because the possibility of intraoperative bleeding increases and the possibility of thoracotomy is higher. Second, chest-enhanced CT could help us understand the relationship between the tumor and the surrounding vessels, particularly the anatomical variation of the vessels. Thus chest CT is a very important method to evaluate the safety of pneumonectomy.

7.1.2.2 Preoperative Preparation for Elderly Patients

The hilar lymph nodes of elderly patients are susceptible to hyperplastic changes, therefore, surgeons should pay higher attention to their preoperative chest scan and enhanced CT examination results, and evaluate the risk of pneumonectomy sufficiently. Furthermore, elderly patients usually have many underlying diseases such as hypertension, diabetes, coronary heart disease, and thromboembolic diseases. These health conditions increase the incidence of postoperative complications in various systems of the body. Consequently, preoperative UCG and lower limb vascular ultrasound examinations are essential. At the same time, surgeons should actively control the patients' basic diseases, and render them rational training and guidance. Only in this way could them achieve the best cardiopulmonary function and psychological state.

7.1.3 Surgical Instrument

Thoracoscopic surgical instruments are listed in Table 7.1

Table 7.1 Thoracoscopic surgical instruments

Surgical unit
Thoracoscope
Illuminant
Image acquisition system
Image display system
Ordinary thoracoscopic surgical instruments
Drive pipe
Electrocoagulation
Endoscopic separation pliers and scissor
Endoscopic acutenaculum
Knot pusher
Oval forceps
Extended tangential clamp
Extended long curved forceps
Video-assisted thoracoscopic pneumonectomy special surgical instruments
Thoracoscopic suction
Thoracoscopic long curved tangential vessel forceps
Thoracoscopic side curved vessel forceps
Thoracoscopic lymph node forceps
Long acutenaculum (Z-type,S-type)
Mechanical suture instruments
Endoscopic section and suture instruments
Multi-fire clipapplier
Hem-o-lock
Operation Energy platform (LigaSure、ultrasound scalpe)

7.1.4 Key Points of Operation

Thoracoscopic pneumonectomy intraoperative considerations are basically the same as the video-assisted thoracic lobectomy. The key points that require special attention are:

7.1.4.1 Dissection of Pulmonary Artery

Dissection of pulmonary artery is an important step in the process of thoracoscopic pneumonectomy. Most patients who need pneumonectomy are central-type lung cancers which may be accompanied by enlarged lymph nodes. This makes handling the pulmonary artery very difficult. Flexible approaches should be chosen by surgeons according to specific situations. For example, when the tumor invades the root of pulmonary artery, the first branch of the pulmonary artery should be manipulated first in order to reveal a longer pulmonary artery trunk for use, or the pulmonary artery trunk should be manipulated inside the pericardium.

7.1.4.2 Manipulation of Auto SutureTA Stapler

Due to the disturbance of the descending aorta in the rear of the left bronchus, incision angle through the front operation incision using common Endo GIA Universal Straight or Endo GIA Universal Roticulator may be restricted, resulting in long bronchial stump. Using Auto Suture DST Series TA3048S can avoid the descending aorta, ensuring the bronchial stump fit.

7.1.5 Postoperative Management

Thoracoscopic pneumonectomy postoperative management is basically the same as the video-assisted thoracic lobectomy. The following aspects need special attention:

7.1.5.1 Management of the Residual Cavity After Pneumonectomy

Some details that require special attention before closing the chest in pneumonectomy are: local hemostasis, bronchial stump, pericardium, thoracic duct, esophagus and azygos vein lesions. There is more pleural effusion in the first 2 days after pneumonectomy involving mediastinal lymph node dissection. Postpneumonectomy space drainage tube is usually clamped to avoid mediastinal shift and released intermittently to drain excessive effusion to monitor chest bleeding. The tube should be removed 24–48 h after the operation. Postpneumonectomy patients often appear arrhythmia and hypertension after changing position. It may be due to that the mediastinal shift changes the function of the contralateral lung and heart blood backflow. Post pneumonectomy space gas should be drained as soon as possible to restore the mediastina back to the middle position.

7.1.5.2 Close Monitoring of Vital Signs

After pneumonectomy, cardiopulmonary functional reserve is reduced significantly, and complications such as cardiac insufficiency and respiratory failure are likely to occur. Therefore vital signs must be monitored closely, such as heart rhythm, heart rate, blood pressure, blood oxygen saturation, and body temperature changes, to estimate the circulation and respiratory function. To prevent cardiac preload increase, the transfusion speed should be controlled strictly. The infusion speed should be controlled by an infusion pump with a speed less than 120 ml per hour. The body fluid must be balanced by accurately recording 24-h intake and output. Means such as continuous low flow oxygen, ultrasonic atomization inhalation, intravenous phlegm drugs and antibiotics, and chest physical therapy should be taken to guarantee the respiratory function.

7.1.6 Postoperative Complications and Treatment

After pneumonectomy, only one side of the lung tissue is functional, so the respiratory function and functional reserve are reduced significantly. At the same time, the cardiac load increases, so complications such as cardiac insufficiency and respiratory failure are likely to occur. Although the types of postoperative complications after pneumonectomy and pulmonary lobectomy are basically the same, the probability of occurrence and mortality in pneumonectomy are significantly higher than that in lobectomy.

7.1.6.1 Arrhythmia

After pneumonectomy, the mediastinal lost the support of one side of the lung tissue. The physical changes need a period of time to adapt, thus postoperative arrhythmia (premature beat, flutter, atrial fibrillation, etc.) is one of the most common complications. Once occurred, the factors that cause arrhythmia should be found out timely, including a clear history of heart disease, improper infusion volume and infusion speed, body temperature, and other possible factors such as infection. Corresponding treatment must be given in time to avoid decompensated heart function.

7.1.6.2 Pulmonary Infection

Postoperative patients have only one side of the lungs for respiratory and circulatory functions. The respiratory reserve function is reduced significantly. Once pulmonary infection appears, the patients are prone to respiratory failure and even mortality. Therefore the patients' chest signs should be monitored closely after pneumonectomy. The patients should take chest imaging examination regularly to detect possible lung infection and atelectasis in time. The following are the special considerations in the process of treatment: (1) the use of efficient and broad-spectrum antibiotics, and the prolonged use of antibiotics;(2) assisting the patients to cough and expectorate, using ultrasonic atomization inhalation, expectorant drug use, sputum suction and tracheostomy fiberoptic bronchoscopy if necessary;(3) other therapies such as auxiliary breathing machine as soon as possible if a significant respiratory failure occurs.

7.1.6.3 Bronchial Pleural Fistula

Bronchial pleural fistula is a rare but serious complication after pneumonectomy. Its final diagnosis depends on the results of fiber bronchoscopy. If the curative effect is poor, it needs continuous drainage and subsequent surgical repair. Reasonable prevention measures include: (1) dissect bronchial anatomy appropriately and avoid excessive free proximal tracheal mucous membrane in order to prevent the residual blood supply insufficiency;(2) check stump leak strictly, and reinforce the bronchial stump by embedding blood rich autologous tissue if necessary;(3) strengthen perioperative nutrition support and apply sensitive antibiotics to control possible local infection.

7.2 Right Pneumonectomy

Guanchao Jiang, Teng Mu, and Jun Wang

Technical Points

- **Management of the pulmonary artery**. Management of the pulmonary artery plays a pivotal role in thoracoscopic total pneumonectomy. Patients who underwent a thoracoscopic pneumonectomy always have a central pulmonary carcinoma and para-arterial swollen lymph nodes, which makes the management of the pulmonary artery more difficult. In these cases, it is advisable to make flexible choice depending on the special intraoperative circumstance. If the tumor is close to the root of pulmonary artery, the division of pulmonary artery will be facilitated by dissection of the intrapericardial part of it and the ready dissection of the truncus anterior, which will make the available main arterial trunk longer.
- **Key to the use of stump closer**. As the interference of the descending aorta posterior to the left main bronchus limits the use of usual or even flexible endostapler, which will result in redundantbronchial stump, it is advisable to use a stump closer with a green cartridge to keep away from the interference of the descending aorta and ensure a proper bronchial stump.

1. **Patient Position and incision choice**
   - Patient Position: left lateral position with a cushion under the shoulder
   - Camera port: an 1.5-cm icision in eighth intercostal space in right mid-axillary line
   - Working port:a 4-cm icision in fourth intercostal space in right anteior axillary line
   - Additional port: an 1.5 icision in eighth intercostal space in right scapular line (Fig. 7.1).
2. **Operation procedure**
   - Retract right lower lobe to the patient's apex with a sponge forceps introduced through the additional port, and divide the pulmonary ligament.
   - Stretch lung forward, incise the mediastinal pleural posterior to the hilum up to the inferior azygos arch, dissect and then divide the branchial arteries superior and inferior bronchus.
   - Pull the lobes forward and lift the mediastinal pleura on the surface of esophagus using a sponge forceps introduced through the additional port. Fist, dissect the esophageal aspect of subcarinal lymph nodes, and divide the minor vessels supplying to the lymph nodes, until the exposure of the lateral aspect of left main bronchus. Then, lift the subcarinal lymph nodes. The dissection and then complete excision of them are achieved by a combination of diathermy and blunt dissection, from the inferior pulmonary vein, anteriorly to posterior pericardium, downward to inferior mian bronchus (Fig. 7.2).
   - Traction on the lobes backward using sponge forceps introduced through the additional port facilliates the exposion of anterior hillum. Open the mediastinal pleura before hillum between pulmonary veins and the phrenic nerve using a diathermy hook, and free the space between the right inferior pulmonary vein and the middle lobe vein.
   - Open all the mediastinal pleura around the hillum using a cautery.

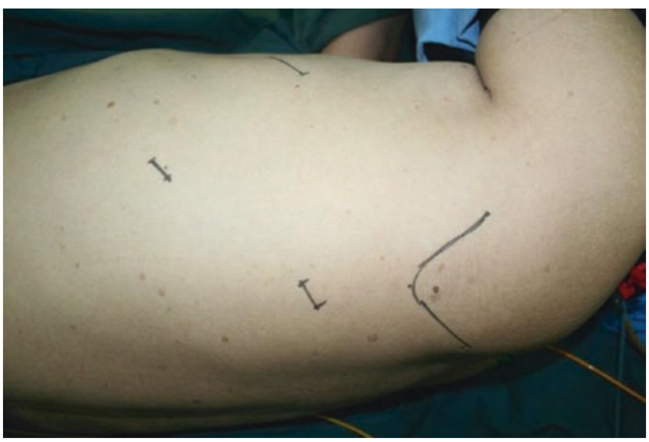

Fig. 7.1 Patient position and incision choice

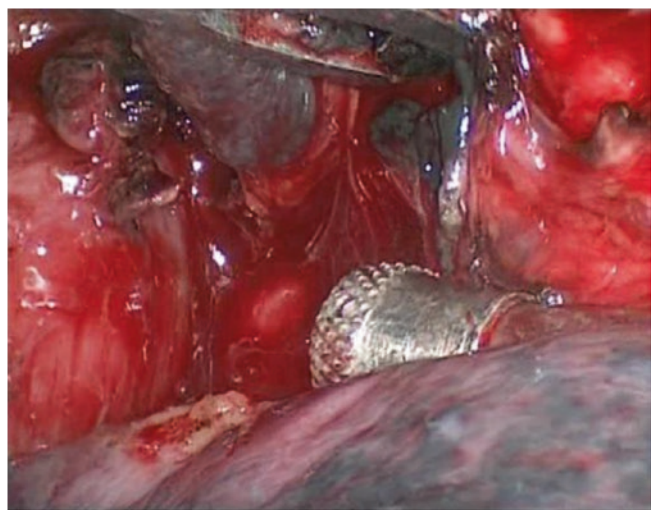

Fig. 7.2 Lift the subcarinal lymph nodes using sponge forceps introduced through the additional port

– Dissect and then divide the right upper love vein and middle lobe veinrespectively using a 30-mm endostapler with a white cartridge introduced from the working port. (Fig. 7.3)

– Dissect and then staple the right inferior pulmonary vein using a 30-mm endostapler with a white cartridge introduced through the working port (Fig. 7.4).

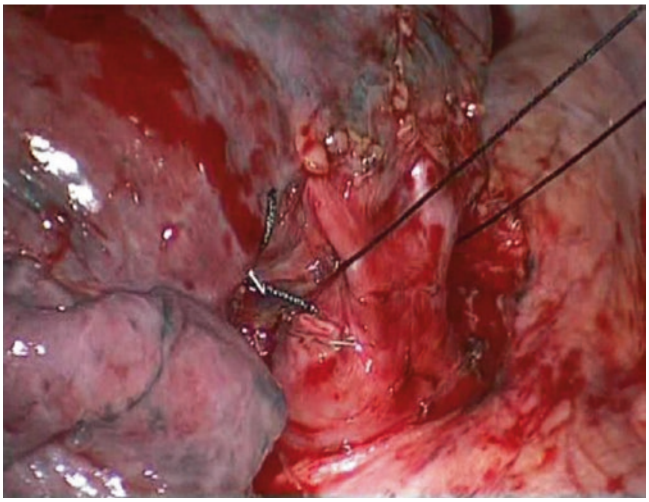

Fig. 7.3 Retract the right upper lobe\vein using a 7# suture. The stump is middle lobe vein

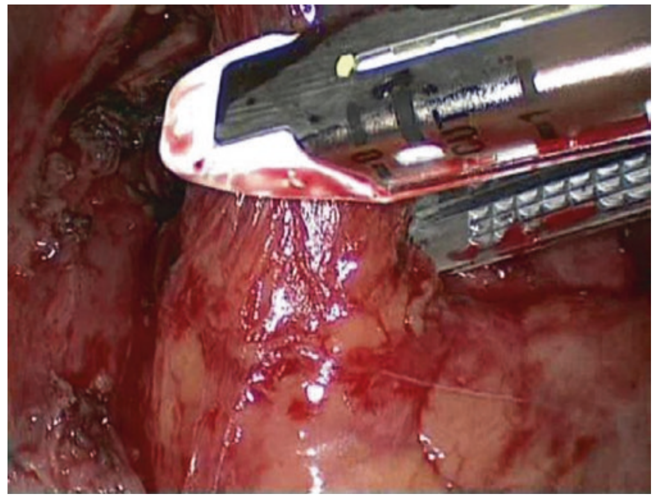

Fig. 7.4 Introduction of a 30-mm endostapler with a white cartridge through the working port

– Dissect the right main pulmonary artery, pass the space around it using a long curved forceps introduced through the working port, and then tract it using a #7 suture. Then staple the right main pulmonary artery using a 30-mm endostapler with a white cartridge introduced through the additional port (Fig. 7.5).
– Free the right main bronchus, pass the space around it using a long curved forceps introduced through the working port, and tract it using a #7 suture. Then finish right pneumonectomy by stapling the right main bronchus using a 45-mm endostapler with a green cartridge introduced through the working port (Fig. 7.6).
– Put the specimen into sterile gloves introduced into the thoracic cavity.
– Open the upper mediastinal pleura, lift the upper mediastinal lymph nodes and the surrounding tissues, and then dissect and completely excise them with a comination of blunt and sharp dissection (Fig. 7.7).

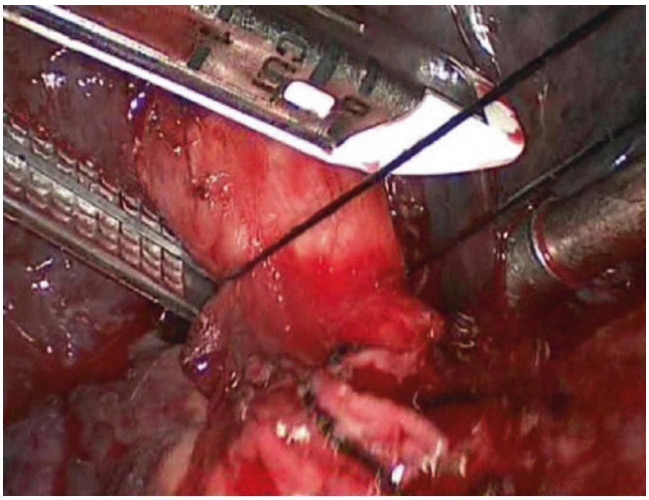

Fig. 7.5 Introduction of a 30-mm endostapler with a white cartridge through the additional port

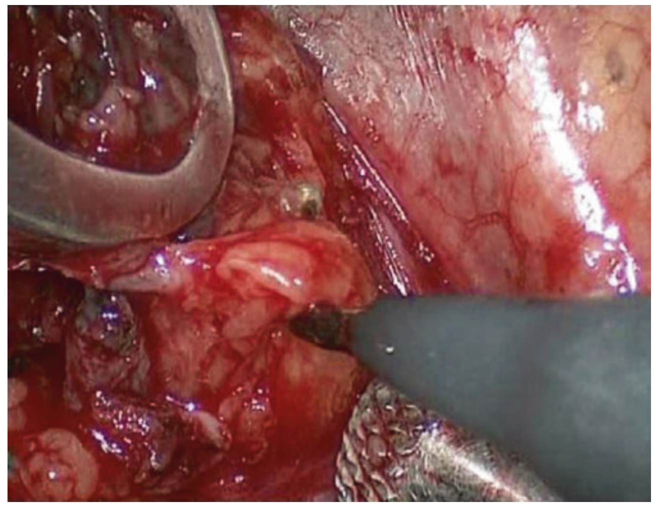

Fig. 7.7 Lift the upper mediastinal lymph nodes and the surrounding tissues

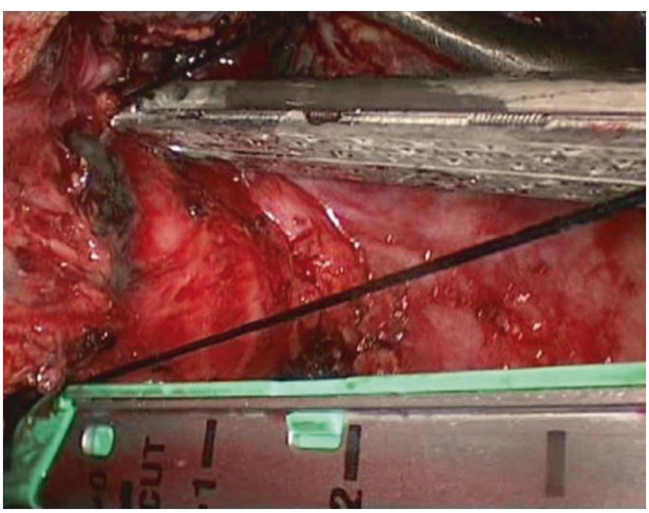

Fig. 7.6 Close the right main bronchus using a 45-mm endostapler with a green cartridge

7.3 Left Pneumonectomy

Guanchao Jiang, Teng Mu, and Jun Wang

1. **Patient Position and incision choice**
   - Patient Position: right lateral position with a cushion under the shoulder
   - Camera port: an 1.5-cm icision in eighth intercostal space in left mid-axillary line
   - Working port: a 4-cm icision in fourth intercostal space in left anteior axillary line
   - Additional port: an 1.5 icision in eighth intercostal space in left scapular line (Fig. 7.8)
2. **Operation procedure**
   - Retract lung to the patient's apex and divide the pulmonary ligament using a electric hook.
   - Stretch lung forward and incise the mediastinal pleural posterior to the hilum sufficiently. Dissect and then divide the branchial arteries along superior or inferior bronchus. Open the sheet of left main pulmonary artery trunk and dissect its posterior aspect.
   - Pull the left lower lobe backward, incise the mediastinal pleura anterior hillum and dissect the inferior and supperior pulmonary vein
   - Open the external sheet of the left main pulmonary artery trunk and dissect the left mian pulmonary artery.
   - Pass the space behind the pulmonary vein using a tangential clamp, round a #7 suture for axillary traction, and staple the superior pulmonary vein using a 30-mm endostapler with a white cartridge introduced through the additional port (Fig. 7.9).

Fig. 7.8 Patient position and incision choice

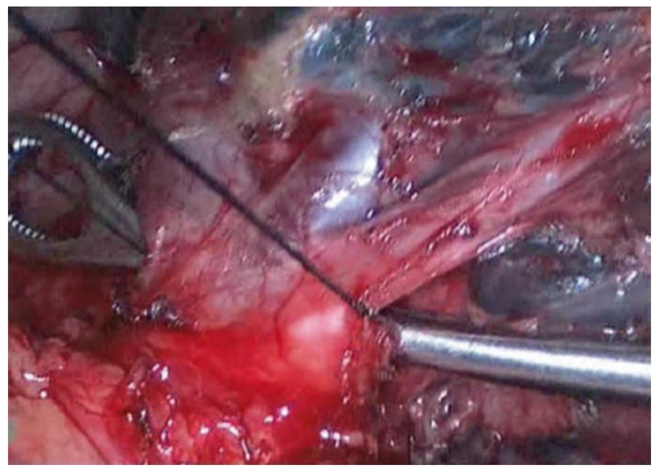

Fig. 7.9 Expand the space behind the superior pulmonary vein properly

- Pull the left upper lobe posteriorly, dissect the space between left main bronchus and left main pulmonary artery trunk, and clear the lymph nodes supperior left mian bronchus.
- Expose the left main pulmonary artery trunk, pass the space around it using a tangential clamp introduced through the working port, and round a #7 suture for axillary traction. Then staple the left main pulmonary artery trunk using a 30-mm endostapler with a white cartridge introduced through the working port (Fig. 7.10).
- Retract the left lower lobe upward, and pass the space around the left inferior pulmonary vein using a suction device introduced through the working sport. Staple the inferior pulmonary vein using a 30-mm endostapler with a white cartridge introduced through the working port (Fig. 7.11).
- Clearance of the subcarinal lymp nodes. Pull the left lower lobe upward using a sponge forceps introduced through the additional port. Fist, dissect the esophageal aspect of the subcarinal lymph nodes until the exposure of the lateral aspectof the right main bronchus and note the division of the minor vessels supplying to the subcarinal lymph nodes. Then, lift the subcarinal lymph nodes and the dissection and clearance of them are achieved by a combination of diathermy and blunt dissection, from the inferior pulmonary vein, anterior to posterior pericardium, and upward to inferior carina (Fig. 7.12).
- Pull the lung backward using a spong forceps introdudced through the additonal port. Free the left main bronchus, pass the space behind it using a right angle forceps introduced through the working port, and tract it using a #7 suture. Then close and staple the left main bronchus using a 45-mm endostapler with a green cartridge introduced through the working port (Fig. 7.13).
- Put the specimen into sterile gloves introduced into the thoracic cavity, and retrieve it through the woring port (Fig. 7.14).
- Check the stump of left main brochus. Ask the anesthetist to reexpand the lung after the infusion of the thoracic cavity with sterile normal saline and check the stump of left main brochus.

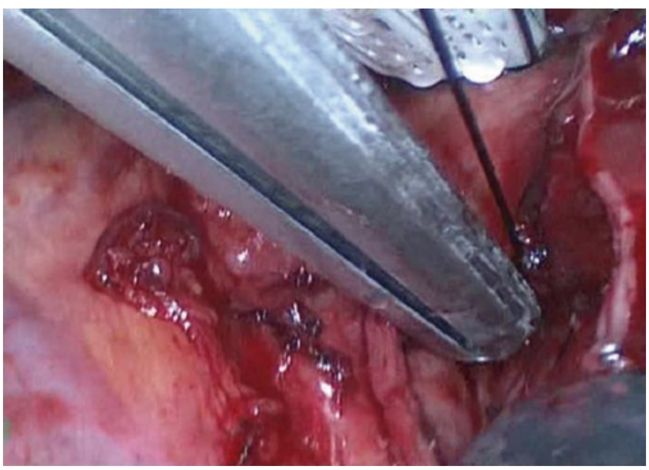

Fig. 7.10 Introduction of a 30-mm endostapler with a white cartridge through the working port to cut off the left main pulmonary artery trunk

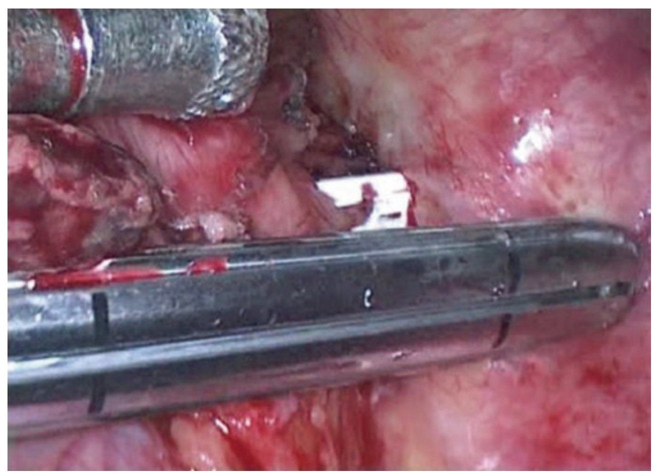

Fig. 7.11 Introduction of a 30-mm endostapler with a white cartridge through the working port to cut off the inferior pulmonary vein

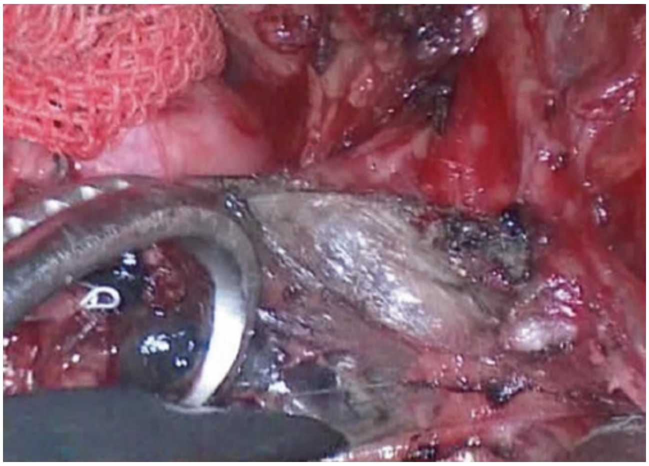

Fig. 7.12 Dissection of the esophageal aspect of the subcarinal lymph nodes

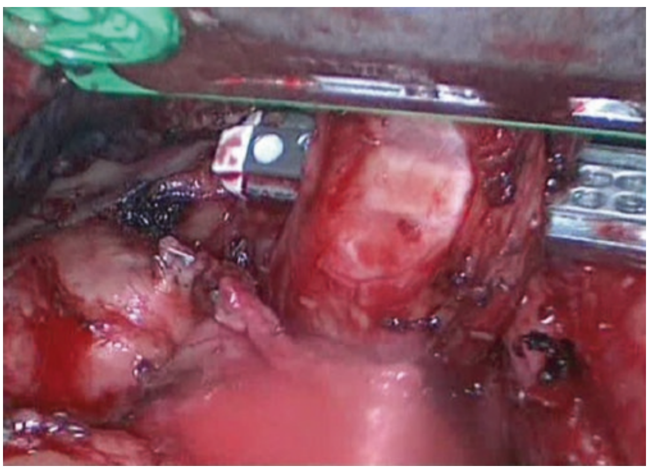

Fig. 7.13 Passage of the ednostapler chopping block through the space behind the left main bronchus

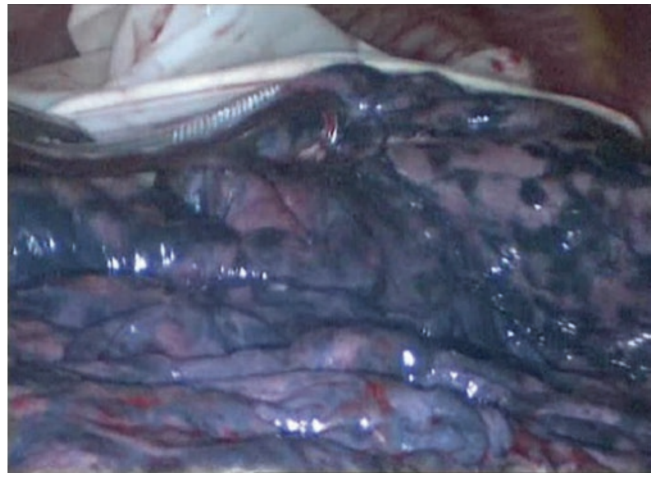

Fig. 7.14 Placement of the specimen into the sterile gloves

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8 Robotic Lung Resection

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Contents

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8.1 Rationale for Robotic Lung Resection

The traditional approach for performing anatomic lung resections has been via posterolateral thoracotomy. This incision allows generous exposure and access to pulmonary hilum at a cost of significant post-operative pain and morbidity. With the rapid improvement in video technology in the 1980s and development of more sophisticated endoscopic staplers, there has be a shift toward a minimally invasive approach to lung resections.

Minimally invasive video assisted thoracic surgery (VATS) lobectomy became established in the 1990s and has gained popularity amongst thoracic surgeons worldwide. The evidence of benefit of this technique over a standard thoracotomy is growing. Areas where VATS lobectomy performs better include postoperative pain, shorter chest tube duration, reduced hospital stay, lower complications and better compliance with adjuvant chemotherapy [1–6].

Despite these benefits, adoption was initially slow. One possible concern was over the oncological efficacy of the procedure for early stage lung cancer. These fears have been allayed by more recent evidence showing similar long-term survival in patients having minimally invasive lobectomy for lung cancer [7, 8]. The other major hurdle to overcome is technical difficulties associated with the procedure. 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 and implementation of telerobotic surgical systems has been driven in part by a desire to address the technical limitations of conventional minimally invasive technology. In thoracic surgery, the da Vinci™ (Intuitive Surgical, Sunnyvale, CA) remains the

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only complete surgical system in widespread use worldwide. The latest generation, the da Vinci Xi system, is currently in use at our institution and has several advantages over conventional thoracoscopy:

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 image can be magnified up to ten times to give unrivalled degrees of detail during dissection and mobilization of hilar structures. The console design with the image display above the surgeon's hands helps enhance the intuitive nature of the system. The other advantage over conventional VATS is the stable nature of the camera that is under direct control by the operating surgeon. This also liberates the tableside assistant to assist with other functions.
2. The da Vinci™ Endowrist instruments restore the degrees of freedom lost with conventional VATS instruments. With seven degrees of freedom the robotic instruments recreates the dexterity associated with the human hand. 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.

8.1.1 Components of the System

The da Vinci™ Surgical System has three main components; the patient cart, surgeon console and the vision cart (Fig. 8.1). The patient cart comprises the bedside console with the four surgical manipulator arms. In the latest Xi model, the endoscope can be attached to any of the four arms leaving three arms for instruments. All four arms including the endoscope are controlled from the surgeon console. This comprises the 3D image viewer, the master hand controls, and the footswitch panel to control electrocautery and allow switching between surgical arms and endoscope control. The endoscope has 30° angulation and a dual camera providing a binocular view of the surgical field to the surgeon console allowing 3D perception.

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 and bipolar energy to the various da Vinci™ Xi instruments mounted to the patient cart. The cautery is activated via the surgeon console.

The robotic instruments and endoscope are interchangeable on the patient cart arms and are inserted into the patient through 8 mm trocars. 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).

Fig. 8.1 Da Vinci Xi surgical system (**a**) Surgical cart; (**b**) Surgeon's console

8.1.2 Patient Selection and Indications

Selection criteria for robotic lung resection follow the same principles as for conventional VATS or open procedure. As with any surgical procedure, there is no substitute for sound judgment. There are no absolute contraindications for robotic lung resection per se. However, particularly during one's early experience with the technique there are several potential relative contraindications:

- Inability to maintain lung isolation
- Adherent hilar nodal disease (either inflammatory or neoplastic)
- Large, central lesions
- Need for sleeve (bronchial or vascular) resection
- Locally advanced tumors invading the chest wall or mediastinum

Pleural adhesions have been cited as a relative contraindication for a VATS approach. This is less so for robotic surgery as the visualization and the extra dexterity offered makes extensive adhesiolysis technically easier.

8.2 Surgical Technique for Robotic Pulmonary Lobectomy

8.2.1 Preparation of the Robotic System

Properly trained technical and nursing staff can 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. Typically, the components of the system remain in dedicated rooms to minimize setup time. 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°, and theoretically the cart may be positioned in virtually anywhere with respect to the operating table.

8.2.2 Anesthetic Consideration and Patient Positioning

The most common anesthetic approach involves general anesthesia with endotracheal intubation and lung isolation, but variations include low tidal volume ventilation with or without CO2 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 mediations.

The patient is positioned in the lateral decubitus position as for a posterolateral thoracotomy or any conventional VATS procedure. Adequate flexion of the operating table is essential, particularly in female patients, to maintain the scapula and iliac crest on the same horizontal plane. This maneuver also aids in opening the intercostal spaces reducing pressure on the intercostal nerve from the trocars. Prior to prepping and draping the patient, the sites for port insertion are carefully planned.

If one is employing the second (S) or third (Si) generation system, an important maneuver is to move the operating table 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 more 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 sufficient length of the circuit tubing is 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.

8.2.3 Port Placement

The same port strategy may be employed no matter which lung resection is planned. The first port is for introduction of the endoscope and positioned in the eighth intercostal space, posterior axillary line. It is prudent once the incision is made to digitally confirm successful entry into the chest. If CO2 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 for a utility incision (Fig. 8.2). 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 extracorporeal instrument arm collisions.

Fig. 8.2 Port strategy for four-arm robotic lobectomy

8.2.4 Docking the Robot Patient Cart

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

S or Si Systems The instrument arms should be placed in a neutral position with the camera arm in the center and the instrument arms on either side. 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 advanced from the posterior aspect of the patient with the center column and camera arm in line with the desired field of dissection. For most pulmonary resections a 45-degree angle relative to the long axis of the patient is sufficient. During the docking process 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 relative to the patient the camera arm is secured first, and the remainder of the ports are placed under direct vision from the robotic thoracoscope. If the anterior port is a utility incision, the port is placed in the middle of the incision to allow for passage of additional non-robotic instruments. It is useful to test the range of motion of each instrument to verify there are no major conflicts (Fig. 8.3).

Xi System Two recent innovations in the da Vinci™ Xi system have lead to substantial simplification of the docking process. First, the instrument arms have been placed on a rotating boom that can rotate 270-degrees. During docking laser cross hairs from the center of the boom allow the circulating nurse to quickly position the boom over the camera port. The cart may be positioned so the cross hairs are anywhere within 5 cm of the camera port. The port is attached to the instrument arm and the endoscope inserted. Once inserted the camera projects its own crosshairs that may be used for targeting the desired anatomic region. In the case of pulmonary resection the pulmonary hilum is centered on the endoscope view. The targeting button on the scope is then depressed, and the boom will rotate the arms automatically so that the other instrument arms are optimally positioned 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 modified to allow quicker and easier connections. Third, a new patient clearance button on each arm 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. 8.4).

Once the instruments are introduced and visible on the endoscope view, the surgeon moves to the console and the tableside assistant stands at the utility incision to provided assistance with retraction and suction as required. The assistant will also be required to pass and fire the staplers for division of the hilar structures and fissures as required.

Fig. 8.3 Docking for da Vinci Si procedure

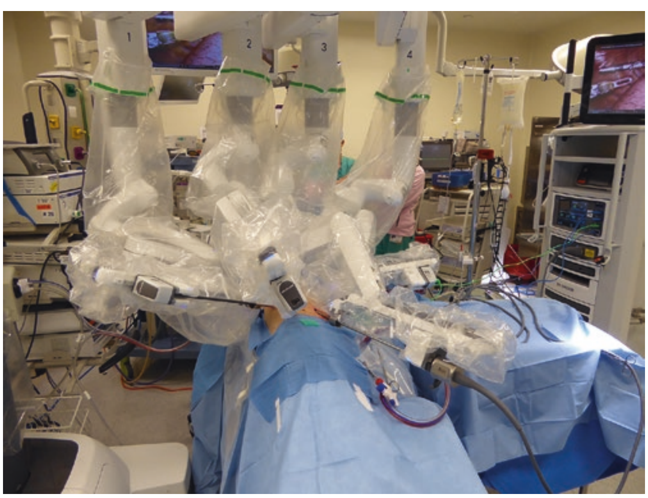

Fig. 8.4 Docking for da Vinci Xi procedure

8.2.5 Instrumentation

S or Si System A forceps is most commonly controlled by one hand for grasping tissue. Several choices are available, including the Cadiere, Prograsp or Fenestrated Bipolar. The authors favor the Fenestrated Bipolar because of the option to apply bipolar cautery to small vessels when necessary. In the surgeon's dominant hand there is typically a dissecting instrument (monopolar spatula, Maryland bipolar, monopolar hook). The authors prefer the monopolar cautery 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.

Xi System Similar instruments are utilized for the Xi System. Of note, the Cadiere forceps is not available on the Xi system. A 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.

8.2.6 Posterior Hilar Dissection

In all cases of anatomic pulmonary resection it is the authors' preference to begin with posterior hilar dissection. The lower lobe is retracted superiorly, and the inferior pulmonary ligament is divided with electrocautery. The inferior ligament and periesophageal nodes are removed. The lung is then retracted anteriorly, and the posterior pleural is divided at its interface with the lung parenchyma all the way 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. 8.5). It is critical, particularly on the left side, to have the tableside assistant provide aid in exposing the subcarinal space, either through lung retraction or by compressing the inferior vein (left) or pericardium (right).

When performing lower lobectomy, during the posterior hilar dissection it is advantageous to sweep the posterior 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. 8.5 Subcarinal (level 7) node dissection from the right side

8.2.7 Right Upper Lobectomy

The initial posterior hilar dissection is performed with resection of the posterior hilar and subcarinal lymph nodes. Removal or partial dissection of the sump nodes with identification of the right upper lobe bronchus greatly enhances division of the bronchus either upfront or during the anterior portion of the dissection (Fig. 8.6). It is our practice to perform an anterior-to-posterior approach without 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. 8.7). Once isolated, the upper lobe vein is divided with an endovascular stapler introduced through the posterior inferior port exposing the basilar pulmonary artery and the truncus arteriosus. 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.

The hilar node adjacent to the truncus arteriosus is mobilized sufficiently to allow for isolation and division of the vessel. At this juncture the peribronchial lymph nodes and any remaining sump nodes that have not been previously excised should be removed completely. This maneuver will result in complete mobilization of the upper lobe bronchus and will clearly delineate the location of the posterior ascending artery branch. These two remaining structures may then be divided in whichever order is practically easiest. On occasion where the posterior ascending branch arises more proximal on the main pulmonary artery, it is necessary to divide this branch first (Fig. 8.8). 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. We perform a "fissureless" technique whereby the horizontal fissure is completely last with multiple fires of the endovascular stapler.

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. 8.9). On completion, intercostal blocks with 0.5 % Marcaine are performed, a single 28Fr chest tube is placed posteriorly and apically. The lung is re-inflated under direct vision and the wounds are closed in a standard fashion.

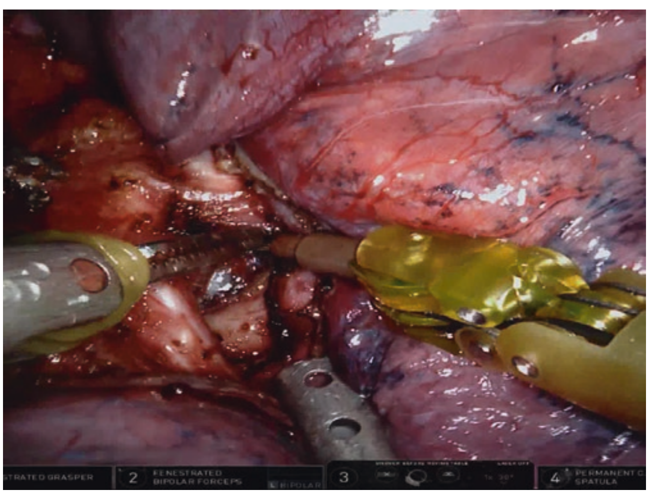

Fig. 8.6 Exposure of right upper lobe bronchus

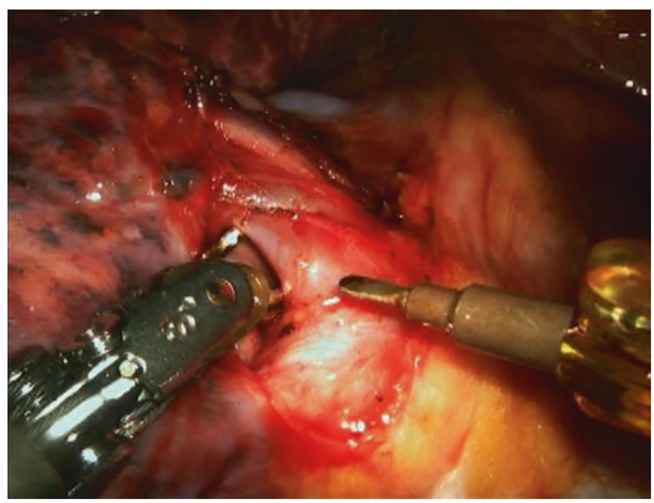

Fig. 8.7 Isolation of the right superior pulmonary vein

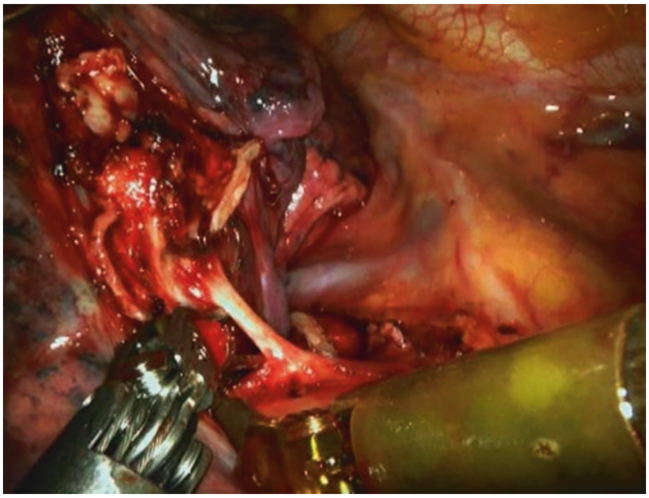

Fig. 8.8 Exposure of the right upper lobe posterior ascending pulmonary artery

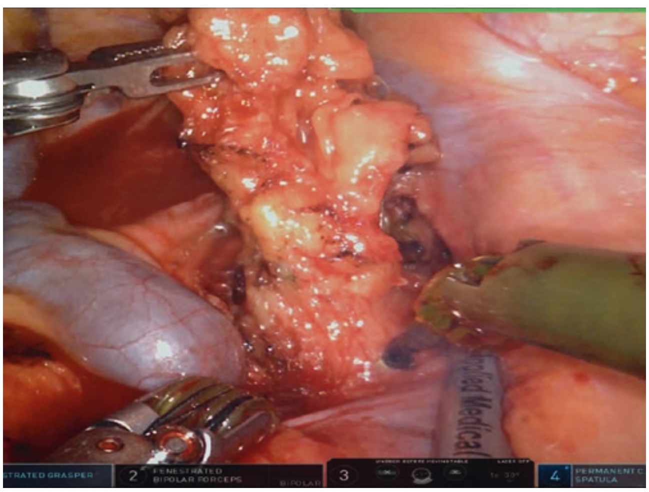

Fig. 8.9 Right paratracheal lymph node dissection

8.2.8 Lower Lobectomy

The steps for completing a lower lobectomy on either the right or left sides are nearly identical.

Following the posterior hilar dissection, if the major fissure is entirely or substantially complete, it is advantageous to divide the pleura over the basilar artery in order to facilitate completion of the fissure anteriorly. Usually, there are level 11 interlobar lymph nodes present overlying the basilar artery. 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. 8.10). The anterior fissure can then be divided either with cautery or endovascular stapler. On the left side it is critical 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.

After division of the anterior portion of the major fissure the plane between the basilar artery and lower lobe bronchus is developed through careful 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 may be a little more difficult than on the left. The posterior portion of the 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. For a lower lobectomy they can all be stapled through the anterior incision. The lung is retracted superiorly, and the tableside assistant removes the instrument arm from the anterior incision. Use of articulating staplers can facilitate passage and division. The inferior vein is divided first (Fig. 8.11) followed by the bronchus, and the basilar artery is often divided last. Once the hilar structures are sequentially divided any remaining posterior oblique fissure is completed with the endoscopic stapler 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.

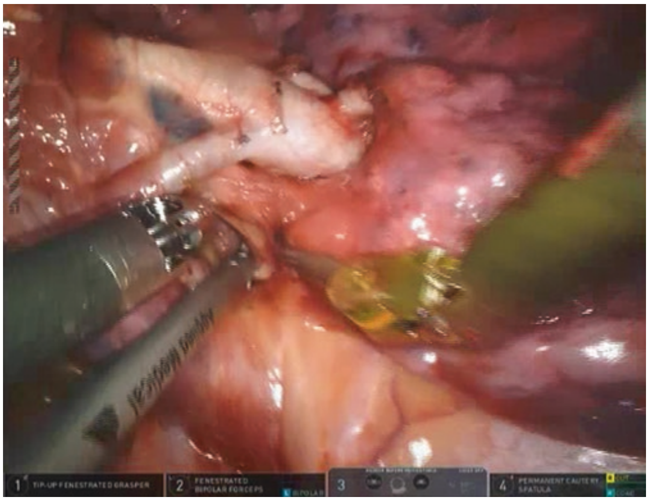

Fig. 8.10 Complete dissection of the anterior major fissure (*right side*)

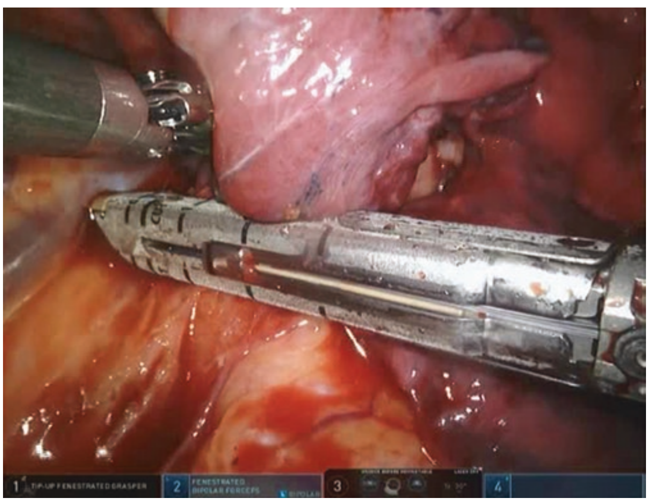

Fig. 8.11 Division of the left inferior pulmonary vein

8.2.9 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. The remaining portion of the fissure anteriorly may be divided with a stapler or with electrocautery if the fissure is complete. 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. 8.12). The middle lobe bronchus is then easily encircled by removing the peribronchial nodes. It may be divided by stapling either through the posterior or anterior incisions. A curved stapler tip is useful for this endeavor. 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. 8.13). The horizontal fissure is stapled last usually by passing the stapler through the anterior incision.

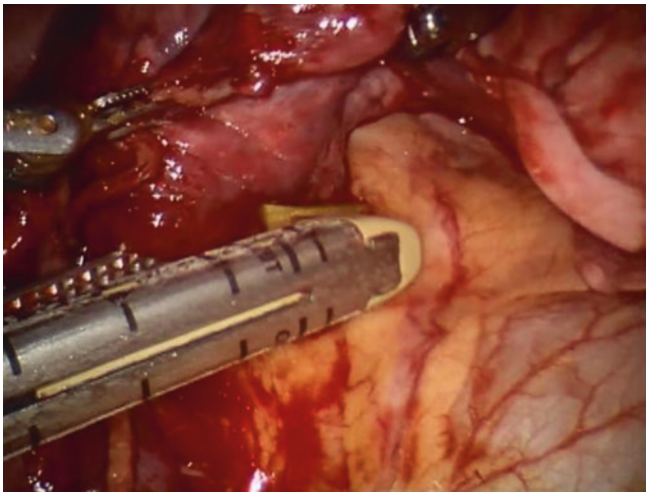

Fig. 8.12 Division of the middle lobe vein

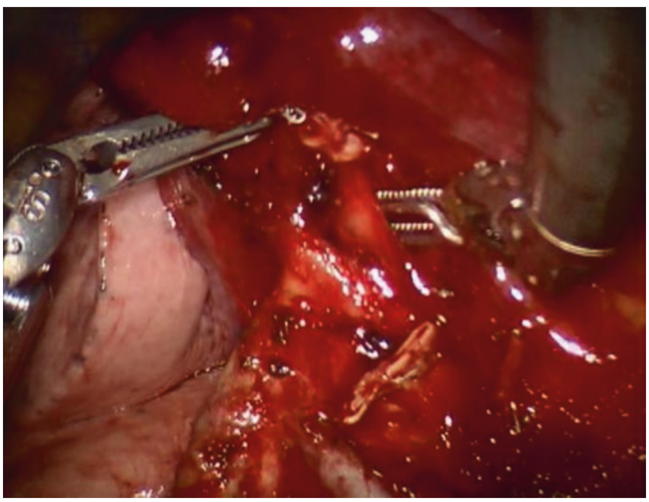

Fig. 8.13 Exposure of the middle lobe arteries

8.2.10 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. 8.14). There are usually hilar 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 stapled (Fig. 8.15). As with right upper lobectomy, the hilar structures may be divided with introduction of the stapler through the posterior incision. 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.

On division of the bronchus lateral and posterior retraction of the upper lobe will expose the pulmonary artery and the upper lobe branches as viewed from the anterior aspect of the hilum (Fig. 8.16). Each upper lobe branch is mobilized under direct vision and divided sequentially to the lingular artery. The precise sequence in which the vessels are taken can vary depending on their relationship to each other giving the best exposure for stapling. Depending on the clinical situation or simply surgeon preference the posterior arterial branches may be isolated and divided prior to dissection of the anterior vessels and bronchus. Typically once all of the hilar structures have been divided the major fissure can be completed with multiple fires of the endovascular stapler.

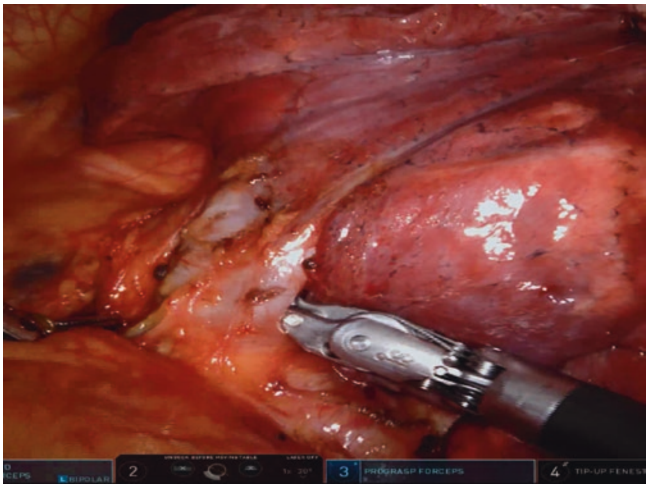

Fig. 8.14 Mobilization of the left superior pulmonary vein

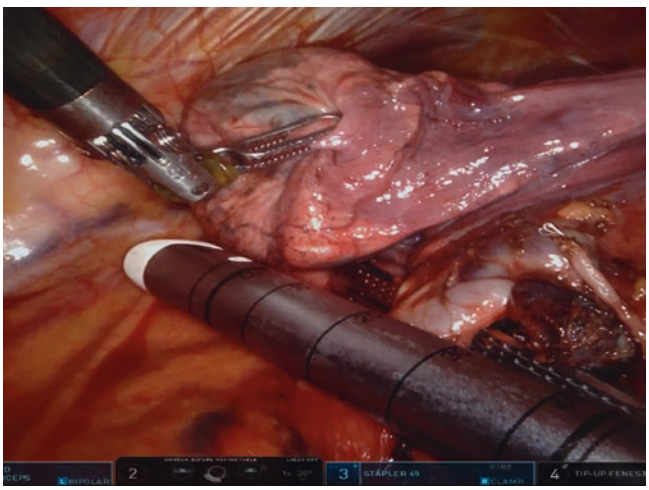

Fig. 8.15 Division of the left anterior/apical pulmonary artery branches

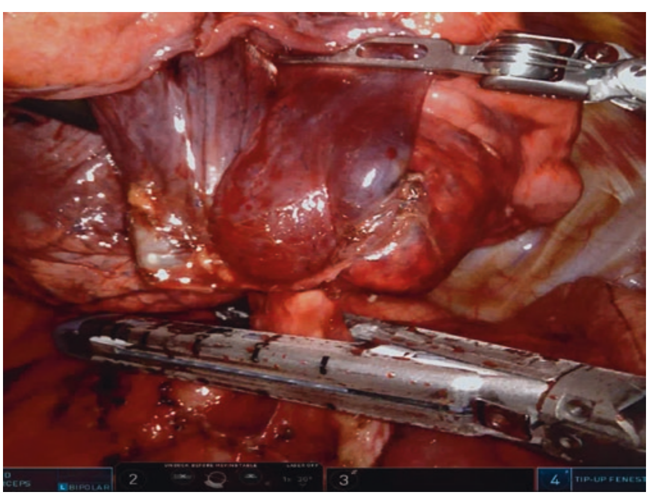

Fig. 8.16 Division of the left upper lobe bronchus

8.3 Results and Discussion

Robotic lung resection has been practiced 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 series consisted of 34 patients having robotic assisted, minimally invasive 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. Our results have been replicated by numerous institutions around the world in the subsequent years [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. This still remains a small proportion of all patients having lobectomy but represents a rapid growth in the case volume [18]. 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.

Limitations of the technique that are often cited include costs associated with this new technology and lack of long term oncologic data for early stage lung cancer patients having this novel technique. We have attempted to address these issues through analysis of our own experience.

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.

The second concern about the procedure is over the oncologic safety of robotic lobectomy. Two recent studies should put these concerns to rest. Firstly, long term oncologic data has been reported from a multi-institutional retrospective review of patients undergoing robotic lobectomy [20]. Three hundred twenty-five patients from 3 separate centers including 123 consecutive patients from our own center were studied. 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 are 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].

Anecdotally, surgeons with experience of both techniques of robotic lobectomy and conventional VATS lobectomy often remark on the ease of performing a complete lymphadenectomy with the robotic technique. This should translate to better staging and therefore appropriate administration of adjuvant therapies when indicated. 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 conclude the rate of robotic pathologic nodal upstaging for clinically stage I NSCLC appears to be superior to the VATS approach and similar to the open approach. Overall and disease free survival rates are comparable to open and VATS technique, albeit with a rather short median follow-up of 12.3 months [24].

Together these studies provide objective evidence of the oncologic equivalence of robotic lobectomy to open surgery and evidence of possible superior staging through better lymph node resection and therefore more accurate staging with this technique. As the previous published series mature with time, more robust long term oncologic data with become available.

8.3.1 Summary

Reported experience in the literature shows robotic pulmonary lobectomy to be a safe, reproducible technique. It provides an alternative to conventional VATS lobectomy with a technique that is more intuitive. Randomized trials comparing the technique to standard open approach and conventional VATS surgery are not available and are unlikely ever to be conducted. Papers from institutions across the world report equivalent perioperative outcomes. Long oncologic efficacy has also been demonstrated with evidence of superior nodal dissection and therefore accurate staging in lung cancer patients.

This intuitive technique should remove the technical barriers that prevent some surgeons from adopting a minimally invasive approach. Fears over excessive costs have been allayed compared to standard thoracotomy. It is anticipated that as the technology becomes more widely adopted, associated costs should fall promoting yet wider adoption across the thoracic surgical community.

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Intraoperative Staging and Node Dissection

9

Hui Zhao, Jian Zhou, and Qun Wang

Contents

9.1 Intraoperative Staging of Lung Cancer: The Sentinel Lymph Node Biopsy in the Intraoperative Staging of Non-small Cell Lung Cancer

Hui Zhao and Jian Zhou

9.1.1 Preface

In the staging of non-small cell lung cancer, the status of the drainage lymph nodes is of great concern. Radiological examinations such as computed tomography (CT) or fluoro-2-deoxy- d -glucose (FDG)-positron emission tomography (PET) scanning can aid in the preoperative staging of non-small cell lung cancer. But several meta-analyses has reported low sensitivities and specificities in the assessment of mediastinal lymph node status, which ranged from 50 to 65 %, and from 65 to 85 %, respectively [1]. PET and PET-CT are superior to CT in the preoperative nodal staging, which has been proved by a large number of studies and meta-analyses [1–6]. PET and PET-CT can provide comparable high sensitivities, and negative predictive values to mediastinoscopy. However, due to lack of pathological proof, the positive predictive value and the specificity pf FDG PET scan is lower than mediastinoscopy [1]. Cervical mediastinoscopy, endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA) and esophagoscopy (EUS-FNA) are useful preoperative staging tools. They can provide reliable sensitivity and specificity

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[1]. But these preoperative staging examinations are performed in patients with enlarged lymph nodes and a high suspicion of N2-N3 disease [7], and they cannot reach all the stations of pulmonary drainage lymph nodes.

Intraoperative lymph node dissection is the most accurate way to determine the pathologic status of lymph node, and is considered as gold standard for the other method to evaluate the pathologic status of lymph node in resectable NSCLC cases.

As the number of the early stage lung cancer increases, more and more sublobar resection, including wedge resection and segmentectomy are performed. And selected lymph node sampling are proved to have a comparable prognosis with complete lymph node dissection in early stage NSCLC patients [8]. Reducing the extent of the lymphadenectomy procedure has been indicated for patients without metastasis to lymph nodes [9–12]. Thus, the point is how to reduce the extent of lymphadenectomy procedure while dissect all the possible metastatic lymph nodes. On the other hand, due to the micrometastasis of NSCLC tumor cells [13], the current pathology evaluation techniques may cause downstaging and undertreatment of the NSCLC patient. A more focused pathologic or molecular staging technique is needed to direct a more focused research for the metastatic disease. The sentinel lymph node identification technique may help in reducing excessive lymphadenectomy procedures and providing more focused pathologic studying,

9.1.2 The History of Sentinel Lymph Node Biopsy

The first sentinel lymph node biopsy was introduced by Cabanas in 1977 in penile cancer [14]. However, the method was found to be unreliable. Because the false negative rate was unacceptably high and too difficult to implement [15]. But in some superficial malignancies such as melanoma and breast cancer, the sentinel lymph node biopsy was well adopted [16, 17]. And used sometimes as standard procedures in the surgeries of these malignancies [18, 19].

In resectable NSCLC surgeries, mediastinal lymph node dissection (MLND) was considered as a standard procedure since Naruke and colleagues created a lymph node map and reported the significance of MLND [20]. And the first sentinel lymph node biopsy was performed by Little and colleagues [21] in 1999, and since then there has been an expanding body of literature.

9.1.3 The Definition and Indication of SLN Biopsy in NSCLC Surgery

The theory of sentinel lymph node is based on the hypothesis that the sentinel node is the first station of nodal drainage, and it can represent the status of the further stations of lymph node. So, the sentinel lymph node biopsy is defined as the first lymph node or group of lymph nodes encountered in lymphatic drainage from the primary tumor [14]. During sentinel lymph node biopsy, one or several tracers is injected near the primary tumor. And the path of lymphatic drainage is mapped using different techniques depending on the characteristics of the tracers. Intraoperative mapping permits selective biopsy of the intrapulmonary, hilar or the mediastinal lymph node. The biopsied specimen is then evaluated using frozen section, touch imprint cytology analysis technique [22] or more accurate techniques such as immunohistochemistry (IHC) and reverse transcription-polymerase chain reaction to identify micro metastasis [23, 24].

The aim of SLN biopsy is to help the pathologic node-negative patients to avoid unnecessary lymphadenectomy without leaving out metastatic lymph nodes, and to reduce the lymphadenectomy complications. So the SLN biopsy should be performed in clinically T1N0M0 patients. The enlarged lymph node indicates increased possibility of metastasis and on the other hand, may block the lymphatic drainage, which may lead to false negative results of the SLN imaging. So the mediastinal lymph node dissection should be performed routinely in radiologically N1 and N2 patients, who might benefit from the thoroughly dissected drainage lymph nodes.

9.1.4 The Tracers Used in SLN Mapping

The first application of sentinel node detection of SLN in non-small cell lung cancer was conducted by Little and colleagues [21] in 1999 using isosulfan blue. The tracer resulted in less than 50 % identification rate. And the primary drawback was the frequently encountered black anthracosis nodes in lung. Since then, a variety of tracers have been reported, including radioactive tracer, fluorescence tracers, magnetic materials, CT contrast agents, and carbon nano-particles. The detection rates and sensitivity of SLN mapping varies between different tracers. A meta-analysis in 2013 shows the pooled detection rate was 80.6 % [76.8–84 %] and pooled sensitivity was 87 % [83–90 %] [25].

9.1.5 Dye

The clinical trial conducted by Little et al. [21] in 1999 was the first application on SLN mapping. In this trial, the group prospectively injected isosulfan blue in 36 patients. Sentinel lymph nodes was identified in 47 % of the patients. The unsatisfying results was caused by original black color of the anthracotic pulmonary lymph nodes and the steep learning curve. Sugi and colleagues [26] and Rzyman and colleagues [27] also reported trials using blue dye staining method for

SLN identification and showed inadequate identification rate of SLN.

9.1.6 Radioactive Tracers

9.1.6.1 Intraoperative Injection

The Technetium 99m (Tc 99m) was first used in breast cancer, and the accuracy was reported to exceed 90 % [28, 29]. Liptay et al. reported the first study of Tc 99m sulfur colloid in NSCLC SLN biopsy [30]. They included 148 consecutive patients who underwent completely resected non-small cell lung cancer. Colloid suspension was injected into tumor and outer margins of the tumor and a standard dissection was performed to anatomic resection of the tumor. A hand held gama-counter was used to read the radiation intensity. They observed successful migration of radioisotope through lymphatics in 120 of 148 patients (81 %), and sentinel lymph nodes was identified in 104 of 120 patients. The identification rate was 70 %, and is much higher than blue dye. In the study, they used immunohistochemistry and serial sectioning and detected eight cases of micrometastatic disease. And they found 25 of 104 patients (24 %) with N2 mediastinal nodes as sentinel nodes. But in the following multicenter phases II trial [31], Cancer and Leukemia Group B 140203 (CALGB140203), the identification rate of SLN was only 61.5 % (24 of the 39 patients). Twenty of 24 patients (83.3 %) was found to be true negative (no other nodes were positive if SLN was found to be negative). The overall true negative rate was 20 of 39 patients (51.2 %). The group contributed the lower identification rate to a difficult learning curve. Rzyman et al. [32] reported sentinel node identification rate of 74 % afterwards.

9.1.6.2 Preoperative Injection

Due to restrictions of handling radioactive substances in Japan, Japanese surgeons performed several preoperative injection of radioactive tracers. Nomori and colleagues [33] performed the largest serials based on Tc 99m tin colloid, a larger particle which can last longer in lymph nodes. SLNs were identified in 40 (87 %) of 46 patients, and no false negative SLNs were detected in 14 patients with N1 or N2 disease.

Kim and colleagues [34, 35] also developed a mannose receptor-binding agent called Tc99m neomannosyl human serum albumin (Tc99m MSA). They performed both preoperatively and intraoperatively. The SLN identification rate was high in both groups: 95.8 in preoperative group and 97.1 % in intraoperative group, with no significant difference. They also proved that intraoperative injection is time-saving and less expensive.

Preoperative injection may have some logistical benefits: (1) Avoid intraoperative handling of radioactive substances, (2) Better identification rate in some trials, which is also proved by a meta-analysis study [25]. On the other hand, it has the risk of pneumothorax, hemopneumothorax, metastasis along the needle tract, and may take longer time in total.

The radioactive tracers may have the following shortcomings: (1) Shine-through effect, which is the tumor and background radioactivity aerosolization phenomenon, may cause low identification rate in hilum or interlobar SLNs. (2) The endobronchial migration of radioactivity may lower the identification rate. (3) Difficult learning curve. (4) Handling of radioactive substance may face restrictions and cause potential damage to both patients and surgeons.

9.1.7 Near Infrared Fluorescent Tracers

Near infrared light can penetrate around 1 cm of solid tissue and can be visualize. Using the real-time visible and NIR images, it is possible to simultaneously display the color and NIR images or overlay the two images. Thus we can get an image which can show the exact location of the fluorescent lymph nodes while the color of the mediastinum is not changed. And NIR imaging can avoid the disadvantage of shine-through effect and the government regulations on the radioactive materials. Currently, there are commercial available NIR cameras for both open and thoracic surgery. Several groups have studied on these non-radioactive tracers and there have been promising results.

Soltecz et al. [36] reported the use of NIR fluorescing quantum dots in pigs. They used a camera system that can merge visible image and the near infrared fluorescence. This technique was found to be reliable in identifying the SLNs in pigs. They also proved lymphatics and nodes could be seen through 1 cm of solid tissue and 5 cm of lung parenchyma.

Yamashita and colleagues applied the NIR guided SLN biopsy in thoracoscopic lobectomy and segmentectomy, and reported the SLN identification rate of 80.7 % They also described some technical difficulties such as steep learning curve and factors that impeded detection of signal such as adhesions to pleura, incomplete fissure, and deep nodes. Gilmore et al. [37] utilized NIR and FLARE system in conducting the clinical phase I trial in 38 patients. They performed an dose-efficacy study, which starts from 3.8 μg of peritumorally injected ICG up to 2,500 μg. Concentrations of dye 1,000 μg or greater were associated with an excellent 89 % SLN identification without adverse reactions, whereas doses of less than 600 μg were associated with poor 25 % identification. They also reported 27 % patients with "skip metastasis" directly to N2 nodal stations. A phase II trial is to be anticipated in the future.

9.1.8 CT Contrast Agents

In 2004, Suga and colleagues [38] reported a method of preoperative CT-guided injection of iopamidol in to peritumoral lung tissue. They reported successfully SLN identification in all nine patients without any complications. Takizawa and colleagues [39] also reported a method of inserting an ultrathin bronchoscope into the target bronchus with the guidance of virtual bronchoscopic navigation system. Then the CT image was acquired at 0.5 and 5 min after injection of 2 or 3 mL of iopamidol through a microcatheter. The SLN identification rate was 92.3 % (12 of 13 patients). Although the number of patients studied was small, the SLN identification rate was high.

9.1.9 Combined Tracers/Mutimodal Imaging in SLN Identification

In order to improve the identification rate of SLNs, some researchers tried to combine different tracers or used a tracer that contain combined features of different tracers.

Schmidt et al. [40] attempted to inject blue dye and Tc99m. They reported SLN identification rate of 81 % in 31 patients, which is comparable to Liptay's study. But in another study conducted by Tiffet et al. [41], they had less success with this combination method, with only 54 % of identification rate in 24 patients. The unsatisfying result may be caused by rushed biopsy of SLN.

Jinzi et al. [42] reported a dual-modality nano liposomal agent (CF800), which can be used as computed tomography contrast and near-infrared fluorescence agent. They performed the application of this agent for preoperative CT three-dimensional surgical planning (>200 Hounsfield units enhancement) and NIR fluorescence guided resection (>5-fold tumor to background ration). This study showed a promising future of this multimodal agent.

9.1.10 Other Tracers

There are also some reports of using positron emission tomography agent (18F-flourodeoxyglycose, FDG) or magnetite in identification of SLN.

9.1.10.1 Positron Emission Tomography/CT Lymphoscintigraphy

Nwogu et al. reported SLN mapping using ^{18}F-flourodeoxyglycose (FDG) peritumoral injections in ten patients [13]. They found three of the ten patients had FDG-positive nodes containing micrometastasis, although these were not SLNs. The group proposed using PET/CT and FDG injections for "ultrastaging" rather than SLN mapping. Eo et al. [43] also reported use of gallium tracer in 34 patients with an identification of 100 %. Although promising, the application was limited by the expense and the small number of the studies.

9.1.10.2 Magnetite

Nakagawa and colleagues [44] reported a method using ferumoxide, a colloidal superparamagnetic iron oxide of nonstoichiometric magnetite, as a tracer. They injected 5 mL of the magnetite in to paratumoral lung tissues intraoperatively. Lung resection and lymph nodes biopsy were performed 15 min late. The resected lymph nodes were examined ex vivo. After the initial study, they developed a more sensitive and sterilizable magnetometer for in vivo examination [45]. The in vivo SLN detection rate was 80 %.

9.1.11 Conclusions

In cases of melanoma and breast cancer, SLN biopsy techniques has been proven to be useful and effective, and have become standard procedures. In NSCLC surgery, the study of the present tracers has progressed. The identification rate was less than 90 % with blue dyes or Tc 99m, complicated by the anthracosis-obscuring dye visualization or shine-through effect. New technologies using different agents such as near infrared fluorescent tracers, CT-contrast agents, multi-modal agent et al. are promising but need additional trials the evaluate the use of various injection strategies.

In future, the SLN biopsy technology may have the potential to reduce the excessive lymphadenectomy. On the other hand, it may also help in identification of the isolated tumor cells (single tumor cells of < =0.2 mm in diameter) or micrometastasis (0.2–2 mm in diameter). Future studies are needed to find more ideal tracers and application strategies.

9.2 Mediastinal Lymph Node Dissection

Qun Wang

9.2.1 Technical Points

- Discriminate adjacent structures of regional lymph nodes, and make en-bloc resection of lymph nodes and surrounding fat tissue.
- Grasp tissue gently, and avoid grasping lymph nodes directly which may crush lymph nodes.

9.2.2 Anatomical Landmarks [46]

#1: Low Cervical, Supraclavicular, and Sternal Notch Nodes, from lower margin of cricoid cartilage to clavicles and the upperborder of the manubrium.

#2: Upper Paratracheal Nodes, 2R: upper border: apex of the right lung and pleural space, lower border: intersection of caudal margin of innominate vein withthe trachea. 2L: upper border: apex of the left lung and pleural space, lower border: superior border of the aortic arch.

#3: prevascular and retrotracheal Nodes, 3a: Upper border: apex of chest, lower border: level of carina, anterior border: posterior aspect of sternum, posterior border: anterior border of superior vena cava (right) and left carotid artery, 3p: Upper border: apex of chest, lower border: level of carina.

#4: lower paratracheal Nodes, 4R: upper border: intersection of caudal margin of innominate vein with the trachea, lower border: lower border of azygos vein, 4L: upper border: upper margin of the aortic arch, lower border: upper rim of the left main pulmonary artery.

#5: subaortic nodes, subaortic lymph nodes lateral to the ligmentum arteriosum, upper border: the lower border of the aortic arch, lower border: upper rim of the left main pulmonary artery.

#6: paraaortic nodes, lymph nodes anterior and lateral to the ascending aorta and aortic arch, upper border: a line tangential to the upper border of the aortic arch, lower border: the lower border of the aortic arch.

#7: subcarinal nodes, upper border: the carina of the trachea, lower border: the upper border of the lower lobe bronchus on theleft; the lower border of the bronchusintermedius on the right.

#8: paraesophageal nodes: nodes lying adjacent to the wall of the esophagus and to the right or left of the midline, excluding subcarinal nodes, upper border: the upper border of the lower lobe bronchus on the left; the lower border of the bronchus intermedius on the right, lower border: the diaphragm.

#9: pulmonary ligament nodes: nodes lying within the pulmonary ligament, upper border: the inferior pulmonary vein, lower border: the diaphragm.

9.2.3 Operating Procedure

9.2.3.1 Dissection of Right Upper Mediastinal Lymph Node

The azygos vein is exposed by retracting the right upper lobe inferiorly (For non right upper lobe resection). The mediastinal pleural caudal to the azygos vein arch is grasped and incised. The lymph nodes and the mediastinal fat pad are divided along the posterior border of the vena cava, the anterior border of the trachea, the lower border of the azygos vein and the surface of the pericardium (Fig. 9.1).

The right upper lobe is retracted caudally. The mediastinal pleural cephalad to the azygos vein can be grasped for better exposure. The pleural over the joint of the azygos vein and the vena cava is incised by ultrasonic scalpel or hook electrocautery, opened in parallel with the vena cava to the innominate artery, along the lower border of the inominate artery, anteriorly to the vagus nerve and above the azygos vein (Fig. 9.2).

The aygos vein arch is retracted caudally to elevate the lymph nodes to the superior mediastinum and to push to the trachea. An ultrasonic scalpel can be used to divide the fat tissue behind the vena cava to the lower border of subclavicular artery. After that, the lymph nodes can be pushed to the appex of the thorax and then be dissected off the surface of pericardium and the front border of the trachea to the subclavicular artery. The en bloc tissue is then dissected along the lower border of the subclavicular artery when it is retracted caudally (Fig. 9.3).

Tips

A small vein draining from the upper mediastinal fat pad into the superior vena cava is encountered frequently. Some lymph ducts may be present on the surface of the pericarium infront of the trachea. Dissetion should be performed tenderly and carefully. Ligation is useful to prevent postoperative lymph leakage.

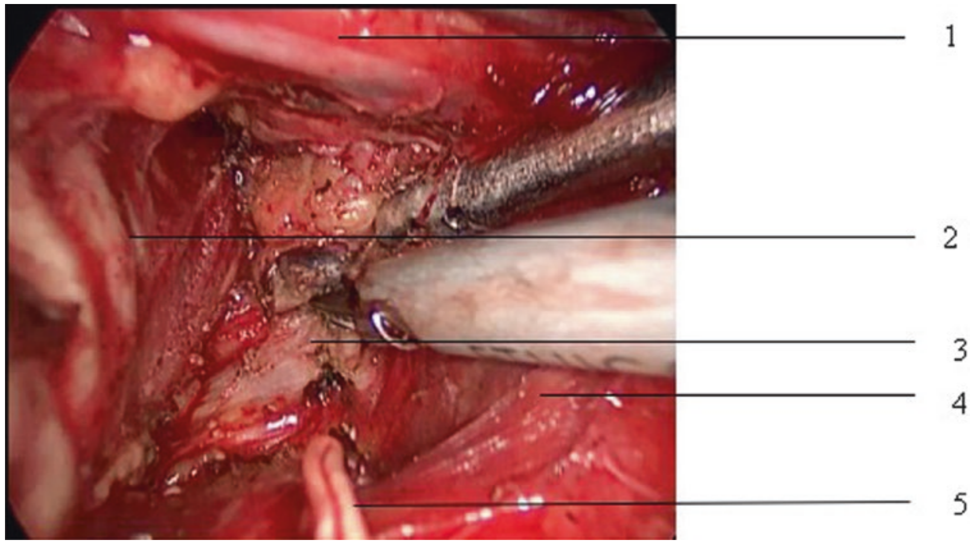


Fig. 9.1 Dissection of right upper mediastinal lymph node. *1* Azygos vein arch. *2* Trachea. *3* Pericardium. *4* Superior vena cava. *5* Stump of trucus anterior

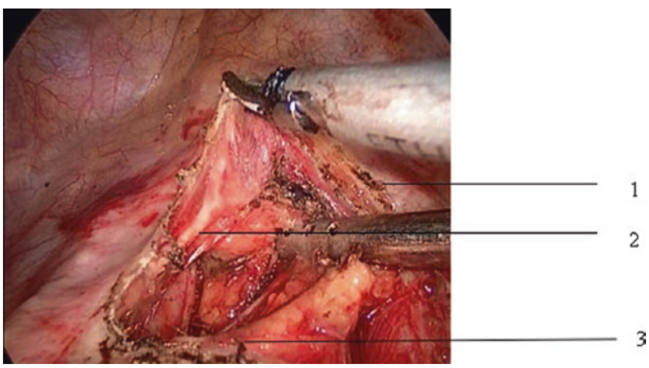


Fig. 9.2 Dissection of right upper mediastinal lymph node. *1* Superior vena cava. *2* Vagus nerve. *3* Azygos vein arch

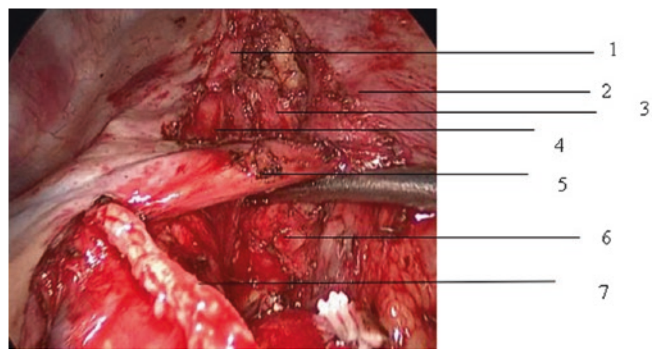


Fig. 9.3 After dissection of right upper mediastinal lymph node. *1* Vagus nerve. *2* Superior vena cava. *3* innominate artery. *4* Trachea. *5* Azygos vein arch. *6* Pericardium. *7* Stump of right upper lobe bronchus

9.2.3.2 Dissection of Right Subcarinal Lymph Nodes

The right lung is retracted anteriorly, and the mediastinal pleural is exposed and then opened from the level of bronchus intermedius to the carina. The subcarinal lymph node packet is divided along the right and left bronchi and the surface of the pericardium. The packet can then be dissected by ultrasound scalpel en bloc (Fig. 9.4a, b).

> **Tips**
> A bronchial artery can be seen in front of the left main bronchus. It must be identified and controlled carefully.

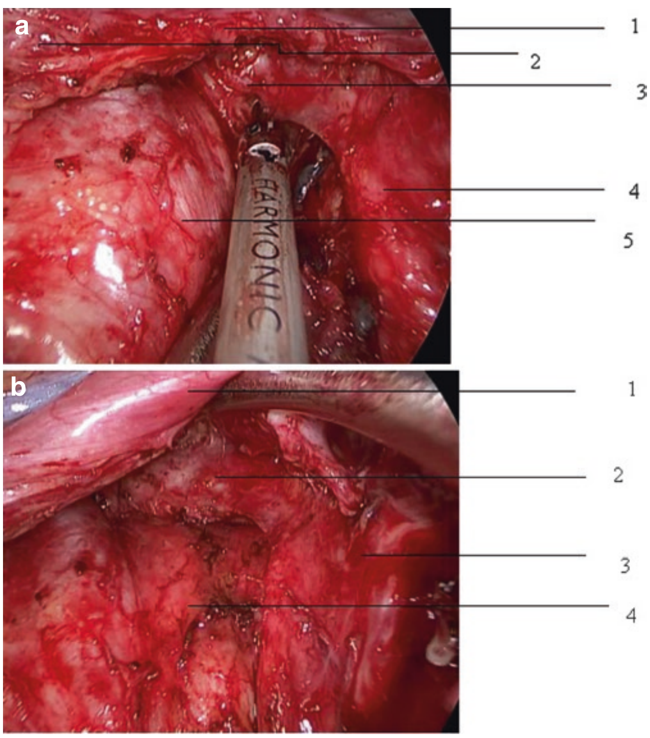


Fig. 9.4 (**a**) Dissection of right subcarinal lymph nodes. *1* Vagus nerve. *2* Esophagus. *3* Left main bronchus. *4* Right main bronchus. *5* Pericardium. (**b**) After dissection of right subcarinal lymph nodes. *1* Esophagus. *2* Left main bronchus. *3* Right main bronchus. *4* Pericardium

9.2.3.3 Dissection of the Right Lower Mediastinal Lymph Nodes

The inferior pulmonary ligament should be divided to the level of the inferior pulmonary vein. The fat pad and the lymph nodes on the surface of the esophagus should be removed from the esophageal hiatus to the level of the inferior pulmonary vein (Fig. 9.5).

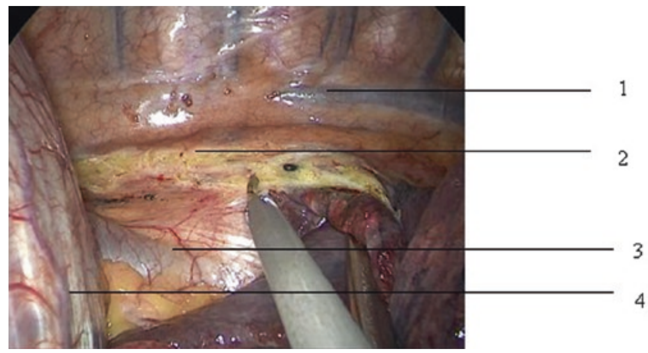


Fig. 9.5 Dissection of the right lower mediastinal lymph nodes *1* Azygos vein. *2* Esophagus. *3* Inferior vena cava. *4* Diaphragm

9.2.3.4 Dissection of the Left Upper Mediastinal Lymph Node

The left upper lobe is retracted caudally to expose the superior mediastinum (for non upper lobe resection). Open the mediastinal pleural on the surface of the phrenic nerve and the vagus nerve. The lymph nodes with the fat pad posterior to the phrenic nerve, anterior to the vagus nerve, on the surface of the aortic arch, arterial ligament and the left pulmonary trunk are dissected (Fig. 9.6).

The phrenic nerve is retracted and the nodes with fat pad anterior to the ascending aorta are dissected (Fig. 9.7).

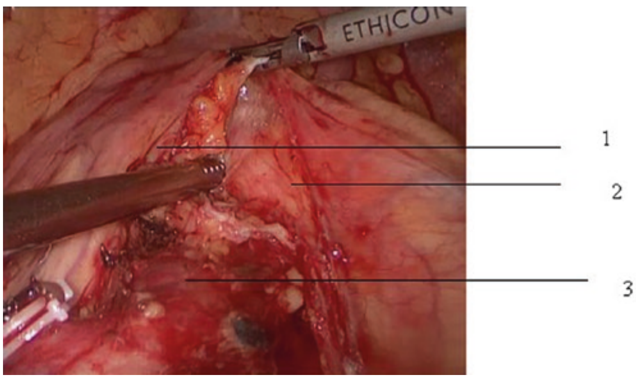


Fig. 9.6 Dissection of the left upper mediastinal lymph node. *1* Phrenic nerve. *2* Vagus nerve. *3* Pulmonary trunk

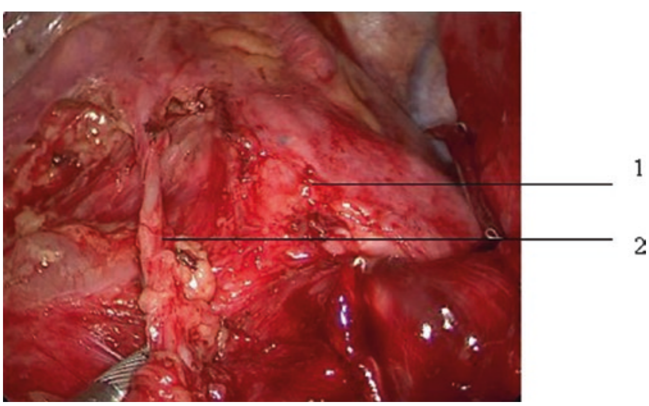


Fig. 9.7 Dissection of the left upper mediastinal lymph node. *1* Vagus nerve. *2* Phrenic nerve

The left vagus nerve and the left recurrent laryngeal nerve are divided and exposed. The left laryngeal nerve is divided to the aortic arch. The pulmonary trunk is then pushed to the ventral side and the descending aorta and the esophagus to the back side. The lymph nodes and the fat tissue posterior to the pulmonary trunk, anterior to the esophagus, caudal to the aortic arch and on the surface of the distal part of the trachea are dissected (Fig. 9.8a, b).

> **Tips**
> Care must be taken not to injure to the left phrenic nerve, the left vagus nerve and the left recurrent laryngeal nerve. Thermal injury should be prevented to the nerves when the dynamical systems are used in the dissection.

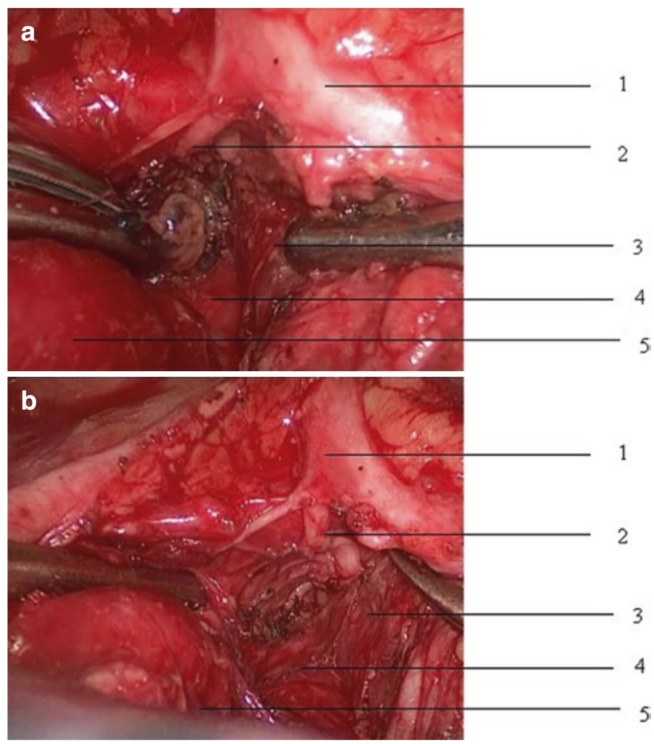
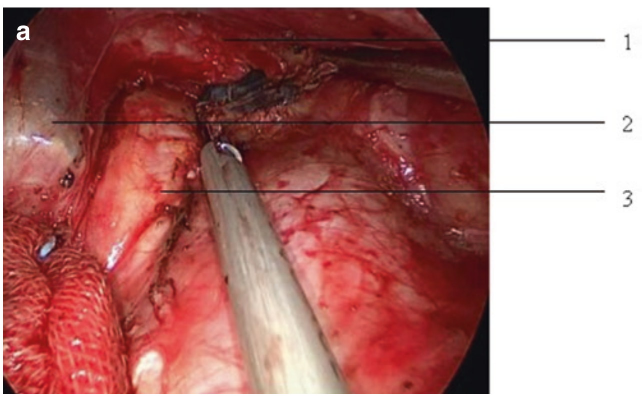


Fig. 9.8 (**a**) Dissection of the left paratracheal lymph node. *1* Left vagus nerve. *2* Left recurrent larygeal nerve. *3* Esophagus. *4* Trachea. *5* Pulmonary trunk. (**b**) After dissection of the left paratracheal lymph node. *1* Left vagus nerve. *2* Left recurrent larygeal nerve. *3* Esophagus. *4* Trachea. *5* Pulmonary trunk

9.2.3.5 Dissection of the Left Subcarinal Lymph Node

The lung is retracted anteriorly to open the mediastinal pleural from the inferior pulmonary vein to the carina and parallel to the aorta. Expose both left and right bronchus divide the subcarinal lymph nodes along the lower border of the both bronchi to the carina and an ultrasonic scalpel can be used to dissect the lymph nodes en bloc from the surface of the pericardium (Fig. 9.9a, b).

> **Tips**
> Tratrealarteries are present in front of the carina. Careful handling is needed to prevent bleeding.



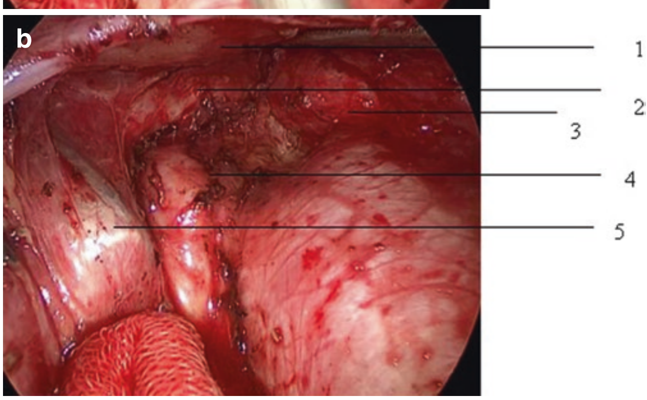


Fig. 9.9 (**a**) Dissection of left subcarinal lymph nodes. *1* Right main bronchus. *2* Left main bronchus *3* Pericardium. (**b**) After dissection of left subcarinal lymph nodes. *1* Esophagus. *2* Right main bronchus. *3* Right lung. *4* Pericardium. *5* Left main bronchus

9.2.3.6 Dissection of the Left Lower Mediastinal Lymph Node

The procedure is similar with dissection of the right lower mediastinal lymph node (Fig. 9.10).

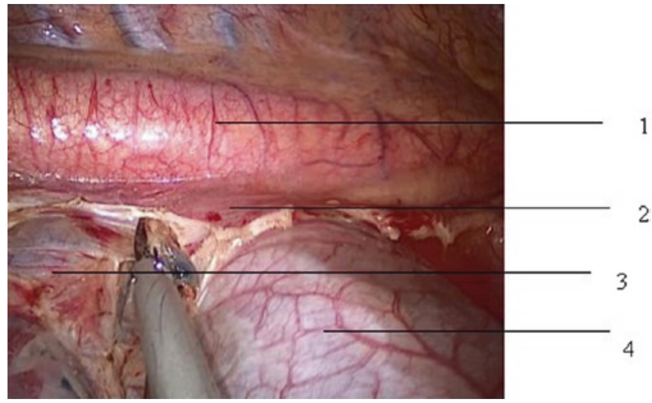


Fig. 9.10 Dissection of the left lower mediastinal lymph node. *1* Descending aorta. *2* Esophagus. *3* Inferior pulmonary vein. *4* Pericardium

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10 Minimally Invasive Approaches to Chest Wall and Superior Sulcus Tumors

Benjamin Wei, Robert Cerfolio, Erin A. Gillaspie, Shanda H. Blackmon, and K.J. Dickinson

Contents

10.1 Minimally Invasive Approaches to Chest Wall Resection and Superior Sulcus Tumors

Benjamin Wei and Robert Cerfolio

10.1.1 Introduction

The resection of chest wall tumors, including superior sulcus tumors, has traditionally been performed via an open approach given the extent of structures to be removed. Recently, more advanced experience with minimally invasive techniques (both VATS and robotic) have allowed thoracic surgeons to perform these operations through smaller incisions and avoid the trauma to the overlying major muscles of the chest wall. One of the earliest reports of VATS-assisted chest wall resection by Widmann et al. described performance of wedge resection of lung with VATS followed by en bloc removal of ribs 3 and 4 along with the wedge of lung, which was accomplished without the use of rib spreading [1]. More recently, Hennon et al. reported a series of 17 patients who underwent VATS chest wall resection, which comprised 36 % of overall chest wall resections

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done at their institution from 2007 to 2013 [2]. The utilization of minimally invasive techniques for chest wall resection has become a more common phenomenon, as surgeons explore the ways in which it may benefit patients in terms of postoperative pain and morbidity. The phrase "minimally invasive chest wall resection" (MICWR) is a bit misleading, as any chest wall resection by definition requires the resection of the same amount of bone and intercostal muscle as in an "open" operation; however the method by which this is accomplished can take advantage of some of the same tools and techniques by which VATS surgery is performed, and hence we will use the term since it reduces the morbidity of cutting muscle.

10.1.2 Indications

Any patient who is undergoing chest wall resection is a candidate to have part, most, or all of the operation performed with minimally invasive techniques. The advantage and feasibility of these techniques are probably more significant for fairly small (<5 cm) tumors that are located in a position where video-assisted rib resection WITHOUT chest wall reconstruction will be feasible. Patients with high tumors (superior sulcus tumors, tumors involving the first and/or second ribs) may be difficult to approach with this method, as removing the ribs that high and dealing with the thoracic inlet structures is more challenging. Patients with large tumors require a larger chest wall resection just to remove the tumor, and thus also we feel benefit less from a minimally invasive approach. Patients for whom defects will definitely require chest wall reconstruction, such as those directly contiguous with the sternum or vertebral bodies, or near the tip of the scapula, may also derive less of a benefit from MICWR, as exposing the area for the reconstruction tends to involve making a larger skin incision and dividing chest wall muscles such as the serratus and latissimus.

Even with the above caveats in mind, many patients requiring chest wall resection will benefit from an initial minimally-invasive approach during the planning phase of the surgery. Placing a thoracoscope first allows the surgeon to rule out pleural metastasis, define the extent of the chest wall invasion, and create a targeted skin incision accordingly.

Patients that require parenchymal resection (including anatomic resections) in addition to chest wall resection are also candidates for MICWR. VATS wedge resection with endoscopic cutting staplers prior to resection of the chest wall can be straightforward, and is the procedure of choice if a negative margin can be obtained for tumors originating from the chest wall and invading the lung. In cases of lung cancer with chest wall invasion, experienced practitioners may choose to perform anatomic lung resection, which may be advantageous from an oncologic standpoint. Division of pulmonary vessels can be done either *after* the chest wall is separated from the remainder of the lobe with a wedge resection through normal lung, or with more difficulty, with the lobe still attached to the chest wall.

10.1.3 Workup

CT scan of the chest is the minimum testing needed. For young patients with an isolated chest wall lesion with no suggestion of lung involvement (ex. chondroma), this may be all that is required. However, patients with suspected lung cancer and patients with a history of cancer or in whom metastasis as the cause for the chest wall lesion is suspected, should also receive integrated whole-body PET-CT scan and possibly brain imaging to determine the extent of disease. If sites of disease other than the chest wall/adjacent lung are located on PET-CT scan, these should be investigated, as elective chest wall resection may not be indicated if these areas prove to be malignant. If parenchymal resection is anticipated, pulmonary function testing is recommended also. Suspected involvement of the subclavian vessels and/or brachial plexus/vertebral body may justify the use of IV contrast and/or MRI, respectively.

10.1.4 Operative Technique

Bronchoscopy is performed if otherwise indicated. The use of a double lumen endotracheal tube is recommended. After positioning of the patient in lateral decubitus, a thoracoscope is inserted to make sure that no pleural metastases exist. The extent of the resection is identified by using a finder needle and the skin marked accordingly. If no parenchyma needs to be resected, a limited utility incision over the area can then be made. The length of the incision depends on the size of the area of chest wall to be resected and how much of the operation is planned to be performed with thoracoscopic as opposed to open techniques. Division of intercostal muscles and ribs can be performed either with VATS instruments via an additional counter incision located away from the area to be resected, or by approaching the chest wall directly via the utility incision with standard, open instruments. Rib division with VATS techniques can involve the use of endoscopic bone shears (Sofamor Danek), high-speed drill burrs (Midas Rex), Gigli saw, or endoscopic rongeurs (Kerrison) [3]. Chest wall reconstruction, if desired, can be performed either with standard open techniques with retraction of the skin incision to permit adequate exposure or alternatively, delivering mesh intracorporeally and using endoscopic devices such as

Carter-Thomason ClosureSure (Cooper Surgical; Trumbull, CT) or Pro Tack fixation device (Covidien Ltd; Dublin, Ireland) for a VATS technique. Pre-punching the holes in the mesh prior to delivery or delivering the mesh with sutures already placed at the outer edges can help facilitate thoracoscopic reconstruction.

If lung parenchyma requires resection, however, this should generally precede resection of the chest wall as the lobe if still attached to the chest wall will become hard to manipulate once the chest wall is separated from the remainder of the thorax. If a wedge resection is feasible, this can be done first with standard VATS technique with an endoscopic stapling device. If this non-anatomic resection is all that is desired, the chest wall resection can then proceed as described above from that point on. If a lobectomy is preferred, this can be done either with or without the preceding wedge resection to separate the lung from the chest wall; however in the latter case, the movement of the lobe may be more limited. The hilar structures are identified, isolated, and divided thoracoscopically through standard port incisions. The chest wall resection is then performed, and the specimen removed through the incision overlying it, thus avoiding rib spreading.

10.1.5 Robotics

The use of robotic techniques to help perform MICWR has been described previously [4]. The keys remain careful clinical staging with CT scan, integrated PET/CT scan, EBUS, EUS and/or mediastinoscopy prior to resection to ensure the mediastinal lymph nodes are benign. If resection is indicated based on the patient's presentation and risks then we prefer the port placement as we have previously published using all four arms of the Davinci Si robot [5] (Fig. 10.1).

The pleural space is entered over the top of the seventh rib with a 5-mm port in the midaxillary line, or as anteriorly as possible, and guided by a 5-mm scope. A 5-mm VATS camera is used to ensure entry into the pleural space, and warmed carbon dioxide is insufflated to drive the diaphragm inferiorly. This incision will eventually be enlarged to allow a 12-mm port, and it will serve as robotic arm 1 (for right-sided operations). A paravertebral block is performed posteriorly with a local anesthetic and a 21-gauge needle. The needle is used to help select the ideal location for the second incision, the most posterior incision. The location chosen is two ribs below the major fissure and as far posterior in the chest as possible, just anterior to the spinal processes of the vertebral body. A small 5-mm incision is made, and a 5-mm reusable metal da Vinci trocar is placed. This will be the position for robotic arm 3. The next few incisions are carefully planned and marked on the skin before they are made. Ten centimeters anterior to the most posterior incision and along the same rib (most commonly rib 8), a third incision is planned. It is an incision for an 8-mm port, and its trocar is an 8-mm metal reusable da Vinci trocar that will be docked with robotic arm 2. A fourth incision is marked on the skin and again planned but not made 9 cm anterior to this port, along the same rib. This will eventually be used for the robotic camera. A 12-mm plastic disposable port is used for the 12-mm camera, and if the 8-mm camera is used, an 8-mm metal reusable trocar is placed. Before these 2 incisions are made, a small 21-gauge needle is used to identify the most anteriorly inferior aspect of the chest that is just above the diaphragmatic fibers. This incision will have a 15-mm port and serve as the access port. A plastic disposable trocar is used. No robotic arms are attached to the trocar that is placed in this incision. This incision is carefully planned. It is made just above the diaphragm, as anterior and inferior as possible and, importantly, to be in between the ports used for robotic arm 1 and the camera. Once these incisions have been carefully planned and their locations have been confirmed, they are made and the appropriate trocars are placed. Finally, the initial 5-mm anterior port that was made first and used to introduce the VATS camera to identify the internal landmarks is then dilated to a 12-mm double-cannulated port for robotic arm 1. The robot is driven over the patient's shoulder on a 15° angle and attached to the four ports. In general, only three robotic instruments were used for all these operations: the Cadiere grasper, a 5-mm thoracic grasper (used exclusively through the most posterior port that is attached to robotic arm 3, which serves as a retractor of the lung), and bipolar forceps.

For rib resection, we have used the Sofamor Danek rib-cutting device. The remainder of our technique is similar to that described above for VATS chest wall resection.

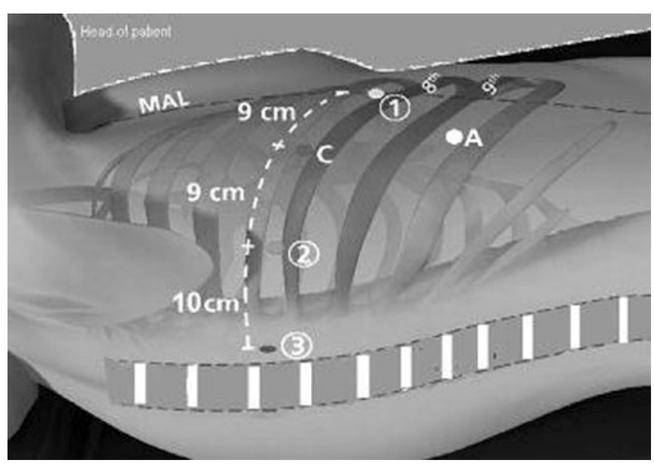

Fig. 10.1 Port placement for robotic-assisted chest wall resection with lobectomy

10.1.6 Discussion

Developing new methods to achieve the same (or better) result that limit the amount of surgical trauma created has been the basis of many developments in minimally invasive surgery. Similarly, ways to achieve chest wall resection with or without associated lung resection have evolved as thoracoscopic and robotic techniques have become refined over the years. We previously described the use of muscle-limiting incisions that spare the extrathoracic (trapezius, rhomboid, serratus anterior) muscles during chest wall resection [6]. Although the operation described in that setting still required a thoracotomy, the application of minimally invasive techniques may permit chest wall resection *without* rib spreading and its attendant disadvantages such as fractured ribs left in situ, acute pain, and long-term neuralgia [7]. Berry et al. demonstrated that such resections can be done with a 100 % R0 resection rate and low likelihood of conversion, while Demmy et al. showed that VATS chest wall resection was associated with a decreased ICU stay (2 vs 6 days, $p = 0.028$), hospital stay (7 vs 13 days, $p = 0.002$), and 90-day major morbidity/mortality (53.3 % vs 87.5 %, $p = 0.036$) compared to chest wall resection via thoracotomy despite being performed on older patients that were more likely to be or have been smokers [2, 8]. One of the final advantages of a MICWR is that often time by leaving the overlying chest wall muscles intact the need for a prosthetic can be eliminated. The risk of the lung billowing out of the incision has to be considered if prosthetic not used. If a prosthetic is desired it can be easily sewn to the pleura inside the chest, as opposed to the ribs.

10.1.7 Conclusion

Although not yet extensively studied, the use of minimally invasive methods for assistance during chest wall resection with or without lung resection is technically feasible, associated with an acceptable safety profile in experienced hands, and may translate to decreased postoperative morbidity and pain compared to resection via rib-spreading thoracotomy.

10.2 Minimally Invasive Approach to Superior Sulcus Tumors and Tumors Involving the Chest Wall or Spine

Erin A. Gillaspie and Shanda H. Blackmon

10.2.1 Preface

As thoracoscopic equipment has evolved and thoracic surgeons have become more adept and comfortable with the technology, more and more complex cases may now be completed with a minimally invasive approach. We describe herein our approach to Pancoast tumors and how to manage the lobectomy, chest wall invasion or nerve root involvement.

10.2.2 Key Words

Pancoast, minimally-invasive, chest wall invasion, nerve root, lung cancer, VATS lobectomy, minimally invasive lung surgery

10.2.3 Introduction

A minimally invasive approach to superior sulcus tumors and tumors involving chest wall is now established practice with advances in thoracoscopic equipment, improved imaging technology and increased surgeon experience. Three-dimensional models in particular have enhanced pre-operative planning have enabled surgeons to rehearse procedures, select and test instrumentation and divide task responsibilities while anticipating potential obstacles prior to the patient even entering the operative theater. A thoracoscopic approach to superior sulcus tumors provides excellent visualization throughout the procedure, and helps to reduce postoperative pain and enhance recovery as it requires no rib spreading or division of the latissimus or serratus.

We discuss herein our minimally invasive and hybrid approach to superior sulcus tumors, tumors with chest wall involvement or nerve root involvement.

10.2.4 Pre-operative Considerations

10.2.4.1 Time Out

A briefing is performed prior to bringing the patient to the room to confirm desired equipment and planned procedure. The patient is brought to the room and a critical pause is performed to confirm patient, procedure, position, administration of appropriate antibiotics and DVT prophylaxis.

10.2.4.2 Anesthesia

General endotracheal anesthesia with a double-lumen endotracheal tube is performed. Tube position is confirmed bronchoscopically and tube is secured into place.

10.2.4.3 Tubes and Lines

Foley catheter is placed. Arterial line and additional venous access is obtained.

10.2.5 Positioning

The patient is placed in the lateral decubitus position with the affected side up. An axillary roll is positioned under the patient to protect the brachial plexus. The arms are placed on either an arm board or in front of the patient. The bed is flexed to open the rib spaces. Hip and leg straps are secured. A warmer should be placed on the patient to maintain warmth during the surgery (Fig. 10.2).

Patient is prepped and draped in sterile fashion.

Fig. 10.2 Patient is positioned in right or left lateral decubitus position. Bed is flexed, pressure points are padded and patient is secured

10.2.6 Pre-operative Antibiotics

Routine prophylactic antibiotics are used.

10.2.6.1 DVT Prophylaxis

Every patient wears bilateral sequential compression devices that are placed upon arrival to the operating room, before the induction of anesthesia. Additionally, patients are administered 5,000 units of subcutaneous heparin.

10.2.6.2 Instruments

Standard VATS lobectomy instruments (Scanlan International Mayo Selection VATS Set)

Kerrison bone cutter

10.2.7 Anatomic Considerations

A Pancoast or superior sulcus tumor is defined as a lung cancer arising in the apex of the chest, involving structures of the apical chest wall. Involvement of the chest only at the level of the second rib or below does not meet criteria for involvement of the apex. Chest wall involvement may be limited to invasion of the parietal pleura or may extend deeper into periosteum or bone in the ribs, vertebral bodies, subclavian vessels or nerve roots of the brachial plexus or stellate ganglion. Pre-operative imaging studies should be performed to delineate anatomy and involvement of tumor into any vital structures [9]. MRI with contrast allows enhanced evaluation of vascular and nerve structures when there is concern of invasion. Three-dimensional printing has become an outstanding adjunctive pre-operative planning tool. Please see further information about 3-D printing later in this chapter (Fig. 10.3).

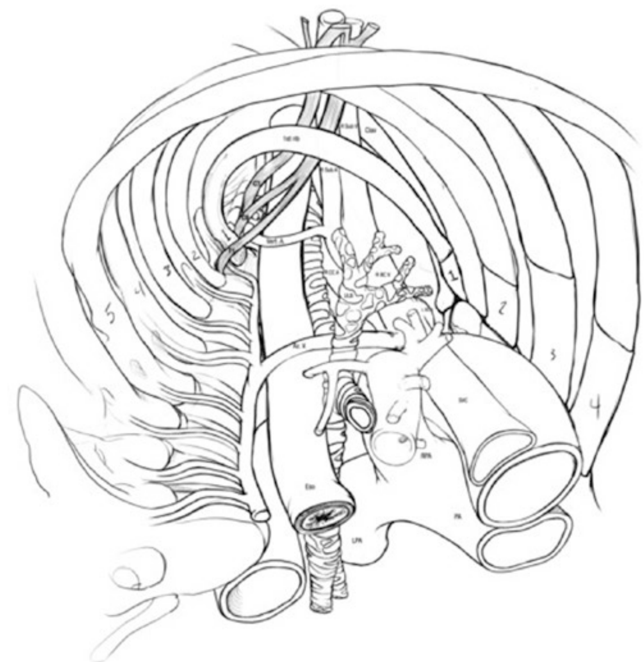

Fig. 10.3 Thoracoscopic view of the chest with the lung and apical Pancoast tumor removed. Ribs are numbered for reference. At the apex, the subclavian vein (sub v), subclavian artery (sub a), and brachial plexus with roots can be visualized. Inferiorly the hilum of the lung with the right main PA (RPA) and bronchus are appreciated. To the right is the superior vena cava (SVC) and ascending aortal. To the left is the esophagus (eso) and spine. The azygous vein (Az V) runs up along the spine then crosses superiorly to the hilum of the lung

10.2.8 Operative Approach to Superior Sulcus Tumor

10.2.8.1 Port Placement

A thoracoscopic port is placed in the seventh to eighth intercostal space in the posterior axillar line. A second port is placed in the anterior axillary line, seventh to eighth intercostal space under direct visualization. The lung and chest wall are inspected for candidacy of lobectomy. A utility incision measuring approximately 3–4 cm is placed in the fourth to fifth intercostal space anterior axillary line under direct visualization. Dissection to the chest wall should spare the serratus muscle, gently separating fibers and then disconnecting underlying intercostal muscles from the superior aspect of the fifth rib. An Alexis wound protector is used in this incision. If needed, an additional port may be placed just posteriorly to the tip of the scapula (Fig. 10.4).

For Pancoast tumors with chest wall involvement, the lobectomy may be approached as the initial portion of the procedure or the chest wall may be approached first, depending on the region of chest wall involvement. In some cases, the tumor will be affixed to the chest wall and actually assists with hilar exposure, as it retracts the lobe out of the way.

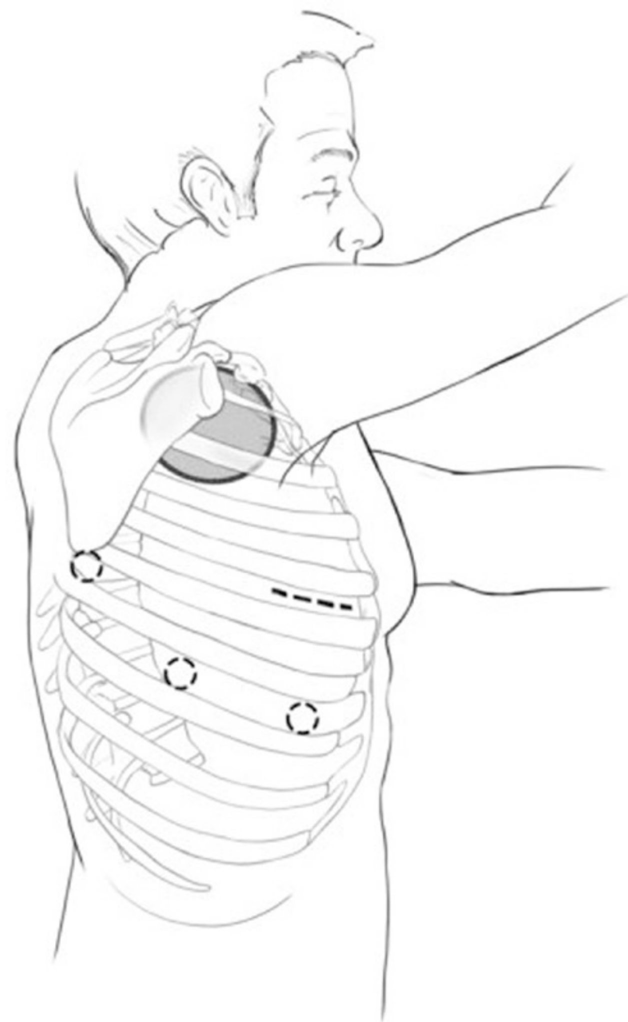

Fig. 10.4 Thoracoscopic port positions for right upper lobectomy. Mirror image port sites are used for the *left*

10.2.8.2 Lobectomy

The anterior mediastinal pleural surface is opened with Bovie electrocautery, paying careful attention to preserve the phrenic nerve. There is frequently a station 10 node between the RUL and RML vein branches. This node should be dissected free and send to pathology to allow for optimal exposure. The upper lobe vein is skeletonized until a curved clamp can easily pass around the RUL pulmonary vein, sparing the RML vein branches. A curved tip vascular load stapler is used to staple and divide the RUL vein after confirming separate middle vein (on the right) and lower lobe vein branches (Fig. 10.5).

Second, the truncus anterior artery is carefully skeletonized. The mediastinal pleura is opened superiorly along the border of the azygous vein on the right and away from the aortic arch on the left to facilitate adequate cephalad arterial exposure. Careful attention must be paid on the left side to avoid injuring the recurrent laryngeal nerve as it passes around the ligamentum arteriosum. Once exposed, the RUL truncus anterior may be divided with vascular load stapler. It is always important to remember to take the tension or retraction off any structure being stapled (Fig. 10.6).

The posterior ascending pulmonary artery branch is identified next and dissected. The artery is sometimes approached anteriorly prior to the bronchus, and other times taken after the bronchus, depending on the relative orientation. The "sump node" (level 11) which resides between the right upper lobe and the bronchus intermedius should also be removed to expose the posterior ascending artery for right upper lobectomy. The fissure may need to be partially divided to provide optimal visualization of the artery and facilitate stapling, and dividing (Fig. 10.7).

The posterior ascending artery varies in size and position. The point of origin is most commonly the interlobar artery, but it may also arise from the truncus anterior. This branch typically arises individually, or may share a common trunk with the right lower lobe arterial branch. The artery should be skeletonized and divided as a separate structure, and not taken concomitant with the fissure. Depending on the size, a stapler, clip or energy device may be employed to seal the vessel prior to division (Fig. 10.8).

The left upper-lobe pulmonary artery anatomy is the most variable among lobes. Left upper lobectomy can be challenging due to variable anatomy with small vessels which can be easily injured or vary in number and caliber. Inadvertent injury or excess traction can rapidly lead to a left main pulmonary artery tear.

The bronchus to the upper lobe is dissected, carefully sweeping lymphatic tissue towards the specimen. Avoid devascularization of adjacent bronchus intermedius and the right mainstem bronchus as this compromises blood supply and impairs healing, leading to higher rates of broncho-pleural fistula formation. The bronchus is encircled, and the stapler is deployed. Anesthesia is asked to give a couple of small breaths to the lung to ensure that the lower lobe inflates. The bronchus is divided with a tissue (Green for Ethicon and Purple for Covidien) stapling device. The remaining fissure is completed with a stapling device or energy source when the fissure is thin. The specimen, if free, should be sent immediately to pathology for frozen section evaluation of margins (Fig. 10.9).

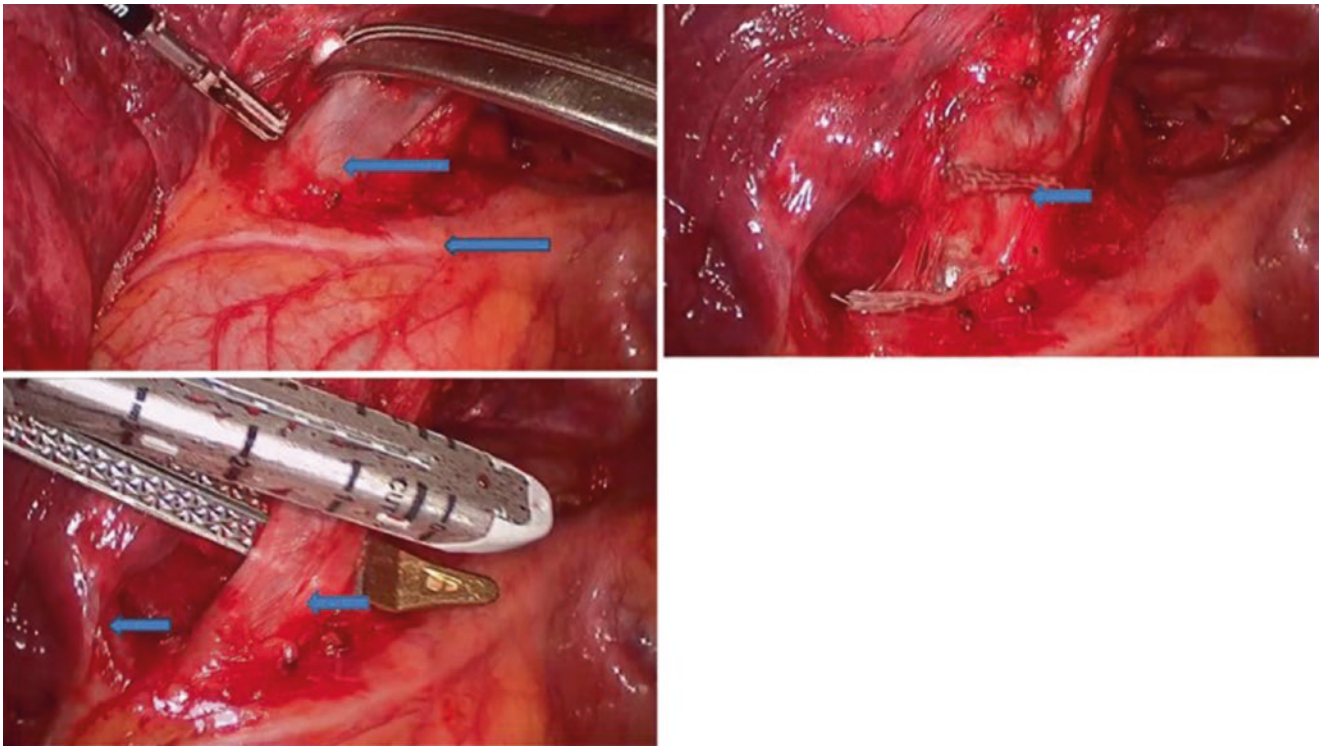

Fig. 10.5 The superior pulmonary vein is skeletonized and transected. The first intra-operative photo shows blunt Kittner dissection around the pulmonary vein to the right upper lobe. The phrenic vein shown inferiorly has been carefully preserved. Prior to transecting the vein, presence of a middle lobe vein (shown in the second intra-operative photo) and lower lobe vein should be confirmed. The stapler is carefully passed around the vein and it is transected with a vascular load stapling device. We prefer to use a stapler with a tip. Staple line is shown in the third photo

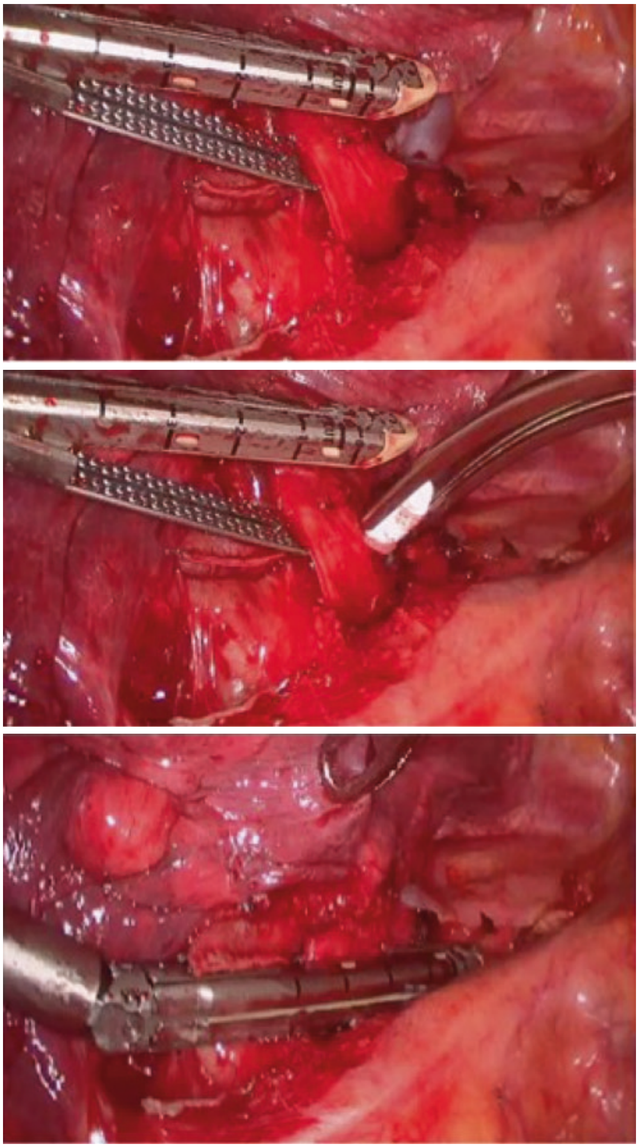

Fig. 10.6 The vascular load stapling device is gently advanced posteriorly to the truncus anterior, the tip is viewed clearly past the structure, and the artery is stapled and divided. The stapler should be articulated to pass around the artery perpendicular to the direction the artery is traveling

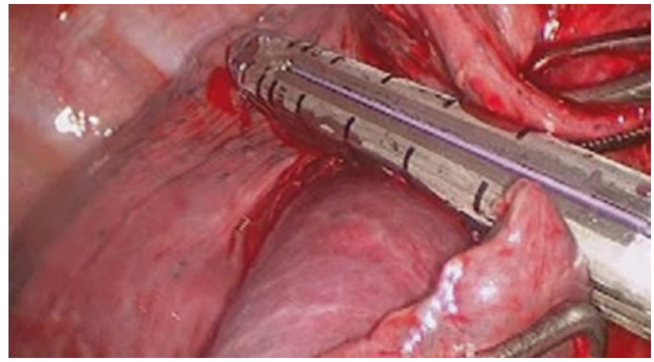

Fig. 10.7 There are times, access to the pulmonary artery is compromised by an incomplete fissure, and partial division of the horizontal fissure may facilitate dissection

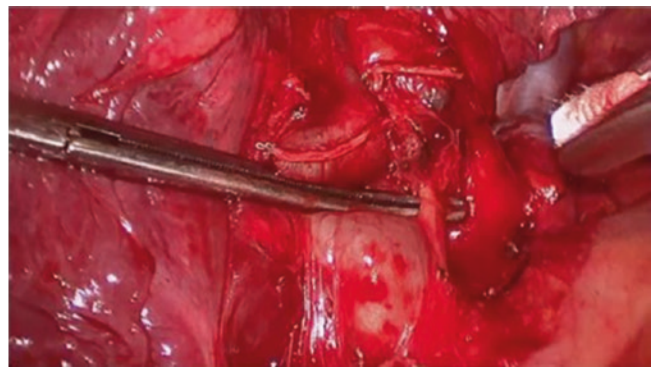

Fig. 10.8 Skeletonization and division of the posterior ascending artery. Depending on the size of the artery, a stapler or clip may be preferred

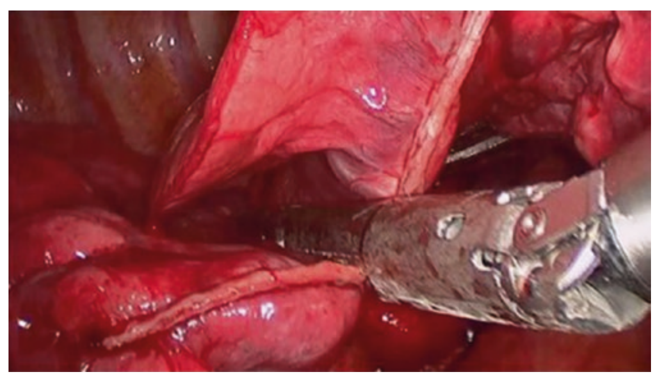

Fig. 10.9 The fissure is completed, thereby finishing the lobectomy portion of the case. The remaining attachments are to the chest wall

10.2.9 Chest Wall Involvement

The chest wall may be approached as the first step of dissection or after the hilar work is complete. In some cases, the tumor size or chest wall involvement may disrupt access to the hilum of the lung.

Bovie electrocautery and bipolar devices are used to divide filmy attachments of the upper lobe to the chest wall. As the mass becomes more adherent to the chest wall, an extrapleural dissection must be initiated. Dissection should be initiated with adequate margins along the length of the tumor, prior to addressing the area of bony involvement. At least 2–3 cm margins and one rib above and below the involved area are taken to ensure complete microscopic resection (Fig. 10.10).

At the level of bony involvement, rib resections must be performed. The Kerrison bone cutter is used to transect ribs anteriorly and posteriorly. Site of transection should be selected 2–3 cm lateral to the extent of tumor involvement. The Kerrison bone cutter (pictured below) transects the bone in piecemeal fashion. Alternatively, a Diamond-tip Burr with extension may be used through established port or small counter port. Attention must be paid to the neurovascular bundle underlying each rib (Fig. 10.11).

Vessels may be skeletonized and clipped or divided with bipolar electrocautery. Final soft tissue and muscular attachments are divided with electrocautery, bipolar energy or Harmonic® (Fig. 10.12).

Bone and soft tissue involved with the tumor should be taken en bloc.

The tumor with involved chest wall is placed into a bag and removed through the utility incision. Extending incision of the intercostal muscle will give additional length to facilitate removal of specimen while avoiding rib spreading. Care must be taken to prevent separation of the bony structures adherent to the tumor during extraction. An x-ray of the excised mass and frozen section confirmation or margins is requested.

Small chest wall defects do not require reconstruction. Any defect greater than 5 cm (which would cause paradoxical chest wall motion) or the fifth to sixth ribs near the tip of the scapula (which could cause scapular entrapment) should be reconstructed with mesh to maintain chest wall integrity and prevent hernia of the lung [10].

A polypropylene, Vicryl or ePTFE mesh may be used. Positive attributes of PTFE include lack of poricity, preventing fluid from the pleural space from draining into the subcutaneous tissues. Newer biomeshes are better in infected cases, where contamination is a concern. Size of the defect is measured and the mesh is fashioned into appropriate size and shape. The mesh should be oversized with several centimeters of overlap allowed beyond the borders of the defect. The mesh may be secured using different methods [10, 11].

A transfascial suture passer may be utilized. For this method, horizontal mattress sutures with 0-Prolene are placed in four quadrants of the mesh. The mesh is inserted into the chest. A small stab incision is created in the skin posteriorly and a transfascial, suture passer is advanced through the posterior hemithorax, and sutures are individually grasped and pulled through. Sutures are tied down to affix mesh to the chest wall. The most difficult edge to access should be sutured first. The mesh should be placed under gentle tension as the suture sites are being selected. Additional tacking sutures or a tacking device should be used to place additional fixation points circumferentially around the chest wall defect and mesh. Care should be taken to avoid intercostal nerve and intercostal artery [12] (Fig. 10.13).

Alternatively, intra-corporeal suturing may be performed. A 0-Prolene suture on a VATS needle driver is used to place horizontal mattress sutures through the mesh circumferentially around the defect. Sutures may be tied intra-corporally or a knot pusher may be used (Fig. 10.14).

Whenever possible, the mesh should be affixed around the ribs [12]. Simply suturing a patch to soft tissues does not afford as much chest wall stability and sutures may tear out during movement. When a large chest wall defect includes the first rib, which occurs more commonly with Pancoast tumors, the superior-most aspect of the patch may be sutured to the fascia [11] (Fig. 10.15).

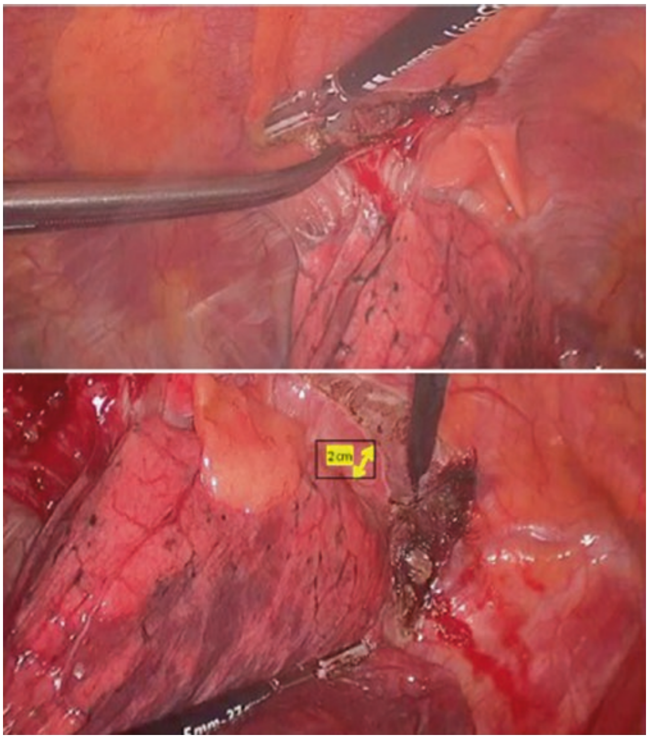

Fig. 10.10 Extrapleural dissection is initiated approximately 1–2 cm circumferentially around the points of chest wall involvement. Pictured above are the postero-lateral and antero-medial extra-pleural dissections being initiated

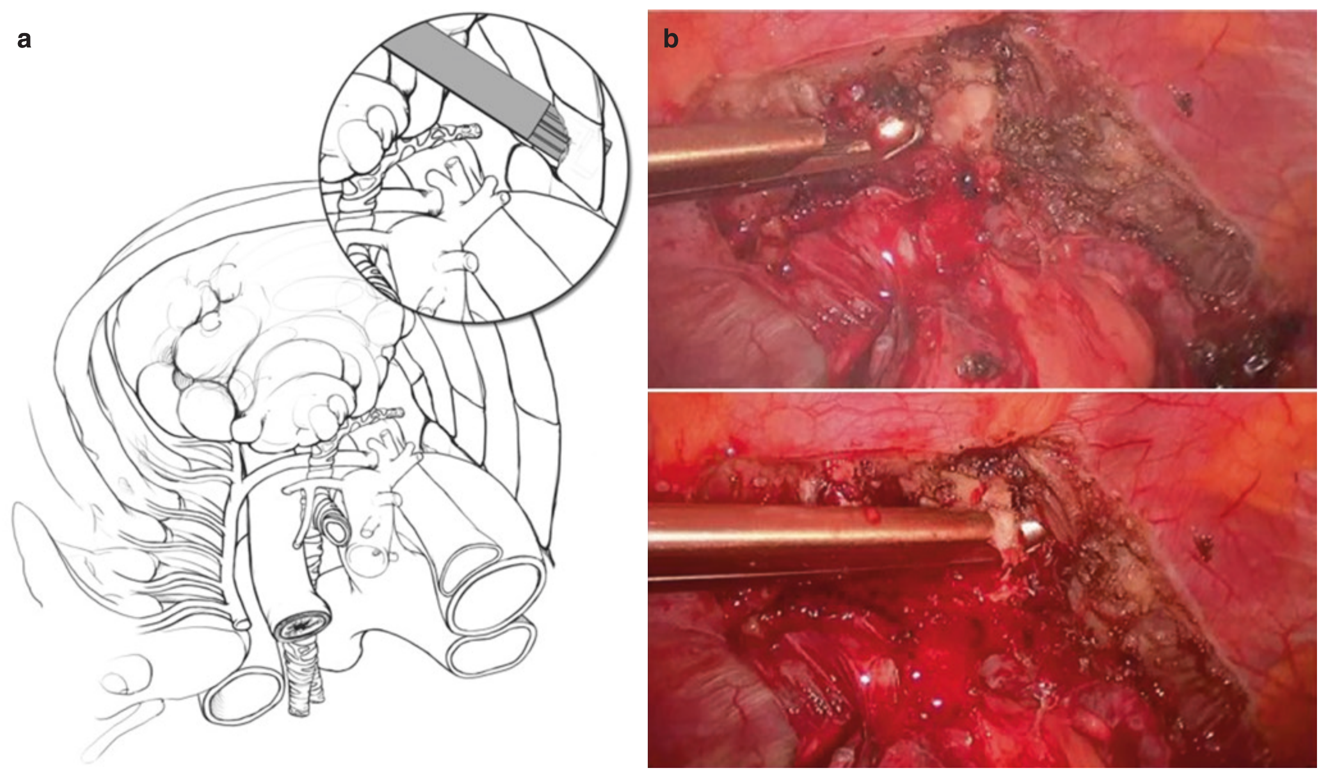

Fig. 10.11 (**a**) The illustration depicts a thoracoscopic view of the apex of the chest. The spine is to the left, the tumor at the apex, the hilum including pulmonary arterial branches and the bronchus are seen inferiorly. A Kerrison is shown cutting a portion of the rib. (**b**)The intra-operative photograph demonstrates a skeletonized rib and a Kerrison being used to transect the bone in piecemeal fashion just as the first bit is being taken (superior) and as the final piece of bone is bring removed (inferior)

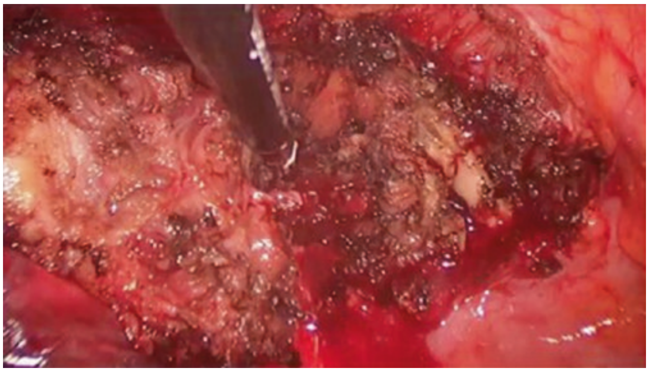

Fig. 10.12 Final soft tissue and muscular attachments are transected

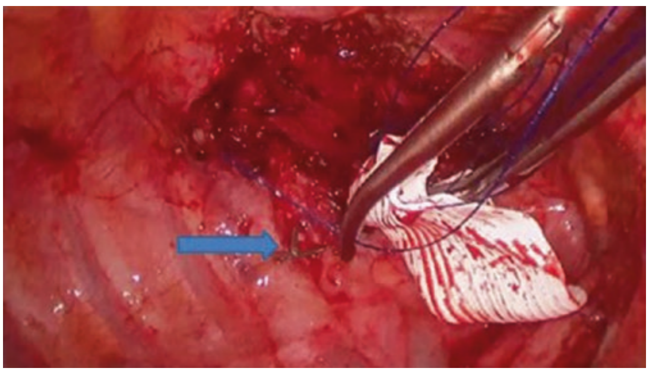

Fig. 10.13 Mesh has already been measured and cut to size. A u-stitch with 0-Prolene is placed extra-corporeally into the mesh. The mesh is inserted into the chest and a suture passer is used to grasp sutures and pull them through the chest wall

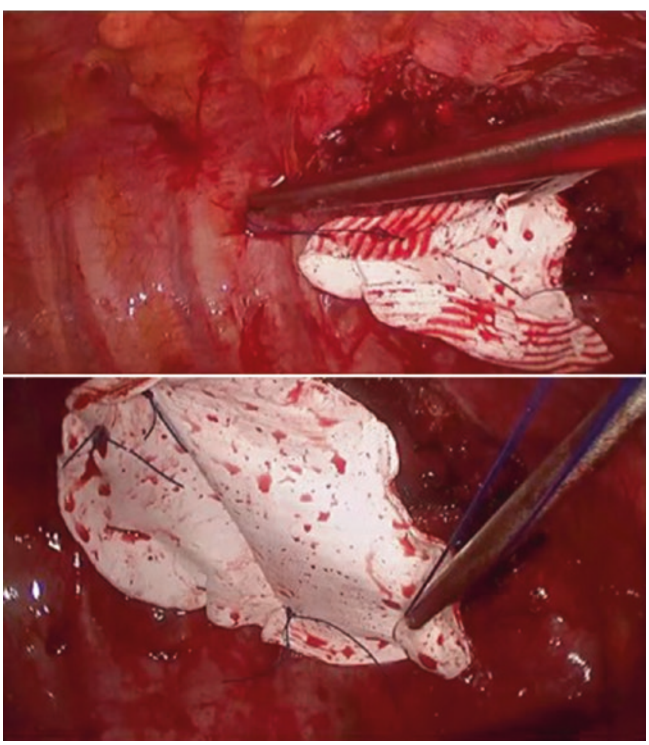

Fig. 10.14 Intra-corporeal suture is placed and a knot pusher is used to cinch down the knot. Sutures are placed circumferentially around the patch at about 1 cm interval

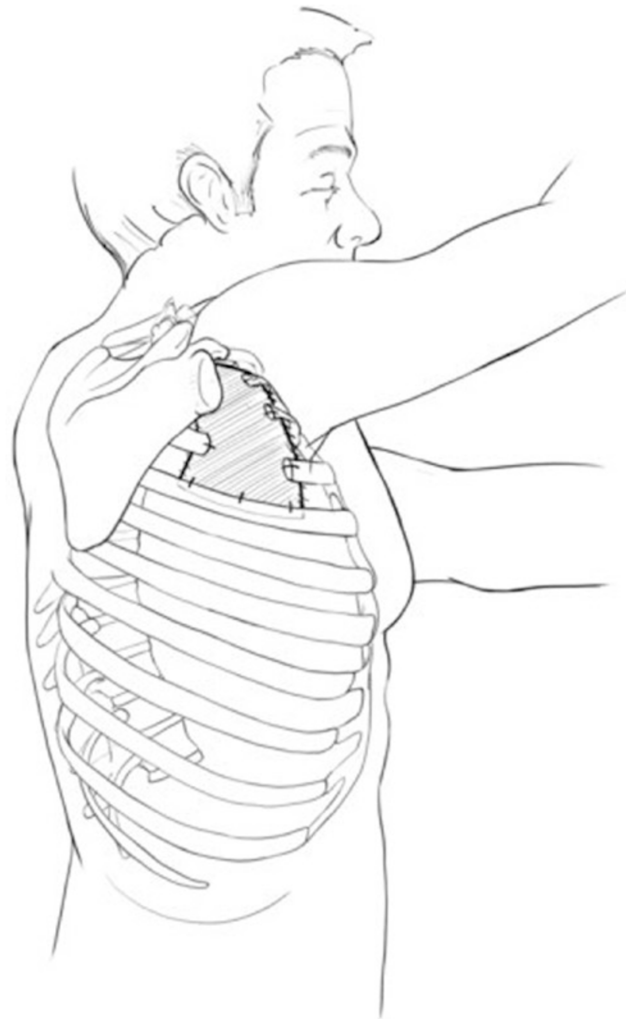

Fig. 10.15 Mesh reconstruction has been completed of an apical chest wall mass. The mesh overlaps the defect circumferentially. Wherever possible, the mesh is secured around ribs to achieve optimum stability of the chest wall and mesh. The illustration depicts the mesh in relation to the apex and hemithorax

10.2.10 Nerve Root Involvement: Hybrid Approach

The lobectomy and anterior chest wall resection are completed by this point as described in the previous section of this chapter. Posterior rib attachments and nerve root involvement are accessed posteriorly. Options at this point include the creation of a posterior accessory incision (hybrid approach), VATS intrathoracic completion of resection or trans-axillar approach depending on the location of the tumor and extent of involvement.

For a posterior-hybrid approach, an incision is created along the lateral border of the scapula extending from the base of the neck to the C7–8 vertebral body. Length of incision will vary depending on the number of posteriorly attached ribs that require separation from the transverse processes. The trapezius, rhomboid and, at times, the levator scapula must be divided. This approach does not require division of the latissimus dorsi or the serratus anterior (Fig. 10.16).

The dorsal scapular artery and nerve are spared by making the incision 1.5–2 cm medial to the scapular border. The scapula is elevated and the inlet is exposed by dividing the anterior and middle scalene muscle insertions off the first rib. Meticulous attention should be paid to preserving the brachial plexus and subclavian vessels.

For posterior chest wall involvement, ribs can be disarticulated directly from transverse vertebral processes. A periosteal elevator or Cobb elevator is used to create a space between the head of the rib and the transverse process of the vertebral body. The rib is elevated away from the spine with gentle pressure. The neurovascular bundle traveling on the underside of the rib should be isolated and ligated (Fig. 10.17).

If the tumor involves the transverse processes, these may also be transected en bloc.

Nerve roots are identified and any involvement with the tumor is noted. Sacrifice of the T1 nerve root is well tolerated with minimal neuromuscular consequence to the patient. If tumor involves the T1 nerve root, this may be sharply transected and ligated. Loss of C8 nerve root leads to devastating neurologic consequences to a patient with significant intrinsic weakness of hand muscles. The C8 nerve root should be carefully preserved, even when this may mean a positive microscopic margin. Imaging should forewarn C8 involvement, and thus a positive gross margin at C8 would not be expected.

This portion of the dissection is carried our posteriorly, but thoracoscopic view is maintained to provide superior visualization of neurovascular structures throughout and avoid collateral injury. Once free, the specimen may be removed through the posterior access port in bag. A frozen section confirmation of margins is requested [13].

A mediastinal lymph node dissection is completed in all cases; sampling nodes from levels 4R, 7, 9, 10, 11 and 12–14.

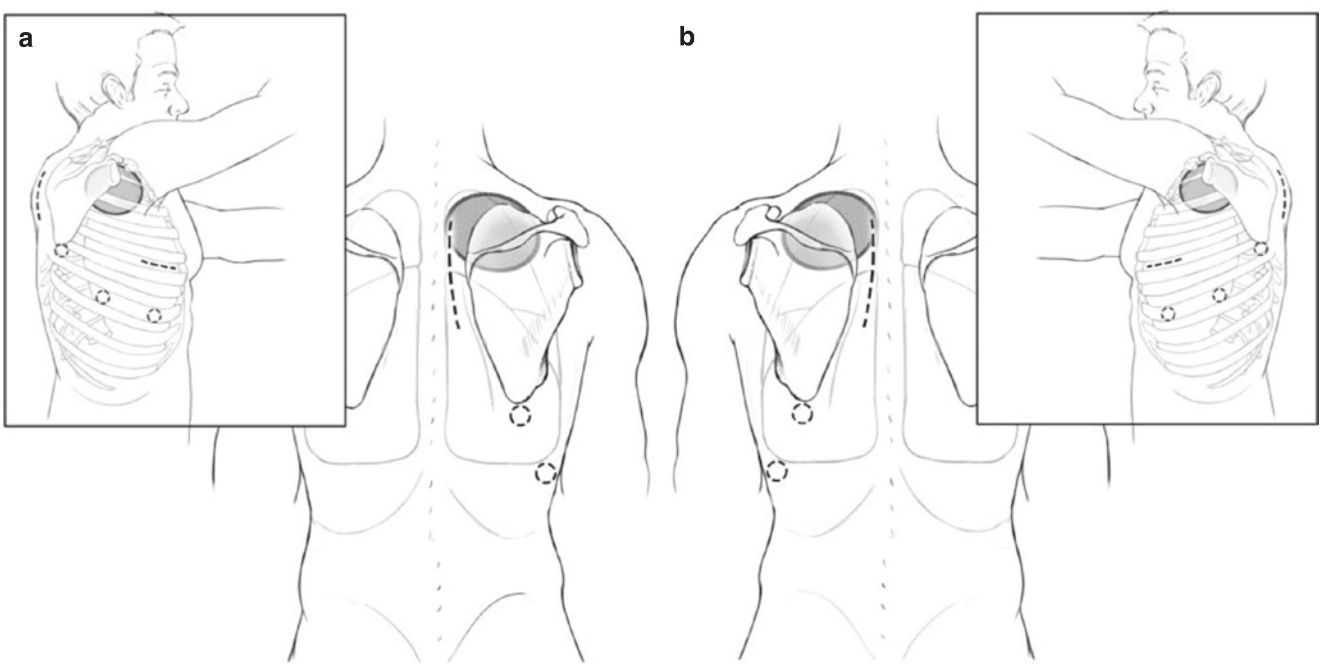

Fig. 10.16 Port sites and posterior access incision to approach posterior/spinal involvement of the Pancoast tumor

Fig. 10.17 Periosteal or Cobb elevator is used to disarticulate the posterior 2nd rib head from the transverse vertebral process

10.2.11 Closure

Pathologic confirmation of negative bronchial margins is made at this point.

The bronchial stump is submerged under water and the lung is hand insufflated with a Valsalva maneuver to a maximum pressure of 30 mmHg to assess for evidence of stump leak. In the setting of neo-adjuvant radiotherapy, the bronchial stump should be covered with a pericardial fat pad or tissue flap. A muscle flap should be used if the patient has received 60 gray or more of radiotherapy.

A straight 32 french chest tube is placed through the anterior-inferior port. The position is guided thoracoscopically to the apex of the chest and sutured in place.

Incisions are closed in standard fashion, re-approximating muscle layers, subcutaneous layers and skin.

10.2.12 Postoperative Considerations

Patients should be ambulatory the morning after surgery and begin pulmonary rehabilitation.

A neurologic assessment should be performed once patient is awake after surgery and daily thereafter.

10.2.13 Key Benefits to Vats

Excellent visualization is maintained throughout the case. There is no need for rib spreading or division of any ribs other than those removed as a part of the specimen.

Enhanced postoperative mobilization, reduced length of stay, reduced pain and improved return to activity or adjuvant therapy are all benefits of VATS Pancoast resection.

10.3 3-D Modeling for Planning Complex Resections Involving the Chest Wall

K.J. Dickinson and Shanda H. Blackmon

10.3.1 Preface

Chest wall resections can be complex and challenging procedures, particularly when the tumors are located at the apex of the chest, near the heart, or when a radical resection has left a large defect for reconstruction. A good chest wall reconstruction is important in order to avoid thoracic instability, poor ventilatory mechanics and vulnerability of intrathoracic contents to trauma and scapular entrapment. There are a number of allografts and autogenous materials available for reconstruction. Pre-operative preparation and careful reconstruction is key to success in these procedures. 3-D images and models have transformed thoracic surgery practice in this area. In this chapter we will address how pre-operative printing of 3-D anatomic models and intra-operative projection of CT images on the patient's body can ensure optimal surgical technique for such difficult cases.

10.3.2 3-D Printed Anatomic Models

3-D printing of life sized anatomic models is changing the way surgeons can understand a patient's anatomy pre-operatively. At the Mayo Clinic, Rochester, the model is prepared from 1 mm slice CT images which are converted to a stereolithography (STL) file format, segmented and processed using Mimics software (Materialise, Belgium) before printing on a 3-D printer. Different materials of different colors and flexibility can be used in order to give a more realistic feel to the final model with liquid photopolymers used for printing on the polyjet 3-D printer (Stratasys Connex 350 multi-material Object, Inc.). These models can convey key anatomical relationships in a way that viewing the images on a computer (even 3-D reconstructions) simply cannot [14]. Pre-operatively the model can be used to rehearse the procedure and to guide the choice of instruments required to perform the resection. For example, different size and shaped instruments can be selected based on the angles required and the access available to perform the operation. The model can be taken into the clinic, multidisciplinary meetings and to the operating room where all members of the team and the patient themselves can utilize it to understand the surgery. The model can convey anatomical relationships and intricacies of the surgery to the patient in a way that sometimes words cannot.

In our practice, 3-D printed anatomic models have been invaluable to the multidisciplinary approach to chest wall resections. For example, Pancoast tumors [15–18], cardiac tumors and chondrosarcoma of the manubrium resections have all been planned using 3-D printed models. One 65 year old ex-smoker presented with numbness in his right hand and was diagnosed on CT with a right Pancoast tumour. Biopsy revealed a non-small cell carcinoma and he was treated pre-operatively with chemoradiotherapy (60 Gy and six cycles of carboplatin and Taxol). Post-treatment, thin slice CT demonstrated treatment response (Fig. 10.18). He also underwent pre-operative MRI for better delineation of nerve root anatomy (Fig. 10.19). A 3-D anatomical model was printed after the thin slice CT had been segmented and converted to a STL file. This allowed better appreciation of the loco-regional anatomy, allowed communication between members of the multidisciplinary team and facilitated enhanced informed consent (Fig. 10.20).

Another 64 year old woman who was an ex-smoker with a 30-pack year smoking history presented with an right upper lobe mass incidentally on chest X ray following PICC line placement. She was diagnosed with a right Pancoast tumor, which, on transbronchial biopsy was a TTF-1 positive adenocarcinoma. She had no metastases on staging and good pre-operative lung function. She was treated with pre-operative etoposide and cisplatin and 45Gy radiotherapy. She had a good treatment response, but demonstrated involvement of the T1 nerve root and first and second ribs on post-treatment scans. Printing a 3-D anatomic model of the anatomy and tumor location allowed the orthopaedic and thoracic surgical teams to communicate effectively (Fig. 10.21). The operative procedure could be rehearsed using the 3-D model before the patient was taken to surgery as a VATS approach was planned [19]. This allowed the appropriate instruments to be selected (including the Kerrison bone cutter and Midas Rex diamond bur) and this tumor was successfully resected via a unique, never previously described hybrid VATS and limited parascapular incision [20] (Fig. 10.22).

A 39 year old ex-smoker with good lung function presented with left upper chest wall pain, left hand weakness and paresthesia and a transient ptosis. She was diagnosed with a left Pancoast tumor (biopsy proved non-small cell) involving the left subclavian artery, T2 and T3 nerve roots, vertebral bodies and the left first rib. She underwent neoadjuvant chemoradiotherapy (60 Gy) with a more than 50% tumor treatment response. Due to the local size of the tumor she underwent a staged resection. The first stage involved mediastinoscopy and VATS mediastinal lymph node dissection with tumor evaluation (stations 2, 4 and 7 negative for tumor). We then proceeded to osteotomy of left ribs one to three, rhizotomy of the left T1-3 nerve roots and osteotomy of the left T1-T3 vertebral bodies. On post-operative day 2 the second stage was performed. This involved an upper sternal split and trapdoor exposure of the left chest. A left upper lobectomy, division of the thoracic duct and first rib resection was performed. A left carotid to subclavian bypass was performed to allow resection of the subclavian artery into which the tumor had invaded. Following this, the previous spinal dissection was completed and the tumor mobilized en bloc and resected from the posterior chest. To allow reconstruction of the chest wall, a Gore-Tex 2 mm biomesh in combination with a medial pectoralis advancement flap was used. This surgical procedure was complex, spanning two operating room days and involving thoracic, cardiac, vascular, plastic and orthopedic surgical teams. The 3-D printed model allowed all team members to gain an excellent understanding of not only their portion of the surgery, but also the surgical steps each other team member was to perform. The locoregional anatomy was demonstrated in such a way to facilitate understanding by the patient of this complicated surgical procedure (Fig. 10.23).

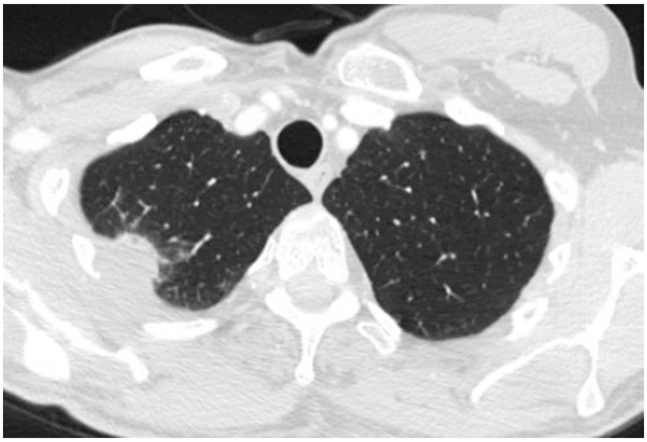

Fig. 10.18 CT images of right Pancoast tumor. Right Pancoast tumor treated with VATS assisted chest wall resection of ribs 2–4 and right upper lobectomy

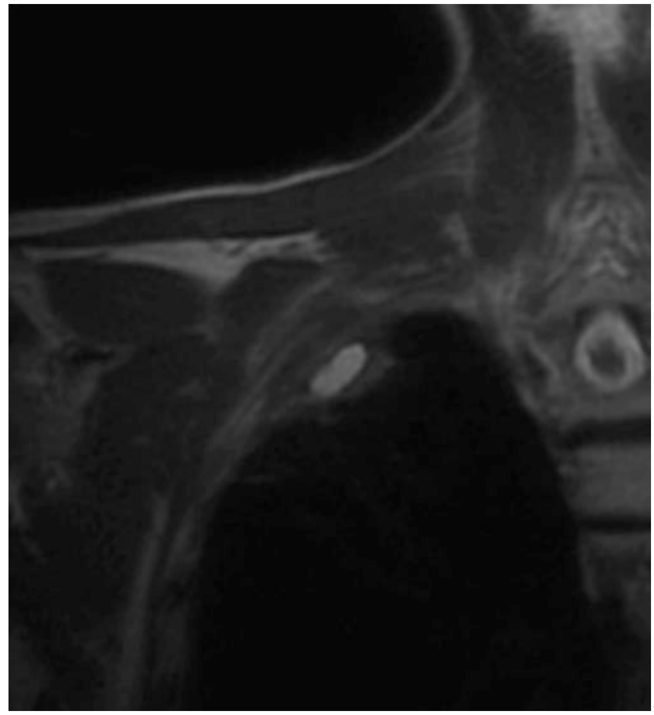

Fig. 10.19 MRI images of right Pancoast tumor. Right Pancoast tumor, pre-operative images showing no evidence of brachial plexus involvement

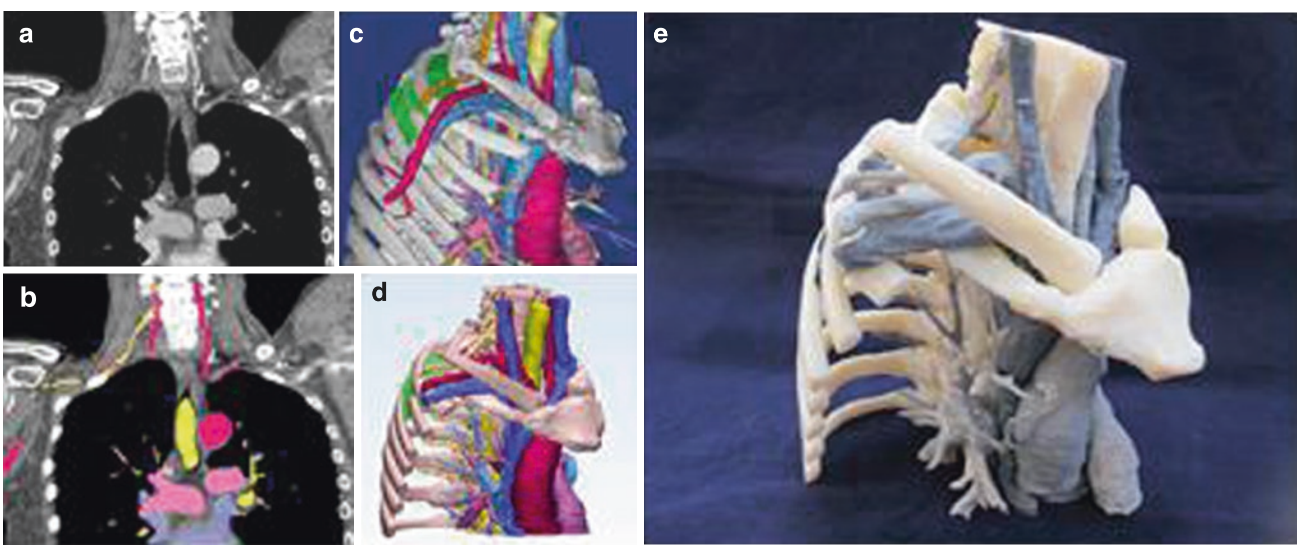

Fig. 10.20 The process of 3-D printing a life sized anatomic model for pre-operative planning. In a patient with a right Pancoast tumor a 3-D model was created after obtaining a thin slice CT (**a**) The imaging data were segmented to highlight and color code the tumor, aorta, brachial plexus, pulmonary arteries and veins, spine, ribs, manubrium and clavicles (**b**). A virtual 3-D model was created and converted into an STL file (**c**, **d**) from which a multi-material, multicolored model was printed (**e**)

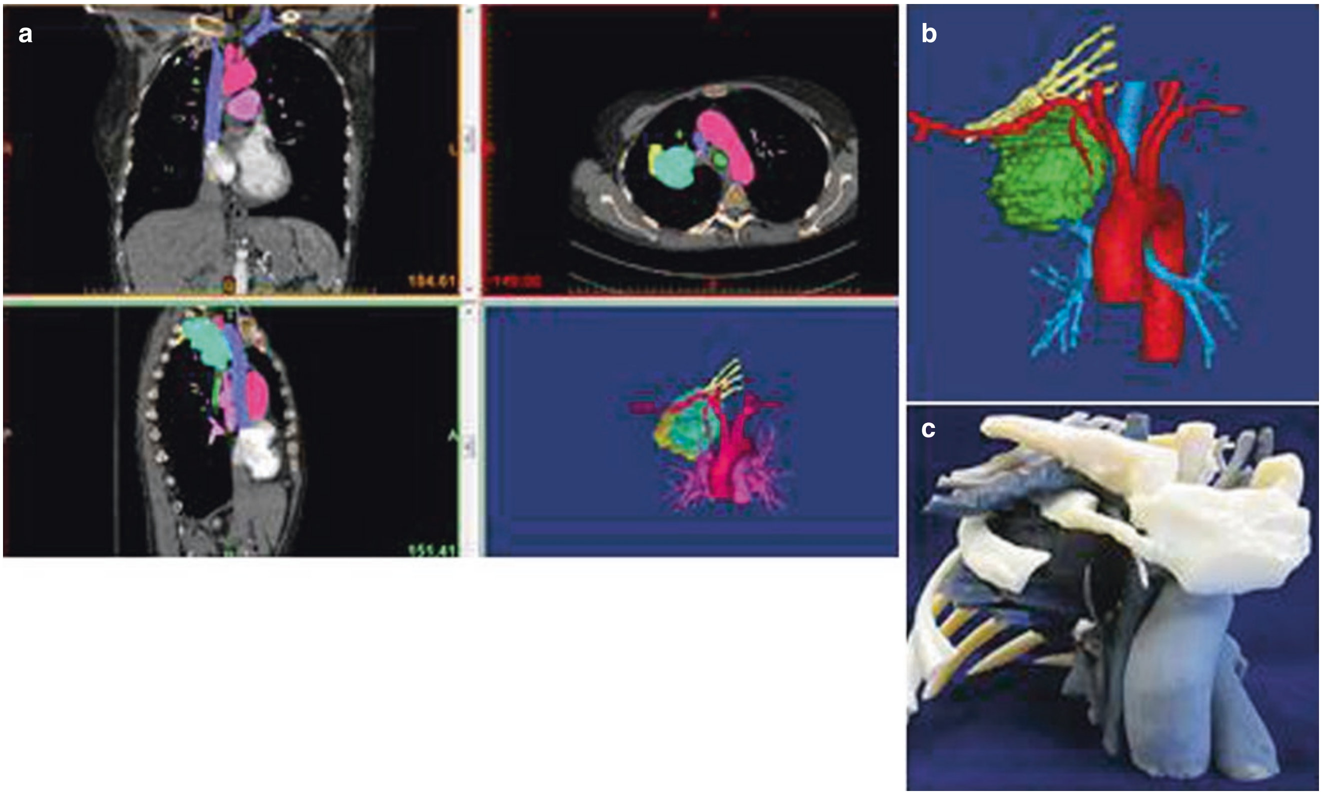

Fig. 10.21 3-D printing a model of a Pancoast tumor allowed a hybrid VATS procedure to be performed. To facilitate thorough pre-operative planning, the CT images were segmented (**a**) and the tumor, brachial plexus, aortic arch and branches isolated (**b**). The 3-D printed anatomic model allowed the procedure to be rehearsed pre-operatively, the approach and appropriate instruments selected and facilitated informed patient consent (**c**)

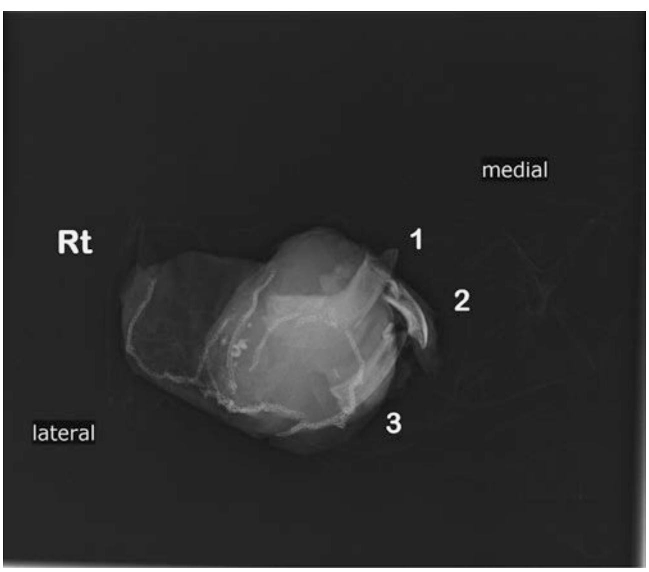

Fig. 10.22 Resected specimen from the hybrid VATS procedure performed for a right sided Pancoast tumor

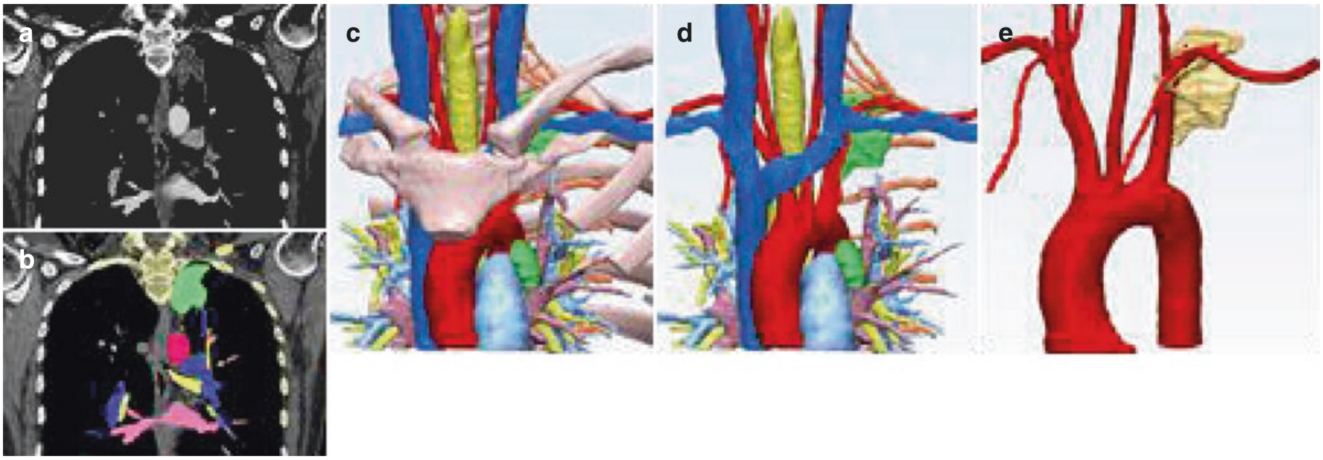

Fig. 10.23 Segmentation of the thin slice CT allows important anatomy to be highlighted when planning Pancoast resection. In a patient with a left Pancoast tumor involving the left subclavian artery, T2 and T3 nerve roots, vertebral bodies and the left first rib a 3-D model was created after obtaining a thin slice CT (**a**). The imaging data were segmented to highlight and color code the tumor, aorta and arch branches, brachial plexus, pulmonary arteries and veins, spine, ribs, manubrium and clavicles (**b**). A virtual 3-D model was created and converted into an STL file (**c**). Manipulation of the STL file allowed for the locoregional anatomy relevant to the surgical approach to be well demonstrated. Removing the bony structures allows the relationship of vessels and nerves to the tumor to be appreciated (**d**), whilst the vascular resection and reconstruction is facilitated by just visualizing the aortic arch, its branches and the tumor (**e**)

10.3.3 Computer Augmented Virtual Environment: Plato's CAVE™

Another application of 3-D technology to complex chest wall reconstructions is the processing of images in order to allow preparation of a pre-operative 'template' for the resection. One way to achieve this is by using a computer augmented virtual environment or 'CAVE' [20]. This technology involves processing the pre-operative CT images to render 3-, 4- and 5-D images of the chest wall and tissue to be resected which are projected onto a multi-touch table (Fig. 10.24). Conventional computer game controllers, motion sensors and voice recognition software are used to navigate through each patient's anatomy pre-operatively. This technology facilitates precise resection of chest wall tumors to obtain clear margins without excess chest wall removal (Fig. 10.25). The images provide increased accuracy of tumor sizing and location and, importantly localization in relation to key anatomical structures. This latter point is critical to achieve a good functional outcome as larger resections are more challenging to reconstruct and may bring problems such as lung herniation and scapula entrapment. The CAVE allows the 3-D reconstructions to be projected onto the patient's body so that the pre-operative briefing can incorporate a thorough discussion of the area to be resected and the proposed method for chest wall reconstruction (Fig. 10.26). This patient had a metastatic renal cell carcinoma of the sternum, and underwent resection of the sternum and medial cartilaginous portions of every rib. Reconstruction was performed using a Synthes plating system plates, a Marlex-methyl methacrylate prosthesis with a window through which the right internal mammary artery and vein protruded to perfuse a supercharged myocutaneous rectus abdominus flap (Fig. 10.27)

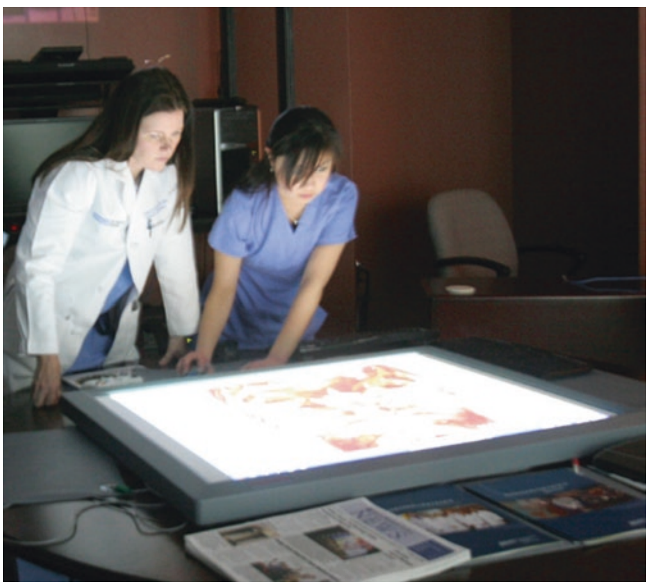

Fig. 10.24 Plato's CAVE (Computer augmented virtual environment). Surgeons and radiologists in Plato's CAVE at the Methodist Hospital, Houston Texas are able to review CT images in 3-, 4- and 5-D on a multi-touch table to familiarize with each individual patients anatomy and facilitate pre-operative planning

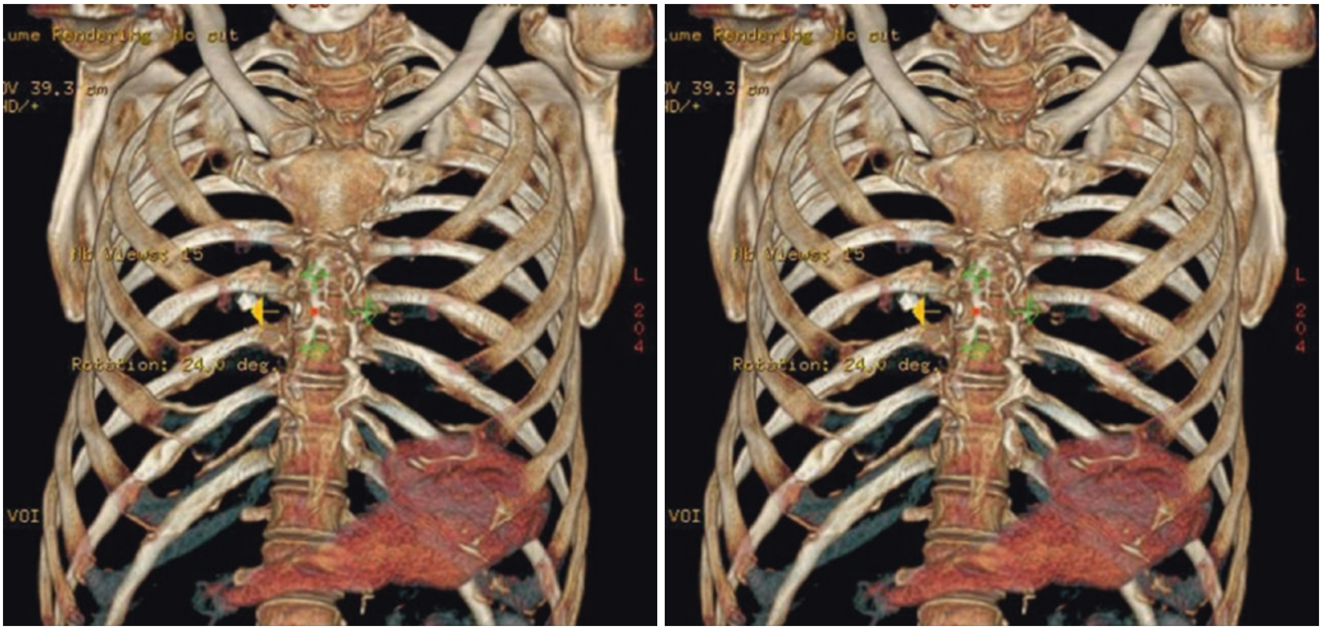

Fig. 10.25 Pre-operative 3-D images of the chest wall tumor and surrounding anatomy. Pre-operative 3-D reconstructions of the chest wall tumor dimensions (*above*) allow the extent of the resection and the reconstruction to be planned (*below*)

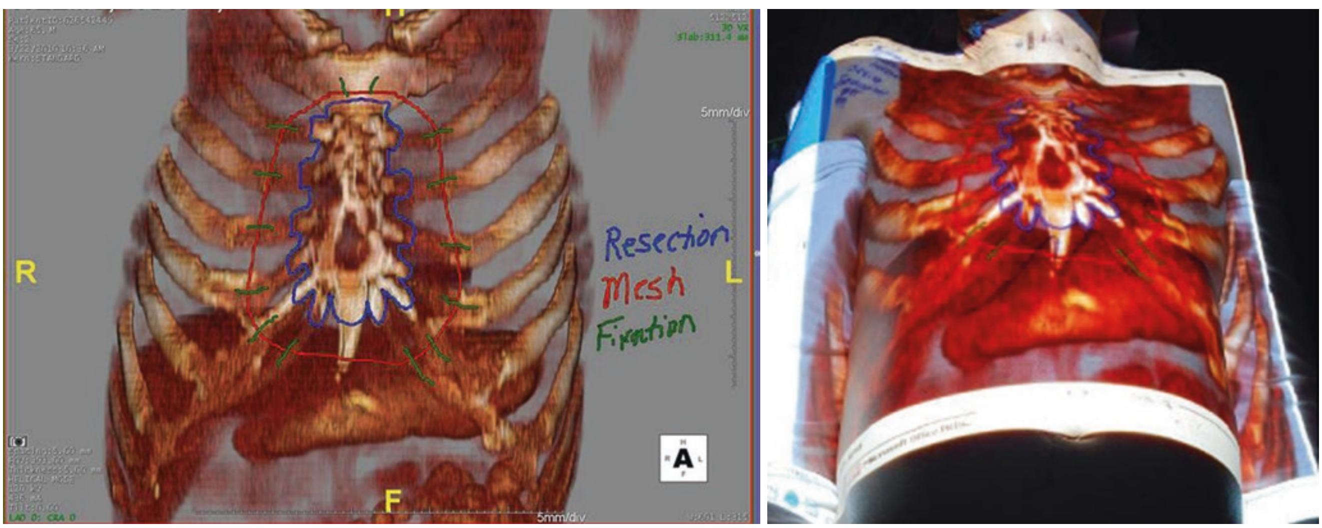

Fig. 10.26 Intra-operative 3-D image projection. The images from the patient's CT scan are projected onto the patient's body before the operation starts (*above*). This allows marking of the patient to plan the resection and reconstruction, preserving functionality (*below*)

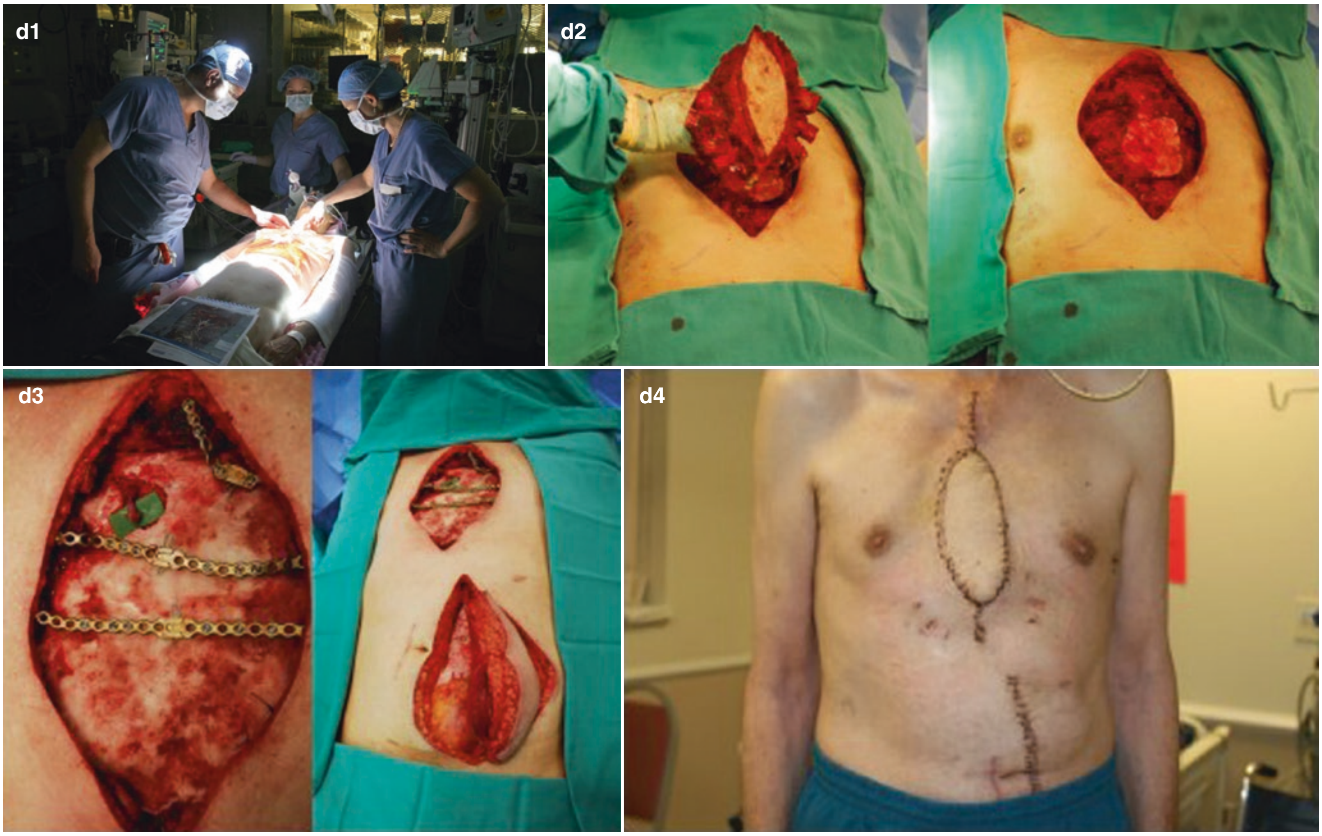

Fig. 10.27 Resection of chest wall tumor and reconstruction. These intraoperative photos demonstrate the extent of surgical resection of this sternal tumor, sufficient to achieve compete resection but also preserving functionality (*above*). The reconstruction was performed using Synthes plating system, Marlex-methyl methacrylate mesh and a supercharged pedicled myocutaneous flap (*middle*). CAVE allowed optimal re-operative preparation for this case to achieve a good clinical outcome (*below*)

Acknowledgements Thank you to Dr Brian Butler, Radiation Oncologist, Houston Methodist Hospital, Texas for the development of Plato's CAVE™.

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Technical Notes

11

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Contents

11.1 Tips and Tricks: "Wang's Technique"

Kezhong Chen and Jun Wang

11.1.1 Introduction

As the leader in developing Video-assisted thoracoscopic surgery (VATS) in China, we accomplished the first case in China in 1992. After 2005, we began regular VATS lobectomy and have completed more than 2500 VATS lobectomies till 2015. Chinese lung cancer patients have many special characteristics, such as more undeveloped interlobar fissures and more calcificatied hilar and mediastinal lymph nodes. This situation has caused us to develop more efficient and safer methods to undertake these difficult surgeries. We summarized and optimized our technique for the long-term minimally invasive thoracic surgical treatment for lung cancer (1). Here, we introduce our Wang's technique to the readers, and wish it can be helpful when you encounter difficult cases.

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11.1.2 Incisions

Operations were performed under general anesthesia with double-lumen endotracheal intubation. Patients are placed in the lateral decubitus position.

A total of three incisions are used. One 1.5-cm camera port is positioned in the seventh intercostal space, posterior axillary line. A 3–4 cm anterior incision is placed in the fourth or fifth intercostal space, anterior axillary line, without rib spreading. A wound protector was used to protect this incision. The posterior 1.5-cm port is then placed in the seventh intercostal space in the subscapular line. The resected lobe is retrieved through the anterior incision in a specimen retrieval bag.

11.1.3 Instruments

We believe that modified instruments and excellent teamwork contribute to the success in completely VATS lobectomy. We use several modified surgical instruments specially designed for VATS lobectomy, such as a double-curved suction with a threaded head (Fig. 11.1), a side-angled vessel-occlusion clamp, a lymphadenectomy clamp and some others. These instruments can be used flexibly to explore any area inside the chest. Two assistants cooperate with the surgeon in teamwork. The scope holder should apply the 30-degree thoracoscope nimbly to expose the complete surgical field for the surgeon and move the camera to just about 5 cm away from operational center when managing vessels or lymph-nodes. The close visual field will offer a clear view for accurate dissection. Another assistant should retract the lobe to protect normal tissue and be familiar with the surgeon's techniques which will increase the operation efficiency.

Fig. 11.1 Double-curved suction with a threaded head

11.1.4 Technique

The main features of Wang's technique are:

(A) A specially-made double-curved suction and an electrocautery hook are handled through a single incision concurrently and cross in the same direction (Figs. 11.2, and 11.3):
The surgeon holds the suction in one hand and the electrocautery hook in the other hand. The two devices enter the thoracic cavity through the main incision simultaneously. Taking advantage of the double curved feature of the suction, the two devices cross at the chest wall incision and the operative region in thoracic cavity, respectively, so as to avoid interlocking of devices in the same incision, permitting a coordinated, fluid and precise operation. The suction can serve as blunt dissection, sucking blood, pushing normal tissue for exposure, preventing vessels and nerves from being injured by electrocautery hook, etc. Most procedures can be accomplished by the surgeon himself using the two devices, and the assistant just needs to retract the lobe to expose the visual field from the posterior port, preventing mutual interference between the two people.

(B) Creation of a perivascular tunnel for interlobar fissure division (Fig. 11.4):
Dissecting vessels after unfolding the interlobar fissure is more secure than fishing out the vessels within the pulmonary parenchyma. We set up a perivascular tunnel with close visual fields (Fig. 11.5) when dividing the interlobar fissure, contributing to locating the vessels accurately. Then we can divide the undeveloped fissure with an endoscopic stapler safely. Rather than fixing the sequence of operation, we prefer a multi-direction, flexible procedure. After interlobar fissure division, we can see vascular and bronchus distribution clearly and deal with any of them at our convenience.

(C) Control bronchial arteries as a priority (Fig. 11.6):
Due to air pollution and pulmonary tuberculosis, many Chinese lung cancer patients have calcified hilar and mediastinum lymph nodes. Since bronchial arteries surround these lymph nodes and supply blood to the bronchial wall, their injury may lead to serious bleeding or even converting to thoracotomy without prioritized handling of these arteries. Controlling bronchial arteries as a priority can decrease hemorrhage in the operative field when dissecting hilar structures.

(D) Dissect vessels in their subadventitial planes (Fig. 11.7):
Dense adhesions between lymph-nodes and vessels is an indication for conversion to an open procedure. Since most of these adhesions are just outside the adventitial sheath, dissecting vessels within the adventitia will obviate this trouble. In addition, after blunt dissection of the connective tissue around the vessel with the suction device, the surgeon should dissect the vessel adventitia over a sufficient length until the vessel is skeletonized in order to permit an efficient and precise lymph node resection, which can increase the safety and also the beauty of an operation.

(E) Dissect the mediastinal pleura around the hilum of the lung (Fig. 11.8);
Cut the inferior pulmonary ligament first, then retract the lung anteriorly, and dissect the posterior mediastinal pleura from inferior to superior. Then retract the lung posteriorly, and dissect the anterior mediastinal pleura in order to show the hilum anatomical structure clearly.

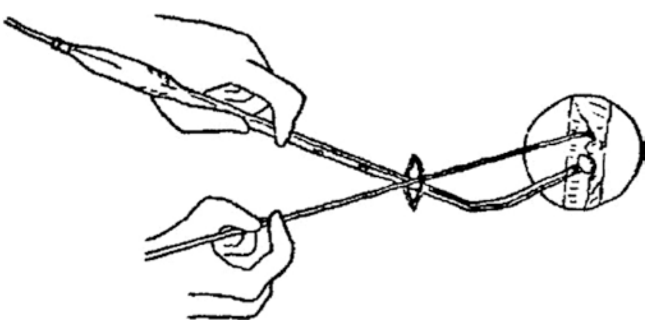

Fig. 11.2 Suction and electrocautery hook are crossed through a single incision simultaneously and thus point in the same direction once inside the chest (freehand sketching)

Fig. 11.3 Suction and electrocautery hook are crossed through a single incision simultaneously (intraoperative photograph)

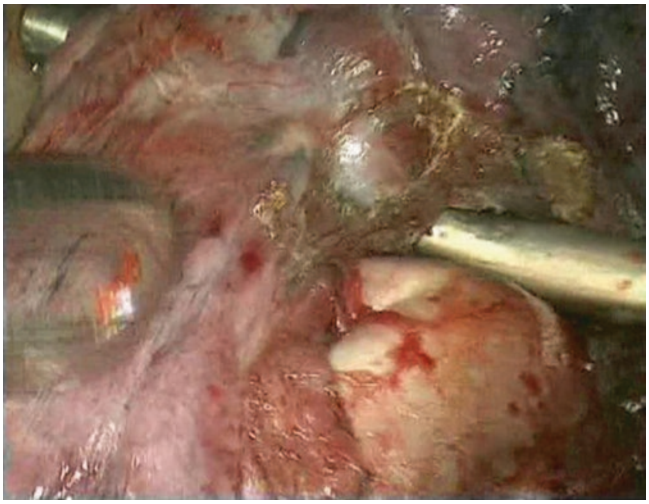

Fig. 11.4 Create a perivascular tunnel for interlobar fissure division (oblique fissure of right lung)

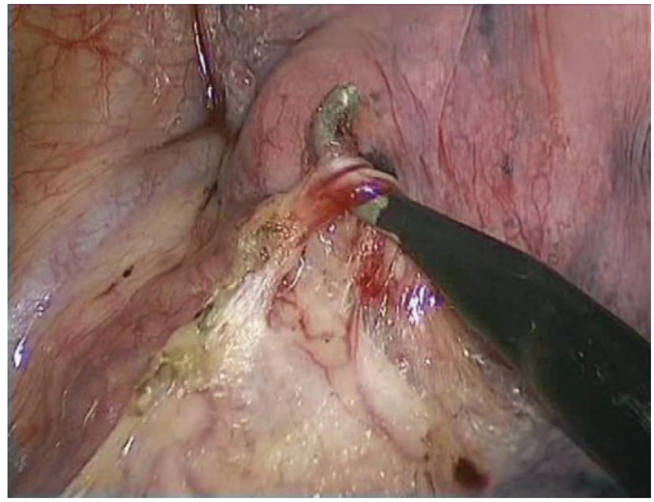

Fig. 11.6 Division of the bronchial artery by electrocautery hook as a priority

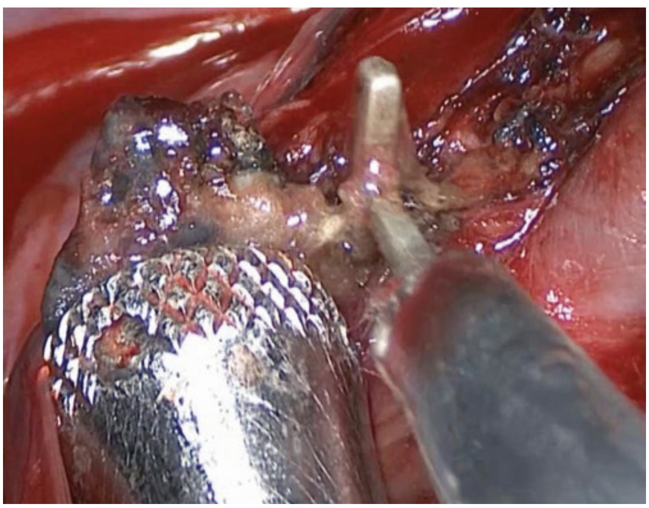

Fig. 11.5 Close visual field

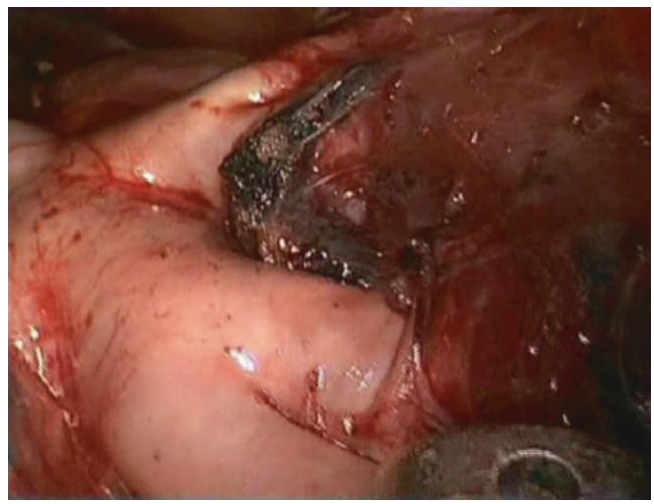

Fig. 11.7 Freeing vessels in their subadventitial planes and skeletonizing exposed vessels

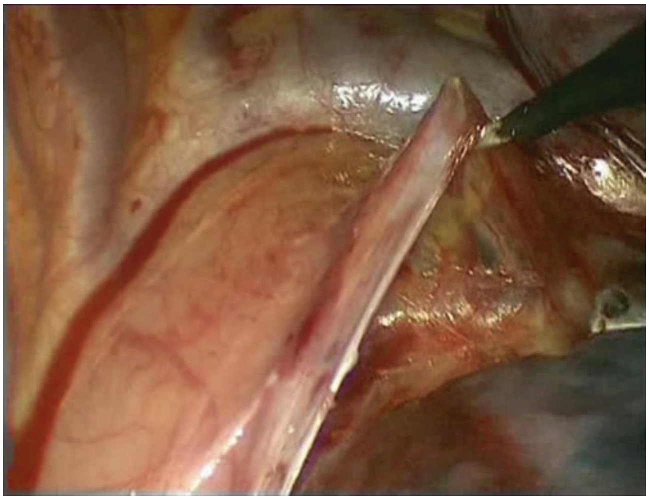

Fig. 11.8 Dissecting the mediastinal pleura around the hilum of the lung

11.1.5 Summary

Through increasing experience, we summarized and optimized our Wang's technique of VATS lobectomy. More than 90 % lobectomies were performed by VATS in our institution and the oncologic efficacy is similar to other studies (Table 11.1). Most previous studies comparing VATS with thoracotomy were limited to early-stage disease, in which the result of VATS for other stage patients was not clear. We believe with continued experience and optimized technique, VATS lobectomy can also be performed in patients that are more complicated without compromising the perioperative outcomes and oncologic efficacy, such as locoregionally advanced cases, patients with previous surgery or neoadjuvant chemoradiotherapy. Randomized controlled trial should be performed to validate the potential benefits of VATS for these patients.

Table 11.1 Long-term survival after video-assisted thoracoscopic lobectomy for non-small cell lung cancer

Author	Date	Number	Stage	3-year OS (%)	5-year OS (%)
Lee [2]	2013	208	I–III	87.4	76.5
Cao [3]	2013	1458	I–III	74	62
Hanna [4]	2013	190	I–II	/	64
Whitson [5]	2008	1634	I	87.2	80.1
Our institution	2014	1131	I–IV	85.4	76.4

11.2 Preoperative Management

Xu Lin

11.2.1 History and Physical Examination

Although the field of thoracic surgery has been dramatically altered by the development of new technologies in both imaging and therapeutics, the history and physical examination remain the most important components of the preoperative evaluation. The following important components should be evaluated: presenting symptoms and circumstances of diagnosis, prior diagnosis of pulmonary or cardiac disease, comorbid conditions (diabetes mellitus, liver disease, renal disease…), prior experiences with general anaesthesia and surgery, cigarette smoking, medications and allergies, and alcohol use. A critical component of the preoperative evaluation is the assessment of a patient's functional status. Functional status is an important component of the decision algorithm for both the pulmonary and cardiac elements of the preoperative evaluation. Patients should also be questioned about symptoms related to paraneoplastic syndromes. These can range from the relatively subtle symptoms of hypercalcemia to more dramatic neurologic symptoms.

The examination of the patient includes an assessment of general overall appearance, including signs of wasting. Respiratory rate and the use of accessory muscles of respiration are noted. The pulmonary examination includes an assessment of diaphragmatic motion (by percussion) and notes any paradoxical respiratory pattern in the recumbent position. The relative duration of exhalation as well as the presence or absence of wheezing should be noted. The presence of rales should raise the possibility of pneumonia, heart failure, or pulmonary fibrosis. The cardiac examination includes assessment of a third heart sound to suggest left ventricular failure, murmurs to suggest valvular lesions, and an accentuated pulmonic component of the second heart sound suggestive of pulmonary hypertension. The heart rhythm and the absence or presence of any irregular heartbeats should be noted.

11.2.2 Pulmonary Function Assessment

Ageing and obesity are risk factors for pulmonary infection after thoracotomy. Age greater than 60 years old is a predisposing factor for postoperative pulmonary complications. The incidence of postoperative pulmonary complications of the patients whose weight exceeds 30% of the standard weight is two times than the standard. The special attention should be paid to the chest X-ray on the basis of comprehensive investigation. Pulmonary function test and total amount of lung function should be performed on the patients undergoing lung surgery, which are important indicators.

Although a variety of pulmonary function tests have been examined in this setting, the two that have emerged as being predictive of postoperative complications are the *forced expiratory volume in 1 s* (FEV1) measured during spirometry and the *diffusing capacity for carbon monoxide* (DLco). Both of these values can be used to provide a rough estimate of the risk of operative morbidity and mortality. In addition, they are used to calculate the predicted postoperative values for FEV1 and DLco (ppo-FEV1 and ppo-DLco, respectively). The postoperative lung function could be predicted by simple calculation. Simple calculation is based on the assumption of homogeneously distributed lung function and requires knowledge of the number of segments to be resected and the preoperative value. For FEV1, the formula is $\text{ppo} - \text{FEV1} = \text{FEV1}\left[1 - \left(\text{number of segments resected} \times .0526\right)\right]$. A similar calculation is done for DLco.

11.2.3 Assessment of Cardiac Function

Thoracic surgery operation has a very significant effect on the respiratory and circulatory function. And two thirds complications are heart and lung problems and there is a gradual increase in the rate of cardiac complications which is one of the main reasons for mortality in the preoperative period. Cardiac assessment is very important for rational control of surgical indications, prevention and reduction of complications and mortality. Therefore, preoperative cardiac function should be evaluated thoroughly.

11.2.3.1 Cardiac Disease History

Cardiovascular risk factors of patients should be full assessed, such as obesity, smoking, hyperlipidemia, history of hypertension, primary or secondary hypertension and blood pressure levels.

11.2.3.2 Heart Function Classification of NYHA

According to the New York Heart Association (NYHA) standard, heart function is divided into four levels. Patients with cardiac function I, II grade can tolerate general surgery. However, patients with III, IV grade tolerates surgery badly and have a high probability of complications.

11.2.3.3 Ladder-Climbing Test and 6 min Walking Test

The two tests are simple and easy approaches for the comprehensive assessment of the state of heart and lung function of patients, but they are not suitable for serious patients.

Respiration and pulse rate of the patients are recorded first in the ladder-climbing test. Then the patients are asked to speed up and down three floors flat. Respiration and pulse frequency and the time required for recovery should be recorded again. Recovery time within 15 min is in the normal range. The extending time of recovery indicates the poor heart function and thoracic surgery should be carefully considered. For 6 min walking test, if the distance traveled is less than 300–375 m, patient have poor cardiopulmonary function.

11.2.3.4 Goldman Cardiac Risk Index

In 1983, Goldman et al. proposed nine risk factors for preoperative cardiac complications and established a cardiac risk index (CRI) of patients with non-cardiac surgery. Goldman non-cardiac surgery cardiac risk index distributes as follows: <5 scores I grade, 6–12 scores II grade, 13–25 scores III grade, >26 scores IV grade.

When CRI distributes in grade I or II, the operation risk is low and the incidence of severe complications is 0.7–5 %. The risk of cardiac death is 0.2–2 %. The surgical risk is high in grade III. The incidence of severe complications is 11 % while the cardiac death is 2 %. The operation is great danger in grade IV. The incidence of cardiac death is 56 % and the severe complications is 22 %. It can be operated only in the case of rescue.

11.2.3.5 ECG

ECG is the most common and basic diagnostic method of coronary heart disease and cardiac arrhythmias. Compared with other diagnostic methods, ECG is easy to use and spread. Dynamic ECG can improve detection rate of the non-persistent ectopic rhythm especially for transient cardiac arrhythmia as well as transient myocardial ischemia.

11.2.4 Exercise of Respiratory Function

Preoperative exercise of respiratory function can improve patients' physical function and tolerance of surgery. Diaphragmatic breathing and shrinkage lip-abdominal breathing are two common training methods, and volumetric exerciser can also be used if available.

11.2.5 Active Cough Training

Respiratory secretions retention is one of the main reason which leads to the pulmonary atelectasis. Therefore, an effective way is needed to expel sputum. Active cough training is an efficient measure which can clear airway and improve the ventilator capacity. Active cough training also significantly decrease the infection rate. There are three routine active cough methods.

11.2.5.1 Cascade Cough

It is the most effective cough way. It can expel the sputum directly from the vertebrate trachea and bronchus. This method is applied in the patients with less pain or taking analgesic.

11.2.5.2 Cough Softly

Sputum moves from the deep parts of bronchia to tracheas by cough softly. This method is appropriate for the patients with severe pain. This method must cooperate with huff cough to expel the sputum.

11.2.5.3 Huff Cough

This approach can expel the sputum out of the tracheas. This method is applied to the patients with less sticky or less deep sputum.

11.3 Postoperative Management

Xu Lin

11.3.1 Postoperative Pain Management

Pain management is of paramount importance post operatively as it is essential for patients to comply for chest physiotherapy and ambulation and they will be unable to do so if they have severe pain. There are various ways by which pain is managed.

11.3.1.1 NASIDs

The NSAIDs usually used for postoperative pain management are diclofenac, ketorolac, lysine acetyl salicylate, indomethacin, piroxicam, and tenoxicam. Intramuscular diclofenac 75 mg/12 h (PMID: 1728708), rectally indomethacin 200 mg/24 h [6] (PMID: 2248838) or continuous intravenous lysine acetyl salicylate (7.2 g/24 h) [7] (PMID: 3919746) decrease the required quantities of morphine and the postoperative Visual Analogue Scale scores. Indeed, the i.v. lysine acetyl salicylate was comparable with i.v. infusion of morphine (40 mg/24 h).

11.3.1.2 Opioids

The traditional use of opioids for postoperative analgesia after thoracic surgery includes morphine, pethidine (meperidine), fentanyl or tramadol. The route of administration may be intravenous, intramuscular or subcutaneous. Usually, the use of opioids is almost always supplemental to other alternative analgesic approaches. The combination of i.v. opioids and NSAID i.v. has become popular, with satisfactory safety regarding anticoagulation and renal function.

11.3.1.3 Ketamine

Ketamine is a non-competitive antagonist which blocks the ion channel associated with NMDA receptor. After thoracic surgery, i.m. administration of ketamine 1 mg/kg resulted in similar pain scores and in weaker respiratory depression in comparison with i.m. pethidine 1 mg/kg (PMID: 1514347) [8].

11.3.1.4 Regional Analgesia

Regional techniques are very important tools in the treatment of postoperative pain after thoracotomy. Intercostal blockade, paravertebral blockade, epidural blockade and spinal blockade are commonly used for pain management.

Patient controlled analgesia (PCA) can approach the near optimal state of analgesia, maintained with minimum sedation and side effects. The patient adjusts the repetition of dose to the analgesic needs, outreaching the minimum effective analgesic concentration. PCA can be used for drug delivery via intravenous (most frequently) or epidural route. Before the initiation of PCA use, a sufficient analgesic state should be established.

11.3.2 Fluid Management

Fluid administration for lung resection patients must be determined on an individual basis. Post thoracic surgery especially in resections intravenous fluids are given in reduced amounts to prevent pulmonary insufficiency. Care is taken not to overhydrate the patient and oral feeding is encouraged as soon as possible. In a review of published reports, Slinger (PMID: 7579118) [9] gives guidelines regarding postoperative fluid management: (1) a maximum of 20 mL/kg fluid to be given intravenously for the first 24 postoperative hours, (2) acceptance of average urine output of 0.5 mL/kg/h the first 24 h, and (3) use of vasopressors if tissue perfusion is inadequate and the 20 mL/kg maximum of fluid has already been administered.

11.3.3 Deep Venous Thrombosis Prophylaxis

The prophylaxis should start when the patients are admitted in the hospital. Everyone should be given a prophylactic dose of heparin subcutaneously if not contraindicated at a dose 5000 IU twice daily and this is continued in the postoperative period till discharge. All patients should have stockings and the high-risk patients should be on compression stockings. If there are signs of DVT then a Doppler in arranged and patients put in treatment dose of heparin infusion and an IVC filter put in if necessary.

11.3.4 Management of Drainage Tubes

Placement and removal of chest tubes should be standardized by protocol after lung resection. If the postoperative chest X-ray shows expanded lung fields the no suction is applied even if there is bubbling. If there is airspace the suction is applied. It is preferable to use a balanced drainage system in all patients. Fluid drainage of 300–400 mL or less per 24 h is acceptable for chest tube removal after lung resection. Chest tube removal after drainage must be tailored to the particular patient's course. When there is any concern about anastomotic leak in the chest or mediastinum after tracheal reconstruction, tubes should be left until resolution of the leakage.

11.3.5 Respiratory Therapy

The most common complications after thoracic surgery are related to the pulmonary system. Vigilant postoperative pulmonary care decreases the incidence of complications. Incentive spirometry and chest physiotherapy, including clapping, postural drainage, and vibratory therapy, aid in mobilizing mucous secretions and allowing patients to clear their own secretions. Ambulation is an excellent method of decreasing atelectasis. Nebulized albuterol is very helpful in curtailing or preventing bronchospastic episodes. If a patient has had multiple manipulations of the upper airway and there is concern about edema and stridor, intravenous and aerosolized steroids and aerosolized racemic epinephrine are effective in reducing edema.

11.4 Uniportal Video-Assisted Thoracoscopic Anatomic Lung Resections

Diego Gonzalez-Rivas, Yang Yang and Gening Jiang

11.4.1 Introduction

Uniportal video-assisted thoracic surgery (VATS) has a history spanning over more than 10 years and has recently become an increasingly popular approach to manage most of the thoracic surgical diseases [10]. Less invasiveness, potential reduction of pain, and a better cosmesis are some of the advantages that have stimulated the spread of the uniportal technique around the world [11]. Thanks to the experience gained since its origins in 2010, as well as the improvement of surgical instruments and other technology, the technique has evolved to become a feasible and safe approach for increased indications for VATS major pulmonary resections. [12–15].

11.4.1.1 Material

The adoption of conventional surgical instruments to a thoracoscopic design (long curved or angled instruments with both proximal and distal articulation) is one of the key requirements in order to accomplish a successful single-incision lobectomy (Fig. 11.9a). In addition, the evolution of HD cameras and curved vascular clip appliers as well as more narrow and angulated staplers have contributed to the improvement of this approach by making it safer for a broad range of indications. The use of videolaparoscope with the distally mounted CCD design facilitates the instrumentation (Fig. 11.9b).

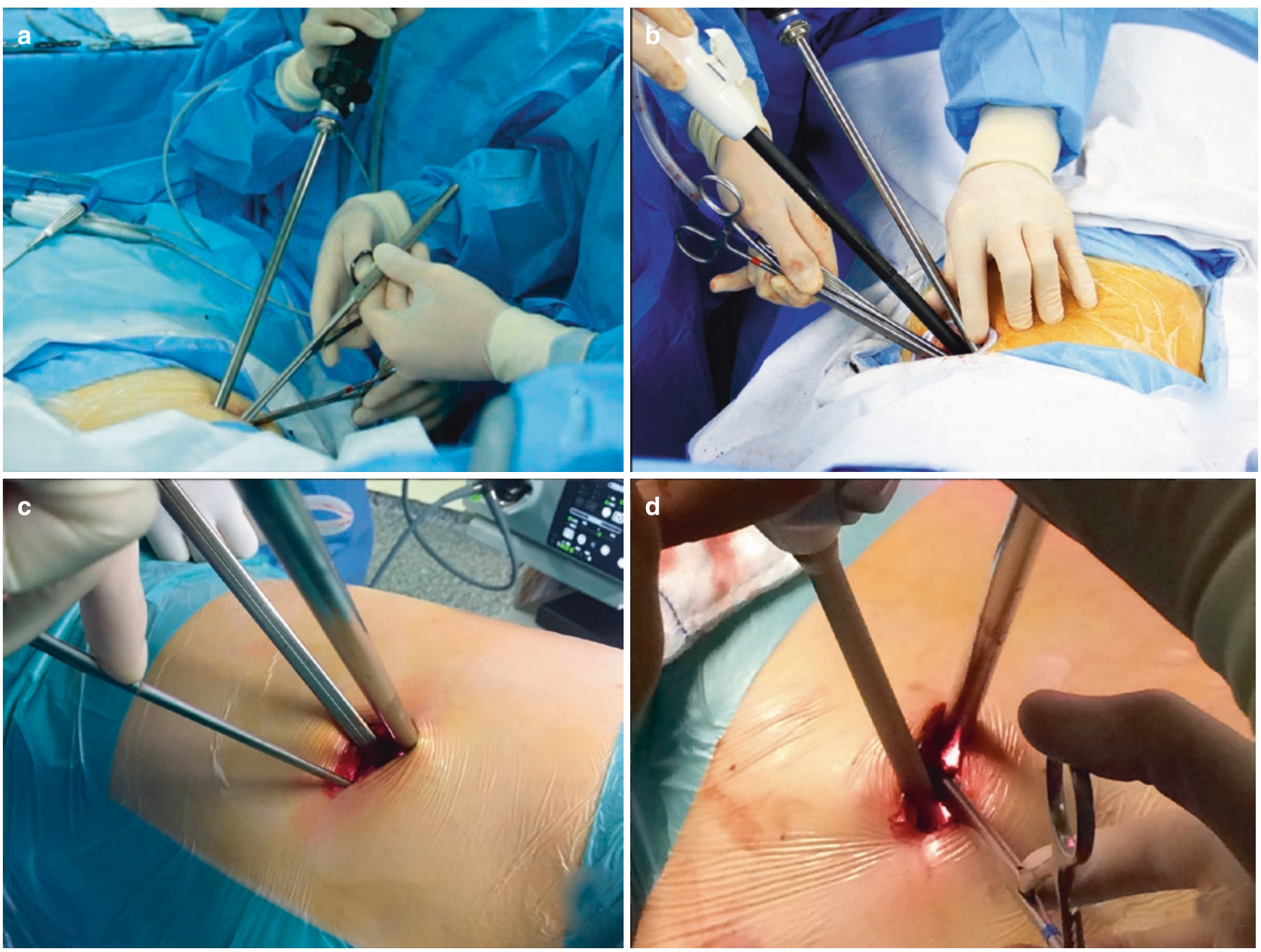

Fig. 11.9 Instrumentation of uniportal VATS lung resections

11.4.1.2 General Aspects

The surgeon and the assistant must be positioned in front of the patient in order to have the same thoracoscopic vision throughout the procedure (Fig. 11.9a). Despite this anterior positioning of the view, thanks to the 30° scope and combined movements along the incision enable different angles of vision. The advantage of using the thoracoscope in coordination with the instruments is that the vision is directed to the target tissue. By doing this, we are lining up the instruments to address the target lesion from a direct, sagittal perspective [16]. An optimal exposure of the hilum is vital in order to facilitate dissection of the structures as well as preventing interference with instrumentation.

The patient is positioned as in a conventional VATS, in a lateral decubitus position. The incision is preferably placed in the fifth intercostal space, a bit anteriorly and is about 3–4 cm long. The location of the incision provides better angles for hilar dissection and insertion of staplers. In order to help with the exposure of the hilum, it is recommended to rotate the surgical table away from the surgeon during the dissection and division of structures. The opposite movement of the table would be advisable for the subcarinal lymph node dissection. We always recommend inserting the staplers through the anterior part of the incision with angulation (Fig. 11.9d). The use of curved-tip stapler technology allows for improved placement around superior pulmonary vein and bronchus through a single incision, which are the most difficult structures to divide through a single port. It is important to dissect the vessel as distal as possible in order to achieve better angles for the stapler insertion. When the angle is difficult for the insertion of the stapler the use of new improved vascular clips (click aV plus,) is recommended (anti sliding system). Alternatively, ligation of the vessels by using sutures can also be done.

It is crucial that the thoracoscope remains positioned at the posterior part of the incision at all times, as it works with the instruments in the anterior part (Fig. 11.9c). The only step where we place the camera below the stapler insertion (anterior part) is for the division of the anterior part of the minor fissure.

When doing upper lobectomies, the pulmonary artery is normally divided first, followed by vein (Fig. 11.10). When the lobectomy is completed, the lobe is removed in a protective bag and a systematic lymph node dissection is performed. At the end of the surgery, the intercostal spaces are infiltrated with bupivacaine under thoracoscopic view. ***Only one chest-tube is placed in the posterior side of the incision***.

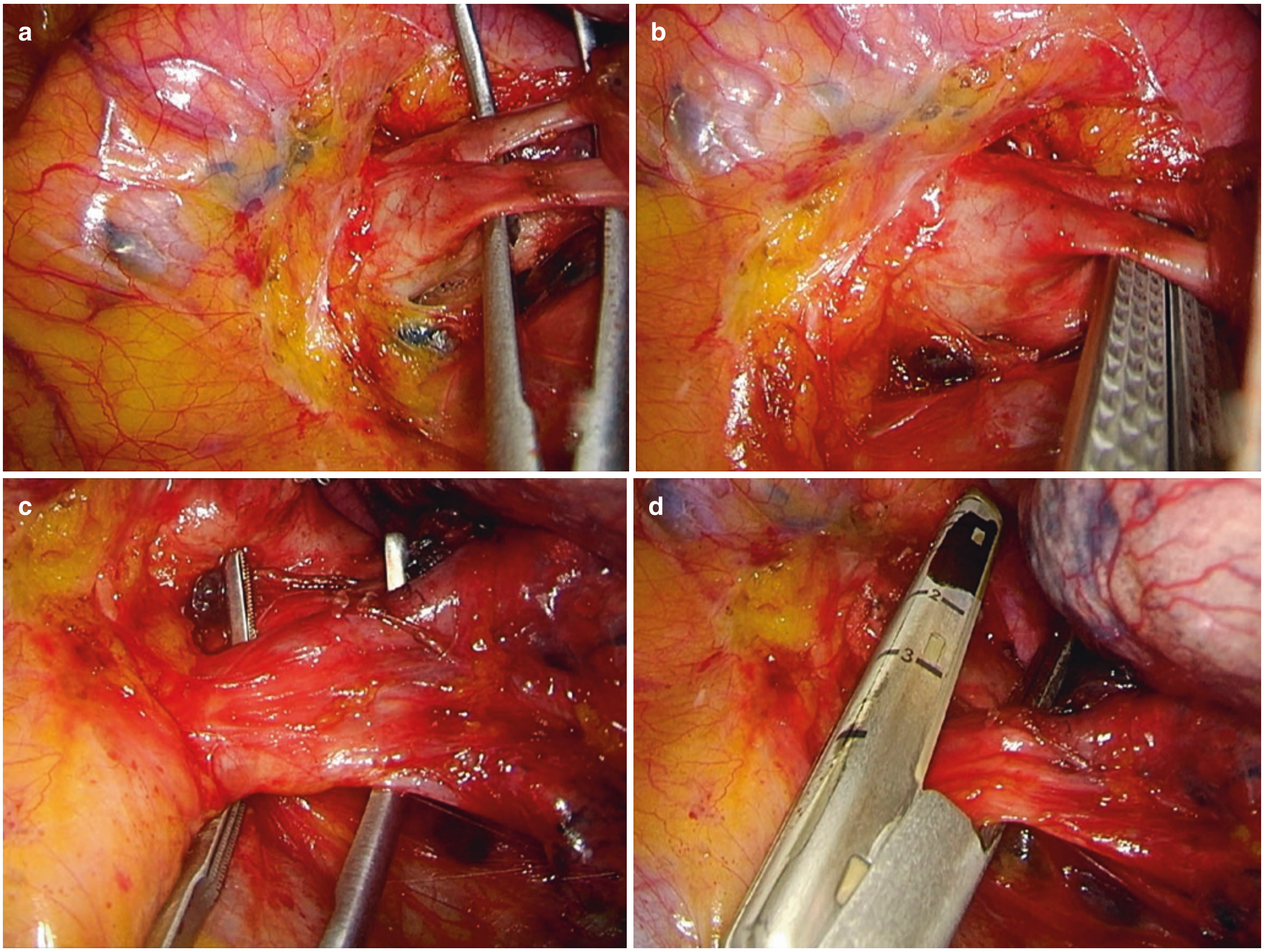

Fig. 11.10 Uniportal VATS left upper lobectomy

11.4.1.3 Surgical Technique

Lower Lobectomy

The technique of the lobectomy may be different depending on whether the fissure is complete or not. If the fissure is complete, the dissection of the artery in the fissure is attempted. There are some cases where the arterial branches of the superior and basilar segments are easier to be divided. The vein is dissected and divided. Then, the lower lobe bronchus is exposed, dissected, and stapled as done with the vein. The last step is to staple the fissure.

In the presence on an incomplete fissure or if there is no visible artery, the technique may change. In order to avoid postoperative air leaks, the preferred method does not involve dissection within the fissure. In this case, the lobectomy must be performed from caudal to cranial, leaving for last, the stapling of the fissure (fissureless technique). The sequence of the dissection should be as follows: inferior pulmonary ligament; inferior vein; inferior bronchus. Subsequently, a plane is created between the bronchus and the artery and the artery is taken, leaving the fissure to be developed last.

When performing a right lower lobectomy, care must be taken in order to identify the bronchus or artery of the middle lobe. Once the inferior pulmonary vein has been stapled, the lower lobe bronchus is exposed, dissected, and divided from its inferior side to its bifurcation with the middle lobe bronchus. After this, the bronchus is dissected and the plane between the bronchus and the artery is developed and further dissected. This exposes the artery. The removal of the peribronchial lymph nodes is recommended to better define the anatomy. Once identified, the segmental arterial branches to the lower lobe (basilar artery and superior segmental artery) are divided, leaving the fissure to be stapled at the end.

Upper Lobectomy

The uniportal view aids in the dissection and division of upper anterior and apical segmental trunks, which are normally hidden by the superior vein when using a conventional thoracoscopic view. We first recommend dividing the upper anterior and apical segmental trunk (Fig. 11.10a, b), in order to facilitate the insertion of the staplers in the upper lobe vein. Once this arterial branch has been stapled, the vein will be easily transected (Fig. 11.10c, d). It is important to dissect the vein as distal as possible to allow for an optimal stapler insertion. Another interesting option for management of the upper lobe vein is to open the fissure as the first step, from a hilar view, and then create a tunnel between upper and lower vein with identification of the bronchus and artery (Fig. 11.11a). The anvil of the stapler is placed over the artery, dividing the anterior portion of the fissure (Fig. 11.11b) and allowing for the mobilization of the lobe (to allow the stapling of the vein from a different angle).

Due to the fact that the lingular artery usually lies behind the bronchus, greater care must be taken during left upper lobectomies. There are four different forms to manage the upper lobe bronchus. The easiest option consists of exposing the lingular artery and subsequently dividing it in the fissure (easy when fissure is complete). From that point on, the insertion of an endostapler for the bronchus is simple. In the second option, a TA stapler is used to divide the left upper lobe and bronchus in cases of incomplete fissure, in order to avoid injury of the lingular artery. The third option entails dividing the bronchus with scissors and then closing it at the end of the surgery (by manual suture or by using a stapler). The fourth option focuses on inserting an endostapler after the division of the superior arterial trunk (and optionally posterior ascending artery) and vein. Only experienced uniportal VATS surgeons should attempt this last option, since it can result in the injury of the lingular artery.

For right upper lobectomy, it is often helpful to partially divide the minor fissure first. The anvil of the stapler is positioned between the upper and middle lobe vein, then the parenchyma is positioned between the jaws of the stapler. This provides a better angle for the insertion of the staples to the upper vein. This maneuver enables a much better field of vision in order to dissect and transect the RUL bronchus or the ascending arteries. Care must be taken during dissection and division of ascending artery (laceration of posterior ascending artery is one the most frequent reasons to conversion).

The last step would be to complete the fissure (positioning the stapler's anvil over the artery). After transecting the vein, artery, and bronchus and identifying the artery for the middle lobe, the fissure can then be divided by putting the stapler over the intermediate artery and pulling the parenchyma anteriorly. It is important to ensure that the middle lobe artery stays out of the left side of the stapler. Care must be taken as well to keep the vascular and bronchial stumps out of the stapler's jaws. Exposing the posterior bifurcation between the upper lobe and intermediate bronchus is recommended. This is done by dividing the posterior pleural reflection as it facilitates the next step, the anterior side of the bronchial dissection.

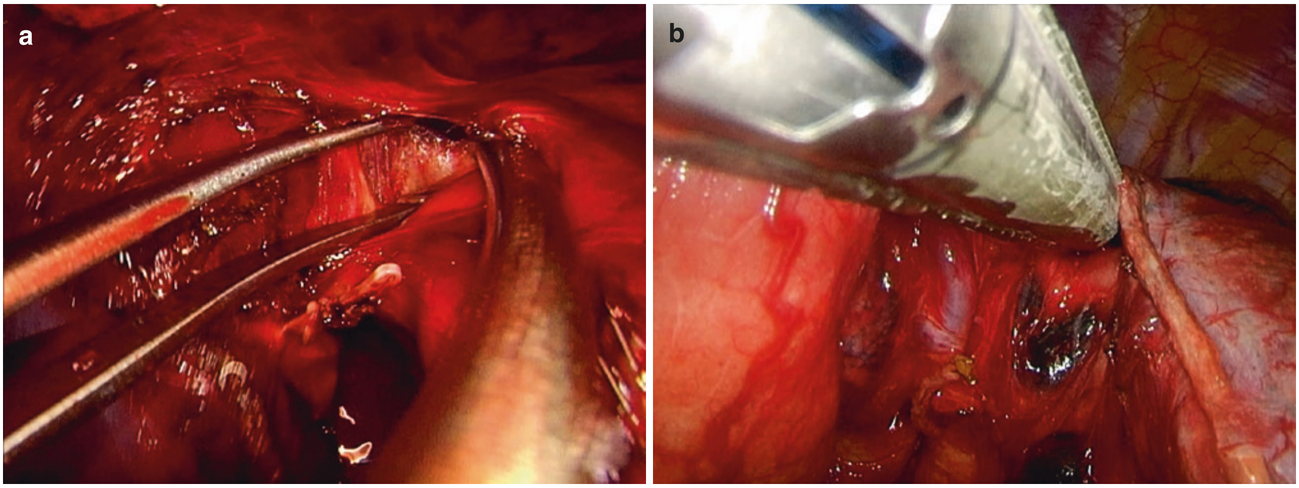

Fig. 11.11 Open the fissure first

Middle Lobectomy

We recommend performing the middle lobectomy from caudal to cranial: anterior portion of major fissure, vein, bronchus, artery, anterior portion of minor fissure and finally the posterior portion of fissure. The identification of medium lower vein (MLV) and lower lobe vein (LLV) indicates where to place the stapler in order to divide the anterior part of the major fissure (the anvil of the stapler is positioned between the MLV and LLV, and the parenchyma is then pulled into the jaws of the stapler). This maneuver facilitates the dissection and insertion of stapler to take the vein.

Once the vein is divided, the middle lobe bronchus can be visualized, exposed, dissected and stapled. After bronchus division, the middle lobe artery is easily exposed and can then be divided. Lastly, the fissures are completed.

11.4.1.4 Lymphadenectomy

Thanks to high definition view, long and specifically adapted instruments and energy devices, the uniportal technique is an excellent approach to radical lymph node dissection. For paratracheal lymph node dissection, the anti-Trendelenburg position is very helpful as it enables the convenient positioning of the lung. Also to facilitate the exposure for the subcarinal lymph node dissection, the trendelenburg position combined with the anterior rotation of the table is recommended. Next to this, by releasing the pulmonary ligament a better access to the subcarinal space is granted.

It is imperative that the camera always be placed in the upper part of the incision***. To complete the systematic lymph node dissection of the right paratracheal and subcarinal space as well as the left subcarinal space and aorto-pulmonary window, three to four instruments can be inserted below the camera.*** The use of bimanual instrumentation, using a long curved adapted instrument on the left hand and energy device on the right, improves the radicality of the procedure and diminishes the incidence of bleeding during dissection.

11.4.1.5 Future

The future of the thoracic surgery depends on the evolution of surgical procedures and technology to reduce surgical and anesthetic trauma [17]. The combination of non-intubated or awake thoracoscopic surgery and single-port VATS technique is promising as it represents the least invasive procedure for pulmonary resections [18, 19]. By avoiding intubation, mechanical ventilation and muscle relaxants, the anesthetic side effects are minimal allowing most patients to be included in a fast-track protocol and therefore avoiding time in the intensive care unit. Since only one intercostal space is opened during the procedure, the use of local anesthesia and blockade of a single intercostal space suffices for pain control during the surgery. This type of non-intubated major pulmonary resections is something that must only experienced anesthesiologists and uniportal thoracoscopic surgeons (preferably skilled and experienced in complex or advanced cases as well as in bleeding control through VATS) should be performing. In our experience, the quality of the pulmonary collapse obtained by iatrogenic pneumothorax via VATS under spontaneous breathing is at least as good as in mechanical ventilation using a double-lumen endotracheal tube. The mechanism of performing this lung collapse is more physiological via a small intercostal incision than via one-lung mechanical ventilation and that would result in less lung inflammation and stress with possible better postoperative recovery and outcomes. It is very important to reduce the surgical and anesthetic trauma in high-risk patients, such as the elderly or those with poor pulmonary function. The influence of mediastinal and diaphragmatic movement do not usually interfere with hilar dissection in experienced VATS surgeons, especially when the cough is inhibited by performing a vagus blockade.

In conclusion, the uniportal approach has created opportunities to develop new technology and to push the boundaries of the minimally invasive thoracic surgery. Further technologic developments can be expected such as narrower endostaplers, sealing devices for all vessels and fissure, improved and refined thoracoscopic instruments, better 3D systems, wireless cameras and robotic surgery advancements which will likely lead the uniportal approach to become the standard surgical procedure for major pulmonary resections in most of the thoracic departments around the world.

11.5 Resection in the Nonintubated Patient

Ming-Hui Hung, Jin-Shing Chen, and Ya-Jung Cheng

11.5.1 Technical Points

Nonintubated video-assisted thoracoscopic surgery (VATS) is an encouraging approach to perform both minor and major pulmonary resections in lung cancer patients. The reasons to use nonintubated VATS are mainly to avoid the perioperative adverse effects derived from general anesthesia and endotracheal intubation for one-lung ventilation, in addition to the beneficial effects of spontaneous breathing in non-intubated patients. In our experiences, nonintubated patients are reported to be associated with less postoperative nausea and vomiting, early resumption of oral intake, regained consciousness faster, better postoperative analgesia, fewer overall complication rates and faster discharge after surgery [20–27].

To be feasible and safe in performing nonintubated VATS, surgical and anesthetic managements should meet the considerable pathophysiological derangements produced from an iatrogenic open pneumothorax in a spontaneous one-lung breathing patient. Our current protocol for nonintubated VATS are as following:

- Standard perioperative monitoring, including electrocardiogram, invasive arterial pressure, pulse oximeter and end-tidal carbon dioxide monitoring.
- Sedation using target-controlled infusion of propofol. A bispectral index (BIS) monitor is used for advanced judgement of anesthetic depth.
- Local infiltration of lidocaine for thoracoscope port incision, following internal intercostal nerve blocks and ipsilateral intra-thoracic vagal block using bupivacaine.
- Patients may manifest tachypneic and paradoxical breathing shortly after an iatrogenic open pneumothorax. The operated lung gradually collapses in next 5–10 min.
- Adjusting the depth of sedation or giving small dose of opioid (25 μg fentanyl) to achieve a favorable respiratory rate and breathing pattern. Supplemental oxygen via a facemask is usually sufficient to maintain satisfactory oxygenation during the procedure. Requirement of propofol infusion always decreases after effective intercostal and vagal blocks.
- Surgeons are still reminded to avoid excessive tractions of lung parenchyma or hilar structures.
- Assisted ambu-bagging of the operated lung for checking on air-leak. The residual air can be aspirated via the drainage bottle after the procedure to promote full expansion of the operated lung.
- A prepared airway algorithm in cases requiring a conversion to tracheal intubation.

11.5.2 Anatomical Landmarks

Effective regional anesthesia is pivotal for non-intubated VATS. While thoracic epidural anesthesia or intercostal nerve blocks offer satisfactory analgesia for somatic wound pain, intra-thoracic vagal blocks are simple and easy to inhibit cough reflex during pulmonary manipulations, both contribute to a sound and stable operating environment.

- **Thoracic epidural anesthesia:** Classical landmark for thoracic epidural catheterization is the inferior angle of scapula at T7. An optimal segmental anesthesia can be achieved between T2 and T9.
- **Intercostal blocks**: Thoracic intercostal nerves run inferior to the intercostal vessels in the costal groove of the corresponding rib. They can be blocked transcutaneously, but internal intercostal blocks can be accurately performed under the direct thoracoscopic vision. Multilevel (T3–T8) blocks are favorable for VATS operation.
- **Vagal blocks**: Irritated airway during pulmonary manipulations may provoke cough reflex. A strenuous coughing can re-expand the operating lung and jeopardize the safety of non-intubated VATS. The afferent limbs of cough reflex run through the intra-thoracic vagal nerves. Right-sided vagal nerve can be clearly visualized between the tracheal and the superior vena cava. Left-sided vagal nerve runs through the aorto-pulmonary window, however, it is not easily visualized.

11.5.3 Operating Procedure

1. Nonintubated patients are sedated using target-controlled infusion of propofol with standard monitoring as conventional intubated general anesthesia (Figs. 11.12 and 11.13).
2. The incision for a thoracoscopy is first created after local infiltration of 2 % lidocaine.
3. The operated lung collapsed gradually after creating an iatrogenic pneumothorax. Further intercostal blocks and vagal block is produced by infiltration of 0.5 % bupivacaine under the video guidance (Fig. 11.12).
4. Operative techniques for thoracoscopic lung resection and mediastinal lymph node dissection are as standard method; however, all pulmonary manipulations should be as gentle as possible (Fig. 11.14).
5. The resected lung parenchyma is removed in an organ retrieval bag. Assisted mask ventilation can expand to the operated lung to check for air leaks.

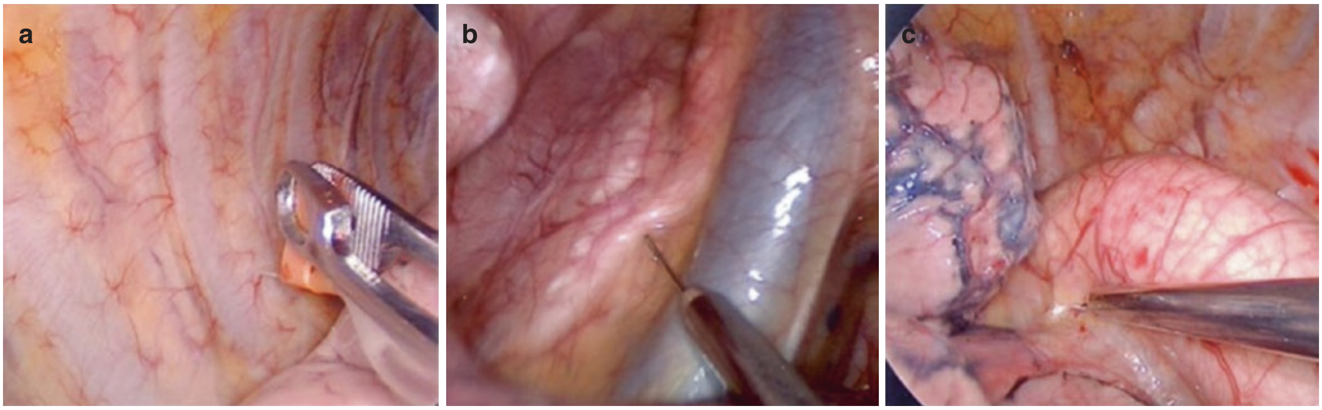

Fig. 11.12 Anatomical landmarks. (**a**) Intercostal nerve. (**b**) Right-sided intra-thoracic vagal nerve lies between the trachea and the superior vena cava. (**c**) Left-sided intra-thoracic vagal nerve runs through the aorto-pulmonary window

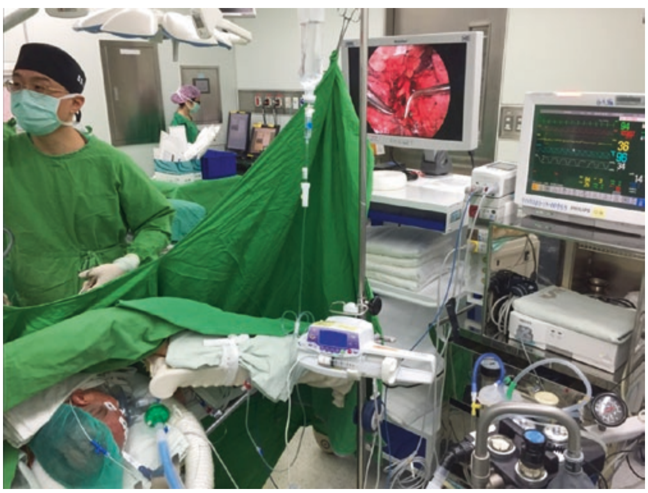

Fig. 11.13 Thoracoscopic surgery in a nonintubated patient. *1* Bispectral index monitoring; *2* face mask for supplemental oxygen; *3* noninvasive monitoring of end-tidal carbon dioxide and respiratory rate

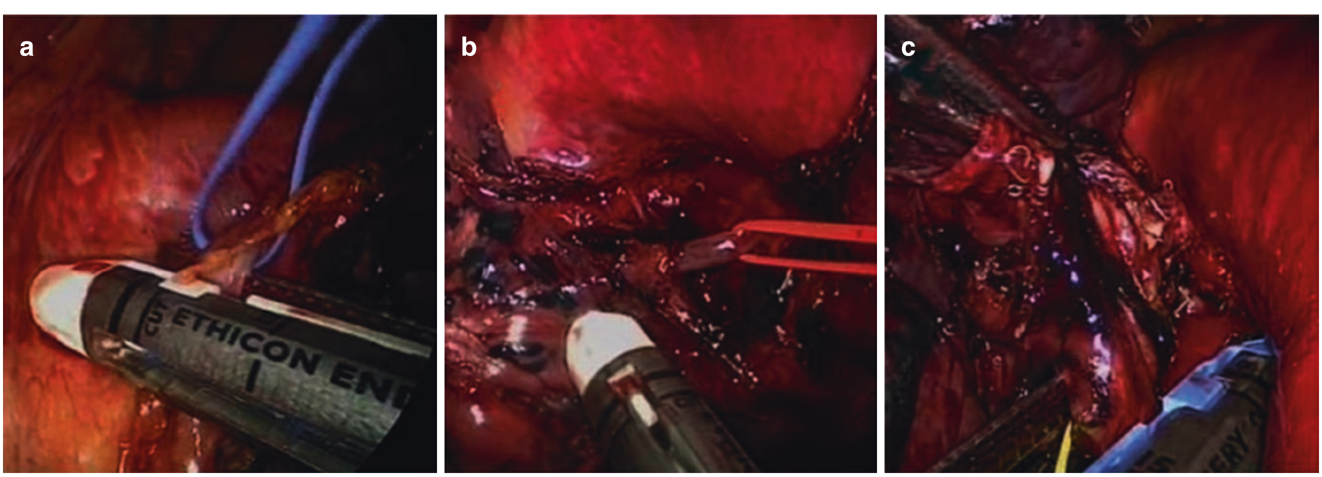

Fig. 11.14 After hilar dissection, branched pulmonary vessels and bronchus were identified and divided with endostaplers

Tips

- **Team work**. A cooperative and communicating thoracic surgical team, including surgeon and anesthesiologist well-experienced with VATS is suggested to start a nonintubated technique.
- **Select patient**. Obese patients are often strenuous abdominal breather with vigorous diaphragmatic movement after iatrogenic pneumothorax. Invasive hilar dissection may be difficult.
- **Conversion protocol**. A conversion protocol in cases of failed nonintubated technique should be prepared in advance.

11.6 Dealing with Doornail Lymph Node and Pleural Adhesion, and VATS Pleurodesis

Lixin Zhou and Jun Wang

11.6.1 Dealing with Doornail Lymph Node

Lymph nodes are an important reason of conversion of complete thoracoscopic lobectomy to open thoracotomy. We termed the proliferative and sclerous lymph nodes closely adhering to the blood vessels and bronchia as "doornail lymph nodes". The "doornail lymph nodes" means the proliferative and sclerous lymph nodes closely adhering to the blood vessels and bronchia, which may cause tears in the artery wall or bifurcation and result in uncontrollable bleeding. Specifically, CT scans shows enlarged lymph nodes around the hilar vessels or bronchia, which are accompanied with or without calcifications and the boundary between the blood vessel and the bronchia is not clear.

11.6.1.1 Technical Points

- Attention should be paid to patients with periportal lymph node calcifications on pre-operative CT scans.
- To avoid the lymph node adhesions to the pulmonary artery or vein, dissect the blood vessel within the sheath.
- If tumor metastasis is excluded by frozen biopsy, the hard core of the lymph nodes closely adherent to the bronchia can be removed and the majority of residual lymph tissue can be sharply dissected.
- conversion to open thoracotomy should be performed when: the boundary of the mediastinal lymph nodes is not clear and the lymph nodes are tightly adherent to the blood vessels; the bleeding is massive.

11.6.1.2 Operating Procedure

Lymph nodes are often located around important blood vessels and bronchia. Lymph node enlargement caused by calcifications and inflammation-related adhesions, tuberculosis, and tumor metastasis usually obscure the local anatomic structures, and increase the difficulty in endoscopic management of the blood vessels and bronchia. Forcible adhesiolysis may cause tears in the artery wall or bifurcation and result in uncontrollable bleeding. During surgery, the lymph nodes are hard and closely adherent to the peripheral blood vessels and bronchia. The peripheral blood vessel sheath cannot be incised. Even if the sheath was incised, the blood vessel could not be dissected. Part of or one side of the blood vessel (mainly the pulmonary artery) wall is completely fused to the bronchia, and cannot be separated with scissors or a scalpel, hence the term "doornail lymph node."

Data from the Department of Thoracic Surgery of Peking University People's Hospital showed that lymph node interference, which made the thoracoscopic dissection of blood vessels impossible, accounted for 71.4 % of the active conversions to open thoracotomy and accounted for 69.2 % of the passive conversions to open thoracotomy.

1. The most effective method of avoiding the lymph node adhesions to the pulmonary artery or the pulmonary vein is to incise the vascular sheath and dissect the blood vessel within the sheath, whether the artery or the vein.
2. If the lymph nodes have already invaded the vascular sheath and sufficient vascular dissection is not possible, even after incising the vascular sheath, sharp dissection can be performed with conventional thoracotomy instruments thoracoscopically.
3. If necessary, the ipsilateral pulmonary trunk can be clipped with an occlusion clamp and the blood vessel repaired after sharp dissection or ligated from the distal end.
4. If tumor metastasis is excluded by frozen biopsy, the hard core of the lymph nodes closely adherent to the bronchia can be removed and the majority of residual lymph tissue can be sharply dissected. Finally, only the outer membrane of the lymph node with adhesions is retained on the wall of the bronchia. Because the outer membrane of the lymph node is soft, it will not affect the stapling and cutting of the endoscopic linear stapler. At this time, the linear stapler can be placed in directly to cut off the bronchia and the remnant lymph node together.
5. If the boundary of the mediastinal lymph nodes is not clear and the lymph nodes tightly adhere to the blood vessels, which cannot be dissected even after incising the vascular sheath, conversion to open thoracotomy should be prepared in advance.

6. If the bleeding is minimal, the bleeding point can be compressed using a peanut or a small gauze ball for 5 minutes, and the surgery can proceed after the bleeding is controlled. If the bleeding is still significant, the main trunk of the ipsilateral pulmonary artery can be blocked to dissect the blood vessel. If the bleeding is massive, the rate of bleeding can be reduced by compressing the bleeding point with gauze and conversion to an open thoracotomy should be performed to control bleeding under direct vision.

11.6.2 Dealing with Pleural Adhesion

Pleural adhesion is very common in thoracic surgeries,which makes VATS techniques complicated, even could lead to bleeding and conversion to open thoracotomy, and was considered as contraindication in the past. It's somewhat predictable before operation. Histories of tuberculosis, pneumonia, pleural effusion, thoracic injury or surgery are suggestive of pleural, even a closed chest. Chest imaging of pleural thickness and elevated diaphragm is also very helpful in preoperative prediction.

11.6.2.1 Technical Points

- "Sucking sound" when making the first port helps estimating pleural adhesion.
- The best anatomical level is being close to but no harm of the lung.
- For a closed chest, gather the fingertips to each other through two ports and make a channel, then you can have an operating field.

11.6.2.2 Operating Procedure

In the very beginning of a VATS surgery, notice if there is a "sucking sound", which is produced when gas enters the pleural space through a small port (the observation port) and the lungs collapse. If you did not hear a sucking sound while making the first port, it implies there may be serious pleural adhesion. After entering the chest, if the lungs did not collapse completely, there may be pleural adhesion on the top of the chest, which could be ignored and then lead to massive bleeding. Most adhesions are not difficult to dissect. With thoracoscopic assistant, you can easily see the adhesion. If there is pleural adhesion, don't be anxious to do other procedures, make sure the adhesion is dissected first.

The anatomical level is very important in pleurolysis. Pleural adhesion is a fibrous band that binds together the visceral pleura and the parietal pleura, and it's comprised of plenty of small but varisized blood vessels. If it's not coagulated well, the vessel stump may retract into the chest wall and make the hemostasis more complicated, so dissection too close to the chest wall may cause bleeding. The best level is being close to but no harm of the lung. We have different ways to treat different kinds of pleural adhesion.

1. For "cord-like" adhesion

There are always some blood vessels in "cord-like" adhesion, so completely coagulation is very important. Coagulation with electric hook, Ligasure or ultrasound scalpel is safe and efficacious for small vessels, while for thicker vessels,you may need titanium clip or hem-o-lock. Choose the right equipment according to the thickness of the vessel. For adhesion suspicious of thick vessels, especially for thick inter-lobar fissure, you can cut directly with cutting stapler (Fig. 11.15).

2. For "membrane-like" adhesion

For membrane-like adhesion, pull the lung with an oval forceps or endoscopic grasping forceps to form some tension of the adhesion, and dissect the adhesion sharply or bluntly. For some loose adhesion, blunt dissection with fingers, suction, oval forceps or peanuts can be used as alternatives, then coagulate the bleeding spots.

Fig. 11.15 Cut the thick adhesion inter-lobar fissure suspicious of vessels with endo-stapler

3. For complete pleural adhesion

Complete pleural adhesion, also named “closed chest”, is the most difficult situation. It is a main cause of giving up thoracoscopic manipulation and conversion to open surgery. In a VATS surgery, with complete pleural adhesion, the lungs don’t collapse and the visual field is seriously limited, so thoracosopic pleurolysis involves risks of bleeding and extension of the operative time. In this situation, many surgeons may choose active conversion to open surgery directly. Open surgery has its limitations too, for example, limited exposing, especially at the top of the chest. While under thoracoscopic vision, there is no blind angle, thus makes it even safer than open surgery. The key point is how to start the dissection under thoracoscopic vision. The first port is very important, for a patient with a history of thoracic surgery or trauma, you should avoid the old wound, and the location of the first port should avoid the elevated diaphragm.

When you realize it’s a closed chest after making the first port, make the second operating port, and put a finger (index finger or little finger) in each port. Dissect the surrounding adhesion around the two ports bluntly with your fingers, then gather the fingertips to each other, and a tunnel is separated in this way. As long as you can have an operation field and put operation instruments in, the thoracoscopic manipulation is much easier (Fig. 11.16).

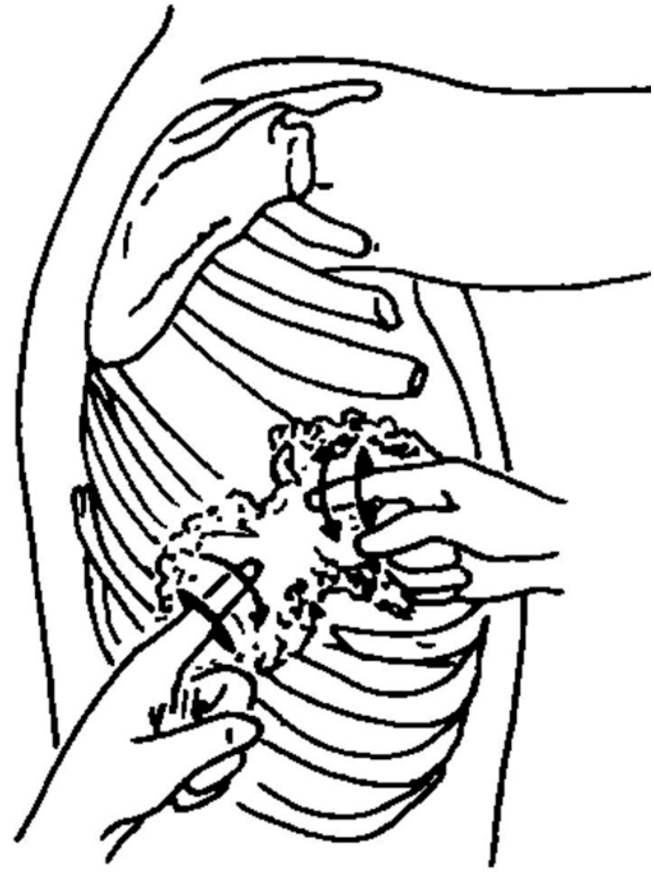

Fig. 11.16 Dissect the surrounding adhesion around the two ports bluntly with fingers, then gather the fingertips to each other

11.6.3 VATS Pleurodesis

Pleurodesis is defined as the symphysis between the visceral and parietal pleura, in order to alleviate symptoms (dyspnea, pain and cough), decrease prolonged air leak, avoid recurrence and improve quality of life.

11.6.3.1 Indications

The main indication for treatment is in the palliative treatment of malignant pleural effusion, to alleviate dyspnea, which is dependent on both the volume of the effusion and the underlying condition of the lungs and pleura. Pleurodesis in benign effusion is highly controversial. Surgical pleurodesis with mechanical abrasion via thoracoscopy is indicated primarily in the treatment of spontaneous pneumothorax.

11.6.3.2 Chemical Pleurodesis

- Pleurodesis agents
- Chemical agents such as talc, iodopovidone, bleomycin, tetracycline, minocycline.
- Procedure
- Bedside procedure: After introducing the mixed the agents into the pleural space through a chest drain or catheter, occlude the drain and charge the patient to keep shifting positions in bed every 5 min for 1–2 h, then open the drain.

Fig. 11.17 Special equipment for introducing poudrage agents into thoracic cavity

Intraoperative procedure: Liquid agents are easy to be introduced, while poudrage agents such as talc need special equipment (Fig. 11.17). With this equipment, sterile talc powder, as the best sclerosing agent, could be administered via a chest tube.

11.6.3.3 Mechanical Pleurodesis

In many patients, tunneled pleural catheters (TPCs) may result in auto-pleurodesis. After a period of time with regular drainage, the drain output reduces and spontaneous pleurodesis occurs, allowing the drain to be removed.

Surgical pleurodesis could be performed via thoracotomy or thoracoscopy, mainly used to control the recurrence of primary spontaneous pneumothorax. Surgical removal of parietal pleura is an effective way of achieving stable pleurodesis. Pleural abrasion is equally effective as pleurectomy and is safer than pleurectomy. It involves mechanically irritating the parietal pleura and inducing bleeding, often with a rough pad. The formation of a fibrin mesh is necessary for the recruitment and subsequent proliferation of fibroblasts in the pleural space. Autologous blood induced by pleural abrasion is an effective and safe sclerosing agent.

- Procedure

Rub the parietal pleura gently with a rough pad, gauze or electric knife cleaning plate, until diffuse capillary bleeding, avoid the apical pleura in case of damaging venae subclavia or brachial plexus, and avoid the sympathetic chain. If there is active bleeding, make sure it being stopped before the chest closed.

Moreover, a tight and complete apposition between the two pleural layers is the most important condition to obtain a successful pleurodesis, so, if lung expansion is incomplete, a vacuum suction is needed.

11.7 Teaching and Learning VATS Lobectomy

Xiao Li and Jun Wang

Video-assisted thoracoscopic lobectomy has a number of potential benefits when compared to open thoracotomy, but is only practiced in a few thoracic surgery centers. With increasing acceptance from the thoracic community, a vast number of surgeons are learning the VATS lobectomy technique internationally.

Several studies have demonstrated that the transition from open to VATS lobectomy is safe with regards to both short-term morbidity and long-term survival [28]. Contemporary VATS surgeons should have an ethical and professional responsibility to undertake specialized training in recognized VATS lobectomy institutions. Surgeons currently performing open lobectomy should consider transitioning to the VATS procedure.

Hereby, we will review the literature about teaching and learning VATS lobectomy to give out some suggestion. We wish it will be helpful for the centers which will set up a VATS teaching program and individuals who is ready to learn VATS lobectomy.

11.7.1 Teaching VATS Lobectomy

Teaching this complex procedure requires adequate case volume, adequate instrumentation, a committed operating room team and baseline experience with open lobectomy [29].

Concerning a number of important issues related to competence and training, consensus was reached on the following points: (i) 50 cases are required for VATS lobectomy technical proficiency; (ii) 50 annual resident cases are required for a VATS lobectomy training centre; (iii) thoracic surgeons should perform at least 20 cases annually to maintain VATS lobectomy operative skills and (iv) surgeons should be proctored while initiating a VATS lobectomy program [30].

Regarding the future directions, consensus was reached for VATS lobectomy to be incorporated into training program for surgical trainees with a special interest in thoracic surgery and standardized international surgical workshops should be made available to enhance the training of thoracic surgeons interested in commencing VATS lobectomy program.

11.7.1.1 Can VATS Lobectomy Be Taught Safely? –Yes

With careful selection of patients, VATS lobectomy can be taught safely in a surgical institution experienced in VATS lobectomies. The surgical outcome for the training surgeons was acceptable in comparison to the outcome of the experienced surgeons. But to our knowledge, surgeons in training did spend more time for the operation.

Ferguson and Walker showed in 2006 that VATS lobectomies can be taught safely to trainees, with no increase in intraoperative blood loss, morbidity, mortality or postoperative stay, but with a significant increase in operating time [31].

In our experience, we have had success in teaching VATS lobectomies to trainees with limited open experience given sufficient supervision and selecting the cases carefully. But they are all experienced in other minor VATS surgeries, which is very helpful for them to carry out VATS lobectomy. The study by Yu et al [32] also reported that trainees, even with limited experience in open lobectomy, can safely learn to perform VATS lobectomy under expert supervision, without compromising outcomes, after they established significant second-hand experience with VATS lobectomy and other minor VATS procedures.

Trainees spent more time in performing the operation as compared with experienced VATS surgeons. There was no significant difference in intraoperative or postoperative complications and outcomes between the two groups. Video-assisted thoracic surgery major lung resection for early stage nonsmall-cell lung cancer can be taught to residents who work under the supervision of experienced VATS surgeons [33].

Richards et al. also demonstrated a senior cardiothoracic surgical trainee can be trained in VATS lobectomy without impacting adversely on clinical outcomes [34].

Furthermore, supervision by an experienced VATS surgeon can save the training surgeon from a rather high conversion rate as reported by self-trained surgeons in the beginning of their programmes. For the pioneer surgeons, conversion was their only option in case of intraoperative difficulties. The conversion rate was in many cases rather high. The conversion rate then declines with experience and number of cases per year.

11.7.1.2 Simulation and VATS Lobectomy

The introduction of simulators of VATS lobectomy is supposed to make the learning curve of VATS lobectomies shorter. Simple simulators with an animal model, usually a porcine heart-lung tissue block filled with ketchup in a box, can simulate real surgery very well. This is a model used to train US thoracic surgery residents in VATS techniques [35]. Other models used in formal VATS courses include VATS procedures on anaesthetized pigs. Although these models are effective at procedural teaching, they are limited by the cost and single use of animal tissue and the need for a thoracic surgeon to instruct.

Virtual reality simulators have become an increasing popular modality for surgical education within recent years. In a recent randomised controlled trial of training with a virtual simulator developed for laparoscopy, the performance level of novices was increased to that of intermediately experienced laparoscopists and operation time was halved [36]. The idea of letting residents practice with the simulator before doing surgery with improvement of cognitive and procedural skills can potentially lead to better patient safety. A recently developed virtual reality simulator uses a model for a right upper lobe lobectomy by VATS. Various anatomic variations and anomalies are randomized and loaded to present a unique surgical experience for each operation. The software is designed to identify common errors in procedural flow, including tears in pulmonary parenchyma that would result in air leaks, inappropriate ligation of vessels or bronchus to close to the pulmonary hilar origin, ligation of the vessels to the middle lobe or inferior lobe, and failure to ligate vessels to the right upper lobe. The model also includes lymph node dissection [37]. Virtual reality simulators will most likely play a significant role in the future training in VATS surgery. There seems to be many benefits. The amount of training is unlimited. The cost for each procedure is small, once the investment in the simulator is made. Performance scoring can be used for validation and credentialing.

The virtual trainer has advantages in ease of set-up and fidelity to human anatomic variants as well as the ability to improve the model as technology improves. The virtual reality platform can be used as often as one likes, and would be a good starting point for novice VATS lobectomy surgeons. The porcine model can then be used once surgeons gain some operative experience and will facilitate the development of fine dissection skills and gain a “feel” for tissue strength with sharp and blunt dissection of hilar vessels. [38]

Further, the porcine lung block model has been shown to have a high fidelity and is perhaps the best studied and most validated model for Intraoperative teaching VATS lobectomy [39, 40].

The team of department of Thoracic Surgery in Peking University People’s Hospital started to do VATS surgeries since 1992, which is the earliest in China. Our team has made a great contribution on teaching VATS lobectomy in China. The majority of Chinese thoracic surgeons, including many famous ones, were trained in our VATS courses. We hold a national VATS course annually for surgeons inexperienced in VATS procedures. The course includes basic introduction of VATS technique and its clinical application, VATS procedures on anaesthetized dogs, and VATS surgery live demonstration. Inexperienced surgeons benefit much from this kind of course. Then they can start to do simple VATS surgeries after the training. In addition, we also have an advanced course just teaching VATS lobectomy 5–6 times per year. The learners of this course are usually with considerable experience in minor VATS surgeries, but not proficient in VATS lobectomy. They can go to the operating room watching operations near the teaching expert, they can communicate with the operating surgeon timely and get their technique difficulties solved. Then such surgeons can carry on their VATS lobectomies more smoothly. We commonly use a three ports technique for our VATS lobectomies, including a camera hole, a main operating hole and an assist operating hole. Less ports are not good for teaching and learning for new learners. With the third incision, the teaching surgeon can teach, guide, and first assist the trainee efficiently, reaching a safer and faster surgery.

11.7.2 Learning VATS Lobectomy

There are many methods for the introduction of new technology into a thoracic surgery practice. Surgeons can: read articles, atlases, and books; observe surgeons who do the procedure; attend Society of Thoracic Surgeons (STS) University; attend industry-supported courses; and study in animal and cadaver laboratories. An individual surgeon must find the best method or methods for his situation.

11.7.2.1 What Need to Be Prepared?

First, it requires more than one observation or active participation of the surgeon before starting doing VATS lobectomy. It is not easy for a surgeon learning the technique only from reading articles and atlases. Live observation can provide the surgeon a continuous operation process with details, from correct placement of the access incisions to precise dissection of blood vessels, which is of great help to new learners.

In addition, the best approach is for the scrub and circulating nurses to have also observed a live case or two so they can also become familiar with the basics of the procedure.

An additional pre-requisite is the need for the appropriate VATS instrumentation, endostaplers, and the necessary instruments should conversion to an open procedure be indicated. Failure to have the appropriate VATS instruments, thoracoscopes and monitors can result in inadvertent intraoperative injuries, prolong the case, increase conversion rates, and demoralize surgeon and team morale and interest in the procedure.

It is important to remember that an open lobectomy is typically performed via a posterior approach while a VATS lobectomy is almost always an anterior approach. Thus, a VATS lobectomy offers a "different view" for many surgeons. So experience with other VATS procedures such as wedge resections, pleural biopsies and cyst resections is an advantage with respect to port placement and working in a monitor based setting.

Finally, a well selected case is also very important in the beginning of the program. The ideal case should be a lower lobectomy with a small peripheral nodule, as lower lobe usually has less variation of blood vessels [41].

There are several important pre-requisites relative to beginning a VATS lobectomy program. One the most important points is that the entire operating room team (nurses, scrub technicians, first assistants) need to be familiar with open procedures before attempting VATS lobectomies. In addition, there should be an adequate volume of lobectomies (>25/year) in the practice. The surgeon who is performing VATS lobectomy procedures should have done a relative large number of smaller VATS procedures (i.e., wedge resection, lymph node biopsies, etc.). In addition, the surgeon should have observed several "live" VATS lobectomies and, if at all possible, assisted in the operations. There is no substitute (i.e., simulation, workshop, or video) for actual experience when one is adopting a new surgical technique [42].

11.7.2.2 The Learning Curve of VATS Lobectomy

Previous studies on VATS lobectomy have suggested that 50 cases are required to overcome the initial learning curve [41, 43]. However, a number of factors may contribute to this process, including initial supervision by experienced VATS surgeons, the size of the center, and the experience of the surgeon in training.

There is a difference in the learning curve between the surgeon who takes up the procedure from scratch and the surgeon who is taught in a centre with experienced VATS surgeons to supervise. In the centers of the pioneers, the next generation learned the technique under guided supervision. The conditions for those surgeons' learning curves were better due to the possibility of learning under supervision by an experienced VATS surgeon and a better possibility for selecting cases suitable for a training surgeon.

The size of the centre and the potential number of VATS lobectomies to be performed also influence the length of the learning curve. Once you begin with a new technique it is an advantage to perform many operations within a short time frame. If there is only a potential to perform 1 or 2 operations a month, it will take a long time to complete a learning curve. It will be like starting all over every time.

The experience of the surgeon in training is important factor affecting the learning curve. Understanding the anatomy of the lung and experience with the many anatomical variations makes the learning curve shorter.

Ferguson et al. reported that, compared to the established surgeon, if carefully supervised, the first 50 cases by the trainee will be slower, but just as safe in terms of survival, blood loss and complications [31]. Other authors have pointed to a learning curve over their first 50 cases at their own institution, demonstrating reduced times and sometimes reduced blood loss and morbidity after this period [44]. Dunning et al suggested that if the operating surgeon is able to spend a significant training period with a surgeon experienced in VATS surgery, then this greatly enhances their confidence when starting in their own practice. They also recommended a period of training, whilst commencing a VATS lobectomy program in one's own institution with frequent re-visits to the original training institution, as inevitably there will be questions and difficulties which may be addressed by maintaining these links.

11.7.2.3 Developing Proficiency in Video-Assisted Thoracoscopic Lobectomy

The Difference Between Mastery and Proficiency

Competence is the benchmark by which physicians are permitted to perform procedures independently. Developing competence in a complex operation entails performing a sufficient number of procedures to demonstrate consistent safety and efficacy. For minimally invasive lobectomy, this appears to require a minimum of 20 to 30 cases, with estimates as high as 50 operations. Progressing to proficiency in a complex procedure not only necessitates substantial additional operative experience but also requires a qualitative leap in knowledge and performance. Two measures that characterize proficiency are efficiency and consistency.

How Many Cases Is Needed to Become Proficiency?

We studied learning curves for video-assisted thoracic surgery (VATS) lobectomy to determine how long it takes to achieve proficiency by analyzing both intraoperative and postoperative factors for efficiency and consistency. We also assessed whether developing efficiency and consistency require similar time frames.

Our study demonstrated that achieving proficiency in performing VATS lobectomy seems to require more than 100 cases of personal experience to develop efficiency, and attaining consistency requires 200 or more cases [45].

It is needed to be point out that the surgeons involved in our study had no VATS mentorship available as their level of expertise developed, and the presence of mentorship may have substantially shortened the time and case load required to achieve proficiency.

Conclusion

My thoughts as to how to define a learning curve is that having completed your learning curve, as a surgeon, in my opinion, you should be able to perform all types of lobectomy. You should be able to manage an incomplete fissure, and manage adhesions. Your operating time should have reached a steady state at a reasonable level, for example, three hours. You should have a conversion rate below 10 %, and your intraoperative complications should be at least comparable to what you have experienced in open surgery.

A recent Consensus Statement by international VATS lobectomy experts recommended that 50 cases are required by a surgeon to achieve technical proficiency; 50 annual resident cases are required for an institution to be recognized as a VATS lobectomy training center, and 20 cases or more should be performed annually by a surgeon to maintain VATS lobectomy operative skills. Perhaps most significant, 100 % of the 50 international VATS experts recommended that surgeons should be proctored during their initial learning experience [30].

We hope that in the near future every patient with early stage lung cancer, suitable for a VATS lobectomy will be offered the procedure.

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Part II

Minimally Invasive Surgery for Esophageal Cancer

12 General Considerations

Hui Li, Diego Avella Patino, Mark K. Ferguson, Jianfeng Li, Xiao Li, Inderpal S. Sarkaria, James D. Luketich, Yi Feng, and Juan Zhu

Contents

12.1 Overview of Minimally Invasive Esophagectomy

Hui Li

12.1.1 Introduction

Esophageal cancer is the eighth most common cancer and the sixth most common cause of cancer-related death in the world, with an estimated 482,300 new cases and 406,800 cancer deaths in 2008 worldwide [1]. Survival is poor, with a high mortality-to-incidence rate ratio of 0.84. As per the data of the American Joint Committee on Cancer, the postoperative 5-year survival rate of stage I esophageal cancer is about 90%, and decreases to 45% for stage II, 20% for stage III, and only 10% for stage IV patients [2].

Surgical resection has been the gold standard for localized esophageal cancer for decades. However, due to a poor 5-year survival rate, numerous clinical trials have investigated the

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role for multimodality therapy [3]. Esophagectomy is associated with high morbidity and mortality rates, not only because it involves the manipulation of both abdominal and thoracic-mediastinal structures but also because the patients are often malnourished or suffer from a variety of co-morbidities.

During the early 1990s, minimally invasive approaches, either transthoracic or laparoscopic-transhiatal, were proposed as a way to reduce morbidity and mortality associated with this operation. To date, Minimally invasive esophagectomy (MIE) has shown the greatest potential to improve outcomes in patients who undergo esophageal surgery. The application of MIE has been explored and found to be feasible in the management of esophageal cancer, although concern has been expressed about its safety, efficacy, oncologic value, and other advantages that justify longer operative times and higher costs. Data to support the claim that minimally invasive esophagectomy (MIE) is associated with less morbidity and mortality than the open approach exist and continue to accumulate.

12.1.2 Historical Review of MIE

Since the first report of thoracoscopic esophagectomy by Cuschieri et al. [4] in 1992, and later refined by Collard et al. in 1993, the adoption of MIE has increased in many countries [5]. These first efforts involved thoracoscopic esophageal mobilization with subsequent laparotomy for gastric mobilization and a cervical anastomosis. Several groups have reported their experience with excellent results with this technique, which currently represents the most popular MIE technique [6, 7]. Refinements in the thoracoscopic technique have been pioneered by Luketich et al. [8] who have described thoraco-laparoscopic esophagectomy. This technique involves thoracoscopic esophageal mobilization in the left lateral decubitus position, followed by supine laparoscopic gastric mobilization and preparation of the gastric conduit with a standard cervical anastomosis. This combination offers the potential benefit of avoiding the need for thoracotomy and laparotomy, while minimizing pain in the postoperative period and possibly leading to rapid recovery.

A minimally invasive transhiatal esophagectomy (THE) was initially described by DePaula et al. [9] in 1995 and then by Swanstrom and Hansen [10] in 1997 as the first totally laparoscopic esophagectomy. This procedure has been utilized by other groups and has undergone several modifications [11]. The main advantage is direct visualization of the lower mediastinum without blind dissection. Using this technique, a laparotomy is avoided.

To facilitate the abdominal procedure, some groups use a laparoscopic-assisted hand-port system, which provides more tactile control and may potentially decrease operative time [12]. Furthermore, a hand-assisted system has been used in the thoracoscopic phase of the procedure to facilitate exposure into the right thoracic cavity [13].

Other modifications to this technique include a thoracoscopic mobilization of the esophagus and mediastinal lymphadenectomy in the prone position [14]. The main advantages described for prone thoracoscopic mobilization of the esophagus are shorter anesthesia time and better postoperative respiratory function compared with the left lateral position. Additional modifications to MIE involve the use of mediastinoscopic methods to aid superior mediastinal dissection [15]. However, the utility of this approach is limited by the extent of possible lymph node dissection. The mediastinoscopic technique is not routinely performed due to technical limitations and rarely offers any additional benefit.

The first robotic-assisted esophagectomy was reported in 2003 [16]. The esophagus was resected using the transhiatal route with the da Vinci robot. The first report of completely robotic esophagectomy was by Kernstine et al. [17] in 2007, who reported the use of surgical robot in 14 patients undergoing esophagectomy. Eight of the 14 patients underwent completely robotic esophagectomy with operating room time of 11.1 ± 0.8 h and estimated blood loss was 400 ± 300 mL. Cerfolio et al. [18] reported first series of successful Robotic Ivor Lewis with chest anastomosis in 22 patients.

At present, no prospective data comparing robotic esophagectomy with standard laparoscopic or open procedures exists. A prospective, randomized controlled trial comparing complications and outcomes in robotic esophagectomy versus open transthoracic esophagectomy (also known as the ROBOT trial) is under way in the Netherlands, with an expected completion in 2015.

Neoadjuvant chemotherapy and radiation are routinely recommended for patients with locally advanced esophageal cancer [19] have found that MIE can be safely performed in patients who have received neoadjuvant therapy, while others do not recommend the procedure in patients with prior radiation [20]. The impact of neoadjuvant therapy has been evaluated in several randomized studies demonstrating that chemoradiotherapy does not significantly increase the morbidity, mortality, or oncologic outcome compared with conventional surgery. Therefore, the current standard for patients with local advanced esophageal cancer who receive neoadjuvant chemoradiation is esophagectomy, MIE may be offered to these patients without compromising surgical or oncologic outcomes.

12.1.3 Indications for MIE

1. For T1 and T2 esophageal tumors.
2. For patients with locally advanced esophageal cancer who receive neoadjuvant chemoradiation, the minimally invasive approach may be offered without compromising surgical or oncologic outcomes.
3. Patient who have received neoadjuvant therapy . However, the indications for minimally invasive esophagectomy

have been expanded to include more advanced cancers. Now, the indications for minimally invasive esophagectomy are almost the same as those for open surgery.
4. Barrett's esophagus with high-grade dysplasia.
5. The right lung should be deflated during the thoracoscopic procedure to provide a good operative field.
6. Patients must be able to tolerate single-lung ventilation for a sufficient time period.

12.1.4 Contraindications for MIE

1. Extensive pleural adhesions;
2. Prior pneumonectomy, bulky tumors;
3. A tumor infiltrating adjacent structures, especially those with airway involvement.
4. Impaired circulatory or pulmonary function prohibiting single-lung ventilation;
5. Presence of concomitant serious medical conditions such as severe diabetes mellitus, chronic renal failure, or liver cirrhosis;
6. Patients' refusal to undergo thoracoscopic surgery.

12.1.5 Surgical Technique

Several minimally invasive esophagectomy (MIE) techniques have been described and represent safe alternatives for the surgical management of esophageal cancer in centers with high volume and surgeons experienced in MIE. In larger series, MIE has proven to have equivalent postoperative morbidity and mortality rates to open esophagectomy. MIE has also been associated with less blood loss, less postoperative pain, and shorter length of stay in the intensive care unit and hospital. Despite limited data, no significant difference in survival has been observed between open approaches and MIE. The myriad of MIE techniques complicates the debate of defining the optimal approach for the treatment of esophageal cancer. Randomized controlled trials comparing MIE with open esophagectomy are needed to clarify the ideal procedure with the lowest postoperative morbidity, the best quality of life, and the longest long-term survival. Robotic approaches may offer advantages over conventional approaches to MIE. However, similar to MIE, these techniques should be performed at high-volume centers by surgeons who have sufficient experience with the open and MIE techniques.

12.1.6 Physiologic Evaluation of Candidates for Esophageal Cancer Resection

The preoperative evaluation for a patient undergoing an MIE is not different from that for a patient undergoing an open procedure. The two primary issues are whether the esophageal tumor is resectable and whether the patient has good general condition especially sufficient cardiopulmonary reserve. Patients should undergo a thorough evaluation to determine medical suitability for operation. This includes a cardiac stress test and, if indicated, coronary angiography. Patients with a significant tobacco history also should undergo pulmonary function testing. In addition, most patients with locally advanced cancer will have some degree of dysphagia and weight loss before diagnosis.

1. A barium swallow is useful for tumor location and assessment of whether there is extension into the proximal stomach.
2. Esophagoscopy enables direct visualization and assessment of the mucosa and allows for procurement of samples for cytology and histology.
3. CT of the chest and abdomen is used to determine the extent of esophageal thickening and celiac or mediastinal adenopathy and to assess whether there is invasion into the tracheobronchial tree and aorta.
4. PET is useful to identify the likelihood of distant metastases when positive, especially the lack thereof when negative.
5. Endoscopic ultrasound allows imaging and needle aspiration of periesophageal and celiac lymph nodes to complete preoperative staging.
6. Nutritional status should be evaluated by history (weight loss 20%) and chemistry (prealbumin 15).
7. Renal, hepatic, nutritional, and hematologic laboratory assessment.
8. Echocardiogram or stress test (if cardiac disease is suspected).
9. Pulmonary function tests (if pulmonary disease suspected)
10. Arterial blood gas should be considered.

12.1.7 Staging and Selection of Patients for Minimally Invasive Esophageal Cancer Resection

Current management of esophageal cancer is mainly based on exhaustive preoperative assessment. The accuracy of the preoperative staging is essential as the decisions of the tumor board regarding the application of multimodal treatment will be directed according to the accuracy and the specifics of the clinical staging assessment. Standardized assessment of a patient being considered for a curative treatment for early or advanced esophageal cancer includes upper endoscopy, high-resolution contrast computed tomography (CT) scan, positron emission tomography (PET) scanning and endoscopic ultrasound (EUS)

1. Upper endoscopy is performed to identify the proximal and distal extent of the tumor, which may impact the type

of procedure performed; this is often done in the operating room at the time of the operation.
2. CT scan provides useful information regarding longitudinal extension of the tumor especially with the trachea and the aorta (T4B disease).
3. EUS provides excellent information with respect to depth of invasion (T status), but its ability to discriminate subtle differences in T1 disease, i.e., T1a versus T1b, is less exact. Patients with T3 or N1 disease are usually treated with induction chemotherapy before esophagectomy.
4. FDG-PET scan provides the most accurate information regarding potential metastatic disease. As a result, FDG-PET scan increases the accuracy for occult metastasis as much as 20% over CT scanning alone
5. Suspicions of direct invasion of the thoracic aorta or the tracheobronchial tree should be confirmed with MRI scanning and bronchoscopy respectively.
6. Thoracoscopic staging, laparoscopic staging, or both are performed in selected patients who are found to have advanced locoregional disease on imaging studies. The utility of laparoscopy in staging is more relevant with adenocarcinomas of the lower esophagus compared with more proximal tumors. Laparoscopy has been reported to be more sensitive and specific than CT scans in detecting lymph node, peritoneal, and liver metastases.

To date, the staging of the disease is of paramount importance and every treatment decisions should routinely be based on multidisciplinary discussion in the tumor board.

12.1.8 Approaches to Minimally Invasive Esophagectomy

12.1.8.1 The Choice of MIE Approach

Minimally invasive esophagectomy (MIE) strategies have been proposed to decrease morbidity and improve quality of life after esophagectomy. Over the last decades, MIE has expanded worldwide. It is estimated that between 15% and 30% of all esophagectomies use such procedures nowadays [21]. There are now centers who are publishing consecutive series of over 1,000 minimally invasive procedures [22]. MIE includes a huge mix of several techniques including hybrid techniques, full MIE and robotic surgery (Table 12.1) [23]. The most appropriate approach to the esophagectomy will vary from center to center, and the choice of technique depends on adapting the surgical approach to individual physiologic and tumor-related issues in each patient, extent of lymphadenectomy, and surgeon's preference [24]. It seems likely that importance of MIE will exceed hybrid techniques that have been probably at the onset of the training and the development of the techniques. Several surgical techniques for the treatment of esophageal cancer are available, but no clear consensus has established the ideal surgical resection. The most common surgical approaches to accomplish resection of esophageal cancer include transhiatal, Ivor Lewis, and McKeown (three incisions) esophagogastrectomy [25].

Table 12.1 Minimally Invasive Esophagectomy (MIE) techniques

Surgical technique	Abdominal phase	Thoracic phase	Location of anastomosis
Hybrid tranthoracic	Laparoscopic or Hand-assisted	Open	Introthoracic hand-assisted
Hybrid tranthoracic	Open	Thoracoscopic	Introthoracic
Hybrid 3-field	Open	Thoracoscopic	Cervical
MIE 3-field	Laparoscopic or Hand-assisted	Thoracoscopic	Cervical hand-assisted
MIE tranthoracic	Laparoscopic or Hand-assisted	Thoracoscopic	Introthoracic hand-assisted
MIE transhiatal	Laparoscopic or Hand-assisted	NA	Cervical hand-assisted
Robotic	Laparoscopic	Thoracoscopic	Cervica/ intrathoracic

Multiple minimally invasive approaches to esophagectomy have been described that combine thoracoscopic procedures, laparoscopic procedures, or both with various operative positions for the patient and anastomotic techniques.

Some limitations of the laparoscopic and thoracoscopic approaches to esophagectomy include instrumentation, the narrow field of the mediastinum, and the two-dimensional view of conventional equipment. Robotic systems provide the possibility to overcome some of these limitations. Some groups have reported their experience with robotically assisted MIE [26]. This technique allows three-dimensional visualization, improved magnification, and a greater range of instrument motion. This potentially could diminish intraoperative complications during the esophageal dissection in the mediastinum.

12.1.8.2 The Choice of Patient Position for MIE

The two operative positions for MIE are the prone position and the left lateral decubitus position.

MIE has been most commonly performed in the left lateral decubitus position. The advantages of the left lateral decubitus position is easier to explore the surgical field in the upper mediastinum, particularly around the left recurrent laryngeal nerve.

However, the advantages of MIE in the prone position have been reported in a large series of nonrandomized historical control studies. Better operative exposure, improved surgeon ergonomics, shorter operative time, less blood loss, and reduced pulmonary infection were observed in the prone position than in the left lateral decubitus position [27]. To minimize the disadvantages of the prone position and the left lateral decubitus position, some surgeons suggested a hybrid position for MIE: the left lateral decubitus position was selected for the upper mediastinum procedure and the prone position for the middle and lower mediastinum procedure. This hybrid position enables surgeons to immediately convert to from thoracoscopic to open surgery in the event of an emergency, which is an obvious disadvantage of the prone position.

However, no randomized prospective studies have compared the two positions, which might be difficult because of the learning curve for both techniques and because the advantages of each technique are influenced by the patients and the surgical staff at each institution. Thus, a standard approach cannot be determined.

12.1.8.3 The Choice of Anastomotic Location and Techniques

Despite the new developments of minimally invasive surgery, esophagectomy for cancer is still associated with a significant risk of perioperative morbidity and mortality [28]. To reduce morbidity and mortality, it is important at the end of the procedure to create a safe gastric conduit-esophageal anastomosis with low risk of leakage. The safety of anastomosis is of interest and concern to thoracic surgeons, regardless what surgical approach, anastomotic method, or esophageal substitute is used. The concern for anastomotic safety has slowed the general acceptance of the MIE technique, and has restricted the widespread acceptance of these procedures. The application of minimally invasive surgery in esophageal cancer is lagging behind its application in other fields; for example, its use in treating lung cancer [29].

Location of Anastomosis

Risk for anastomotic leakage in the thorax with possibly fatal consequences has resulted in the development of the three-stage approach with a cervical anastomosis by McKeown [30], and the transhiatal approach with a cervical anastomosis by Orringer and Sloan [31]. In case of anastomotic leakage in the neck, a subsequent cervical fistula is a manageable complication. However, some evidence shown that cervical anastomosis has some significant disadvantages, including excessive tension on the anastomosis, an ischemic tip of the gastric conduit resulting in a higher leak rate, a risk for recurrent laryngeal nerve injury, and development of postoperative oropharyneal dysfunction. Therefore, a simple and safe thoracoscopic intrathoracic anastomosis technique has always been the challenge for thoracic surgeons.

An Ivor Lewis procedure may reduce recurrent nerve lesion and other complications associated with a cervical dissection. Moreover, a shorter gastric conduit will permit a more extended gastric resection and a well-vascularized anastomosis lead to less anastomotic leakages and stenosis. This transthoracic procedure may be performed by a minimally invasive approach. MIE is increasingly implemented with potential benefits of having less pain, less respiratory infection, and reduced intensive care unit stay, preserving the completeness of the resection. The combination of Ivor Lewis esophagectomy with minimally invasive surgery has the potential to improve the postoperative outcome.

Techniques of Anastomosis

Anastomosis can be accomplished by a handsewn or stapler technique.

Handsewn Techniques

The first description of a totally endoscopic Ivor Lewis esophagectomy with an intrathoracic anastomosis was reported in 1999 by Watson et al. [32]. They described two patients in which the intrathoracic anastomosis was achieved with a handsewn single-layer technique. However, a higher incidence of dysphagia and a fourfold higher incidence of stricture were found after the handsewn technique. Therefore, stapler esophageal anastomosis is more often used in current clinical practice than handsewn techniques [33].

Stapled anastomosis in the thoracic cavity has been supported by Blackmon et al. [34] who analyzed three techniques of intrathoracic esophagogastric anastomosis: handsewn, circular stapled, and side-to-side stapled anastomosis. In this matched analysis, no significant differences were reported concerning anastomotic leakage.

Stapler Techniques

Stapler technique include circular and side-to-side stapled anastomosis.

Circular Stapled Anastomosis

Transthoracic Technique

In 1997, Lee et al. [35] described a one-stage right lateral thoracoscopic esophagectomy with intrathoracic stapled anastomosis in a series of eight patients with carcinoma of the lower esophagus. Esophago-gastric anastomosis was fashioned by stapling device using the ligature method described by Allsop and Hg [36, 37].

The major difficulty of intrathoracic anastomosis lies in the purse-string suture and anvil head placement, especially by using the thoracoscopic technique. In 2001, Nguyen and colleagues reported the first successful case of totally laparoscopic and thoracoscopic Ivor Lewis esophagectomy. However, the author believed that the intrathoracic anastomosis was technically challenging. Until 2008, they reported another 51 cases of minimally invasive esophagectomy. Fourteen in 45 cases, the anvil was placed transthoracically with a purse-string suture. Only in six cases was a transoral approach used to place the anvil. Therefore, finding a simple and safe technique for thoracoscopic intrathoracic anastomosis has always been the goal of thoracic surgeons.

In past few years, surgeons have created other methods of placing the anvil to obviate the necessity of the placement of a pursestring suture or a manually tied knot, including side-to-side stapler anastomostic technique [38]. However, the placement of the anvil head in the thoracoscopic esophagogastric anastomosis remains the major challenge to thoracic surgeons. So far, the ideal method for placing anvil has still to be found.

Transorally Technique

An important development is the introduction of the anvil transorally into the proximal esophagus, as described originally by Wittgrove et al. [39] for the gastrojejunostomy construction of the gastric bypass in bariatric surgery after the initial work of Sutton et al. in 2002 using a self-adopted circular anvil system [40].

Nguyen et al. [41] described the transoral technique in a series of ten patients to perform the intrathoracic anastomosis after esophageal resection. Campos et al. [42] confirmed the good results using the transoral anvil technique in 37 patients with a distal esophageal cancer.

Side-to-Side Anastomosis

Side-to-side stapled anastomosis is another significant intrathoracic anastomotic technique. Ben-David et al. [43] described in 2010 six patients with gastroesophageal junction cancers in whom after laparoscopic dissection and formation of the gastric conduit, the thorax was approached through a lateral right thoracoscopy. Gorenstein et al. [44] described a slight different side-to-side anastomosis technique in which the proximal esophagus was not stapled, and used the whole lumen for the construction of the side-to-side anastomosis by means of a linear stapler. Some evidence shown that there were no differences for both circular stapled and side-to-side stapled methods.

Summary

There are different techniques used to perform a safe intrathoracic anastomosis after an Ivor Lewis thoracoscopic procedure. None of the techniques are found superior to the others, but stapled anastomosis offered a safe outcome with a low percentage of anastomotic leakage and stenosis. Furthermore, no important differences were found between the two most used stapled anastomoses: the transoral introduction of the anvil, and the transthoracic introduction. Clinical trials are needed to compare different methods to improve the quality of the intrathoracic anastomosis after esophagectomy for cancer.

12.1.9 Type and Conduction of the Anaesthesia

Preoperative evaluation at the anesthesia clinic is advisable for all patients to define the patient's functional status and operative risk.

Two large-bore intravenous (IV) catheters are placed in peripheral arm veins for rapid volume resuscitation during the operative procedure. Note that the average blood loss is less than 500 mL. An epidural catheter augments postoperative pain management to improve pulmonary function. A standard endotracheal tube is used. In the event of a posterior membranous tracheal tear during tumor dissection, the tube can be advanced into the distal trachea or left mainstem bronchus, allowing one-lung anesthesia while the repair is undertaken, thus avoiding a double lumen ET tube.

12.1.10 Pitfalls of Minimally Invasive Esophagectomy

1. Preoperative evaluation requires CT imaging, EUS, and PET imaging. On-table endoscopy is also performed to evaluate tumor extension.
2. The multidisciplinary evaluation of patients with esophageal cancer is essential. Induction therapy esophagogastrectomy is the best option for most patients with T2N0 disease or greater.
3. Careful preservation of the gastroepiploic artery is essential in the creation of the gastric conduit, and the arcade must not be injured during the gastric mobilization.
4. Centers and surgeons with more extensive experience have the best outcomes.
5. The choice of operative approach should be based on tumor location and surgeon experience (Fig. 12.1).

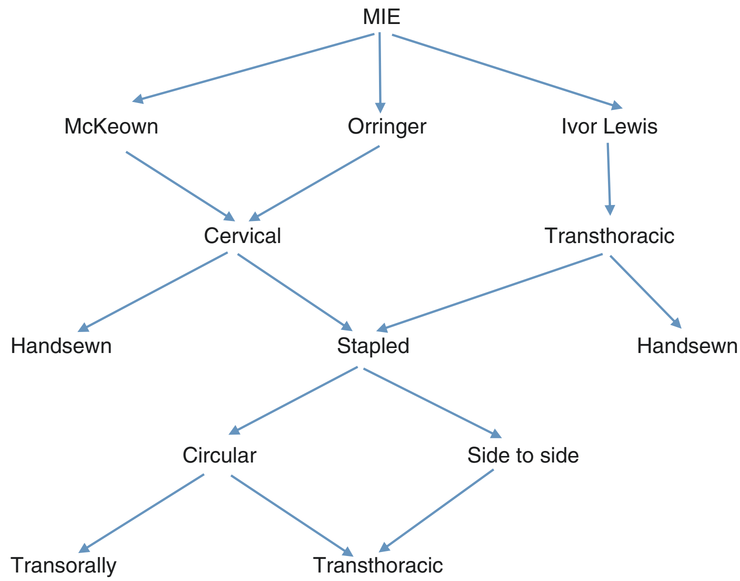

Fig. 12.1 Overview of MIE anastomosis techniques

12.2 Physiologic Evaluation of Candidates for Esophageal Cancer Resection

Mark K. Ferguson

12.2.1 Background

Esophagectomy is a mainstay of curative therapy for adenocarcinoma of the esophagus and gastroesophageal junction, and often plays an important role in the management of squamous cell esophageal cancers. However, whether by virtue of stage, age, or comorbidity, not all patients are appropriate candidates for esophagectomy. In addition to a staging evaluation, the physiologic evaluation of individuals who are potentially operable is key to appropriate patient selection. Assessing risk for esophagectomy determines the need for preoperative interventions to mitigate physiologic risk, focuses the need for perioperative resources, and assists in informed discussions with patients and their families.

More than almost any other common operation, esophagectomy is associated with high risks of postoperative morbidity and mortality. The most common postoperative complications are listed in Table 12.2 [45–48]. Pulmonary complications typically top the list, although minimally invasive approaches to esophagectomy have mitigated their risk somewhat. The risk continues after the traditional 30-day assessment period, with mortality rates increasing by 2-fold by 90 days postoperatively [49]. Complications are associated with increased costs of medical care and decreased quality of life [50–52]. There is also evidence that postoperative complications also adversely affect long-term survival [53].

There are reasonable alternatives to surgical therapy for esophageal cancer, including definitive chemoradiotherapy and palliative radiation therapy. Although the alternative therapies may not provide as good long-term outcomes as when resection is performed, their immediate risk is less than that associated with surgery. It is therefore appropriate to perform a careful physiologic evaluation of esophagectomy candidates in order to adequately assess their risk of postoperative morbidity and mortality and optimize patient selection for surgery.

Table 12.2 Frequency of complications after esophagectomy

Category	Lin 2004 [45]	Rice 2005 [46]	Markar 2015 [47]	Sihag 2016 [48]
Pulmonary	32%	17%	38%	26%
Cardiovascular	26%	15%	14%	–
Infectious	16%	13%	25%	13%
Surgical	27%	10%	17%	16%
Other	34%	8%	–	–

12.2.2 Pulmonary Assessment

Pulmonary complications are generally considered to be the most common after esophagectomy and contribute the most to the incidence of operative mortality. Complications after esophagectomy have recently been codified into a consensus-based list [54]. Pulmonary complications typically include pneumonia, acute aspiration, adult respiratory distress syndrome (ARDS), pleural effusion, pneumothorax, atelectasis due to mucus plugging, respiratory insufficiency, tracheobronchial injury, and persistent air leak. Factors associated with pulmonary complications in multivariable analyses include advanced age, poor spirometry, low diffusing capacity, poor performance status, renal dysfunction, diabetes, hypertension, alcohol consumption, prior cardiac surgery, underweight status or sarcopenia, and current cigarette use [55–59]. In addition to these typical clinical factors, it has also been shown that colonization of the airway with pathological bacteria is associated with an increase in the incidence of pneumonia [60]. Similar findings have been reported for pathologic colonization of dental plaque, and efforts to eradicate such plaque have been shown to reduce the incidence of postoperative pneumonia after esophagectomy [61, 62]. A number of studies, including a randomized trial, have demonstrated no increased risk of pulmonary complications after induction chemoradiotherapy [45, 46, 63].

Scoring systems have been developed that help identify patients at increased risk for postoperative pulmonary complications. One is based on a composite score comprised of age, spirometry (forced expiratory volume in the first second, or FEV1), diffusing capacity, and performance status [55]. The utility of this system has been validated in a large contemporary single institution dataset [64].

Most of the predictors of pulmonary complications can be assessed with a careful medical history (age, alcohol consumption, cardiac status, body mass index, blood pressure, smoking history; diabetic status), physical examination (performance status), and simple blood work (serum creatinine). The single evaluation that may not be performed routinely is pulmonary function testing, including spirometry and diffusing capacity. This is particularly important in patients undergoing induction therapy, in whom a substantial change in lung function as a result of the induction therapy, particularly higher doses of radiation therapy, with a mean reduction in DLCO% of 20% [65]. These patients should have baseline lung function testing prior to initiation of therapy, and retesting following completion of induction therapy. A decrease in diffusing capacity of more than 10 percentage points should lead to consideration of postponing surgery until the DLCO improves; typically a period of 1 month is sufficient for this to occur.

There are methods that may mitigate the adverse effects of lung function on postoperative outcomes. Inspiratory muscle training preserves muscle strength postoperatively and has been shown to decrease the incidence of overall pulmonary complications [66–68]. Preoperative nutritional support has been shown to reduce the incidence of pulmonary complications in some studies, but strong evidence to support this is lacking [69]. Obviously cessation of tobacco use and alcohol must be accomplished at least several weeks in advance of the planned operation. Most of the other risk factors are not remediable.

12.2.3 Cardiovascular

Cardiovascular complications after esophagectomy include arrhythmias (particularly atrial fibrillation), thromboembolic events, and, rarely, myocardial infarction. Risk factors for myocardial infarction include hypertension, diabetes, and coronary artery disease as manifested by prior myocardial infarction or the presence of angina. Most patients can easily be screened for this complication using the Revised Cardiac Risk Index (RCRI), which provides an algorithm for evaluation for major non-cardiac surgery. This and professional society guidelines indicate when additional testing is necessary [70, 71]. Intervention for patients who are at increased risk due to coronary artery disease should be considered preoperatively.

Atrial fibrillation presents an important challenge to the esophagectomy patient. New onset atrial fibrillation frequently is associated with other complications, and may be a harbinger of an undiagnosed problem such as anastomotic leak or pneumonia. The incidence of new postoperative atrial fibrillation is 15–20% [72, 73]. Preoperative risk factors for atrial fibrillation include male sex, advanced age, diabetes, a prior cardiac history, and induction therapy. At present there are no means for reducing preoperative risk factors for atrial fibrillation.

Venous thromboembolism (VTE) is an insidious complication that can affect esophagectomy patients from the period of induction therapy and extending a month after the operation. Risk factors include older age, female sex, black race, increased comorbidity index, prior VTE, and lower socioeconomic status [74]. An overall reported incidence of 6% [75] is likely underestimated because of lack of routine screening and absence of screening/reporting during the preoperative period. In my institution the overall incidence of symptomatic perioperative VTE is 11%, and among those undergoing induction therapy the incidence is 13% [unpublished data]. The development of VTE is associated with a 2-fold increase in operative mortality [74]. Use of preoperative screening for VTE in patients who are at increased risk, especially those with chronic venous stasis changes and a history of prior VTE, should be routine. In patients at substantially increased risk, prophylactic insertion of a temporary inferior vena cava filter should be considered. Whether routine use of prophylactic anticoagulation should be considered in patients undergoing induction therapy is a topic of current discussion.

12.2.4 Infectious

Infectious complications are common after esophagectomy. They are categorized as, in order of decreasing frequency, anastomotic leak, empyema, wound infection, and intraabdominal abscess. The etiologies of infectious complications are quite varied, and include anastomotic leak, aspiration, respiratory compromise, and intraabdominal iatrogenic injury. Risk factors for complications include advanced age, male gender, black race, and multiple comorbidities [76]. There is no specific evaluation possible for assessing the risk of infectious complications; it is appropriate to use prophylactic intravenous antibiotics as the most likely preventive measure currently available.

12.2.5 Nutrition

Many patients with esophageal cancer suffer weight loss and associated nutritional deficiencies prior to beginning treatment. This may be a result of dysphagia resulting from the primary tumor, loss of appetite, and cancer cachexia. Cachexia is manifested by loss of fat and skeletal muscle as well as systemic inflammation; it is a primary cause of protein malnutrition, which in turn affects tolerance to aggressive therapies including surgery [77]. A combined assessment of BMI and percentage of normal body weight lost is a reliable predictor of mortality, particularly in patients with esophageal cancer [78]. Increased catabolism can be assessed by measurement of C-reactive protein (CRP), serum albumin, and the Glasgow Prognostic Score or its modification (GPS/MGPS) [79, 80]. Other elements of cachexia, including decreased caloric intake, reduced fuel stores, and impaired function, are readily measured through calorie counts, history and physical, and screening for frailty.

Unfortunately, anticancer therapies, specifically including induction therapy, are associated with weight loss and can contribute to the development of pre-cachexia or cachexia in patients for whom esophagectomy is intended. In one study two-thirds of patients experienced substantial weight loss after induction therapy, and 50% of the patients suffered loss of more than 10% of their normal body weight [81].

Interventions for severe nutritional deficiencies have not been proven successful in the short term, and long-term interventions do not take into consideration the need for timely and aggressive management. Parenteral nutrition has offered little benefit and some have demonstrated negative outcomes associated with this intervention. Laparoscopic placement of a feeding jejunostomy tube is appropriate in undernourished patients and those who have moderate to severe dysphagia, particularly patients for whom induction therapy is planned. Once a patient transitions from a pre-cachectic state to cachexia, interventions are unlikely to be successful. Progression to refractory cachexia is associated with patients being unresponsive to anticancer therapies, and portends a short expected survival.

12.2.6 Frailty and Sarcopenia

Sarcopenia is a condition represented by abnormally low core muscle mass and density. Frailty is a state of increased vulnerability to physiologic stressors, which reduces resiliency and places affected patients at increased risk for postoperative complications. There is increasing recognition that sarcopenia and frailty are closely linked. Frailty or pre-frailty is present in about many patients undergoing esophagectomy for cancer. In my institution it pre-frailty or frailty is identified in about 70% of patients who are candidates for major thoracic surgery. Its presence is associated with a substantial increase in complications and mortality after esophagectomy. In particular, a modified frailty index is linearly associated with increasing incidences of life-threatening complications overall, pneumonia, respiratory failure, cardiac arrest and myocardial infarction, VTE, shock, and operative mortality [82]. With the exception of age, frailty was the only determinant of adverse outcomes after esophagectomy in a multivariable analysis in Hodari's study.

Sarcopenia is present in 25–75% of patients undergoing esophagectomy for cancer [59, 83]. Its presence is associated with increased postoperative complications after esophagectomy. It has been shown to be an independent predictor of postoperative respiratory complications [58, 59]. Sarcopenia may not be present at the time of diagnosis but instead may develop during induction therapy for esophageal cancer, a change that is associated with an increased rate of postoperative complications [83, 84].

Frailty can easily be assessed using simple screening tools in the outpatient setting. A typical screening assessment includes gait speed, grip strength, weight loss, energy levels, and the level of recent physical activity. Patients may be classified using the Fried criteria as not frail, pre-frail, or frail [85]. Assessment of sarcopenia is not as simple. In general, underweight patients are often sarcopenic, especially older underweight patients. But a large segment of the population, the so-called sarcopenic obese patients, cannot be screened using this assumption. Methods are being developed for automated measurement of core muscle density and mass that may facilitate the diagnosis of sarcopenia using routine staging computed tomography (CT) scans in the near future.

It may be possible to mitigate the adverse effects of sarcopenia and frailty on postoperative outcomes through strength training. This is aimed at improving core muscle strength, balance, and endurance. Strength training for a period of only 4 weeks has been shown to substantially improve muscle strength and endurance in elderly frail patients [86]. Studies are currently underway to determine whether these improved metrics correlate with improved postoperative outcomes.

12.2.7 Other Comorbidities

Hepatic insufficiency and esophageal cancer, particularly squamous cell cancer, may share a common etiologic pathway such as alcohol abuse. Fortunately there are few patients who are potential candidates for esophagectomy who also suffer from cirrhosis. Hepatic cirrhosis raises concerns for esophagectomy because of related blood coagulation disorders, the risk of esophageal and gastric vascular abnormalities may that preclude successful reconstruction, the development of difficult to manage ascites and pleural effusions, and the possibility of hepatic encephalopathy. Common etiologies for mortality in patients with cirrhosis include pneumonia, hepatorenal syndrome, and sepsis. It is suggested that patients in Child-Pugh 'A' cirrhosis may be a reasonable candidate for esophagectomy, but patients in Child-Pugh 'B' and 'C' are at substantially increased risk for mortality and likely should not be recommended for esophagectomy [87, 88].

Preexisting renal insufficiency poses perioperative management problems for esophagectomy patients. Fluid shifts during long operations and the occasional need for high volume fluid resuscitation over a period of several days can create challenges. There is no strong evidence to suggest that preoperative renal insufficiency increases the risk of postoperative complications or surgical mortality after esophagectomy.

The presence of diabetes offers management challenges in the perioperative period that must be considered, including glucose management during preoperative dietary changes, intraoperative management of glucose levels, and changing needs for insulin in the postoperative period as patients are transitioned to enteral feedings and then to oral intake. Diabetes is a risk factor for surgical complications, specifically anastomotic leak and dehiscence [89, 90].

12.2.8 Recommended Evaluation

Candidates for esophagectomy should be carefully evaluated prior to receiving recommendations regarding surgery (Table 12.3). A careful history will disclose information regarding general activity levels and any recent changes, performance status, weight loss, dysphagia, caloric intake, cardiovascular risk, and co-morbidities. Formal screening for frailty and nutritional deficiencies should be performed in appropriately selected patients. All patients should undergo pulmonary function testing and assessment of cardiac risk score (RCRI). Patients who are at increased cardiac risk should have additional evaluation by a cardiologist. Cardiopulmonary rehabilitation can be considered in selected patients who are de-conditioned but are able and motivated to improve their physical condition preoperatively.

Table 12.3 Suggested preoperative assessment related to specific postoperative complication categories

Risk category	Patient group	Recommended assessment
Pulmonary	All	Spirometry, diffusing capacity, evaluate oral hygiene
Cardiac	All	Calculate Relative Cardiac Risk Index (RCRI)
Vascular	Increased risk for venous thromboembolism	Lower extremity duplex scan
Nutrition and infection	Patients with significant weight loss	C-reactive protein, albumin, Glasgow Risk Score
Frailty and sarcopenia	Patients ≥65 years of age	Frailty screening, calculation of BMI
Other organ dysfunction	Suspected hepatic insufficiency Renal dysfunction	Liver function tests Creatinine clearance

12.2.9 Conclusions

Esophagectomy represents one of the highest risk routine operations for cancer. In addition to the extent of the operation, risk is increased because patients are often deconditioned and malnourished, and many have recently completed induction therapy. Careful assessment across a number of domains is essential in assessing risk and in making appropriate recommendations that balance oncologic outcomes with perioperative risks.

12.3 Staging and Selection of Patients for Minimally Invasive Esophageal Cancer Resection

Diego Avella Patino and Mark K. Ferguson

12.3.1 Introduction

There is considerable morbidity and mortality associated with esophageal resections. These are related to perturbations in respiratory muscle function, substantial interstitial fluid shifts, contamination of the surgical spaces, occasional recurrent nerve or thoracic duct injury, and a high incidence of anastomotic leak, to mention just a few contributing factors. The frequent use of induction chemotherapy or chemoradiotherapy may compound these risks. Although perioperative complications associated with esophagectomy have decreased as a result of increasing regionalization of care and the introduction of minimally invasive techniques, the mortality rate is still about 5% and morbidity rates range from 15–50% [91, 92]. Given these risks, appropriate selection of patients for esophagectomy is crucial in optimizing operative outcomes. Selection is based on clinical cancer stage and specific patient characteristics, including anatomy, physiology, and comorbidities. Surgeon experience and judgment are critical in this endeavor.

12.3.2 Esophageal Cancer Staging

The incidences of squamous cell carcinoma (SC) and adenocarcinoma (AC) of the esophagus have increased worldwide over the last decade [93, 94]. Historically, important variations among staging and treatment modalities around the world have made the comparison of treatment outcomes difficult. Fortunately, unified criteria for staging esophageal cancer derived from a collection of worldwide data were first established for the Seventh Edition of the American Join Committee on Cancer (AJCC)/International Union Against Cancer (UICC) manual [95]. Anatomic and histologic variables were incorporated, including histological type and grade, tumor location, and number of lymph nodes involved.

In Western countries routine staging studies include a combination of endoscopic ultrasound (EUS) with or without EUS-directed needle aspiration (EUS-FNA), computed tomography (CT), and positron emission tomography fused with CT (PET/CT). Some centers routinely perform abdominal or neck ultrasound to evaluate for liver nodules and enlarged cervical or supraclavicular nodes. In developing countries the routine use of many of these modalities is considerably constrained by access and cost. Clinical staging in many of these countries is limited to CT. Staging of the primary tumor is performed with CT and EUS, and in select circumstances bronchoscopy. Nodal staging is accomplished with CT, PET, and EUS. Evaluation of distant metastases is performed with CT, PET, and possibly EUS to evaluate for potential liver metastases or nodal metastases outside of the regional nodal stations.

Metastatic disease to the peritoneal cavity is difficult to identify with routine testing. This is particularly relevant in patients with distal esophageal and gastroesophageal junction tumors because of the higher rate of metastases to the peritoneal cavity. Laparoscopy and peritoneal fluid cytology have a sensitivity of 96% to detect peritoneal metastases particularly in patients with esophageal AC [96]. Some studies have demonstrated un upstaging in close to 12% of patients with esophageal tumors after staging laparoscopy who did not have evidence of peritoneal involvement in the traditional radiographic methods (CT, PET/CT, EUS) [97]. However, the risks and costs associated with an additional anesthetic and surgical procedure should be taken into consideration. In addition, patients undergoing minimally invasive esophagectomy can have a thorough assessment of the peritoneal cavity before proceeding with a formal resection, thus eliminating the need for a prior staging laparoscopy. Occasionally, mediastinoscopy, thoracoscopy, bronchoscopy (routine for tumors abutting the major airways) or image-guided percutaneous biopsies are utilized when suspicious abnormalities are identified during routine assessment.

12.3.2.1 Esophageal Cancer Staging System

Location

The esophagus is divided into four anatomic regions for purposes of classification and staging: cervical esophagus (from the cricopharyngeous muscle to the sternal notch); upper thoracic esophagus (from the sternal notch to the azygos vein); midthoracic esophagus (from azygos vein to the inferior pulmonary veins); and lower thoracic esophagus (from the inferior pulmonary veins to the first 5 cm of the stomach [95] (Fig. 12.2). Cervical cancers are not included in the esophageal cancer staging system, as they are primarily treated in a manner similar to head and neck cancers. Squamous cell carcinoma arises 10% of the time in the upper third, 58% of the time in the middle third and 32% in the lower third of the esophagus [99]. The influence of the location of adenocarcinomas was not incorporated to the 7th edition of the staging system because the overwhelming majority of adenocarcinomas of the esophagus are located in the lower third of the esophagus or the gastroesophageal junction. Tumors located within the first 5 cm of the stomach that invade the gastroesophageal junction (GEJ) are included as part of the esophageal cancer staging because they behave biologically like esophageal cancers [100].

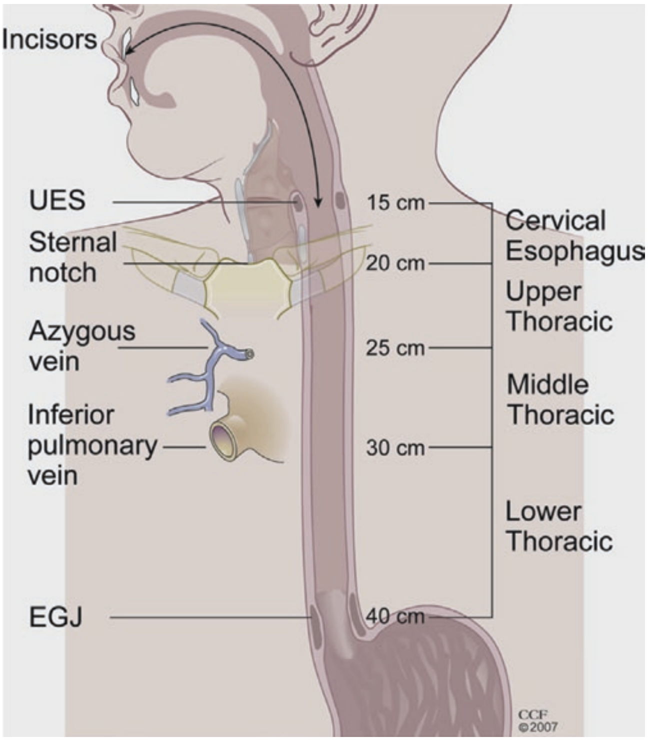

Fig. 12.2 Anatomical division of the esophagus. *UES* upper esophageal sphincter, *EGJ* esophagogastric junction (Adapted with permission from Rice et al. [98])

Primary Tumor Classification (T)

T corresponds to the extent of local invasion of the primary tumor. T1 is subdivided into T1a (invasion limited to the mucosa) and T1b (invasion to the submucosa). Lesions limited to the mucosa (T1a) have a 0–3% risk of lymph node involvement, whereas lesions that penetrate the submucosa (T1b) h ave a 15–50% risk of lymph node involvement preoperative [101, 102]. Invasion to the deepest third of the submucosa has the highest rate of metastases to lymph nodes, whereas invasion of the two more superficial thirds of the submucosa has similar rate of lymph node invasion compared to invasion limited to the mucosa [103]. T2 tumors extend into but not through the muscularis propria, and T3 tumors extend through the muscularis propria but do not invade surrounding structures. T4 represents the deepest invasion of the esophageal wall with involvement of neighboring organs. Based on the potential for an en bloc resection of the organs involved, T4 is divided in T4a and T4b (Table 12.4).

CT signs of tumor invasion into adjacent organs include loss of the normal para-esophageal fat planes as well as signs of fibrosis or inflammation. However, CT and PET/CT have a poor sensitivity for assessment of the primary tumor depth, only reaching 67% compared to EUS [104].

EUS is the preferred method for evaluating the depth of tumor invasion. The overall accuracy of EUS is 80–90%, which is superior to CT or PET/CT [105, 106]. The accuracy of EUS varies by T stage and the frequency of the ultrasound signal. Lower frequencies enable a greater depth of view but provide less detail. The most commonly used echoendoscopes, which emit a frequency of 5–12 MHz, do not visualize the muscularis mucosa very well. In patients with Barrett's esophagus in whom early esophageal cancers are frequently found, the echographic assessment of the muscularis mucosa is even more difficult due to inflammation and frequent duplication of this layer [107, 108]. Low frequency echoendoscopes are associated with a T staging accuracy for early superficial tumors of only 49%. Higher frequency ultrasound (HFUS) probes increase the accuracy to 64% [109]. Due to its increased accuracy in determining the depth of early superficial tumors, endoscopic mucosal resection (EMR) has emerged as an alternative that permits simultaneous tumor diagnosis, T staging and possible curative treatment for superficial tumors.

Table 12.4 TNMG classification [95]

T	Tumor depth extent
TX	Primary tumor can not be assessed
T0	No evidence of primary tumor
Tis	High-grade dysplasia
T1	Tumor invades lamina propria, muscularis mucosa or submucosa
T1a	Tumor invades lamina propria or muscularis mucosa
T1b	Tumor invades submucosa
T2	Tumor invades muscularis propria
T3	Tumor invades adventitia
T4	Tumor invades adjacent organs
T4a	Tumor invades pleura, pericardium or diaphragm (resectable)
T4b	Tumor invades other adjacent organs (aorta, trachea, vertebral bodies, etc) (unresectable)
N	**Regional nodes involvement**
NX	Regional lymph nodes can not be assessed
N0	No regional lymph nodes metastases
N1	Metastases to 1–2 regional lymph nodes
N2	Metastases to 3–6 regional lymph nodes
N3	Metastases in 7 or more regional lymph nodes
M	**Distant metastases**
M0	No distant metastases
M1	Distant metastases
G	**Histologic grade**
G1	Well differentiated
G2	Moderately differentiated
G3	Poorly differentiated
G4	Undifferentiated

Regional Lymph Node Classification (N)

N refers to the status of locoregional lymph nodes, including any paraesophageals node from the cervical to the celiac regions regardless of the location of the primary tumor [95].

Esophageal lymphatics are located in the submucosal layer and can drain omni-directionally to mediastinal, cervical and abdominal lymph nodes (Fig. 12.3). Typically, cervical and upper thoracic esophageal tumors drain preferentially to cervical nodes and distal esophageal tumors drain to abdominal lymph nodes. Midthoracic esophageal tumors frequently spread in both directions. However, cervical nodal involvement has been reported in 21% of patients with SC located in the lower third of the esophagus [110]. The rate of lymph node invasion increases with advancing T status, with nearly 80% of T3 tumors having nodal involvement [111]. The staging system subdivides lymph node staging in four groups depending on the number of nodes involved, which is a predictor of long-term survival (Table 12.4) [95]. Dissemination of disease to lymph nodes beyond the loco-regional boundaries is considered metastatic disease.

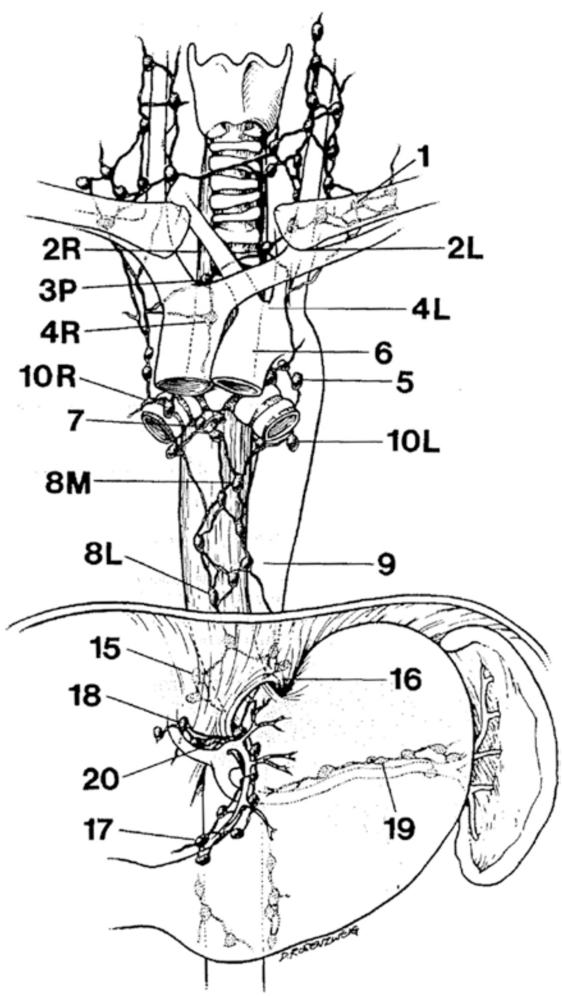

Fig. 12.3 Esophageal lymphatics (Adapted with permission From Surgery of the Alimentary Tract. 5th edition. Carcinoma of the esophagus and cardia)

The accuracy of CT scan in assessing local LN involvement, which is based on ill-defined size criteria, ranges from 50 to 70% [112]. Adding PET to the CT scan does not improve the sensitivity of the assessment of local lymph node involvement [113, 114]. EUS of suspicious lymph nodes has a diagnostic accuracy approaching 75% [115]. Adding fine needle aspiration to the EUS increases the accuracy from 70 to 93%, the sensitivity from 63 to 93%, and the specificity from 81 to 100% [116].

Classification of Metastatic Disease (M)

Metastatic disease is subdivided into nonregional lymph nodes (M1) and distant metastases (M2) [95] (Table 12.4). Nonregional lymph nodes include middle cervical, upper cervical, and retroperitoneal nodes inferior to the celiac axis. The most common places for distant metastases, in descending order, are liver, lung, bone and adrenal glands [117]. About one third of patients with esophageal cancer have metastatic disease at the time of diagnosis, which is associated with a 3% 5-year survival. PET/CT is the optimal method for the diagnosis of distant metastatic disease, with a good sensitivity and specificity. About 20% of metastatic disease is diagnosed with PET/CT that is not detected with CT scan or EUS, potentially preventing futile surgery [118, 119].

Histologic Grade (G)

The complex interplay between histologic type, histologic grade, and tumor location was incorporated into the 7th edition of the AJCC classification. The histological grade is an important component of the staging in early tumors (Tables 12.5 and 12.6). Squamous cell tumors with less differentiation tend to have a worse prognosis than adenocarcinomas with similar degrees of differentiation [95].

Table 12.5 Staging system for adenocarcinoma [95]

Stage	T	N	M	G
0	Tis	N0	M0	G1
IA	T1	N0	M0	G1–2
IB	T1	N0	M0	G3
	T2	N0	M0	G1–2
IIA	T2	N0	M0	G3
IIB	T3	N0	M0	Any
	T1–2	N1	M0	Any
IIIA	T1–2	N2	M0	Any
	T3	N1	M0	Any
	T4a	N0	M0	Any
IIIB	T3	N2	M0	Any
IIIC	T4a	N1–2	M0	Any
	T4b	Any	M0	Any
	Any	N3	M0	Any
IV	Any	Any	M1	Any

Table 12.6 Staging system for squamous cell carcinoma [95]

Stage	T	N	M	G	Location
0	Tis	N0	M0	G1	Any
IA	T1	N0	M0	G1	Any
IB	T1	N0	M0	G2–3	Any
	T2–3	N0	M0	G1	Lower
IIA	T2–3	N0	M0	G1	Upper, middle
	T2–3	N0	M0	G2–3	Lower
IIB	T2–3	N0	M0	G2–3	Upper, middle
	T1–2	N1	M0	Any	Any
IIIA	T1–2	N2	M0	Any	Any
	T3	N1	M0	Any	Any
	T4a	N0	M0	Any	Any
IIIB	T3	N2	M0	Any	Any
IIIC	T4a	N1–2	M0	Any	Any
	T4b	Any	M0	Any	Any
	Any	N3	M0	Any	Any
IV	Any	Any	M0	Any	Any

12.3.2.2 Response to Induction Therapy

The goals of induction therapy include decreasing the tumor burden, potential downstaging the tumor and possibly increasing the chances of an R0 resection. Pathological staging after induction therapy has better prognostic value than pretreatment (clinical) staging for both AC and SC [120, 121]. Patients who are downstaged after induction therapy have a better survival rate than patients with similar clinical tumor stages who did not undergo induction therapy.

PET/CT has higher accuracy than EUS and EUS-FNA in assessing therapeutic response to induction therapy [122, 123]. A decrease in maximum standardized uptake value (SUV max) of 35–60% between the baseline PET/CT and post-induction therapy PET/CT correlates with a low percentage (<10%) of viable cells in the resected specimen and better survival rates [124, 125]. Furthermore, a persistent positive uptake in the primary tumor greater than an SUV max of 4 is consistent with residual viable tumor and correlates with poor outcomes [126]. Potential false positives can be seen in the setting of a recently performed endoscopic guided biopsy and esophagitis or ulceration of the esophagus mimicking viable tumor.

Seventeen percent of patients develop systemic metastatic disease over the course of induction therapy that precludes surgery [127]. This is more commonly seen in patients with more locally advanced tumors. A whole-body PET/CT may be useful after induction therapy to rule out systemic disease in patients with locally advanced tumors.

12.3.2.3 Prognosis by Stage

The staging groups are created with the aim of illustrating declining survival with increasing stage group, and ideally provides for distinctly different survival between groups and similar survival within a group. A combination of cancer characteristics determines prognosis and therefore stage grouping of esophageal cancer. Early stage adenocarcinoma has better survival than early stage squamous cell carcinoma. Survival decreases as T classifications increase for both histologic types and N0 cancers. The prognosis of esophageal cancer correlates most strongly with nodal status. At the time of diagnosis many patients have involvement of regional lymph nodes, a feature associated with poor 5-year survival. For node positive cancers, as the number of involved lymph nodes increases, survival decreases but remains dependent upon depth of invasion (T) for both histologic types. The 5-year survival rates for tumors based on a combination of anatomic and non-anatomic variables are represented in Figs. 12.4 and 12.5 [100].

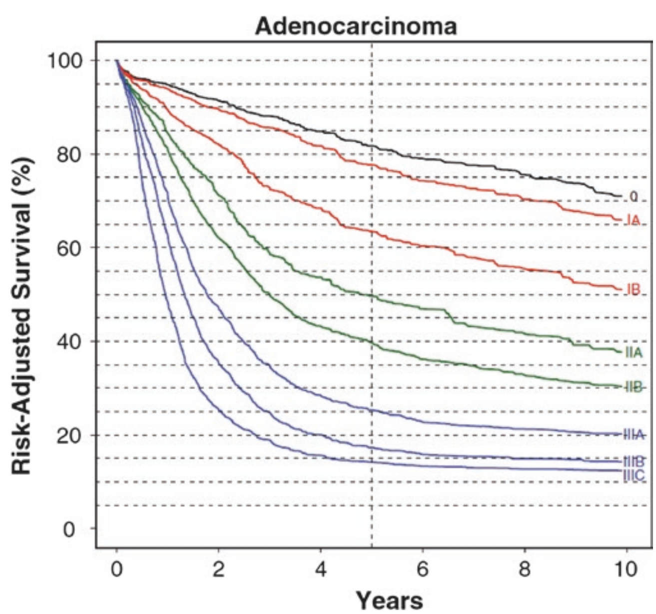

Fig. 12.4 Risk-adjusted survival for adenocarcinoma according to the American Joint Committee on Cancer Cancer Staging Manual, 7th edition, stage groups (Adapted with permission from Rice et al. [128])

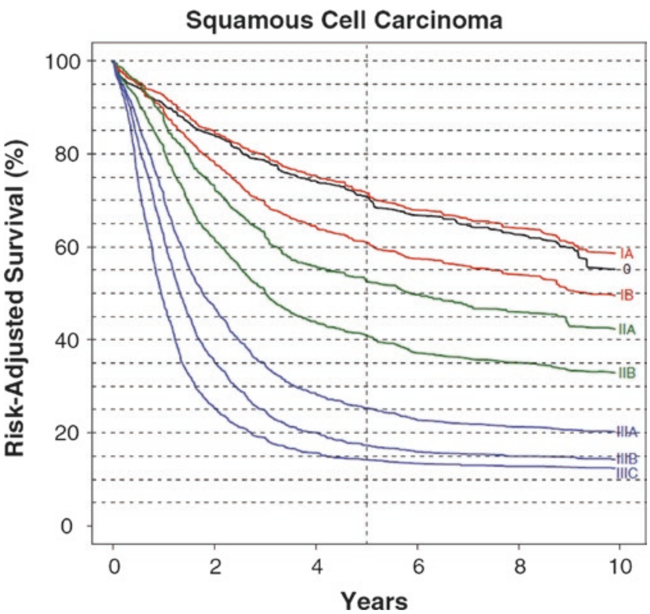

Fig. 12.5 Risk-adjusted survival for squamous-cell carcinoma according to the American Joint Committee on Cancer Cancer Staging Manual, 7th edition, stage groups (Adapted with permission from Rice et al. [128])

12.3.3 Selection of Patients for Minimally Invasive Esophagectomy

The use of minimally invasive esophagectomy (MIE) has increased substantially since the feasibility of its routine use was demonstrated in the late 1990s. Some centers have reported series of more than 1,000 patients with comparable or better results than those published for open esophagectomy [129]. Meta-analyses have demonstrated similar 30-day mortality and 3-year survival comparing MIE to open esophagectomy [130]. Randomized controlled trials and meta-analysis have demonstrated that MIE has a lower rate of respiratory complications, shorter hospital length of stay and improved short-term quality of life, with oncologic results comparable to open esophagectomy [131, 132]. The number of lymph nodes resected with MIE is significantly greater than with open approaches. This outcome might be attributed to an improved visualization of the surgical field with the MIE [133]. No difference in long-term survival benefit has been reported in small series but definitive evidence for improved oncologic results associated with MIE is lacking [134, 135].

Early T stage tumors (pTis-pT1b) without nodal involvement are amenable to surgical therapy alone (esophagectomy or endoscopic mucosal resection). Recommendations for treatment of tumors with nodal involvement or more advanced T stage (T2-4a) include multimodality approaches involving induction therapy (chemotherapy or chemoradiotherapy) followed by surgery. For more advanced disease (T4b) in the absence of distant metastases, definitive chemoradiation is the treatment of choice. Some patients may benefit from salvage esophagectomy when there is persistent or recurrent local disease after definitive chemoradiation that is completely resectable [136, 137].

Based on the reported better perioperative outcomes and equivalent oncologic benefits for MIE relative to open esophagectomy, MIE is appropriate for most resectable esophageal tumors. The lack of a surgeon's experience is perhaps the main limitation for use of a minimally invasive approach. In the early experience with MIE, patients were selected who had benign disease or early stage tumors and had not undergone induction therapy. There is no question that induction therapy, particularly radiation therapy, increases the intraoperative technical challenges of MIE. However, most surgeons have had to develop expertise in MIE while including patients undergoing induction therapy from their initial forays with the technique, as most centers don't have a sufficient number of patients with early stage or benign disease to facilitate the learning curve. Our experience has been that induction therapy does not importantly alter the surgical outcomes.

Patients undergoing a salvage esophagectomy, defined as an esophagectomy performed more than a few months after definitive chemotherapy or chemoradiotherapy, present special challenges to using a minimally invasive approach. Periesophageal fibrosis can be particularly bothersome, and adequate dissection of regional lymph nodes is often difficult. Moreover, it's often not appropriate to perform the anastomosis in the irradiated field, often requiring surgeons to alter their usual surgical approach.

When the stomach is not available due to extensive involvement of the stomach by the tumor itself or a history of prior gastric surgery, an open approach with colonic or jejunal interposition may be considered. For T4a tumors involving the pericardium or diaphragm, or for tumors for which there is concern about possible aortic or airway involvement, an open approach might be necessary. In patients with a hostile hemithorax or abdomen owing to prior surgery or inflammatory conditions a minimally invasive approach might be challenging due to presence of dense adhesions. If the safety of the procedure seems compromised, conversion to open is appropriate (Table 12.7). Recent large series of MIE have reported a low rate of conversion to an open thoracic approach. The main reasons for conversion are bleeding and the presence of dense adhesions [138, 139]. Neoadjuvant therapy has no demonstrable effect on the rate of complications or conversion to open [139]. Conversion from laparoscopic to laparotomy for the abdominal part of the procedure is rarely reported.

Table 12.7 Contraindications for MIE

Stage
T4a
Location
High thorax or thoracic inlet
Gastric conduit unavailable
History of gastric surgery
Extensive invasion of the stomach by tumor
Technical considerations
Presence of extensive thoracic or peritoneal adhesions
Lack of surgeon's experience with MIE

12.3.4 Conclusions

Careful preoperative staging of esophageal cancer is essential in identifying appropriate candidates for surgical resection. Due to potential oncologic benefits and better perioperative outcomes, MIE is advantageous compared to an open approach for a large percentage of resectable esophageal tumors. Accurate staging of patients is critical in determining resectabiity and for identifying potential contraindications for use of a minimally invasive approach.

12.4 Approaches to Minimally Invasive Esophagectomy

Jianfeng Li and Xiao Li

12.4.1 The Evolution of the Approaches to Minimally Invasive Esophagectomy

Minimally invasive esophagectomy has a more than 20 years of history. It has a rapid development and higher proportion especially in the past 5 years. The difference in the pathological types of esophageal cancer between the East and the West results in the different location of the tumor. As well as the habits of the surgeons and the economic considerations, the approaches of the esophagectomy is more diversified than the lung resections.

The four main surgical approaches utilized world wide for esophageal cancer (including GE junction cancers) are the following: (1) Ivor-Lewis, laparotomy, and right postero-lateral thoracotomy, with an intrathoracic anastomosis; (2) McKeown, the three stage trans thoracic resection (i.e. right postero-lateral thoracotomy, laparotomy and cervicotomy) with a cervical anastomosis; (3) transhiatal, laparotomy and cervicotomy with cervical anastomosis. (4) Sweet or trans-thoracic, which involves a chest incision. The previous two approaches are more essential aspects as they are more in line with the standard of oncology. And Sweet approach is only used in treating GE Junction tumor in Western now. Treatment with traditional surgery, requiring esophagectomy and digestive tract reconstruction, results in surgical trauma, slow postoperative recovery, and patient discomfort, among other complications. Reducing the surgical trauma is the fundamental purpose of introducing minimally invasive surgery into esophagectomy. The approaches of minimally invasive esophagectomy are quite similar to open ones, except for the Sweet approach. Ivor-Lewis and Mckeown are two main surgical methods.

Since its description by Cuschieri in 1992, the use of minimally invasive oesophagectomy (MIO) has increased. In 1993, Gossot also reported thoracoscopic approach for esophagectomy with 12 successes in 15 esophageal patients. Surgeons could only use minimally invasive approach to mobilize esophagus, still using laparotomy and cervicotomy with cervical anastomosis (McKeown) in that time. And in the same year,Bumm reported a series of 30 transhiatal cases underwent endodissection of the thoracic esophagus with a novel mediastinoscope. The endodissection which allowed identification of mediastinal structures and controlled biopsy of mediastinal lymph nodes was safer with less recurrent nerve damage. Sadanaga reported laparoscopy-assisted surgery for transhiatal esophageal dissection in 1994, a more minimally invasive approach with more clear surgical vision and less bleeding. Then Drs DePaula and Swanstrom in 1996 and 1997 published articles with more cases of laparoscopic transhiatal total esophagectomy for benign and malignant disease of the esophagus separately. They concluded that laparoscopic esophagectomy was a technically feasible but difficult procedure. Despite the long operative times, patients could benefit from a shorter hospital stay and more rapid recovery compared with open esophagectomy. With the explosion of minimally invasive surgical technology, more complex procedures were being performed through smaller incisions in an attempt to decrease morbidity and mortality. In 1999, Nguyen et al. from University of Pittsburgh described combined thoracoscopic and laparoscopic approach to esophagectomy. The patient was positioned in lateral decubitus position, and underwent thoracoscopic part. Circumferential mobilization of the esophagus with all surrounding lymph nodes and periesophageal tissue and fat was performed from the diaphragmatic reflection to the thoracic inlet. Then in the supine position the patient underwent gastric dissection, gastric tube making, pyloroplasty, and laparoscopic jejunostomy tube placing. An anastomosis was performed in the neck using an EEA stapler. This minimally invasive McKeown approach became an classic technique in treating esophageal cancer patients. Then in 2003, Dr. Luketich from the same medical center reported a much larger series of MIE cases. With more than 200 cases experience, they demonstrated MIE offered results as good as or better than open operation with a lower mortality rate and shorter hospital stay than most open series. With resolving the challenge of intro-thoracic anastomosis, Dr. Luketich and his team using more and more minimally Ivor-Lewis approach, with lower anastomosis leak rate and recurrent nerve injury rate.

12.4.2 The Feature of Different Surgical Approaches

1. McKeown approach: With anastomosis in the neck, this approach can avoid the challenge of intro-thoracic anastomosis. That is why this approach is the earliest minimally invasive technique in esophagectomy. The highlights of this procedure are as follows, the mediastinal lymph nodes can be completely dissected, especially the upper mediastinal lymph nodes, which are in accordance with the standard of oncology, and the cervical anastomosis is easy and simple to carry out. But it also has some disadvantages. The procedure is very complicated with many steps and more injury. Recurrent laryngeal nerve injury frequency is higher. The anastomotic leak rate is higher because the anastomotic site is close to the top of the gastric tube with poor blood supply. The operation sequence is first thoracoscopic and then laparoscopic, which makes the making of the gastric tube diffi-

cult, so the surgeons usually needed to do an abdominal incision and take the stomach out to make a gastric tube. So it is not quite recommended for lower and some middle part esophageal cancer.

2. Ivor-Lewis approach: This approach combines the advantages of open surgery with two field lymph node dissection, and minimally invasive surgery. It is more appropriate for GE Junction tumor and middle and lower part esophageal cancer whose incidence rate is higher. The advantages of this approach are obvious. First, you do not need to worry about the length of the conduit, and for lower part tumors, not the whole esophagus is needed to be cut off. Second, literatures report that incidence of anastomostic leak is lower than cervical anastomosis as for the stomach tube with good blood supply. The only challenge of this procedure is the anastomosis in thoracic cavity under thoracoscope. Thoracic surgeons world wide have proposed several different ways to resolve such difficulty recently. There are three solutions which are accepted widely. The first solution is using an OrVil with a circular stapler device. Second is hand suture, or making a pouch with the help of pouch pliers, then use a circular stapler device. And the third one is making side by side anastomosis using linear stapling device. With these novel techniques advanced, MIE with Ivor-Lewis approach developed fast in the recent 2–3 years, even more than McKeown approach in quantity now.
3. Transhiatal approach: Using laparoscope instead of laparotomy, the approach can avoid open laparotomy and reduce the influence to the respiratory system. But this approach is only applicable to some tumors with early stage and small size. It will face challenge when coming with tumors in large diameter, or with dense adhesion with surrounding tissues. As well as the consideration of lymph node dissection, this approach is not used quite common world wide.

12.5 Type and Conduction of the Anesthesia for MIE

Yi Feng and Juan Zhu

The most common type of anesthesia used for thoracoscopic esophageal surgery is thoracic epidural anesthesia combined with general anesthesia. One of the most dangerous complications of anesthesia in esophageal surgery is aspiration. This usually occurs during the induction of anesthesia or during recovery from anesthesia. Lung function and arterial blood gas examinations can help in predicting perioperative pulmonary complications and the likelihood of postoperative mechanical ventilation. Common fatal respiratory complications related to esophagectomy include atelectasis, aspiration pneumonia, lung infection, acute lung injury and respiratory distress syndrome. Common analgesia strategies are similar to those used after video-assisted thoracoscopic lobectomy. The specific action of thoracic epidural analgesia reduces postoperative complications, accelerates gastrointestinal function recovery as well as reduces the possible adverse influence of NSAIDs on gastrointestinal function

12.5.1 General Consideration of Anesthesia

The most common type of anesthesia used for thoracoscopic esophageal surgery is thoracic epidural anesthesia combined with general anesthesia. General anesthesia may be selected if epidural anesthesia is contraindicated. One lung ventilation is required to facilitate surgical exposure. The details of pre-anesthesia risk evaluation, the choice of intubation, the management of one lung ventilation and thermoregulation treatment during thoracoscopic esophageal surgery can be referred to in related Sect. 1.4.1.

12.5.1.1 Anesthesia Risk Evaluation Before Surgery

Appropriate acknowledgement of anesthesia risk is crucial for surgical timing. In addition to the anesthesia risks mentioned in Sect. 1.4.2, one of the most dangerous complications of anesthesia in esophageal surgery is aspiration. This usually occurs during the induction of anesthesia or during recovery from anesthesia. This complication generally affects patients with esophageal obstruction, dynamic esophageal abnormalities and sphincter disorders whose presentation are difficulty in swallowing, palpitation, acid reflux, coughing and difficulty in breathing in the supine position. When chronic aspiration leads to fibrosis, lung function declines, and rapid shallow breathing or difficulty in breathing can be seen. Metoclopramide, H2 antagonists and proton pump inhibitors may be administered preoperatively to decrease the risk of aspiration. Nasogastric tube placement while the patient is awake can also help prevent aspiration.

Candidates for esophageal surgery are usually elderly patients with complications. Malignancy can be accompanied by anorexia and weight loss. Many patients with esophageal cancer have a long-term history of smoking and respiratory system damage. In these patients, lung function and arterial blood gas examinations can help in predicting perioperative pulmonary complications and the likelihood of postoperative mechanical ventilation (for example, if arterial blood gas examination when the patient is breathing air shows hypoxemia or hypercapnia, the patient is more likely to have postoperative complications and thus require postoperative ventilator support). Patients with hypovolemia and malnutrition caused by dysphagia or anorexia may show poor tolerance to anesthesia, and need to be treated for these conditions before the operation.

12.5.1.2 Management of Common Intraoperative Problems Related to Anesthesia

Body Temperature Protection

Most patients undergoing esophageal surgery are elderly. Compared to lung surgery, esophageal surgery is longer, involves greater intraoperative fluid intake/loss and is associated with a greater risk of hypothermia. Perioperative measures to protect against a decrease in body temperature have been described in Sect. 1.4.5.

Patient Positioning

Minimally invasive thoracic procedures for esophageal malignant tumors often involve frequent position changes and a long operative time. Different positions may be used depending on the type of surgery. The supine position is usually required for laparoscopic dissection of the lower esophagus and stomach. However, dissection of the middle and lower esophagus necessitates a change to the lateral position, while anastomosis of the cervical esophagus requires a 45° lateral position. Considering the frequent position changes under anesthesia, measures should be taken to avoid nerve stretching, muscle squeezing and spinal dislocation. It is important to ensure that the spine and head of the patient are always in the neutral position regardless of the position of the body. More importantly, hypsokinesis, hyperflexion, neck rotation as well as damage to the brachial plexus should be avoided. When patients are placed in the lateral position, anesthesiologists should pay special attention to the patients' eyes and ears to avoid prolonged compression and ischemia. In male patients, the perineum should be protected, and in female patients, the breasts should be protected.

Apparatus Placement

The most obvious difference between minimally invasive thoracic surgery and thoracotomy is that the former requires a light source and display lying next to the patient's head, which is the place that anesthesiologists would usually occupy. Occasionally, endoscopic positioning is required during thoracoscopic surgery, for example, during the resection of a smooth muscle tumor. The cephalic position is important for anesthesiologists, because from this position it is possible to observe the devices monitoring the patient's vital signs, the breathing apparatus connecting the patient with the anesthesia machine and the tubes through which various drugs are being administered. Without access to the cephalic region, the anesthesiologist may not be able to closely monitor the above devices and tubes, and catastrophic results may occur if early changes are not discovered timely. Therefore, anesthesiologists should keep a close eye on the patient's cephalic region and ensure that all devices are connected properly. Furthermore, surgeons must be instructed not to accidently move any of the above devices and connections. Moreover, during thoracic surgery, anesthesiologists must stay by the patient's head and focus on the surgical progress. Thus, the placement of the light source and display in the cephalic position hinders the observation of anesthesiologists. Hence, when possible, the cephalic region of the patient should be reserved for the anesthesiologist, or a special display with a stretch rod that can be pulled over the patient's cephalic region from distant areas should be used. By using these methods, enough space can be left in the cephalic region for anesthesiologists to safely administer anesthesia to patients.

12.5.1.3 Management of Common Peri-Anesthetic Problems

Pneumothorax of the Dependent Lung

In thoracic surgery, a chest drain is typically placed on the operated side after surgery. Occasionally, pneumothorax of the contralateral, unoperated lung can develop during or after the surgery. This can occur if the mediastinal pleura of the contralateral side is purposely or accidently slit during the operation. Pneumothorax can occur during suturing of the pleura. Furthermore, with continuous mechanical ventilation, tension pneumothorax can develop immediately. Symptoms might include hypotension, tachycardia, asymmetric chest bulging in the supine position, bronchospasm, high airway pressure and decreasing pulse oxygen saturation.

The best way to prevent and treat this problem is through sufficient communication between surgeons and anesthesiologists. Surgeons should inform the anesthesiologists of the situation in time, and discuss the most reasonable and safest way to resolve the problem. In addition, anesthesiologists should keep an eye on the progress of the surgery to avoid catastrophic consequences.

Airway Injury and Subcutaneous Emphysema

Minimally invasive esophagectomy usually requires double-lumen intubation. Owing to their wide diameter and hard texture, double-lumen tubes can easily damage the patient's respiratory tract, especially, when the tube is inserted too deep (pressure overload resulting from bronchial cuff inflation). In such cases, the achievement of optimal lung isolation requires massive adjustments to the position of the double-lumen tube. Many factors can damage the tracheal and bronchial walls, or even lead to their rupture and subcutaneous emphysema.

The best way to prevent and treat these complications is gentle intubation, timely withdrawal of the guidewire, stopping the insertion upon encountering resistance and deflating the cuff before repositioning to reduce friction. Preoperative fiberoptic bronchoscopy can be used as a comparison to ascertain whether any new airway damage was caused during the operation. Once tracheobronchial rupture has occurred, the surgeon should be informed in time, and the breakage sutured.

Postoperative Respiratory Complications

Common fatal respiratory complications related to esophagectomy include atelectasis, aspiration pneumonia, lung infection, acute lung injury and respiratory distress syndrome. The main risk factors include age, preoperative functional status score, preoperative pulmonary function parameters, neoadjuvant chemotherapy, preoperative complications of the respiratory and circulatory systems, and intraoperative cardiopulmonary status.

Aspiration is an important cause of postoperative complications. Patients undergoing thoracic surgery are more likely to develop gastro-esophageal reflux, which can cause aspiration. Esophageal sphincter dysfunction in esophageal cancer patients often leads to a higher probability of intra- and postoperative aspiration. Anesthesia management techniques for reducing the risk of aspiration are as follows: rapid induction of anesthesia, tight airway seal with a balloon catheter and the use of single- or double-lumen intubation catheters with lubricating gel. Surgery for esophageal cancer often necessitates changes in the patient's position, which can lead to changes in the position of the endotracheal tube, and these changes are another factor that may lead to aspiration. Often, continuous gastro-esophageal decompression is recommended during anesthesia, as it can reduce the incidence of gastric acid aspiration during esophageal cancer surgery. Additionally, due to the accumulation of throat secretions caused by intraoperative reflux and light anesthesia after surgery, patients may hold their breath and cough, which could result in increased intra-abdominal pressure and thus cause reflux. Therefore, repeated and sufficient suction of the gastric tube and oropharyngeal secretions before and after extubation is a crucial precaution against aspiration.

The pulmonary complications associated with mechanical ventilation after esophagectomy are as common as those associated with tracheal ventilation after other procedures. These complications include barotrauma, hospital-acquired pneumonia, reduced cough reflexes caused by sedation and lower respiratory self-clearing ability. Both experimental and clinical studies have shown that early extubation can reduce respiratory complications. Therefore, extubation should be performed early provided it does not interfere with the surgery. Although a clear unified definition of early extubation is still lacking, extubation is now performed 1 h after the surgery rather than immediately in the operating room or after 6–8 h. Early extubation following the surgery could markedly decrease the incidence of respiratory complications. It has been shown to be safe and to reduce the length of stay in the intensive care unit as well as the patient's medical expenses.

12.5.1.4 Postoperative Analgesia

Common analgesia strategies are similar to those used after video-assisted thoracoscopic lobectomy. The specific action of thoracic epidural analgesia reduces postoperative complications, accelerates gastrointestinal function recovery as well as reduces the possible adverse influence of NSAIDs on gastrointestinal function.

Thoracic epidural analgesia has shown many benefits in esophagectomy, such as providing gold-standard analgesia, decreasing the level of stress and reducing possible respiratory complications and the incidence of post-thoracotomy pain. It is also the most important component of the clinical pathway. Thoracic epidural analgesia has been associated with improving the microcirculation in the gastric conduit, promoting intestinal peristalsis after the surgery, improving blood supply to the anastomosis (which contributes to the healing of the anastomosis) and helping to decrease postoperative mortality in middle- and high-risk patients.

12.6 Pitfalls of Minimally Invasive Esophagectomy

Inderpal S. Sarkaria and James D. Luketich

12.6.1 Introduction

Minimally invasive esophagectomy (MIE) has become an accepted standard of care. However, the complexity of the operation, requiring both laparoscopic and thoracoscopic approaches for most transthoracic operations (i.e. Ivor Lewis and McKeown), has a significant learning curve [140]. It is imperative that surgeons utilizing these techniques are aware of the potential pitfalls of these operations to avoid recapitulation of known, and often avoidable, morbidity during the conduct of surgery. While many pitfalls may be generic to esophagectomy, they are potentially heightened during MIE due to relative loss of tactile feedback, and the long learning curve necessary to master these techniques. This chapter focuses on key technical challenges in standard MIE and robotic assisted MIE (RAMIE) in combined laparoscopic/thoracoscopic operations.

12.6.2 Patient Positioning

- Pitfall(s): Repositioning during RAMIE
- Technical point(s):
  Standard precautions should be taken during positioning, including padding of all pressure points. It is imperative to remember that during RAMIE operations with currently available systems, patient bed position cannot be altered once the robotic platform is docked to the ports. Undocking, movement of the bed, and re-docking must occur in order to adjust position. This can be a major or minor inconvenience, depending on the urgency of the situation requiring repositioning. In the hemodynamically unstable patient, it is important the bedside assist be adept at undocking the robotic instrumentation to allow quick return to supine, or even Trendelenburg, position. During initial supine positioning for the laparoscopic phase during RAMIE, full reverse Trendelenburg position must be obtained prior to docking and requires coordinated maneuvering of the operative be and robotic cart to prevent inadvertent patient collisions. Newer robotic platforms will likely allow for repositioning during operation.

12.6.3 EGD

- Pitfall(s): Excessive insufflation
- Technical point(s):
  If EGD is performed at the outset of the case, as we do for all esophageal operations, the procedure should be kept short and use of gas insufflation minimized to reduce distention of the intestines, which can greatly hamper, or even preclude, adequate visualization during laparoscopy.

12.6.4 Gastric Mobilization

- Pitfall(s): Gastric grasping injuries, Gastroepiploic vascular injury, Gastro-splenic dissection
- Technical point(s):
  Early identification and meticulous handling and preservation of the right gastroepiploic vascular arcade is imperative to creation of a well-perfused gastric conduit. During MIE, a “no-touch” technique may be employed with efforts made to avoid serosalinjury to portions of the stomach that will constitute the neo-esophagus, as well as the omental tissues adjacent to the vascular supply. If necessary, grasping of the stomach should occur along the lesser gastric curve above the incisura, which is resected along with the specimen for most tumors of the gastroesophageal junction. This alone can often provide the necessary exposure to the greater curve, where maintaining a minimal 2–3 cm distance from the vascular arcade during division of the omentum is advised to avoid undue thermal conduction to the blood supply, or inadvertent/unrecognized division of the vessels (Fig. 12.6). Undue traction or grasping of the conduit or adjacent omentumcan also cause endothelial vascular injury and intravascular hematoma with resultant compromise of the conduit, and should be carefully avoided.

  In the obese patient, clear direct visualization of the vascular arcades may be challenging, increasing the risk of inadvertent injury, especially along the apex of the greater curve, where the position of the arterial arches are most variable and may course a significant distance from the stomach. Use of intraoperative Doppler ultrasound may help confirm the position of these vessels. Near infrared fluorescence imaging (NIFI) is also emerging as a potential modality to better visualize these structures intra-operatively (Video 1) [141]. If there remains significant doubt as to the location of the vascular supply despite additional maneuvers, conversion to open operation and direct tactile palpation or Doppler ultrasound localization of the artery should be considered.

  Division of the short gastric vessels near the gastrosplenic attachments should be cautiously approached, and undue tension on the splenic hilum and capsule meticulously avoided to prevent significant hemorrhage. Identification of the splenic artery, which has a highly variable course, is imperative to avoid undue injury or division. Minimizing omental retraction near the splenic attachments can minimize the risk of traction injury, with much of the exposure obtained by gentle medial retraction of the stomach along the line of the short gastric vessels. In standard MIE procedures,

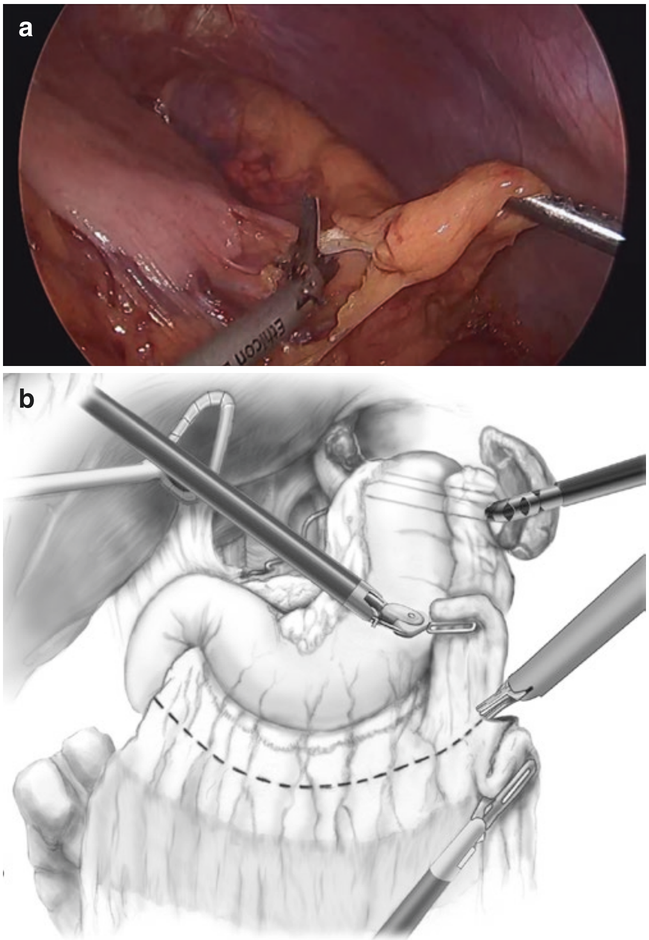

Fig. 12.6 Gentle handling of the stomach and gastroepiploic vascular arcade is vital during greater curve mobilization. (**a**) During short gastric division, some distance should be maintained between the stomach and line of dissection. (**b**) The vascular arcades should be well visualized during division of the omentum, leaving a distance of approximately 2–3 cm from the vessels

changing the port in which the camera is introduced can greatly improve visualization and allow for more confident dissection. More current robotic platforms also allow for camera "swapping" between the various ports, greatly increasing the operative field of view. If approached carefully, the incidence of hemorrhage during gastro-splenic dissection is rare. However, the surgeon must be prepared to convert to an open operation if severe hemorrhage is encountered, often necessitating splenectomy.

12.6.5 Pyloroplasty

- Pitfall(s): Pyloric orientation, Trans-lumenal injury, Duodenal traction injury

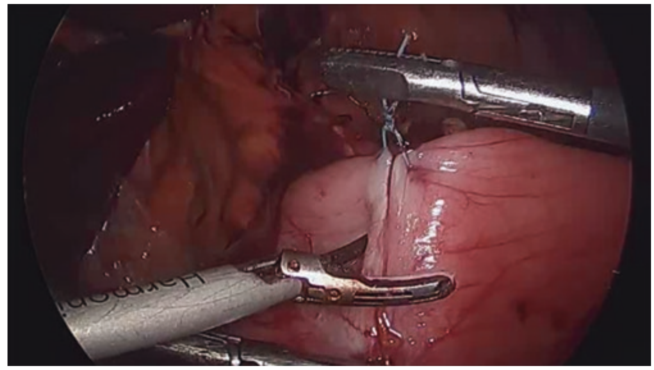

Fig. 12.7 Perpendicular orientation of the ultrasonic shears to the pylorus during pyloromyotomy can be optimized by use of lateral stay sutures

- Technical point(s):
  Pyloroplasty during MIE can be technically challenging. Care should be taken to avoid injury to the contralateral mucosal or serosa during initial creation of the pyloromyotomy. Placement of stay sutures and gentle traction to appropriately orient the pylorus at 90° from the ultrasonic shears (our energy source of choice) is imperative to avoid undue "skiving" of the initial luminal entry (Fig. 12.7). During suturing, unrecognized tissue tension may be avoided by releasing traction on stay sutures, preventing additional tissue injury. This is particularly important to avoid longitudinal tears to the thin duodenal wall, which can extend quickly and be challenging to repair.

12.6.6 Creation of Gastric Conduit

- Pitfall(s): Inadequate conduit visualization, length, and orientation
- Technical point(s):
  Creation of an optimal gastric conduit requires careful visualization of the stomach along its full axis from the fundus through to the greater curve. This may be challenging during MIE, but can be accomplished with cranial traction on the most mobile portion of the fundus towards the left upper quadrant, and gentle caudad traction on the antrum. This allows optimal pre-visualization and planning of the gastric tube as it is formed (Fig. 12.8). During RAMIE, this can be accomplished with gentle "posting" of the instruments along the new "lesser curve" as it is formed. These maneuvers also serve to continuously straighten the evolving conduit with each additional application of the endogastrointestinal stapler (Video 2). Generally, we leave a small antral reservoir, and the first staple application is along the lesser curve within 5–8 cm of the pylorus itself. Of note, the gastric wall can be quite think and may require a larger staple height to initiate the

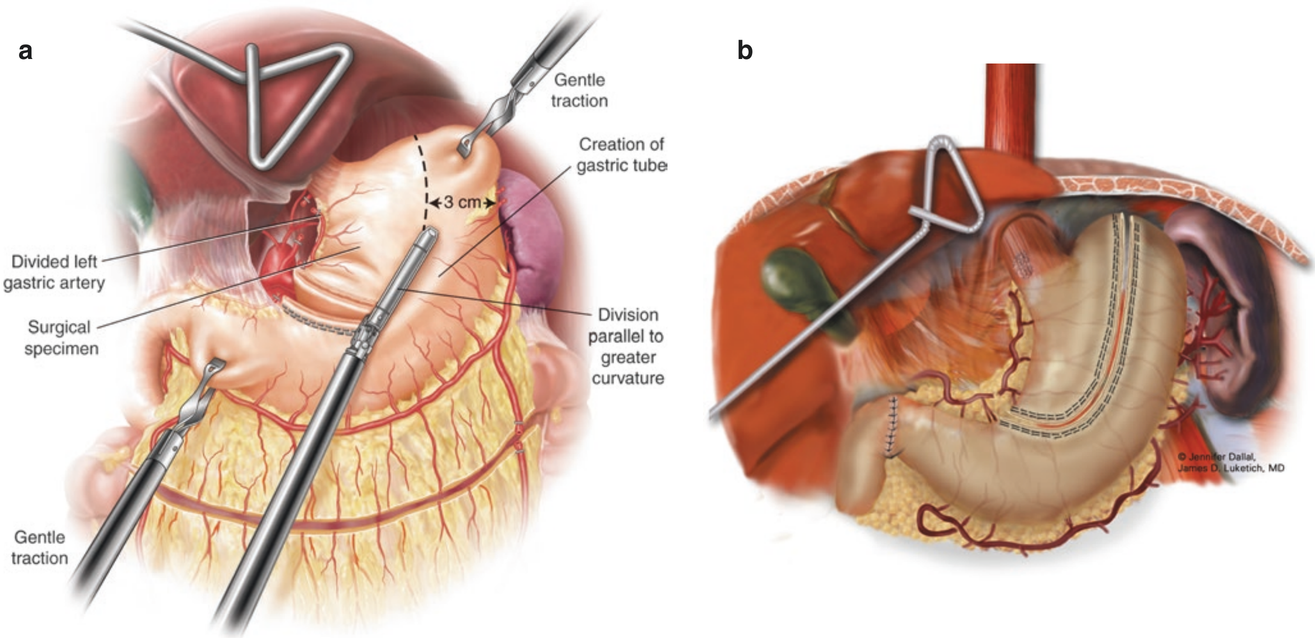

Fig. 12.8 (**a**) During creation of the gastric conduit, retraction of the mobile fundus cranially and visualization of the *line* of the greater *curve* vasculature is vital in maintaining proper orientation of the gastric tube with sequential stapler applications. (**b**) Completed gastric conduit

staple line. Also, it is imperative to visualize the line of the greater curve vasculature at all times to avoid "spiraling" of the conduit with successive stapler applications. Once the staple line is started, each successive application should be parallel to the line of the short gastrics.

12.6.7 Transhiatal Traverse of Conduit

- Pitfall(s): Conduit mal-orientation ("twisted" conduit), Gastric traction injury, Vascular traction/avulsion injury
- Technical point(s):
  Traverse of the formed conduit through the hiatus and into the chest (Ivor Lewis) or neck (McKeown) must be accomplished with attention to avoiding undue traction and potential serosal or vascular injury, while simultaneously obtaining adequate length and ensuring proper orientation. In our practice, this process begins with division of the specimen from the conduit during the laparoscopic phase of the operation. The most proximal (and least perfused) portion of the conduit is re-secured to the specimen with apposition of the two staple lines. During Ivor Lewis operations, with the patient in the left lateral decubitus position, the conduit is brought through the hiatus into the chest from the abdomen in tandem with the specimen (Fig. 12.9). Right lateral orientation of the conduit staple line confirms proper orientation of the gastric tube without torsion or twisting of the neo-viscus (Video 3). The proxi-

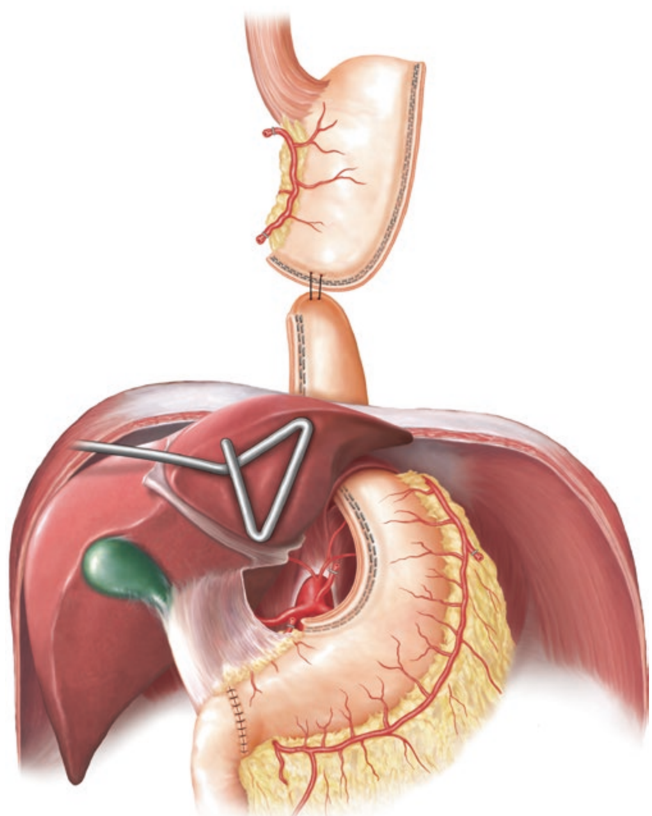

Fig. 12.9 Transhiatal traverse of the gastric conduit in tandem with the specimen and maintaining proper orientation

mal gastric conduit is grasped to bring additional length into the chest. Gently posting under (rather than directly grasping) and "lifting" the distal conduit laterally through the hiatus, as opposed to pulling directly cranially, can minimize the risk of serosal and/or avulsion vascular injuries, and also ease traverse of bulky omental tissue or flaps. During McKeown operations, the conduit can simultaneously be advanced via "pulling" from the neck after securing to a penrose drain or chest tube, and "pushing" via a laparoscopic approach from the abdomen. In this manner, conduit orientation can be directly observed, and undue tension avoided while achieving adequate length.

12.6.8 Airway Injury

- Pitfall(s): Thermal airway injury, Airway-enteric fistula formation
- Technical point(s):
  Airway injury due to use of thermal dissection devices and subsequent airway-viscus fistula formation can be devastating complications. Lack of haptic feedback is a likely factor in the higher incidence of these complications in MIE operations, including RAMIE [142]. Careful identification of airway anatomy and meticulous attention to careful surgical technique during subcarinal lymph node dissection are paramount to preventing these complications, which are almost entirely technical (and avoidable) in nature, and often subtle and unrecognized at the time of operation (Fig. 12.10). Specific attention should be paid to identifying the left main stem bronchus which can lie deep in the dissection bed and be obscured by the lymph nodes and bleeding. Meticulous dissection and hemostasis are important in obtaining adequate visualization. During RAMIE, we have found it advantageous to switch to available bipolar dissectors during this portion of the dissection if the angles of instrument intersection with the airway do not allow for appropriate distance between the ultrasonic shears and dissection planes [142] (Video 4). Initial exposure of the distal and proximal planes along the bronchus intermedius and trachea (respectively), prior to dissection of the subcarinum, can also aid in safe "in-continuity" identification of the right and left mainstem bronchi. Early division of the azygous vein may aid in this exposure as well.

12.6.9 Creation of Circular Stapled Intrathoracic Anastomosis

- Pitfall(s): Mal-orientation ("twisted conduit"), Redundant intrathoracic conduit
- Technical point(s):
  During creation of intrathoracic anastomoses with circular anastomotic staplers, it is imperative to maintain proper orientation of the conduit during application of the device to avoid twisting of the conduit. The operator should ensure lateral position of the conduit staple line during deployment. Care should also be taken to avoid advancing excessive conduit into the chest and potentially creating a "shelf" of viscus above the hiatus onto the diaphragm. Securing the conduit to the hiatus with suture may help prevent this occurrence post-operatively, and avoid poor drainage due to a less-than-linear neoesophagus. We have also found laparoscopic placement of marking sutures 2–3 cm above the antral reservoir on the gastric tube "lesser-curve" staple line useful in identifying optimal lengths of gastric tube advancement. During the thoracoscopic phase of operation, this marking suture can be easily identified on entry into the chest through the hiatus as the conduit is retrieved. This maneuvermaintains subdiaphragmatic positioning of the gastric antral

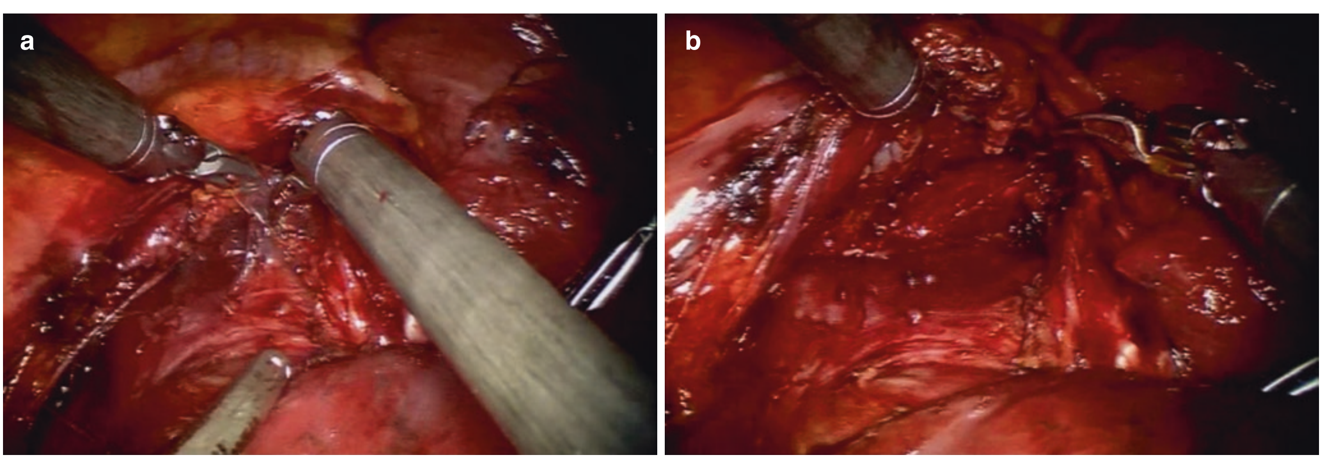

Fig. 12.10 (**a**) Use of bipolar energy instrumentation during RAMIE subcarinal lymph node dissection. (**b**) The left mainstem bronchus is clearly identified and the esophagus and adjacent lymph nodes dissected free from the membranous airway

reservoir and tubular conduit transition point, with only neo-esophagus present in the chest.

12.6.10 Para-Conduit Hiatal Hernias

- Pitfall(s): Post-operative hiatal herniation
- Technical point(s):
  The incidence of para-conduit hiatal herniation of colon and small bowel after MIE or RAMIE has an incidence believed to be approximately 5%, higher than seen with open approaches [143]. Herniation often occurs between the conduit and the left crural pillar and into the left chest. In our experience, this is thought to be more common in thin patients, and in those with entry into the left pleura during the initial operation. These can be difficult to durably repair, and are prone to recurrence. This technical issue is readily addressed during McKeown operations, where suture fixation of the left crus to the conduit can readily and safely be performed from the abdomen after completion of the neck anastomosis. For Ivor Lewis operations, we have yet to identify any single technical step to avoid this complication short of repositioning patients back to the supine position, replacing ports, and placing tacking sutures. In our practice, this is rarely performed given the clear pragmatic concerns of additional operative and anesthetic time involved. In patients with favorable anatomy, these tacking sutures can be placed from the chest, an approach that may be enhanced with the additional dexterity afforded during suturing with robotic instrumentation in RAMIE procedures. In addition, we frequently add a crural approximation suture during the final steps of the laparoscopic portion of the operation to narrow the hiatus to some degree (Fig. 12.11). There are obvious downsides to excessive approximation of the crura, the most serious being significant compromise of venous drainage above the crural pinch. This may lead to venous congestion, thrombosis, and, ultimately, necrosis of the conduit. This devastating complication must be avoided at all costs, with judgement of the surgeon the primary factor in prevention. Erring on the side of hiatal laxity is advisable. As described above, several carefully placed tacking suturesplaced thoracoscopicallybetween the crura and the conduit can minimize the incidence of post-operative para-conduit herniation

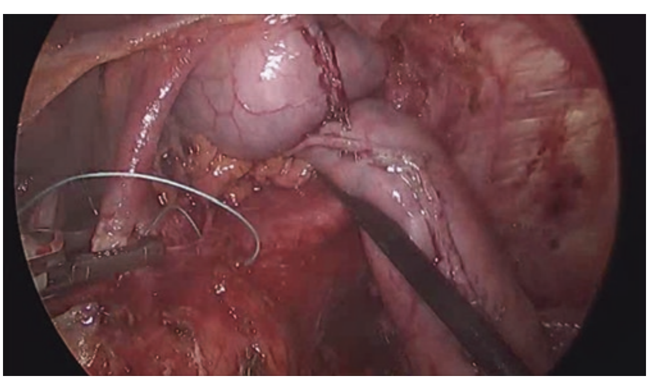

Fig. 12.11 Partial posterior hiatal approximation

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Thoracoscopic and Laparoscopic Esophagectomy with Cervical Anastomosis

13

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Contents

13.1 Introduction and Technique

Vivek Prachand and Mark K. Ferguson

13.1.1 Background

Esophagectomy is the best means of achieving local tumor control in patients with esophageal cancer, and arguably is the only treatment that reliably offers the possibility of cancer cure, especially in patients with early stage disease. Traditional approaches to esophagectomy, including open transthoracic resection and transhiatal esophagectomy, have demonstrated similar outcomes for most complication categories and similar long-term survival. The high rates of postoperative complications reported for these techniques, including operative mortality, have prompted the development of minimally invasive techniques for esophagectomy. The potential advantages of minimally invasive esophagectomy (MIE) include reduced postoperative pain, less activation of inflammatory mediators, reduced perturbation of pulmonary function, shortened length of hospital stay, and faster return to full activity.

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13.1.2 Indications

MIE is an appropriate consideration for most patients who require esophagectomy for either benign or malignant disease. Potential technical advantages of the technique include improved visualization for lymph node dissection and preservation of recurrent laryngeal nerves, and reduced blood loss and requirements for perioperative transfusion. However, considerable expertise in advanced minimally invasive techniques, including intracorporeal suturing and knot tying, is necessary to take full advantage of these potential advantages. MIE should not be undertaken by surgeons without substantial experience in open esophageal surgery. A team of surgeons, nurses, anesthesiologists, and critical care specialists is required to achieve optimal outcomes, and the learning curve for the operation is often difficult and prolonged. It is estimated that 50–100 procedures are required before a stable, low rate of complications is achieved. Complications that may occur more often with MIE include airway injury, herniation of abdominal contents through the esophageal hiatus, increased tension on cervical anastomoses leading to a higher rate of anastomotic leak, and jejunostomy feeding tube dislodgement. Increasing experience with MIE has led to methods for reducing the incidence of these complications.

13.1.3 Patient Selection

There are few definite contraindications to MIE. Most patients with esophageal cancer in our practice have undergone induction chemotherapy and radiation therapy. These patients require a careful preoperative assessment of their physiologic status to ensure adequate pulmonary function (spirometry and diffusing capacity), adequate performance status, and satisfactory nutritional status. At times it is necessary to put off MIE until the patient's status has improved after completion of induction therapy. If the interval between completion of radiation therapy and possible surgery grows too long, open esophagectomy, especially for the thoracic portion of the operation, may be a better option. Other contraindications include prior major ipsilateral thoracic surgery, a frozen abdomen, and possibly an indwelling esophageal stent, which inhibits adequate displacement of the esophagus to permit adequate visualization.

The modified Ivor Lewis MIE with cervical anastomosis is applicable to patients with disease in any location other than those in whom an extended gastrectomy is planned, such as those with Siewert III tumors. It is most suitable for patients with disease in the middle and upper thirds of the thoracic esophagus, in whom a 5 cm margin on the esophagus from the proximal margin of gross tumor may otherwise be difficult to achieve.

13.1.4 Operative Technique

A bowel prep is performed the day prior to surgery to reduce intraluminal intestinal contents. Antibiotic bowel preparation is not required. An epidural catheter is used routinely to assist with postoperative pain management, and may help reduce the incidence of postoperative supraventricular arrhythmias. Arterial line monitoring is standard, but placement of a central venous line for monitoring fluid status is not usually necessary. Prophylactic subcutaneous heparin and lower extremity intermittent compression devices (ICDs) are used in all patients. A left-sided double lumen endotracheal tube is placed. In morbidly obese patients or those who have a history of venous thromboembolic disease, a temporary inferior vena cava (IVC) filter is placed after induction of general anesthesia.

13.1.4.1 Thoracic Portion

The patient is placed in the left lateral decubitus position. The right lung is isolated. A 5 mm port is placed in the anterior axillary line in the ninth interspace for inspection of the pleural space; this is eventually upsized to a 12 mm port. A 5 mm port is placed in the posterior axillary line at the level of the diaphragm, and a 5 mm port is placed medial to the scapular tip, at the level of the arch of the azygos vein. A 5 cm access incision is created in about the fourth interspace in the anterior axillary line; no rib spreading is performed. This incision is often used to accommodate two instruments simultaneously. A heavy silk suture is placed through the tendinous portion of the diaphragm and is brought through a low intercostal space anteriorly to retract the diaphragm away from the esophageal hiatus.

The lung is retracted away from the esophageal hiatus. The telescope is placed through the posterior inferior port, and the other inferior port and the superior 5 mm port are used for the primary surgeon's instruments. A 30° 5 mm telescope is used routinely. The pleura is divided on either side of the esophagus to the azygos arch, sparing the azygos vein and thoracic duct. The esophagus is dissected circumferentially at the level of the inferior pulmonary vein, preserving the contralateral pleura, and is surrounded with a Penrose drain, which is used to retract the esophagus during the subsequent dissection. The esophagus and all adjacent soft tissues are dissected from the esophageal bed from the hiatus to the azygos arch. All periesophageal lymph nodes are taken with the specimen other than the subcarinal (level 7) lymph nodes, which are dissected separately.

The azygos vein arch is divided with a linear cutting stapler placed through the anterior inferior port site. The pleura overlying the esophagus is divided from the level of the azygos arch to the thoracic inlet. The esophagus is dissected superiorly directly on its wall into the neck. Any enlarged lymph nodes are removed from above the level of the azygos vein, taking care to preserve the recurrent laryngeal nerves. The Penrose drain surrounding the esophagus is pushed into the neck to facilitate retrieval of the esophagus through the subsequent cervical incision. One or two chest tubes are placed through the inferior port sites to the apex of the hemithorax. The lung is re-expanded as the remaining two port sites are closed in layers.

13.1.4.2 Abdominal Portion

The patient is reposition supine position with both arms tucked against the torso to permit access to the neck. The surgeon stands on the patient's right side while the first assistant and camera operator stand on the patient's left. Ports are placed somewhat caudal to those for antireflux procedures to facilitate gastric mobilization, gastric emptying procedure, and tube jejunostomy. Initial peritoneal access is gained just to the left of midline approximately 16 cm below the xiphoid. For individuals who have had prior upper midline incision, access is obtained just lateral to the right midclavicular line four fingerbreadths below the costal margin. A 45° laparoscope is routinely utilized for the entire abdominal portion of the procedure. A Nathanson liver retractor (Cook Medical; Bloomington, IN) is inserted through a 5-mm subxiphoid incision and is secured using a self-retaining holder. A 15-mm dilating port is placed in the right medial mid-abdomen to accommodate the 4.8 mm staple-height cartridges used to create the gastric conduit, and a 5 mm left upper abdominal port site is ultimately used as the jejunostomy tube site.

The gastrohepatic ligament is widely opened and celiac axis lymphadenectomy is performed. Circumferential dissection of the origin of the left gastric pedicle is performed, and the pedicle is transected with a 60–2.5 mm stapler with bioabsorbable buttressing material.

The gastrocolic omentum is opened and the lesser sac entered at the level of the proximal antrum lateral to the gastroepiploic arcade. Dissection proceeds proximally using a bipolar sealing device or ultrasonic coagulating shears, with division of the short gastric vessels and complete mobilization of the fundus to the left crus. The cephalad aspect of the dissection is facilitated by division of the posterior gastropancreatic adhesions. Dissection then proceeds distally along the gastroepiploic arcade near the origin of the right gastroepiploic vessels, requiring posterior mobilization of the antrum and pylorus to the level of the gastroduodenal artery. A formal Kocher maneuver is performed. A gastric emptying procedure (pyloroplasty or pyloromyotomy) is typically performed.

The neurovascular arcade along the lesser curve of the stomach is divided using a bipolar sealing device or vascular stapler at the level of the incisura. The gastric conduit is created using multiple firings of a thick tissue roticulating endoscopic stapler (60–4.8 mm), with the assistant providing gentle retraction to allow the stapler to be oriented parallel to the greater curvature. The conduit measures approximately 5 cm in diameter.

The remaining circumhiatal attachments and distal esophagus are mobilized. The proximal aspect of the conduit staple line is reapproximated to the specimen using a short (1.5–2 cm) running suture to allow the conduit to be pulled up into the chest in appropriate orientation. The hiatus is assessed at this time, and if it will not easily accommodate the width of the conduit, the right crus is divided to the necessary extent.

The ligament of Treitz is identified and a site 40–50 cm from the ligament is selected for the feeding tube. Two 35 cm semicircular pursestring sutures are placed in the antimesenteric aspect of the jejunal loop. The 5 mm left lateral port is removed, and the tails of the sutures are brought out through the fascia and the port site. While maintaining tension on the proximal suture, the feeding tube is placed using Seldinger technique with care taken to ensure proper distal orientation of the tip. The sutures are then tied, affixing the bowel loop to the anterior abdominal wall and providing circumferential serosal coverage of the tube entry site.

13.1.4.3 Anastomosis

The left neck is opened transversely from the midline to a site between the heads of the sternocleidomastoid muscle, just below the level of the cricoid cartilage. Dissection is carried between the carotid sheath and the strap muscles to the prevertebral plane, taking care to avoid injuring the recurrent laryngeal nerve. The Penrose drain surrounding the esophagus is used to pull the esophagus into the wound.

The lungs are permitted to collapse to eliminate tension while the stomach is transposed. The specimen, which is attached to the gastric tube, is drawn through the mediastinum and into the neck, pulling from above and pushing from below, taking care not to injure the serosa or the gastric blood supply. The specimen is divided from the gastric tube. The esophagus is divided with a linear cutting stapler to provide an adequate margin from the tumor and sufficient length to perform the anastomosis. The specimen is removed.

The gastric tube is positioned posterior to the esophagus with the greater curvature facing anteriorly. Inspection verifies the absence of twisting of the gastric tube. Stay sutures of heavy silk are used to position the esophageal stump at least 5 cm below the tip of the gastric tube. Small openings are created in the stapled end of the esophagus and in the adjacent wall of the stomach near the greater curvature, as far from the lesser curvature suture line as possible. A 45 mm cartridge with 3.5 mm staples is inserted, one end into the gastrotomy and one end into the open esophagotomy, and is fired, creating a V-shaped opening between the stomach and esophagus that forms the back wall of the anastomosis. A nasogastric tube is positioned across the anastomosis to the level of the hiatus or just below. The anterior wall of the anastomosis is then sutured or stapled. If there is redundant omentum, this is sutured over the anastomosis to reinforce it.

The gastric tube is pulled inferiorly to eliminate redundancy and is sutured in two to three places to the esophageal hiatus to prevent herniation of abdominal contents. The liver retractor is removed, and after exsufflating the abdomen and removing the ports, the skin incisions are closed using subcuticular sutures. The skin of the neck wound is closed; no neck drains are typically required.

13.1.4.4 Postoperative Management

The patient is awakened, extubated in the operating room, and transported to the intensive care unit where vigorous pulmonary toilet exercises are begun. The patient is usually ambulated the day following surgery. Enteral tube feedings are begun slowly the morning of postoperative day 1 and are gradually increased as tolerated. The chest tubes are removed when the drainage is relatively clear and of moderate quantity, typically on postoperative day 3. The epidural catheter is removed and the patient is switched to intravenous and enteral pain medicine. The nasogastric tube is removed with the patient exhibits bowel activity by passing gas or having a bowel movement, typically on postoperative day 4 or 5. No swallow studies are performed routinely. A clear liquid diet is then started, and the patient subsequently is advanced to a full liquid diet, at which time the tube feedings are changed so that they are administered only for 12 h at nighttime but are maintained at the same hourly rate. The patient is typically discharged on postoperative day 6–8.

13.1.5 Discussion

Minimally invasive esophagectomy is challenging even for the most advanced minimally invasive surgeon. Ideally, technical skills encompassing laparoscopic and thoracoscopic specialists are used in combination to achieve the best possible results. Having a management algorithm encompassing the preoperative evaluation, intraoperative management, and postoperative care of MIE patients, along with frequent assessment of results and reassessment of the algorithm, permits adjustments as necessary if adverse outcomes are experienced. Even with these steps, the learning curve for MIE is appreciable.

The potential benefits of MIE are increasingly recognized. The feasibility of MIE as a safe and oncologically sound procedure has been proven. Whether it has oncologic equivalence to open operations remains to be seen. Additional information from prospective, randomized trials may help in clarifying the role of MIE in the management of esophageal cancer.

13.2 Laparoscopic Gastric Mobilization and Creation of Gastric Tube

C.S. Pramesh, Sabita Jiwnani and George Karimundackal

13.2.1 Technical Points (or Tips)

Laparoscopic gastric mobilization and creation of gastric tube is usually done after the thoracoscopic mobilisation of the esophagus while doing a McKeown esophagectomy. Laparoscopic gastric mobilisation may also be the initial procedure in a minimally invasive Ivor-Lewis or transhiatal esophagectomy. The procedure may be performed totally laparoscopically or with the creation of a minilaparotomy.

The key points to remember are:

- Minimal/atraumatic handling of the gastric conduit
- Maintenance of the blood supply by avoiding injury to the right gastro-epiploic arcade
- Adequate mobilization to enable tension free anastomosis

The following difficulties may be faced:

- The omentum may be fused, especially in obese patients making it difficult to visualise the right gastro-epiploic arcade.
- Bulky lymph nodes present around the left gastric, hepatic and splenic arteries may make the D2 lymphadenectomy tedious.
- Care must be taken to identify and preserve an aberrant/replaced left hepatic artery arising from the left gastric artery.
- Splenic injury may occur if dissection of short gastric vessels is carried out close to the splenic hilum.

13.2.2 Anatomical Landmarks

A thorough knowledge of the surgical anatomy, especially of the celiac axis and its branches supplying the stomach is essential for laparoscopic gastric mobilization.

- The blood supply of the gastric conduit is based mainly on the right gastro-epiploic artery, a branch of the gastroduodenal artery, which in turn arises from the common hepatic artery, a direct branch of the celiac axis. The right gastro-epiploic artery runs in the greater omentum along the greater curvature from the pylorus towards the fundus (right to left).

- The left gastro-epiploic artery, a branch of the splenic artery and short gastric arteries, which also arise from the splenic artery and supply the upper part of the greater curvature and the fundus.
- The right gastric artery, a branch of the hepatic artery proper and the left gastric artery, which is a direct branch from the celiac supply the lesser curvature.
- The left gastric, right gastric and right gastro-epiploic veins drain into the portal vein whereas the left gastric epiploic and short gastric veins drain into the splenic vein.

13.2.3 Operating Procedure

13.2.3.1 Ports, Pneumoperitoneum, Instruments

- We position the patient supine with arms by the side and a roll is placed under the scapula for extension of the neck to aid in neck extension and dissection.
- The patient is given a reverse Tredelenberg position. The surgeon stands to the right of the patient, the assistant to the left with monitors on either side of the patient. An alternative position is with the operating surgeon standing between the abducted thighs of the patient.
- We place five ports for the laparoscopic gastric mobilization (Fig. 13.1) – an umbilical port for the camera, an epigastric port for liver retraction, two dissecting ports for the surgeon on the right (one subcostal and one at the level of the umbilicus) in the mid-clavicular line and one assistant port on the left lateral abdominal wall.
- After insertion of the camera port by the open method, pneumoperitoneum is created and an inspection of the liver (Fig. 13.2), peritoneal surfaces and pelvis is carried out to rule out any metastases. The other four ports are placed under vision.

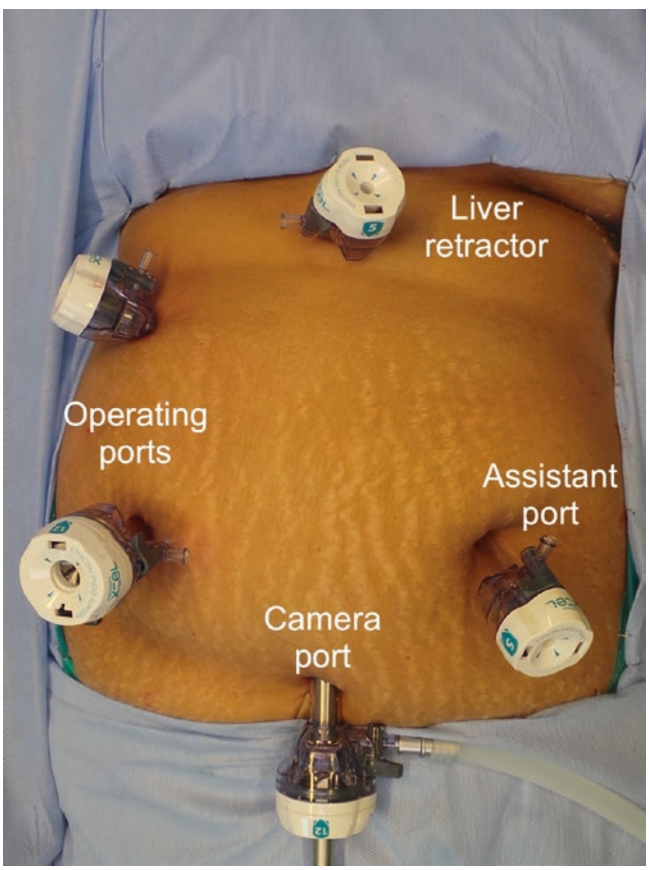

Fig. 13.1 The abdominal port positions are as shown in the figure. The surgeon operates using the right sided ports while the assistant uses the left port

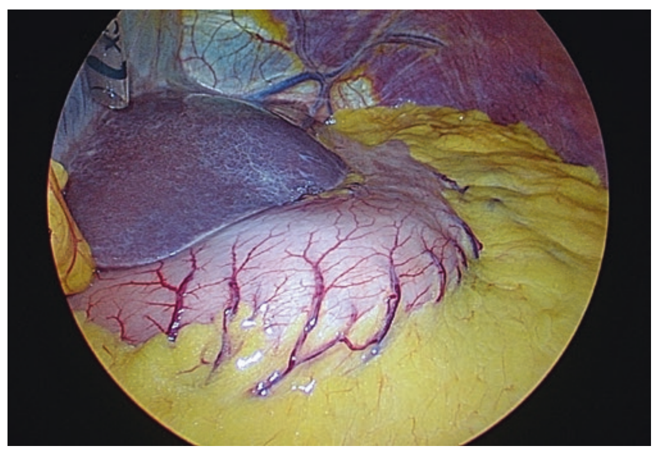

Fig. 13.2 A preliminary inspection of the liver and peritoneal surfaces is done to rule out metastases

13.2.3.2 Mobilisation

- Mobilisation is started along greater curvature after visualizing the right gastro-epiploic arcade. The gastrocolic omentum is divided using harmonic shears (Fig. 13.3). We prefer to start the mobilization midway in the gastrocolic omentum (where the omentum is thinnest, enabling the gastroepiploic arcade to be visualized without difficulty) and progress initially towards the fundus and subsequently towards the pylorus.
- After creating a window in the gastrocolic omentum, the mobilization continues towards the fundus, initially dividing the posterior peritoneal reflection over the superior border of the pancreatic body and tail (Fig. 13.4) and subsequently sealing and dividing the posterior short gastric vessels (Fig. 13.5).
- Next, the short gastric vessels from the splenic artery are carefully sealed and divided (Fig. 13.6). The short gastric vessels can cause troublesome bleeding, sometimes necessitating conversion to open surgery and/or splenectomy if not visualized and coagulated well. It is important to be patient while coagulating these vessels and divide them only after complete sealing to prevent this complication, especially when the omentum between the greater curve and the splenic hilum is very short.
- The mobilization of the stomach on the right should be carried out till the pylorus to ensure adequate length. Care must be taken to avoid injury to the right pastor epiploic pedicle at this level (Fig. 13.7).
- **Care must be taken to identify and preserve the entire right gastroepiploic artery throughout this mobilization to avoid ischemia of the gastric conduit.**
- The lesser omentum is opened after retracting the liver and serially divided starting from the lesser curvature of the stomach and progressing towards the hiatus (Fig. 13.8). Any accessory/replaced left hepatic arteries arising from the left gastric should be identified and preserved.
- The above maneuver exposes the left gastric vessels which can be identified by lifting the lesser curvature upwards. The left gastric vessels are then dissected (Fig. 13.9) along with the adjacent lymph nodes.
- A D2 lymphadenectomy along the hepatic, left gastric, splenic and celiac vessels is completed now (Fig. 13.10).
- The left gastric vessels are now ligated (Fig. 13.11) using hemolok clips (our preference) or a vascular stapler and then divided.
- The dissection is then carried out posteriorly upto the hiatus; division of the gastrohepatic omentum and phrenoesophageal ligament should not be completed at this stage to avoid the escape of gas and loss of pneumoperitoneum (Fig. 13.12).
- After ensuring that the entire stomach has been mobilized from the pylorus to the fundus, the hiatal dissection is initiated. The phrenoesophageal ligament and crura are dissected and the gastroesophageal junction is freed from the all the attachment to the retroperitoneum, spleen and crura. This is continued till the thoracic cavity is entered and the lower esophagus is visualized.

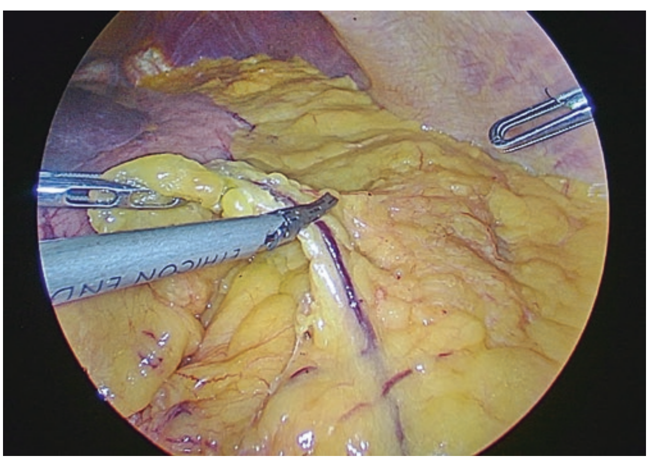

Fig. 13.3 The gastrocolic omentum is serially divided at a safe distance from the right gastro epiploic arcade taking care to avoid injury to the arcade

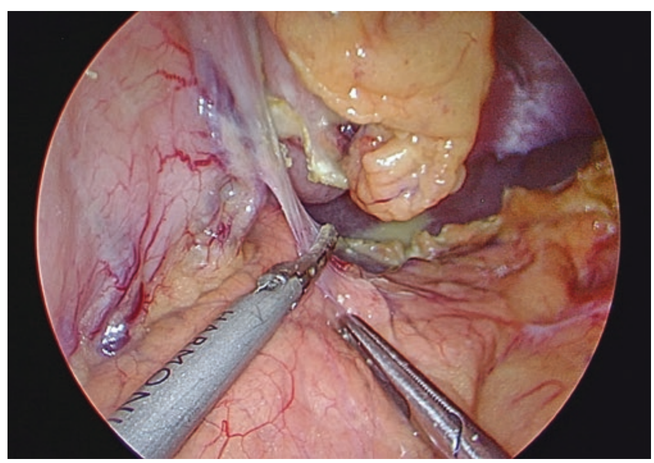

Fig. 13.4 The posterior peritoneal reflection is then divided to further free the stomach

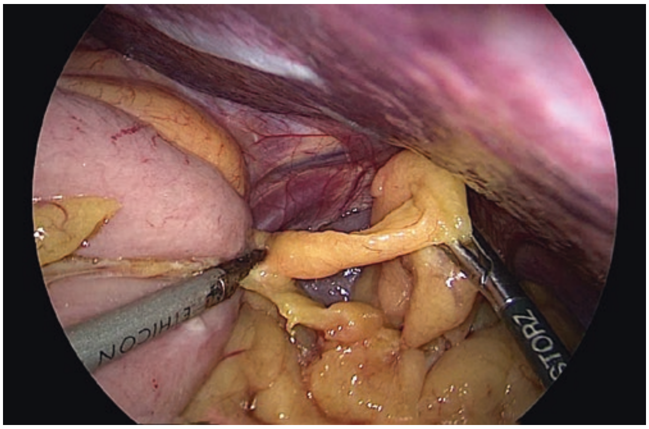

Fig. 13.5 The short gastric arteries are carefully sealed and divided, taking extreme care to avoid bleeding

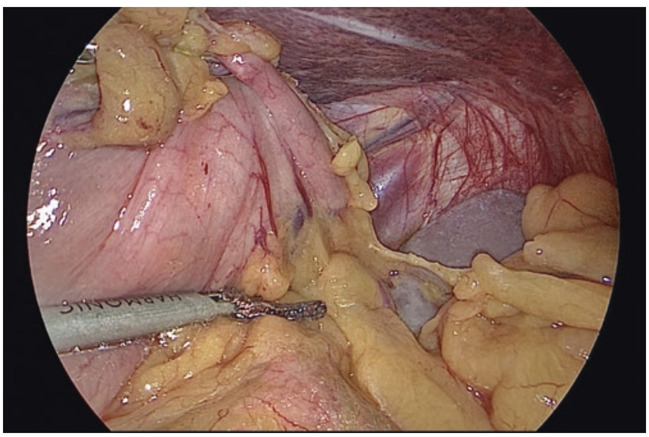

Fig. 13.6 The posterior short gastric vessels need to be separately sealed and divided

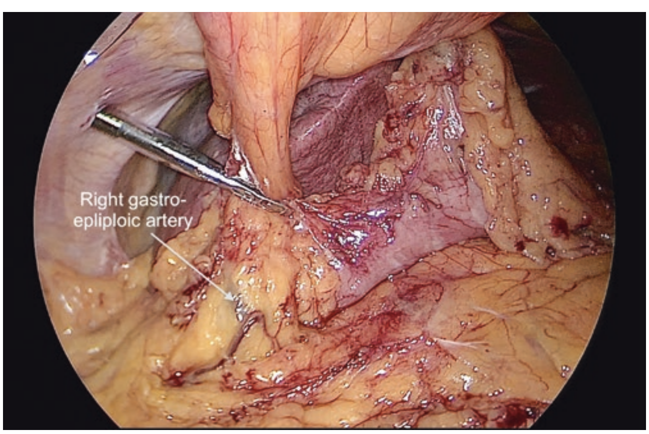

Fig. 13.7 The division of the gastrocolic omentum is continued to the right up to the level of the pylorus, preserving the right gastro epiploic pedicle

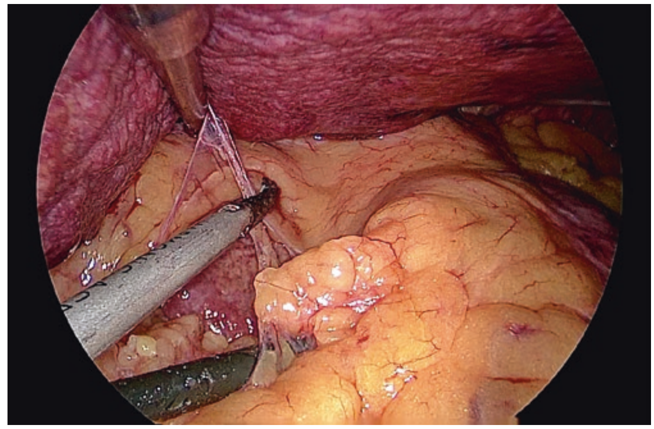

Fig. 13.8 The gastrohepatic omentum is divided, taking care to identify and preserve any aberrant hepatic arteries that are occasionally seen

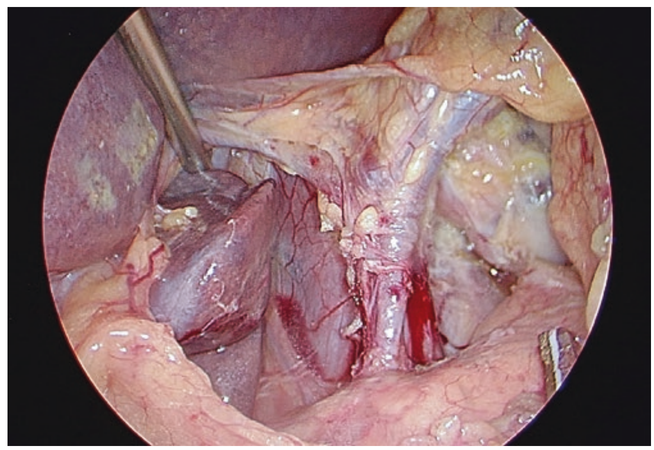

Fig. 13.9 The left gastric vein and artery are dissected, along with the lymph nodes around them

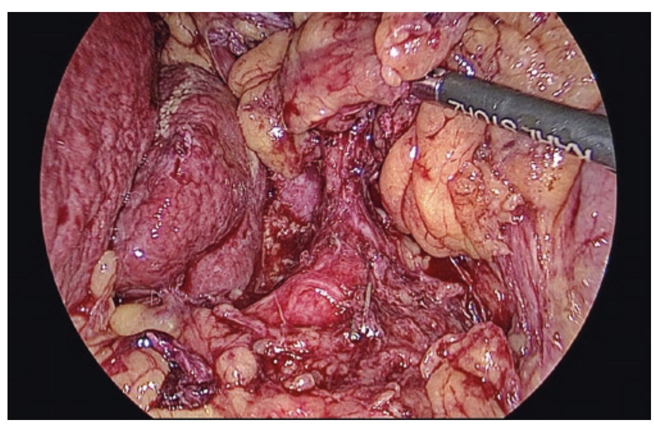

Fig. 13.10 The hepatic, left gastric and splenic group of lymph nodes are dissected off the named vessels

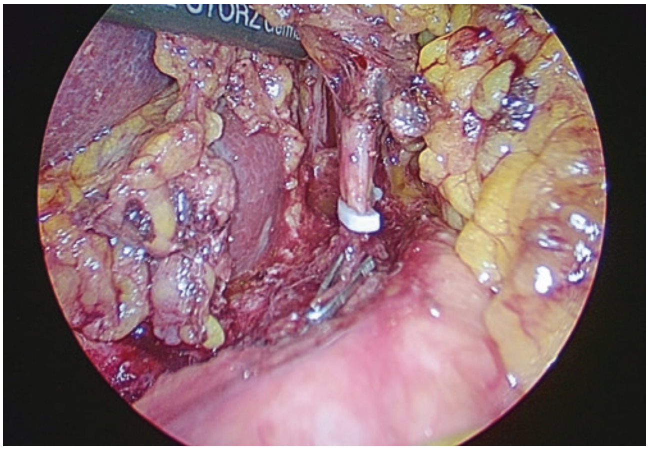

Fig. 13.11 The left gastric vein and artery are ligated using clips

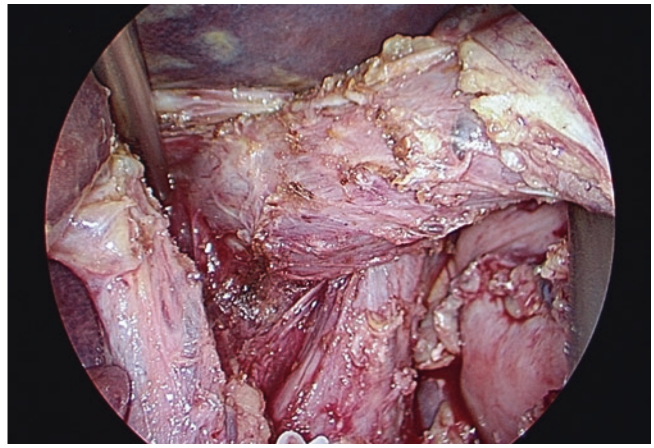

Fig. 13.12 The dissection is continued up to the hiatus without opening it to prevent escape of pneumoperitoneum

13.2.3.3 Creation of Stomach Tube

- The stomach tube can be created either intracorporeally or extracorporeally through a small 5 cm minilaparotomy.
- When the tube is being created intracorporeally, we start the stapling of the lesser curve at a predefined point (Figs. 13.13 and 13.14), usually at the junction of the left and right gastric artery branches.
- We progressively form the stomach tube using serial staples, taking care to keep the stomach tube neither too broad nor too narrow (Fig. 13.15). The final staple is not fired from the abdomen to facilitate pulling up of the stomach tube along with the esophagus into the neck wound (Fig. 13.16).
- The neck is opened using a transverse incision (see section "Cervical Esophageal Anastomosis") and the esophagus mobilized.
- The esophagus with the stomach tube (connected by the last part of the stomach tube which remains intact) is then pulled through the posterior mediastinum (Fig. 13.17) into the neck wound and the final staple fired to complete the formation of the stomach tube.
- When the stomach has been adequately mobilized, the pylorus will be seen just below the hiatal opening (Fig. 13.18) facilitating a tension free anastomosis in the neck.
- When the stomach tube is being created extracorporeally, we extend the 5 mm xiphisternal (liver retractor) port incision downward for about 5 cm, introduce a wound protector, and retrieve the full stomach with the mobilized esophagus into the abdomen wound.
- The stomach tube is then created extracorporeally using serial stapling (Fig. 13.19), stutured to a tape and pulled into the cervical wound.
- The stomach tube is then anastomosed with the proximal esophagus in the neck using a triangulated stapled or a handsewn technique (see section "Cervical Esophageal Anastomosis").

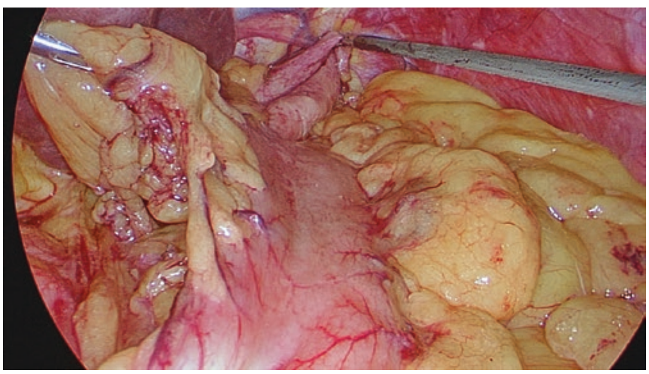

Fig. 13.13 The point on the lesser curvature of the stomach where the stomach tube creation is planned is marked

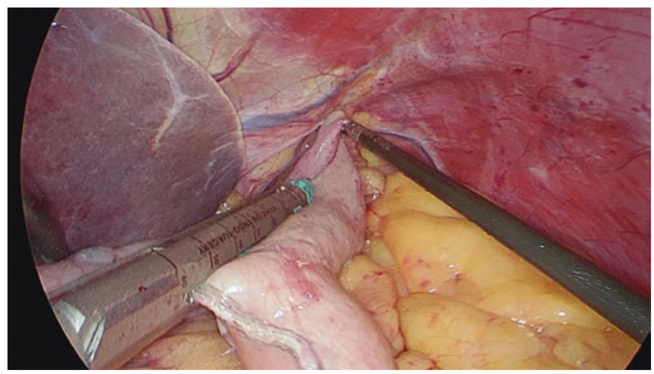

Fig. 13.15 The stomach tube is created by serial firings of the stapler

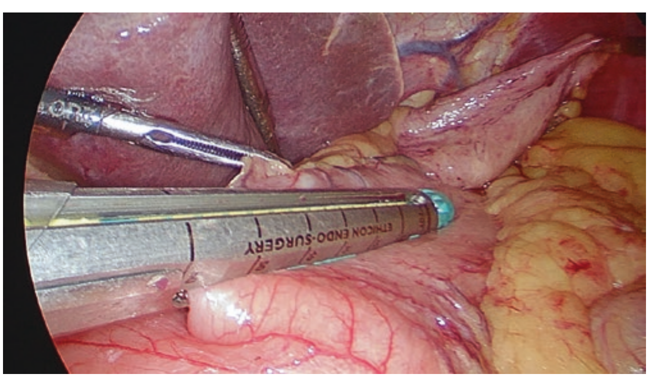

Fig. 13.14 The first stapler is fired to fashion the stomach tube

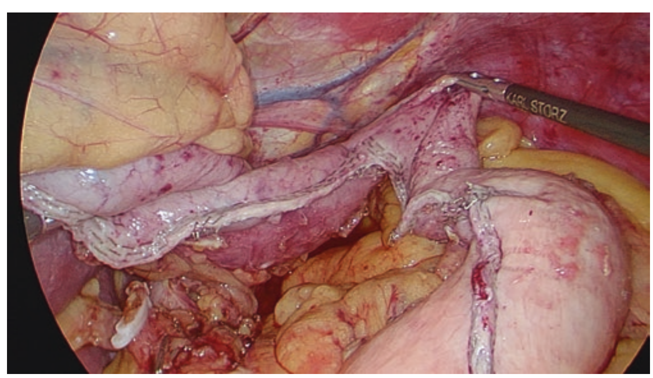

Fig. 13.16 The stomach tube is formed except for the last firing to maintain the connection between the specimen and the stomach tube

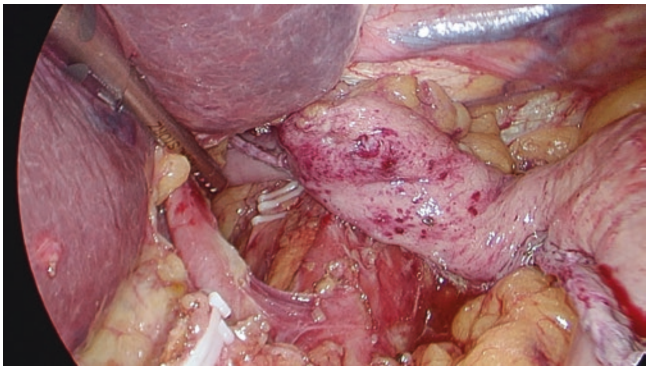

Fig. 13.17 The connection between the stomach tube and the specimen permit pulling of the stomach tube along the posterior mediastinum

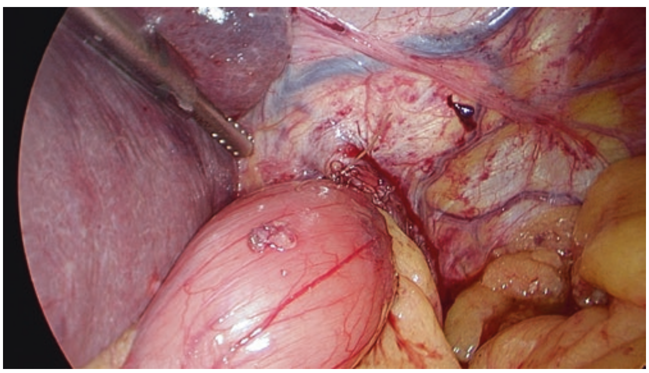

Fig. 13.18 The stomach tube is pulled up along the mediastinum; the pylorus reaches just below the hiatal opening to ensure a tension-free anastomosis at the neck

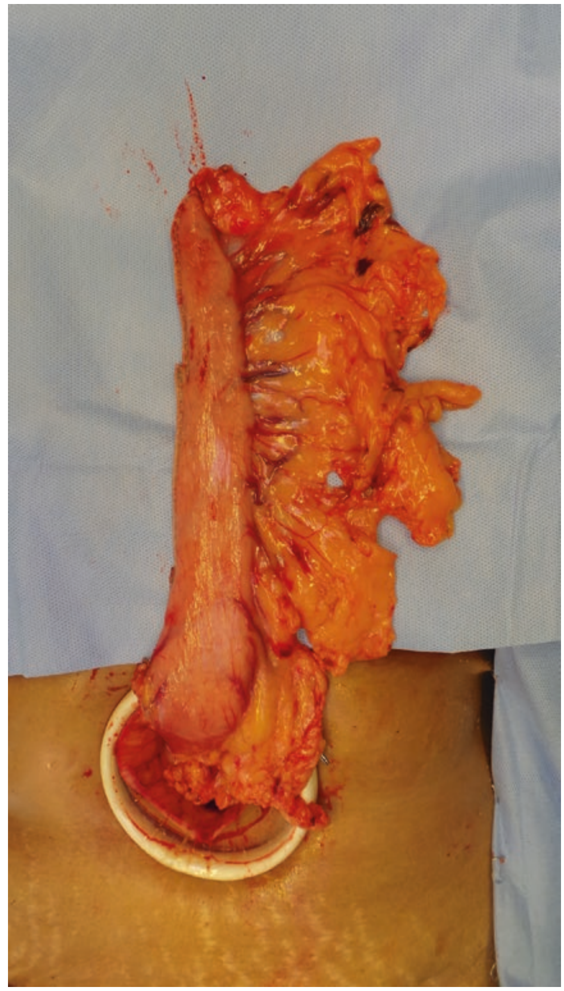

Fig. 13.19 Extracorporeal stomach tube creation (all other steps are identical to the intracorporeal stomach tube formation)

13.3 Laparoscopic Percutaneous Feeding Jejunostomy

Zuli Zhou and Xiao Li

13.3.1 Technical Points

Early initiation of enteral nutrition is preferred over parenteral nutrition for patients undergoing esophagectomy. Laparoscopic percutaneous feeding jejunostomy is a safe and simple technique that adds little to the morbidity and cost of managing patients with esophageal cancers undergone MIE. It facilitates optimization of nutrition in the perioperative period for these patients, especially in those receiving preoperative chemotherapy.

13.3.2 Anatomical Landmarks

Identifying the ligament of Treitz and locating the proximal direction of the bowl are crucial to the technical. A helpful anatomical note is that there is less mesenteric fat in the proximal small bowel compared to the ileum and the presence of "windows" between the mesentery and bowel wall suggests a proximal location.

13.3.3 Operating Procedure

1. The bowel is grasped and run in one direction or the other until the ligament of Treitz is identified. When the ligament of Treitz is identified, a segment of small bowel about 20–30 cm distal is grasped and pushed to the abdominal wall to ensure that the bowel will move that far anteriorly without tension (Fig. 13.20).
2. An appropriate location for the jejunostomy is identified and marked on the antimesenteric surface of the small bowel. The 5 mm trocar incision in the left upper quadrant was chosen as the entry site of the jejunostomy tube on the abdominal wall. Loose Purse-string suture is made with 3-0 MERSILK® around the jejunostomy location (Fig. 13.21).
3. The silk suture is taken out of the abdominal cavity with a latch needle. So the bowel can be pulled to the abdominal wall (Fig. 13.22a, b).
4. While retracting the small bowel with the T-Fasteners, an 18 gauge needle is passed through the center of the T-Fasteners into the jejunum. A guidewire is then passed through the needle distally into the jejunum and the needle removed. A split catheter sheath is then passed over the guidewire into the bowel, the guidewire removed, and the jejunostomy tube passed through the split catheter sheath into the jejunum. The split catheter sheath is removed and the T-fasteners are secured to hold the jejunum in place against the abdominal wall (Fig. 13.23).
5. A second purse-string suture is sewn with 3-0 MERSILK® at the distal part around the insertion site of the catheter into the jejunum. The silk suture is also taken out with a latch needle as step 3, but through a different puncture point (Figs. 24 and 25).
6. The two sutures are pulled tight and tied on the anterior abdominal wall (outside). This maneuver will attach the jejunum against the anterior abdominal wall securely. The suture will be closed at skin level. The jejunostomy tube is fixed using the fixing devices after confirming the tube is not blocked (Fig. 13.26).

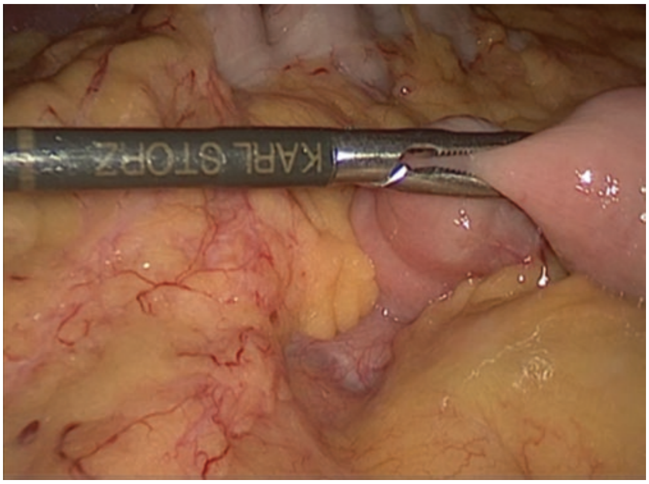

Fig. 13.20 A segment of small bowel is grasped and pushed to the abdominal wall to ensure that the free bowel is long enough

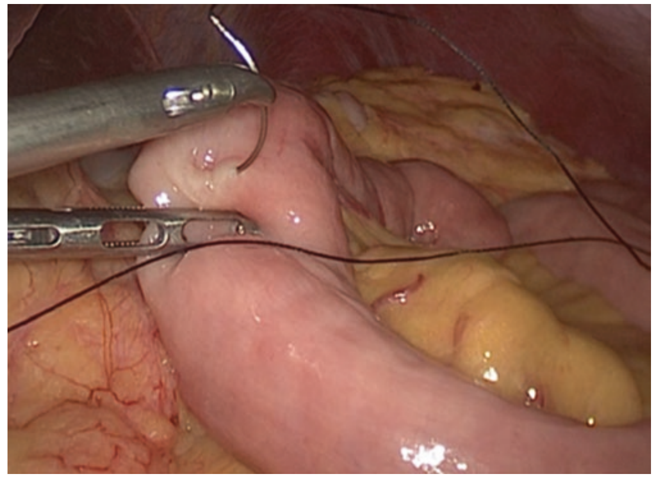

Fig. 13.21 Loose Purse-string suture is made with 3-0 MERSILK® around the jejunostomy location

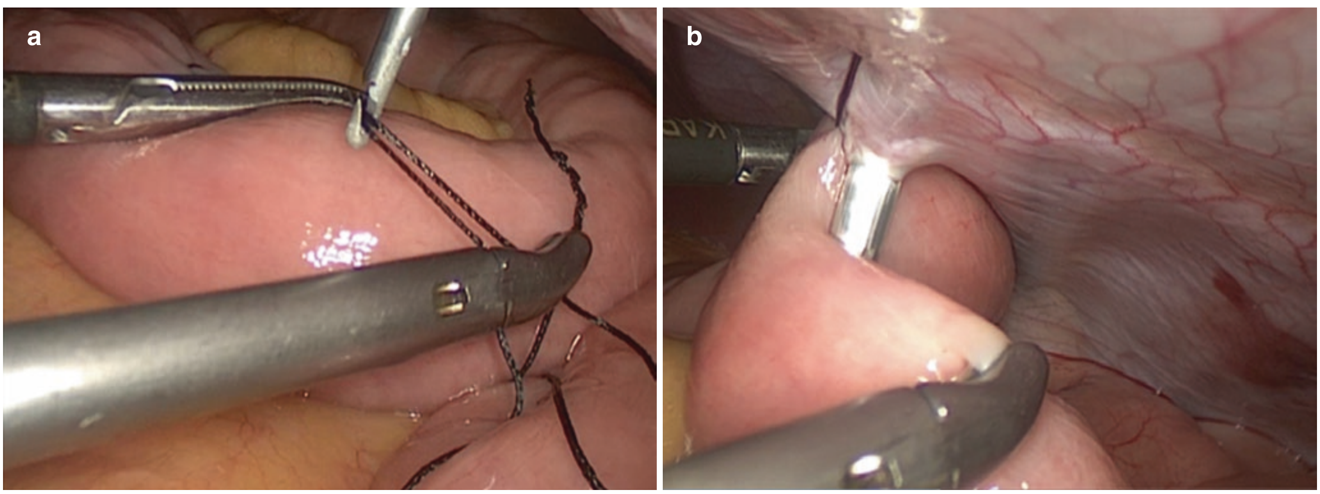

Fig. 13.22 The silk suture is taken out of the abdominal cavity with a latch needle. The bowel is pulled to the abdominal wall then

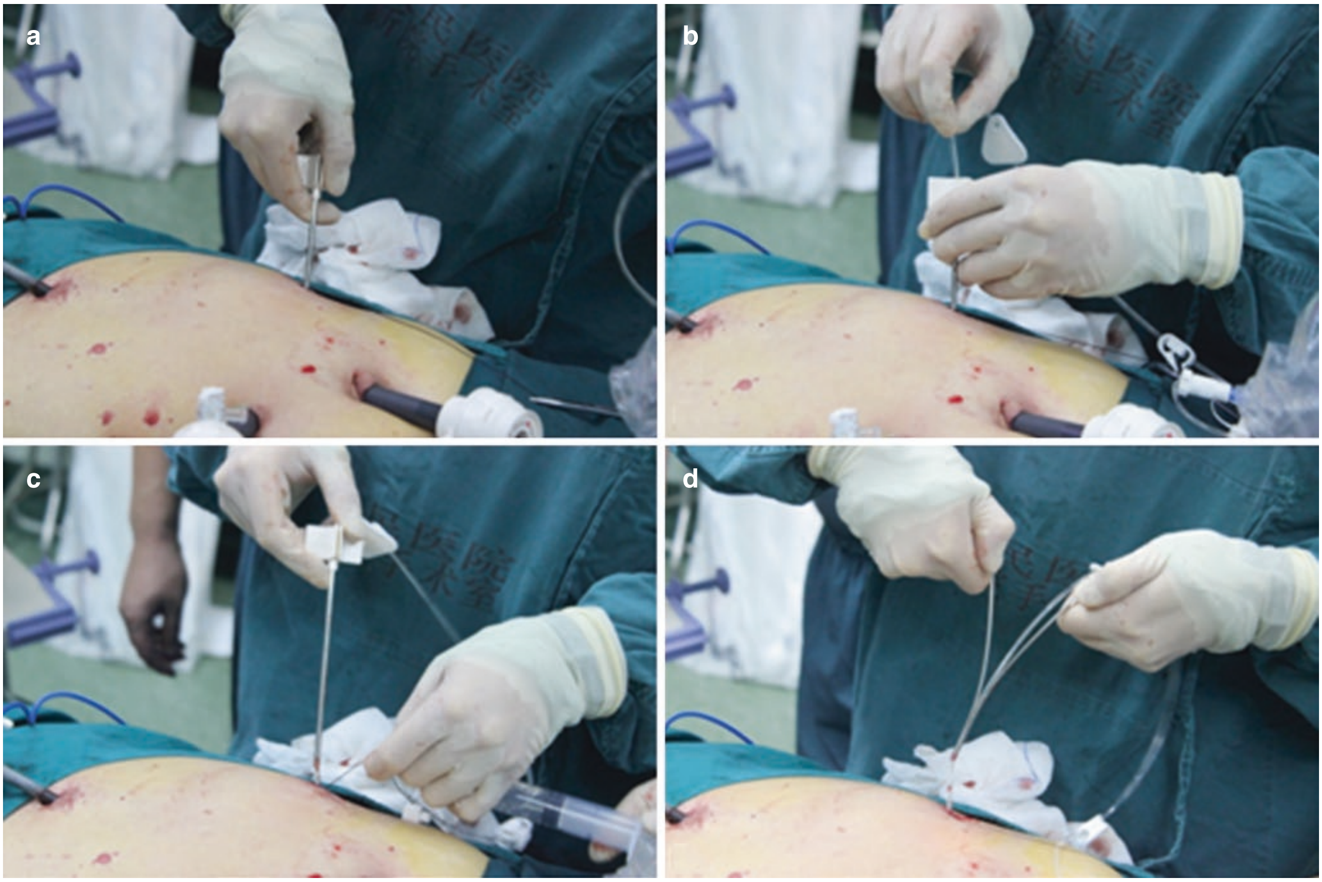

Fig. 13.23 The process of placing feeding tube

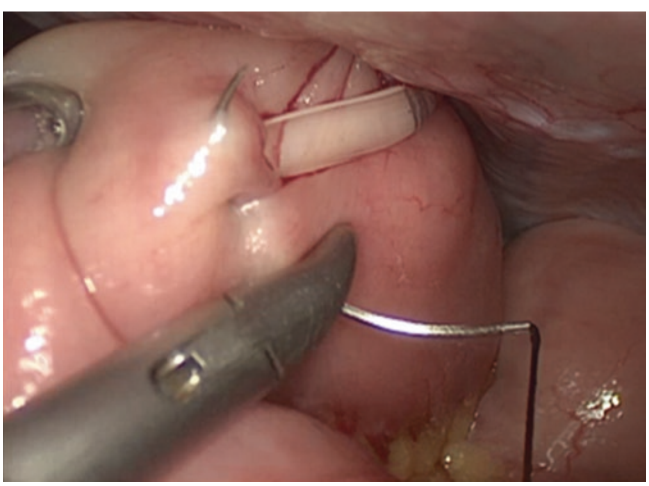

Fig. 13.24 A second purse-string suture is sewn

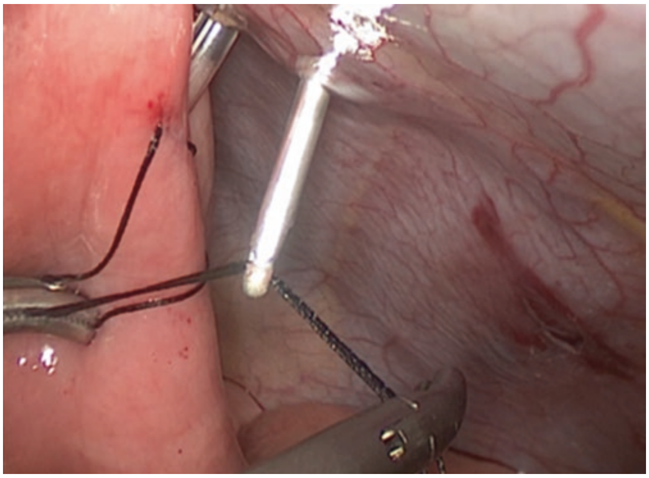

Fig. 13.25 The silk suture is taken out with a latch needle

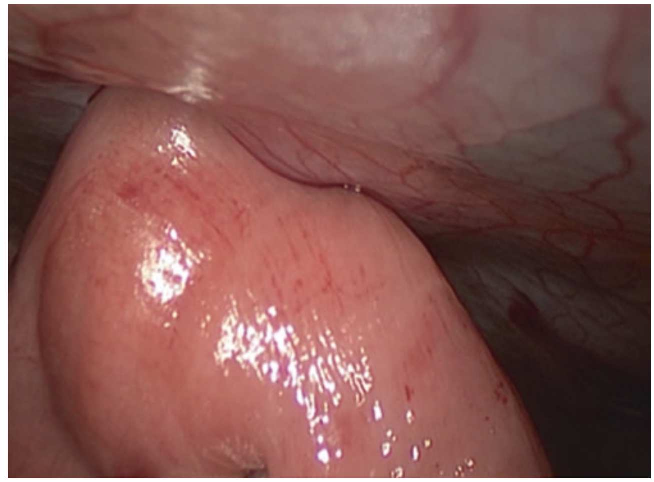

Fig. 13.26 The inner sight after the jejunostomy tube is fixed

13.4 Thoracoscopic Esophageal Mobilization

C.S. Pramesh, George Karimundackal and Sabita Jiwnani

13.4.1 Technical Points (or Tips)

Thoracoscopic esophageal mobilization is an integral part of the McKeown three phase and the Ivor-Lewis esophagectomy procedures.

The key points to remember are:

- Confirm operability before extensive esophageal mobilization to avoid esophageal necrosis in case of inoperability
- Avoid injury to the tracheobronchial tree, descending thoracic and arch of aorta
- Ligate the thoracic duct if injured, dissected or exposed

The following difficulties may be faced:

- Lung collapse may be suboptimal either due to extensive lung adhesions or a smoker's lung, making dissection difficult.
- Meticulous dissection in the regions of the right and left recurrent nerve (RLN) lymph nodal groups is necessary to avoid temporary or permanent RLN paresis/palsy.
- Care must be taken to identify and preserve an aberrantsubclavian artery arising from the descending thoracic aorta.

13.4.2 Anatomical Landmarks

Thoracoscopic esophageal mobilization is relatively straightforward as there are very few variations in the anatomical landmarks.

- The blood supply of the thoracic esophagus arises primarily from direct branches of the descending thoracic aorta.
- The upper half of the esophagus closely abuts the membranous wall of the trachea and the left main bronchus anteriorly.
- The pericardium offers a good plane of dissection with the lower half of the esophagus anteriorly.
- The horizontal part of the azygous vein with the bronchial artery forms the roof of a tunnel through which the esophagus courses (junction of the upper and middle thirds).
- The thoracic duct runs vertically parallel to the vertical part of the azygous vein between it and the descending thoracic aorta, and crosses over to the left side at the level of the tracheal bifurcation.
- The right RLN branches out from the right vagus nerve just after it crosses the right subclavian artery; the left RLN has a much longer course and is given off from the left vagus just after it crosses the aortic arch, and runs along the left tracheo esophageal groove

13.4.3 Operating Procedure

13.4.3.1 Ports, Pneumothorax, Instruments

- We place the patient on the right edge of the operating table, in the left lateral position, with the operating surgeon standing posterior to the patient and the assistant standing anterior. Monitors are placed both anterior and posterior to the patient to facilitate good visualization for both the surgeon and the assistant.
- The patient's arms are raised and the table flexed (or 'broken') midway to avoid the hip getting in the way of the operating instruments. The upper (right) leg is flexed at the knee and a pillow placed between the thighs.
- We place five ports for the thoracoscopic esophageal mobilization (Fig. 13.27) – a seventh/eighth space 10 mm camera port just anterior to the anterior axillary line, a 10 mm port just below the right nipple for lung retraction and a second retraction port between the camera and the lung retraction ports. We use two dissecting ports for the operating surgeon, a 5 mm port one finger breadth below and anterior to the tip of the scapula and a 5 or 10 mm port between this and the camera port. Sometimes, we use an axillary port in the second intercostal space in the mid axillary line to facilitate supracarinal lymphadenectomy.
- We usually perform the thoracoscopic esophageal mobilization with right lung collapse using a left sided double lumen endotracheal tube. We have rarely needed a CO_2 pneumothorax though it may be used to improve the lung collapse.

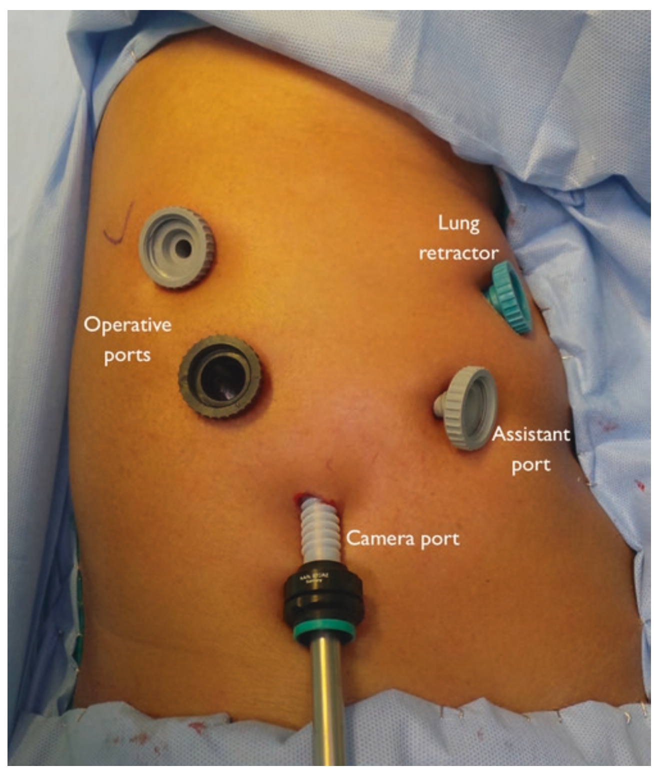

Fig. 13.27 Thoracoscopic port positions: the ports are placed in the shape of a gentle 'U' when viewed from below, as shown in the figure. A detailed description of the port positions is available in the text

13.4.3.2 Mobilisation

- We prefer to confirm that the growth is operable prior to mobilizing the rest of the esophagus – failure to do so has occasionally resulted in esophageal necrosis and leaks in case the growth is subsequently found to be stuck to the aorta or the tracheobronchial tree.
- Two parallel incisions are made in the mediastinal pleura anterior (Fig. 13.28) and posterior to the esophagus at the level of the primary growth. We proceed with dissection on a deeper plane at this level circumferentially to confirm operability (Fig. 13.29).
- Once the growth is confirmed to be free from the tracheobronchial tree and the aorta, we continue the mediastinal pleural incisions superior (Figs. 13.30 and 13.31) and inferior to the growth, separating the esophagus from these major structures. We use either a monopolar cautery hook or harmonic shears or bipolar Maryland for dissection. Direct branches from the aorta are adequately coagulated by the harmonic device or the bipolar forceps.
- Extreme care is necessary while dissecting the esophagus off the tracheobronchial tree anteriorly (Fig. 13.31), especially as the posterior wall of the tracheobronchial tree is membranous.
- The pericardium offers a good plane of dissection anterior to the lower half of the esophagus.
- Care must be taken to avoid unduly exposing or injuring the thoracic duct which runs between the aorta and the vertical portion of the azygous vein. If the growth is advanced and is close to the thoracic duct, it may be resected to achieve a negative margin (Fig. 13.32). We have a low threshold for ligating the thoracic duct in case the duct is mobilized or exposed extensively (Fig. 13.33).
- We then proceed with the supracarinal part of the esophageal mobilization. Similar to the infracarinal part, we take parallel cuts in the mediastinal pleura to expose the esophagus (Fig. 13.34). We then proceed with most of the periesophageal dissection posteriorly, which is a relatively avascular plane anterior to the vertebral body and the prevertebral fascia (Fig. 13.35). Next, we dissect anteriorly between the trachea and the esophagus, taking care not to injure the posterior membranous wall of the trachea (Fig. 13.36).
- We prefer to preserve the azygous vein – bronchial artery complex to preserve the bronchial supply to the tracheobronchial tree unless the growth is located close to it. It is quite simple to dissect around the esophagus without ligating the azygous vein (Figs. 13.37 and 13.38). However, we ligate the complex while performing a supracarinal lymphadenectomy to improve access to the bilateral RLN group of lymph nodes.

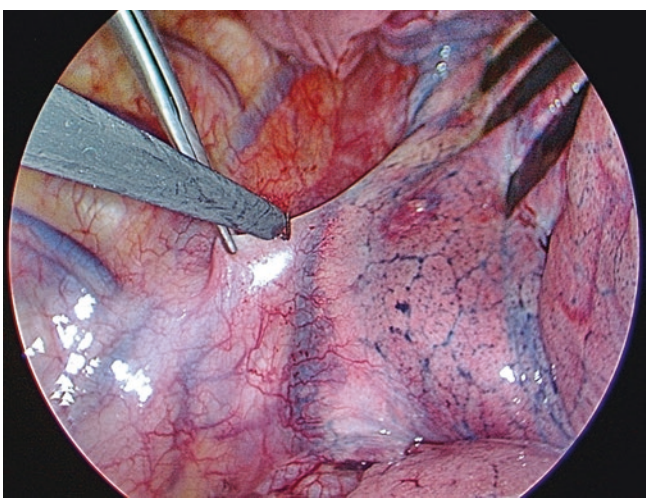

Fig. 13.28 The anterior mediastinal incision runs parallel to the anterior border of the esophagus at the level of the growth. Notice the traction from the forceps posteriorly and the counter-traction by the lung retractor anteriorly

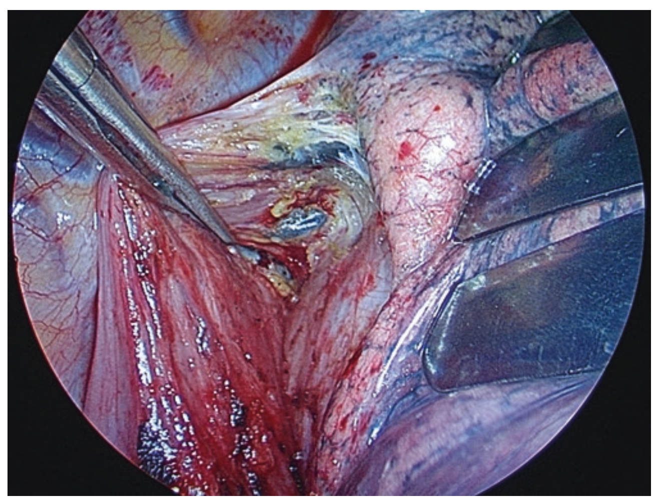

Fig. 13.29 The dissection is carried out deeper around the esophagus, separating it from the pericardium anteriorly. Again, notice the counter-traction offered by the lung retractor anteriorly against the pericardium, facilitating the dissection

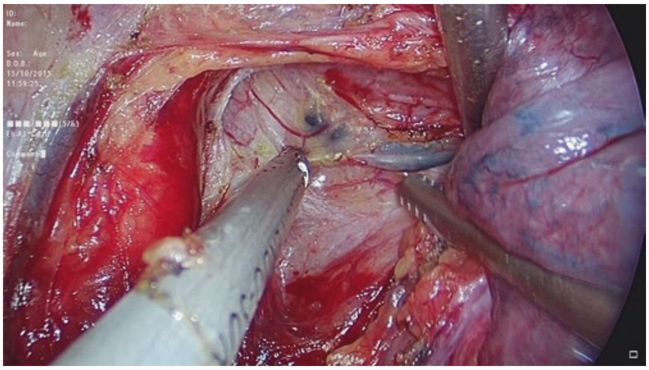

Fig. 13.30 The esophagus is mobilized along its length infracarinally, dissecting it off the thoracic aorta and the aortic arch posteriorly

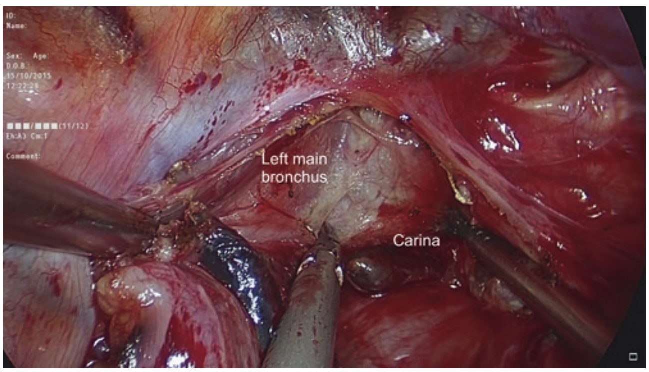

Fig. 13.31 The esophagus is dissected off the carina and left main bronchus anteriorly, taking care to avoid injury to the posterior membranous wall

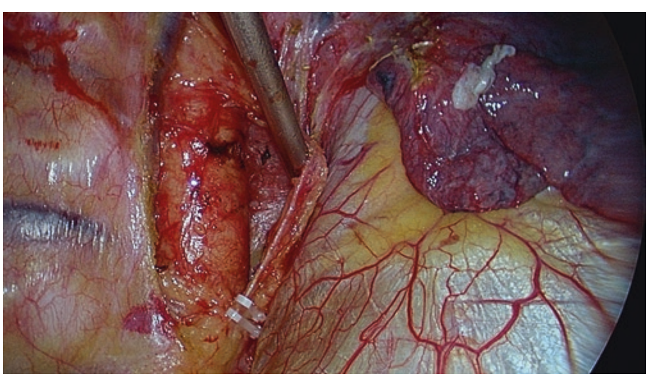

Fig. 13.32 The thoracic duct can be included along with the esophagus to achieve a wider circumferential margin, especially if the growth is more advanced and involves the adventitia or pleura

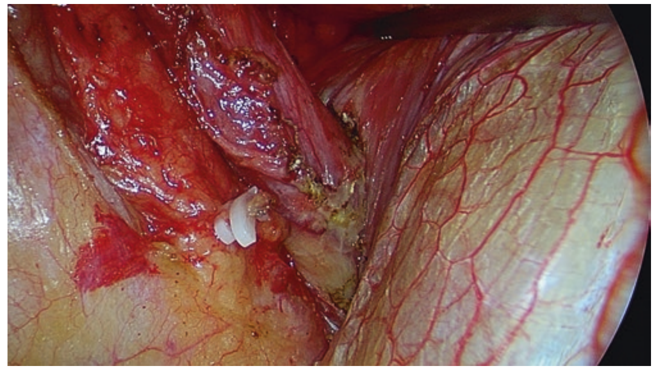

Fig. 13.33 The thoracic duct has to be securely clipped using locking or regular liga clips lower than the lowest point where it has been dissected to reduce the chances of a postoperative chyle leak

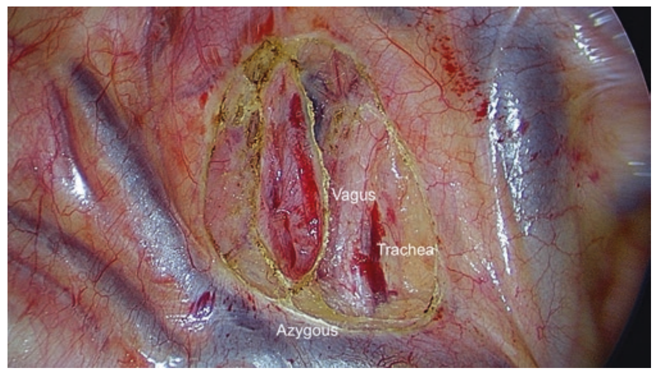

Fig. 13.34 Similar to the pleural cuts in the infracarinal mediastinal pleura, parallel cuts are taken in the mediastinal pleura supra carinally to expose the upper esophagus

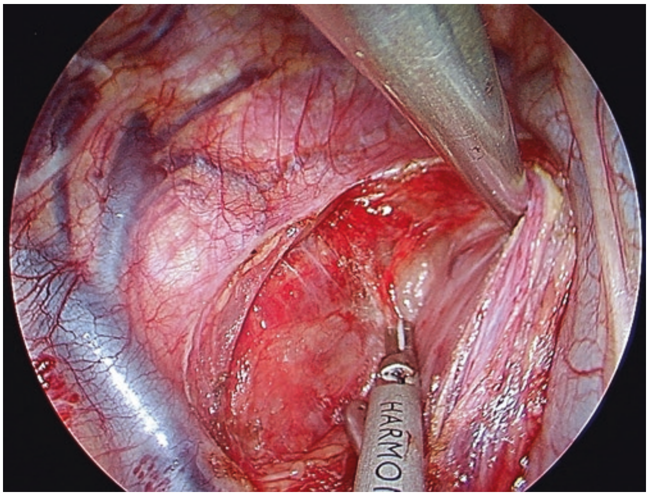

Fig. 13.35 The plane posterior to the upper esophagus is relatively avascular and is easily developed

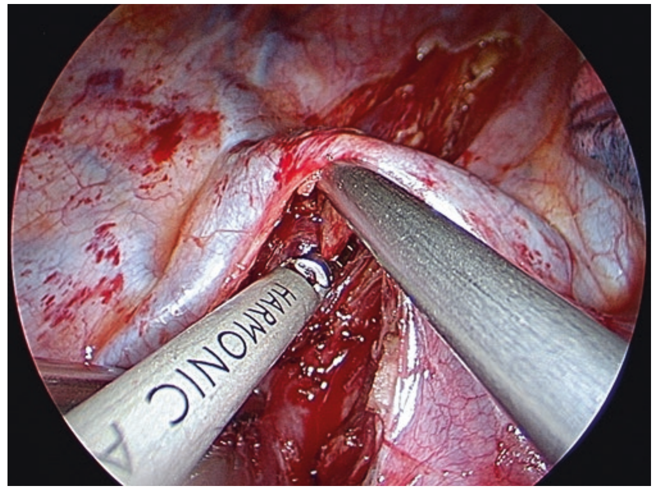

Fig. 13.37 The retroazygous part of the dissection can be done without dividing the azygous-bronchial artery complex, by careful dissection of this complex

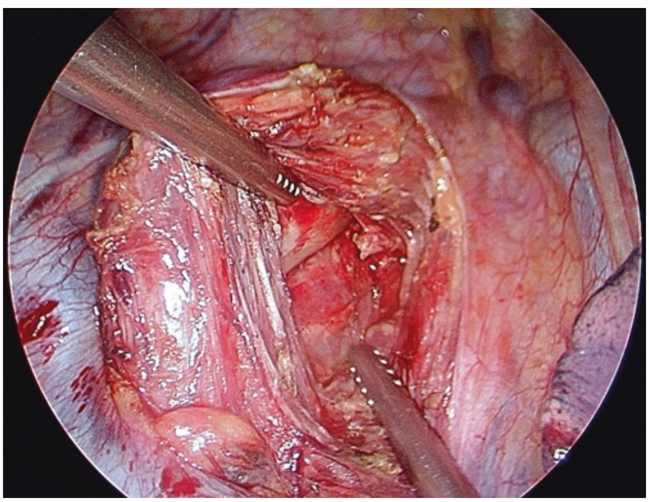

Fig. 13.36 The plane between the upper esophagus and the trachea is now developed carefully, and the esophagus separated from the trachea

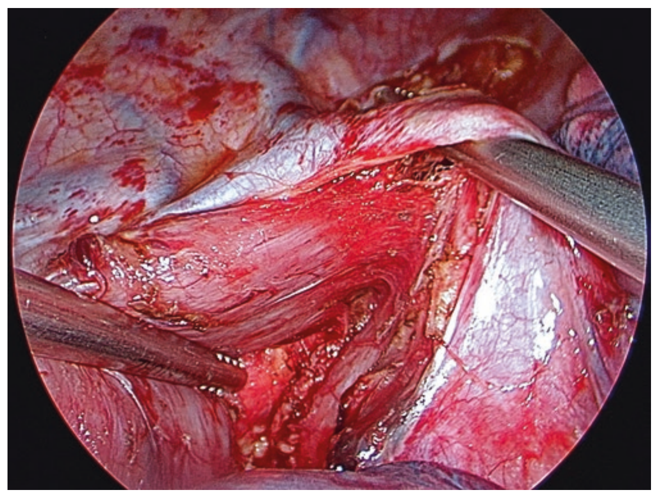

Fig. 13.38 The azygous vein is retracted upwards to allow complete dissection of the retroazygous esophagus

13.4.3.3 Lymphadenectomy

- We perform a systematic mediastinal lymphadenectomy including the subcarinal, middle and lower para esophageal lymph nodes in all patients; in addition, we also perform supracarinal lymphadenectomy as part of three field lymphadenectomy and include the bilateral RLN groups, aorto pulmonary nodes and upper para esophageal lymph nodes.
- The subcarinal nodes are best approached by dissecting just medial to the medial walls of the right and left main bronchi, taking care to avoid injury to the posterior wall of the bronchi. The entire subcarinal area needs to be cleared of all lymphatic and fibrofatty tissue (Fig. 13.39)
- The right RLN group of nodes are identified by following the right vagus nerve superiorly where the right RLN curves around the right subclavian artery (Fig. 13.40). Care must be taken to avoid directly handling the nerve to avoid vocal cord paresis.
- We retract the tracheobronchial tree anteriorly to expose the left tracheobronchial angle – this exposes the aorto pulmonary group of lymph nodes for dissection (Fig. 13.41). Dissection in this region has to be extremely careful to avoid injury to the pulmonary artery. The left RLN can be identified in this region as it curves around the arch of the aorta.
- The left RLN is dissected along the left paratracheal border in the groove between the trachea and the esophagus – exposure to this area is facilitated by retracting the trachea anteriorly using the fan retractor with the blades closed (Fig. 13.42). The left RLN group of nodes are carefully dissected taking care not to handle the nerve directly.
- We confirm that the entire thoracic esophagus has been mobilized and is free from surrounding structures. We leave the supra diaphragmatic mediastinal pleura intact and do not open the hiatus to facilitate maintenance of the pneumo mediastinum during the laparoscopic part of the procedure.
- The thoracoscopic ports are closed after ensuring hemostasis.

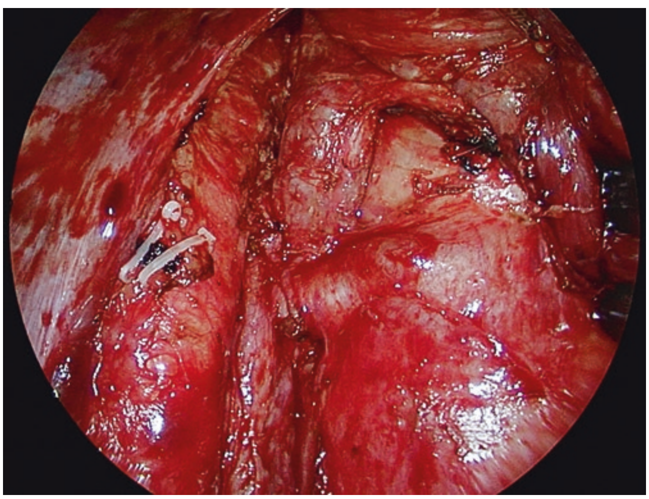

Fig. 13.39 The subcarinal group of nodes should be completely dissected, laying bare the medial borders of the right and left main bronchi. Notice the left inferior pulmonary vein which serves as the deeper extent of circumferential esophageal mobilization

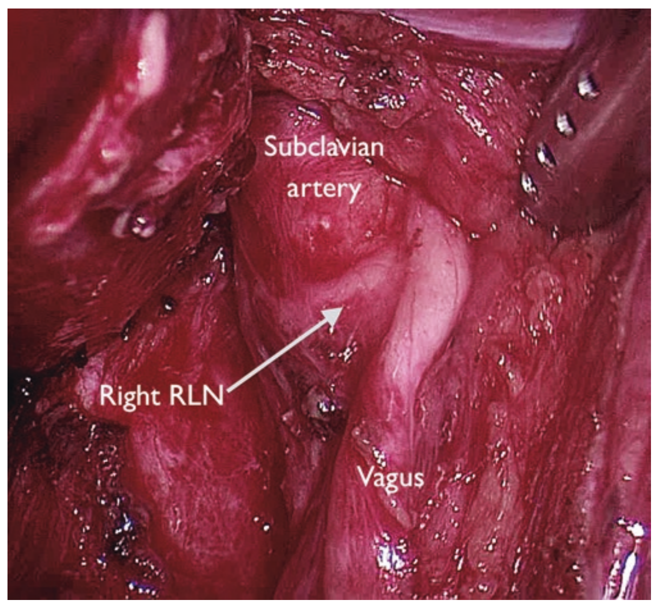

Fig. 13.40 The right recurrent laryngeal group of nodes is dissected at the thoracic apex where the vagus nerve crosses the subclavian artery

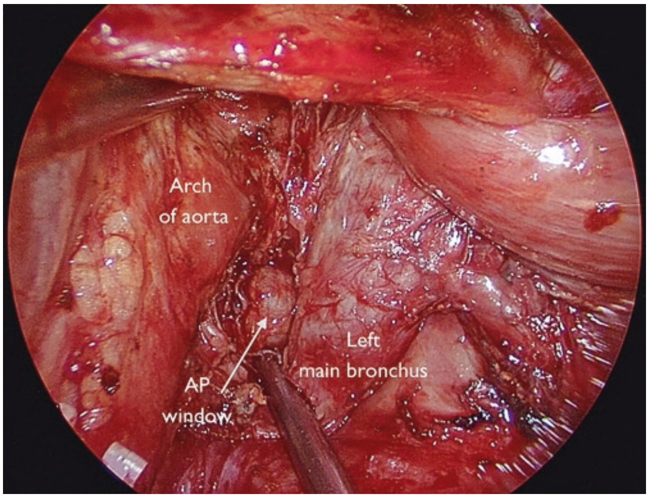

Fig. 13.41 The aorto-pulmonary group of nodes is dissected along the left tracheobronchial angle, and the left recurrent laryngeal nerve may be seen here as it curves around the aortic arch

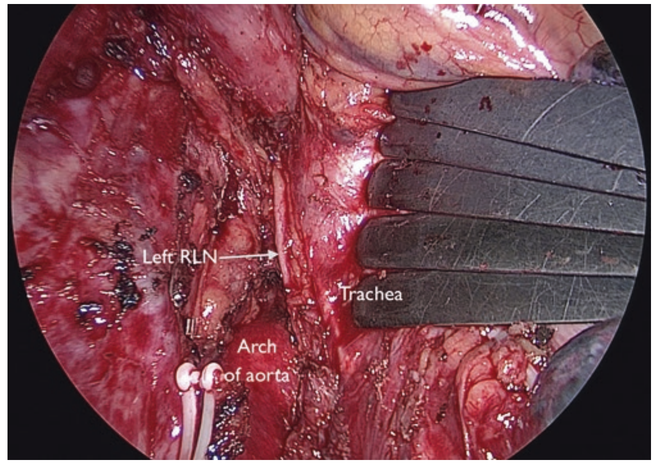

Fig. 13.42 The left recurrent group of nodes are dissected along the left paratracheal border taking care not to directly handle the nerve

13.5 Cervical Esophageal Anastomosis

C.S. Pramesh, George Karimundackal and Sabita Jiwnani

13.5.1 Technical Points (or Tips)

The esophagogastric anastomosis is a crucial part of esophagectomy and is an integral part of the McKeown three phase and the Ivor-Lewis esophagectomy procedures.

The key points to remember are:

- Ensure minimal handling and maintain good vascularity of the stomach tube preserving the arcade along the greater curvature
- Adequate mobilization of the esophagus at the neck and a avoid tension at the esophagogastric anastomosis
- Either a stapled or a handsewn anastomosis may be done adhering to the basic principles of any gastrointestinal anastomosis

The following difficulties may be faced:

- The length of the stomach tube may be inadequate to ensure a tension-free anastomosis in the neck.
- A short right gastroepiploic arcade may compromise the vascularity to the tip of the stomach tube.

13.5.2 Anatomical Landmarks

Careful attention to the anatomical landmarks in the neck facilitate this simple procedure and reduce complications from the cervical esophagogastric anastomosis.

- The esophagus may be approached either between the two heads or medial to the medial head of the sternomastoid.
- The esophagus is located posterior to the trachea and anterior to the prevertebral fascia and the vertebral bodies in the neck.
- The carotid sheath containing the carotid artery and internal jugular vein is lateral to the esophagus and retraction of this structurelaterally improves access to the esophagus.
- The middle thyroid vein drains into the internal jugular vein at this level and may require to be ligated
- The left recurrent laryngeal nerve runs along the left tracheo esophageal groove and requires careful dissection to avoid vocal cord paresis.

13.5.3 Operating Procedure

- We position the patient with the neck slightly extended (either by placing a roll below the shoulder blades or by 'breaking' the table) and turned to the right.
- We take a transverse incision one finger breadth above and parallel to the medial half of the left clavicle and deepen it to the subplatysmal plane (Fig. 13.43); alternately a hockey-stick incision may be taken though we find it cosmetically less acceptable.
- The sternomastoid is retracted either between the two heads or medial to the medial head of the muscle.
- Dividing the medial fibres of the strap muscles improves access to the cervical esophagus; the carotid artery and the internal jugular vein (Fig. 13.44) are gently retracted laterally to facilitate the exposure; the middle thyroid vein may need to be ligated.
- The left recurrent laryngeal nerve is identified in the trachea esophageal groove and carefully preserved (Fig. 13.45).
- The plane posterior to the cervical esophagus is flimsy and avascular and should be developed first; subsequently the esophagus is dissected off the trachea anteriorly. The esophagus is then hooked up into the cervical wound (Fig. 13.46) and divided taking care to divide the mucosa 0.5–1 cm distal to the adventitial cut (Fig. 13.47).
- If a minilaparotomy is planned to create the stomach tube (see Sect. 12.2), the esophagus and mobilized stomach are then pulled into the abdomen and through the minilap wound using a wound protector; if the stomach tube is being created intracorporeally, the esophagus and stomach tube are pulled into the neck.
- The specimen is removed with completion of the stomach tube either through the minilaporotomy or the neck incision.
- The stomach tube is brought up to the neck wound and the end of the tube is divided (Fig. 13.48); this gives the surgeon an opportunity to confirm adequate vascularity of the stomach tube.
- Stay sutures are taken in the esophagus and the end of the stomach, bringing them up into the incision like a double-barrel (Fig. 13.49).
- A linear cutter is then introduced vertically into the lumen of the esophagus and the stomach up to the 3 cm mark (Fig. 13.50). The posterior layer of the anastomosis is created by firing a 55 or 60 mm staple (Figs. 13.51 and 13.52). Once the posterior layer of the anastomosis is complete, we place the nasogastric tube across the anastomosis (Fig. 13.53) in the stomach tube, with the tip midway in the chest.
- The anterior layer of the esophago gastric anastomosis is brought together using approximating sutures (Figs. 13.54

and 13.55); the anastomosis is then completed using two more 55 or 60 mm staples with a triangulated technique (Figs. 13.56 and 13.57). If there is redundant omentum available, it may be loosely wrapped around the anastomosis.
- Alternately, a handsewn anastomosis may be done, especially if the length of the cervical esophagus in the neck is too short to accommodate the linear stapler (especially for upper and middle third esophageal growths). Our preference here is to use a single layer of interrupted PDS sutures.
- The main advantage of a triangulated stapled anastomosis over a handsewn one is that it creates a very roomy anastomosis, almost eliminating anastomotic strictures. Anastomotic leak rates have remained almost identical with the stapled and handsewn anastomosis in our hands.

Fig. 13.43 The skin incision is taken one finger-breadth parallel and above the medial half of the clavicle

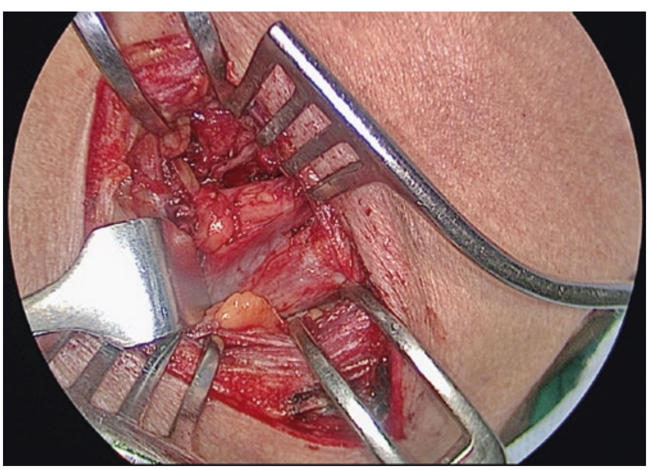

Fig. 13.44 The carotid artery and internal jugular vein are dissected and retracted laterally

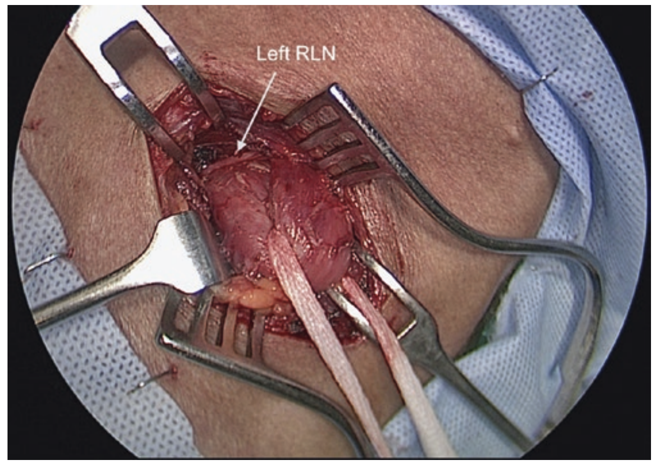

Fig. 13.45 The left recurrent laryngeal nerve is identified and dissected in the tracheo esophageal groove

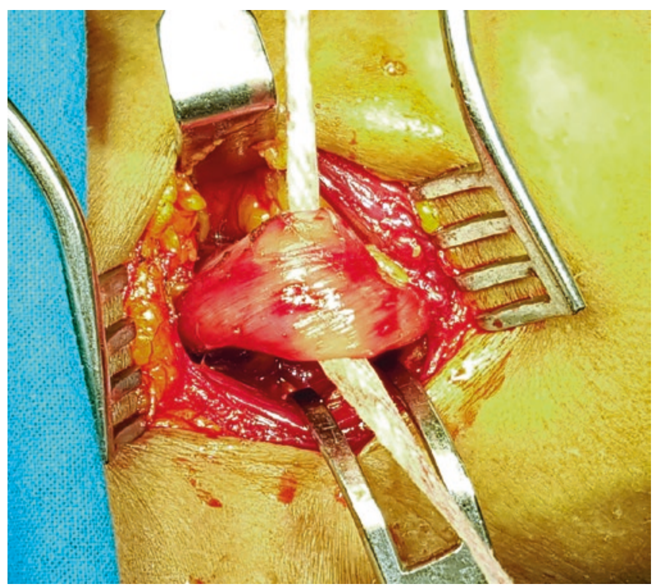

Fig. 13.46 The cervical esophagus is dissected off the trachea, and looped up into the neck incision

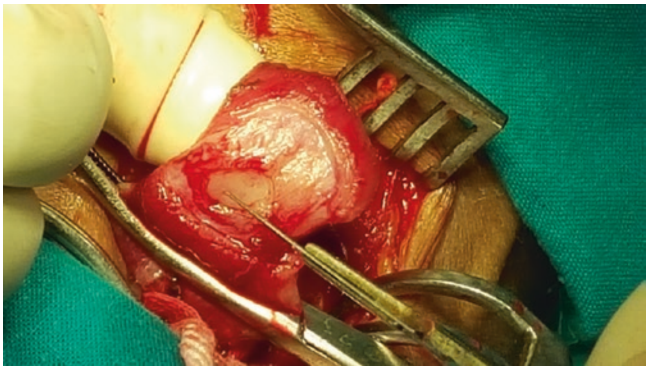

Fig. 13.47 The esophagus is divided with the adventitial division about 0.5–1 cm above the mucosal division

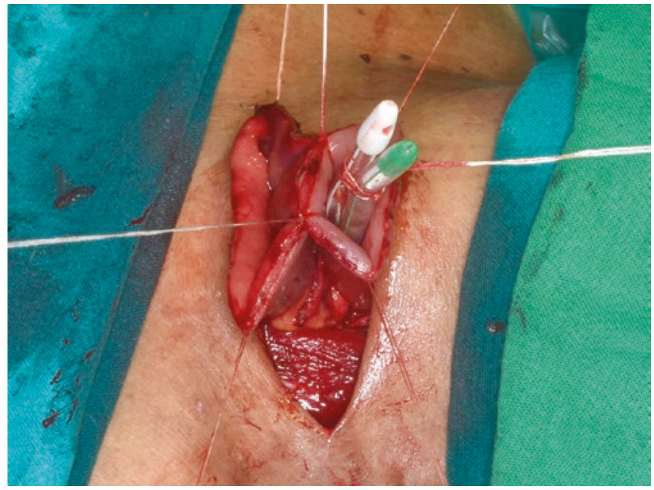

Fig. 13.49 Two holding sutures are placed paramedian in the posterior wall of the stomach

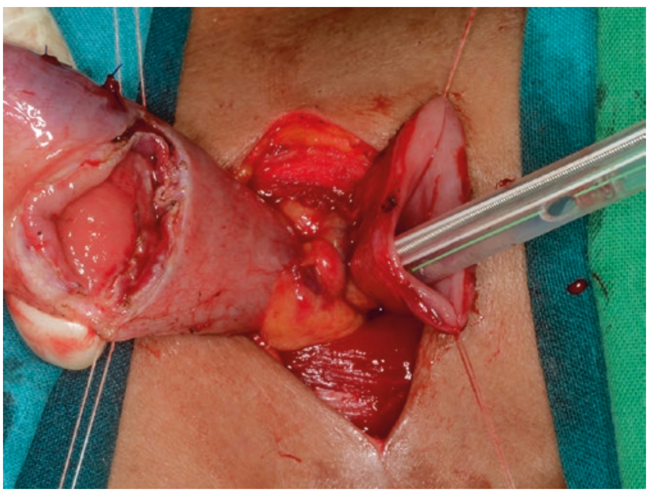

Fig. 13.48 The stomach tube is brought up into the neck and divided with stay sutures on both the esophagus and the stomach tube

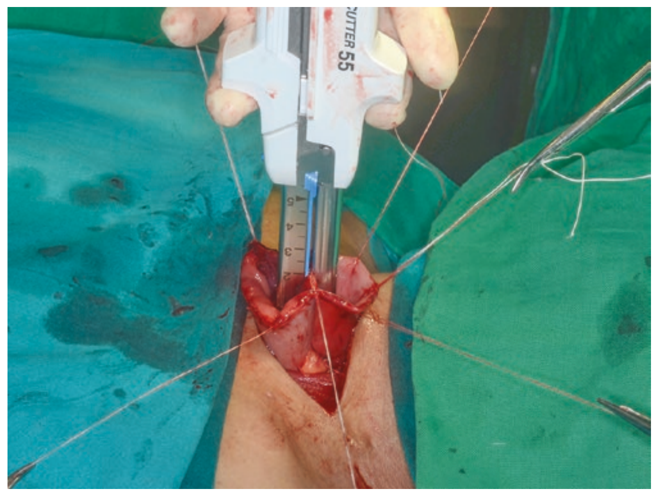

Fig. 13.50 The linear cutter is placed in the two 'barrels' of the esophagus and stomach tube, making sure that the nasogastric tube is not caught within the stapler

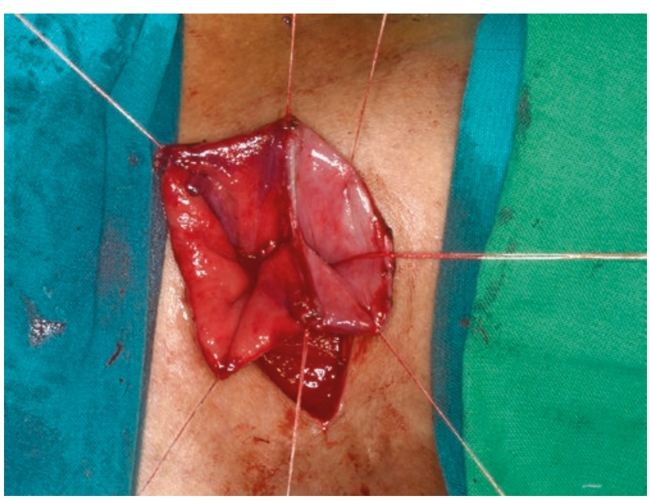

Fig. 13.51 The posterior wall of the anastomosis is fashioned by firing the linear stapler. This opens up the anastomosis like a flower as seen in the figure

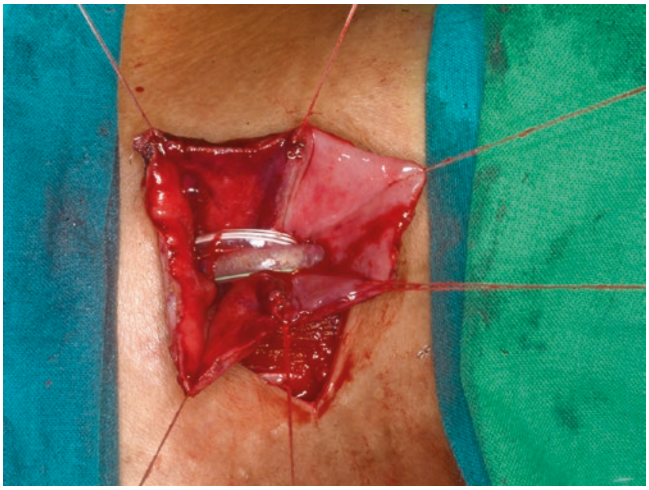

Fig. 13.52 The nasogastric tube is placed across the anastomosis with the tip placed in the middle of the stomach tube for decompression

Fig. 13.53 The anterior surface of the anastomosis is brought together using approximating sutures

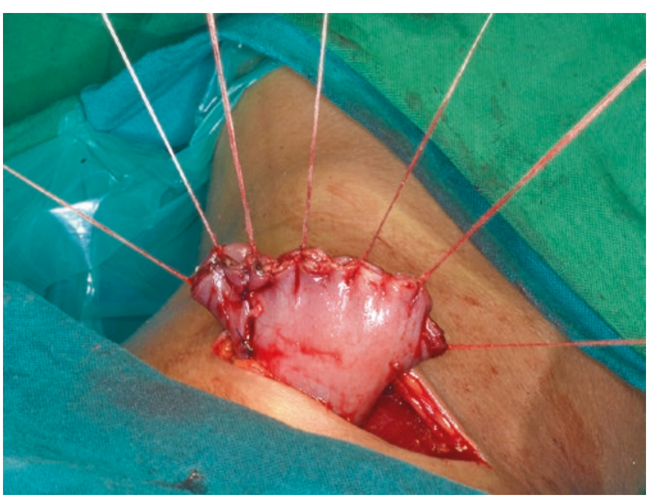

Fig. 13.54 A few additional sutures approximating the anterior wall of the anastomosis prepares it for the remaining two staples for the triangulated anastomosis

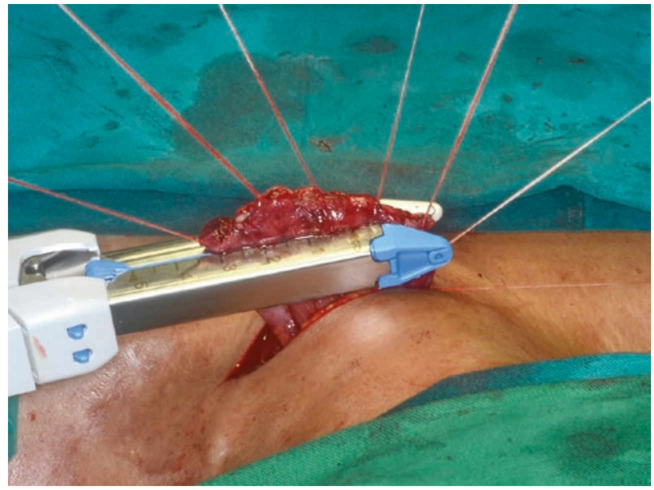

Fig. 13.55 The first horizontal stapler is fired, completing half the anterior layer of the anastomosis

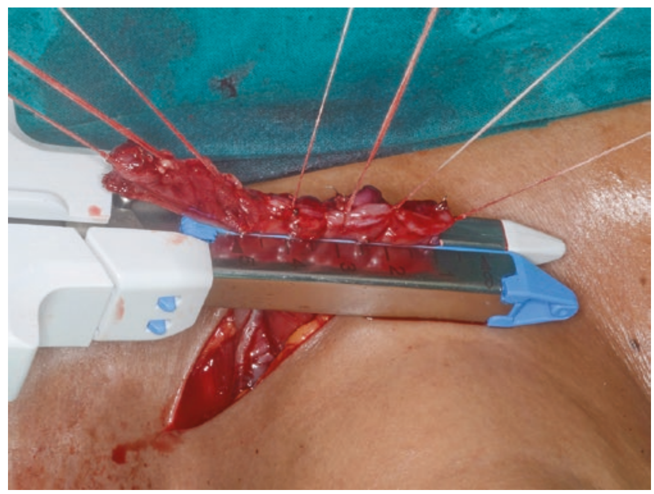

Fig. 13.56 The second horizontal stapler completes the anterior layer of the anastomosis

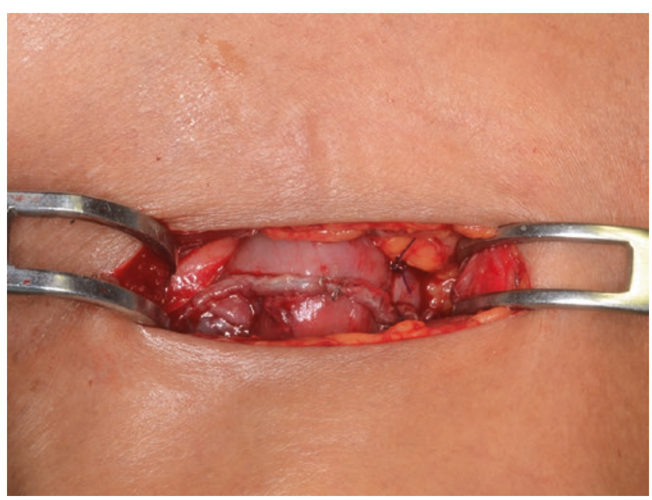

Fig. 13.57 The completed esophagogastric anastomosis is dropped back into the neck wound

13.6 Lymph Node Dissection

Jianfeng Li

Squamous cell carcinoma is the most common pathological types of esophageal cancer in East Asia. The most common location of the tumor is middle esophagus, followed by the lower part and the upper part of it. Type of the lymph node metastasis of esophageal squamous cell carcinoma (ESCC) is significantly different from that of adenocacinoma in esophageal-gastirc junction. ESCC can either have upper mediastinal lymph node and cervical lymph node dissemination, or have abdominal lymph node metastasis. Postoperative local (regional lymph node) recurrence is the main cause for the failure of surgical treatment in ESCC. The number of lymph node dissected is related to the prognosis. Therefore, it is emphasized that the two-field lymph node dissection is crucial during MIE.

13.6.1 Mediastinal Lymph Node Dissection

13.6.1.1 Technical Points

Upper mediastinal lymph node dissection is an essential component of radical esophagectomy for esophageal squamous carcinoma. However, it is associated with significant morbidity and requires a great deal of skill when bilateral recurrent laryngeal nerves (RLNs) dissection is performed with minimally invasive surgery. Excellent exposure of anatomy is the key point during the lymph node dissection, and the following tips can be very helpful:

- "Freestyle" posture: The patient is placed in a true left lateral decubitus position with 45° rotation anteriorly, head side elevation of 30°, and right arm stretched forward. The heart and large blood vessels can fall forward at this position because of gravity, so that the space around the esophagus is enlarged, which is helpful to the operation.
- Intrathoracic continuous inflation of CO_2 maintaining a pressure of 8–10 cm in H_2O can enlarge the operating space with pressing the lung collapsing thoroughly and pushing the mediastum towards to left thoracic cavity. It is also helpful in reducing capillary vessels oozing blood which can supply a more clean operative field. But it is crucial to keep the thoracic cavity airtight to maintain a positive pressure.
- Single lumen tracheal intubation with continuous inflation of CO_2 into the thoracic cavity makes it more convenient when pulling the trachea and exposing the upper mediastinal lymph node. If a double lumen tracheal intubation is placed, releasing the main air bag of the intubation is helpful to give a better exposure.
- Do not use the electric hook or ultrasonic knife too close to RLNs, and reduce the energy output time. This is helpful to prevent burns. It is the key point to prevent RLNs injury by avoiding skeletonized of the RLNs and using blunt dissection of lymph nodes.

13.6.1.2 Anatomical Landmarks

- **Right recurrent laryngeal nerve** (**RLN**): Branching off the right vagus nerve, looping under the right subclavian artery, then traveling upwards on the right front of esophagus. The right RLN may have one to several small branches in a downwards and inwards, and often accompanied by small arteries. Right RLN lymph nodes are just located between the nerve and the esophagus.
- **Left recurrent laryngeal nerve** (**RLN**): Branching off the left vagus nerve at the aortic arch, passing in front of the arch, and then wraps underneath and behind it. After branching, the nerves typically ascend in a groove at the junction of the trachea and esophagus. The left RLN is located very deep, and can be found after the esophagus being dissected thoroughly. But the location of this part of the left RLN is relatively stable, so it is easy to locate it.
- Thoracic duct: The lymph duct traverses the diaphragm at the aortic aperture and ascends the superior and posterior mediastinum between the descending thoracic aorta (to its left) and the azygos vein (to its right). The duct extends vertically in the chest and curves posteriorly to the left carotid artery and left internal jugular vein at the T5 vertebral level to empty into the junction of the left subclavian vein and left jugular vein. It is easy to find the offwhite duct after opening the pleura mediastinalis at the superior border of the azygos vein. It is risky to have chylothorax if you do not ligate the lymph duct when dissecting the paraesophageal lymph nodes.

13.6.1.3 Operating Procedure

1. Dissecting the right RLN lymph nodes (2R, 4R lymph nodes). Open the mediastinal pleural upwards until to the cupula pleura along the vagus trunk and right subclavian artery posterior edge. And find the origin of right RLN. Dissect the 2R, 4R lymph nodes with en bloc resection, and protect the right RLN at the same time. Try to keep the electric hook away from the recurrent laryngeal nerve (above 1 cm), and reduce the energy output time. These can effectively avoid the recurrent laryngeal nerve burns (Figs. 13.58 and 13.59).
2. The azygos arch is cut off, and the upper esophagus is dissected. The thoracic duct is just located at the anteromedial of distal part of azygos vein, at the right front of vertebral. The 3P lymph nodes in this area can be dissected.
3. Free the middle part of the esophagus and dissect the station 8R lymph nodes which are close to the esophagus and the inferior pulmonary vein. Once station 8R has been dissected, the esophagus is retracted posteriorly with a blunt tip instrument, thus exposing the subcarinal

lymph nodes and the left main bronchus clearly. Station 7 can be dissected, then station 10R and station 10L (Fig. 13.60).
4. The mediastinal pleura is incised downward, in continuity of the dissection of stations 8L and 9.
5. Once the esophagus is completely freed, it is pulled laterally to expose the left recurrent laryngeal nerve lying in the trachea-esophageal groove. Nodes along this nerve are removed. The right recurrent laryngeal nerve is also identified at the thoracic inlet near the innominate artery. Downward the left RLN, stations 4L and 5 can be found below the aortic arch. Upward the nerve, station 2L can be dissected at the level of the middle third of the left lateral aspect of the trachea (Figs. 13.61, 13.62, and 13.63).

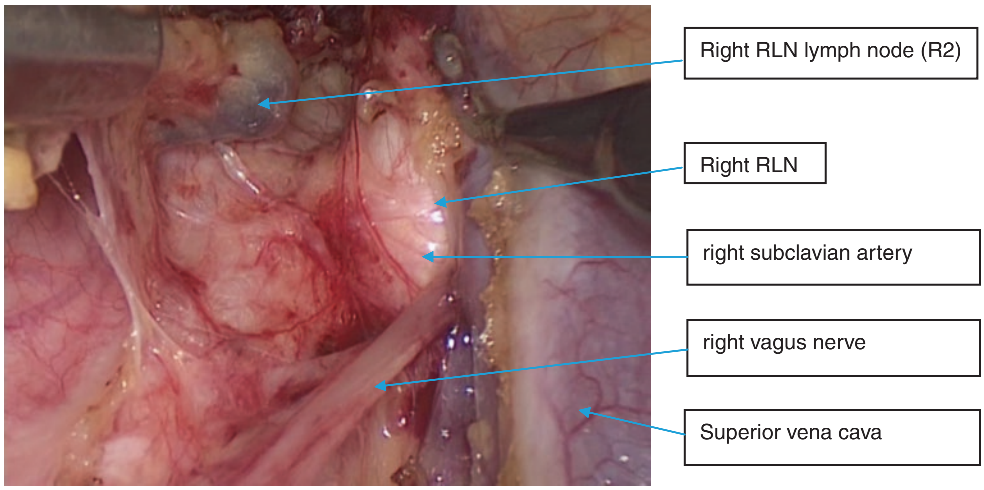

Fig. 13.58 Dissecting the right RLN lymph nodes, showing R2 lymph node in the figure

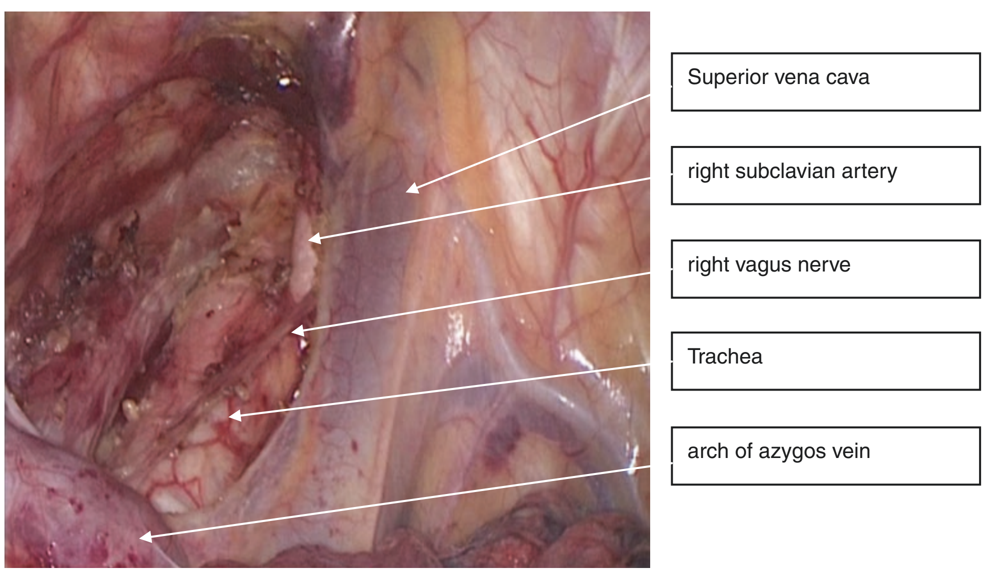

Fig. 13.59 The right upper mdiastinum after clearance of right RLN lymph nodes

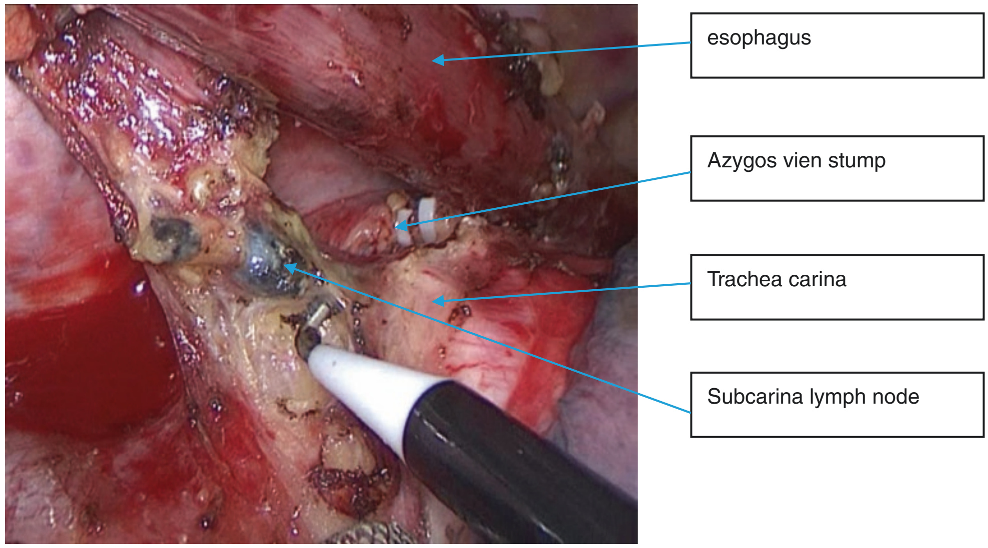

Fig. 13.60 Station 7 is being dissected

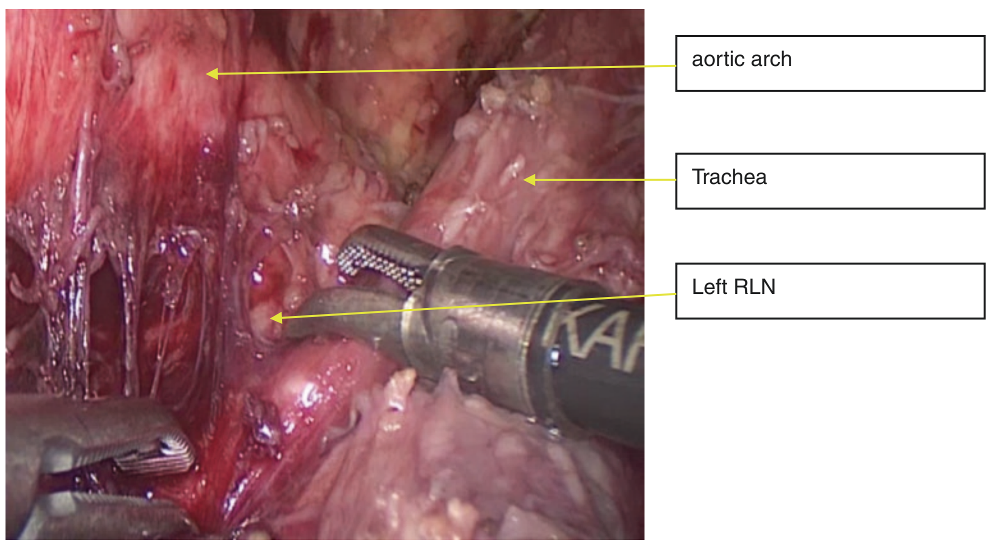

Fig. 13.61 Dissecting stations 4L and 5 lymph nodes near left RLN

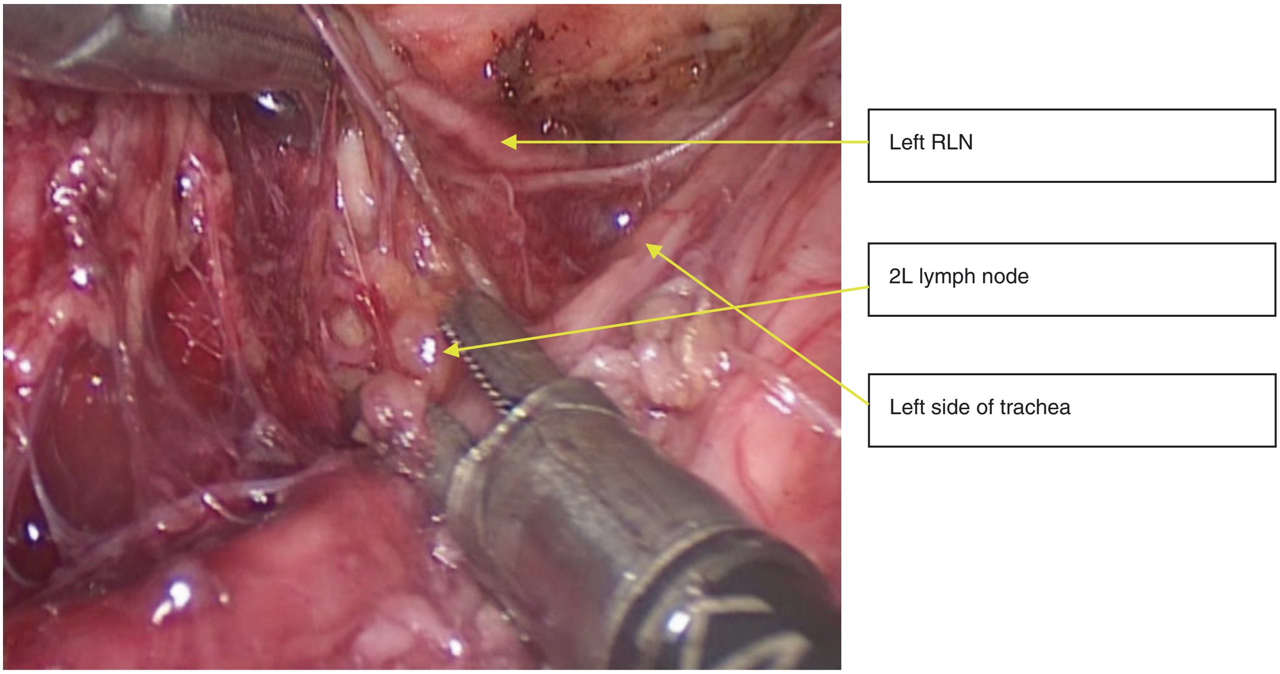

Fig. 13.62 Upward the left RLN, station 2L can be dissected

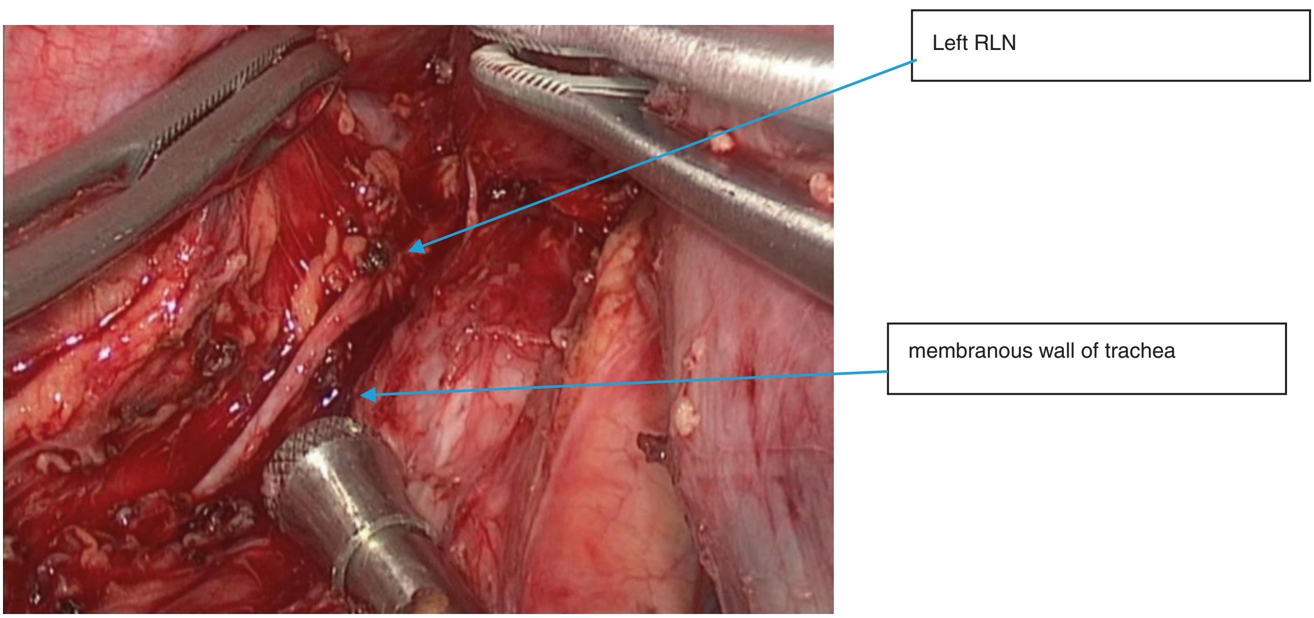

Fig. 13.63 Left RLN can be clearly exposed after dissection of 4L、 2L lymph nodes

13.6.2 Abdominal Mediastinal Lymph Node Dissection

13.6.2.1 Technical Points

- Cut off the hepatogastric ligament downwords the left lateral aspect of hepatoduodenal ligament and right gastric vascular arch. The pancreas head and branches of the coeliac axis in the lesser omentum can be revealed clearly. The assistant can gently depress the cranial part of the head of pancreas. This helps to show the splenic vessels well during the lymph node clearance (Fig. 13.64).
- After left gastric artery is cut, dissection is continued cranially with ultrasound knife along with crura of diaphragm. This makes the para-cardia soft tissue including lymph nodes resected en bloc (Figs. 13.65, 13.66, 13.67, and 13.68).

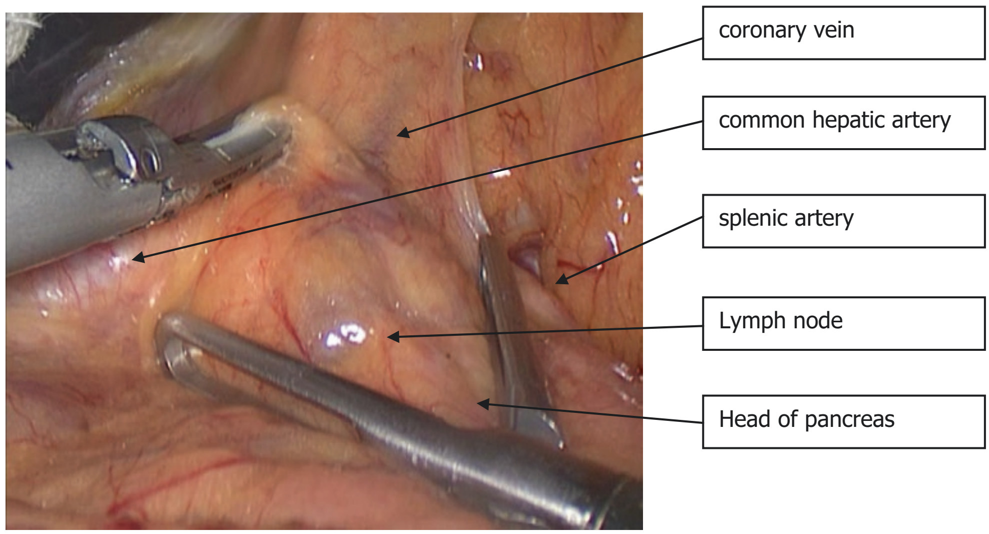

Fig. 13.64 The pancreas head and branches of the coeliac axis in the lesser omentum being revealed

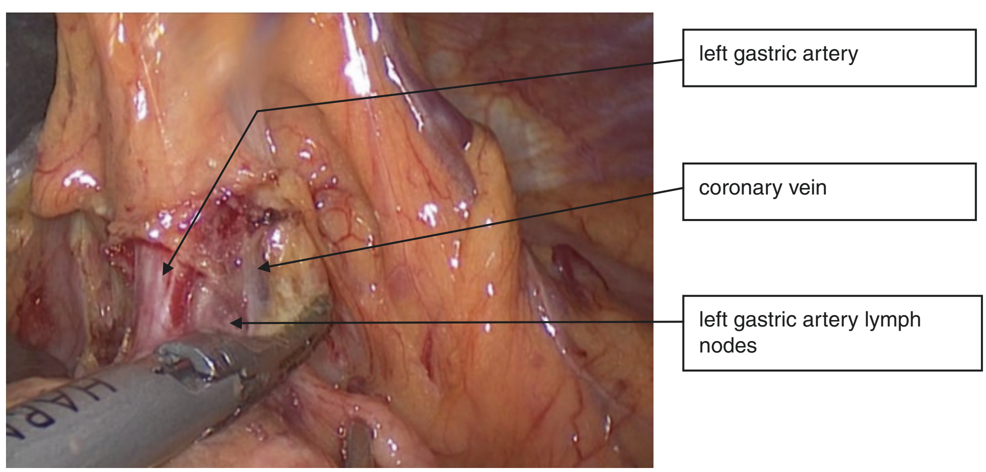

Fig. 13.65 The left gastric artery and nodes around the base of the left gastric vessels are revealed after cutting off the gastric coronary vein

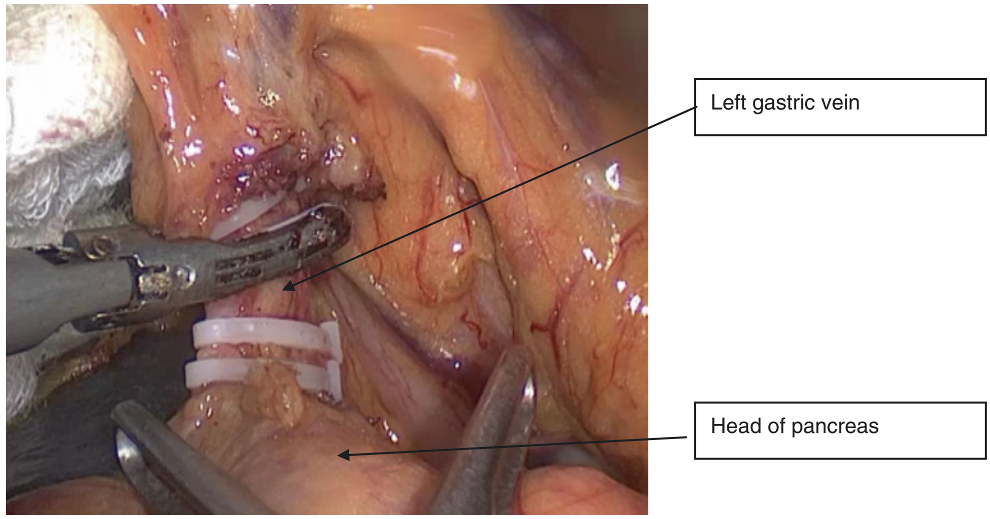

Fig. 13.66 Cutting off the left gastric vessels

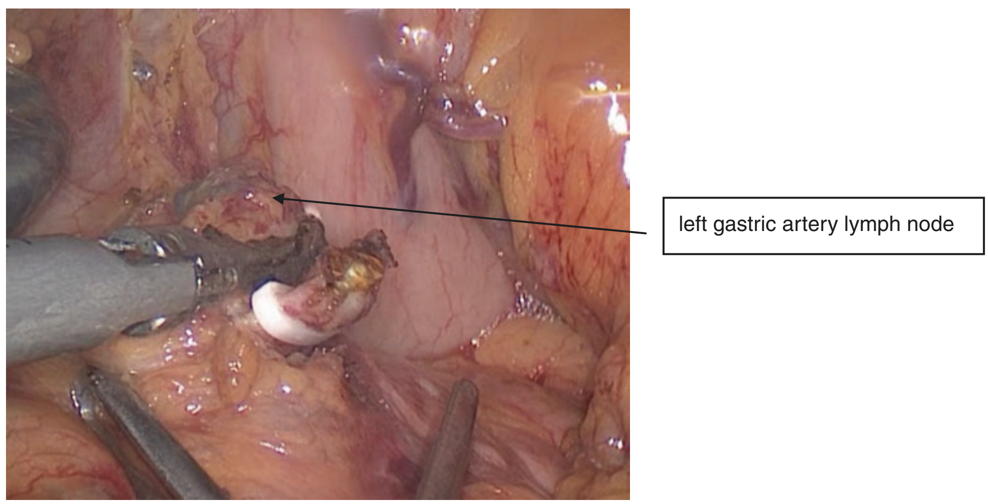

Fig. 13.67 Nodes around the base of the left gastric vessels are dissected

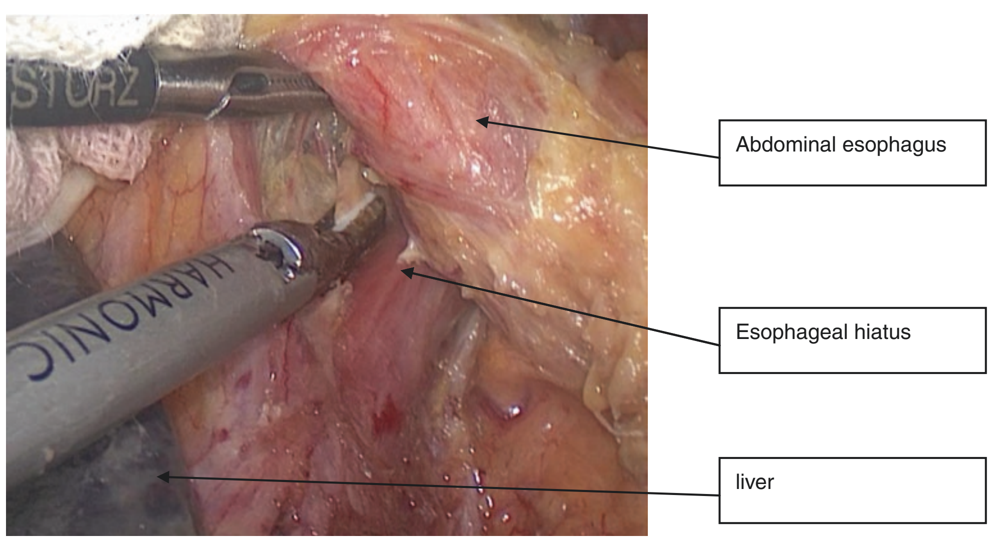

Fig. 13.68 View after clearance of the para-cardia soft tissue including lymph nodes

13.6.2.2 Anatomical Landmarks

- The left gastric artery: arises from the celiac artery and runs along the superior portion of the lesser curvature of the stomach. Gastric coronary vein runs along with it and more superfacial, which is a good anatomic landmark.
- Pylorus part: connects the stomach to the duodenum, below which is the original of gastroepiploic arcade. It is the right edge when open the gastrocolic omentum.

13.6.2.3 Operating Procedure

1. Cut off the hepatogastric ligament on the left lateral aspect of hepatoduodenal ligament and upward side of right gastric vascular arch. The gastric coronary vein can be revealed, and the left gastric artery is just located below. Nodes around the base of the left gastric vessels are dissected to delineate the left gastric artery and vein separately. The areolar tissue and nodes along the common hepatic artery are dissected and taken medially, along with the gastric nodes (Figs. 13.65 and 13.66).
2. The assistant depress the cranial part of the head of pancreas gently to show the splenic vessels well. The nodes along the splenic artery are then taken (Fig. 13.69).
3. After left gastric artery is cut, dissection is continued cranially with Harmonic Ace along with crura of diaphragm. This makes the para-cardia soft tissue including lymph nodes resected en bloc (Figs. 13.67 and 13.68).
4. The stomach tube can be fashioned intra-corporeally using staplers. Lymph nodes at the lesser curve can be resected at the same time. Lymph node dissection is finished.

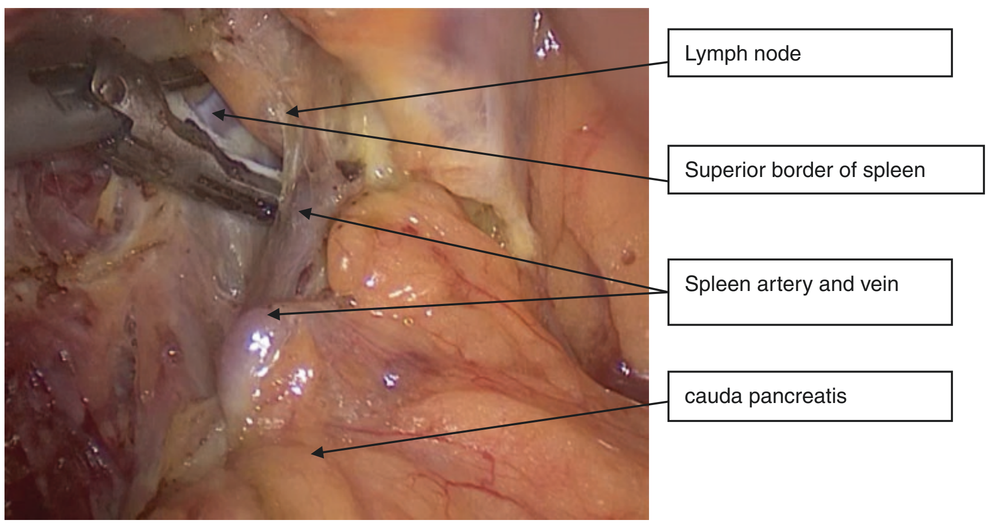

Fig. 13.69 The nodes along the splenic artery are taken

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Thoracoscopic and Laparoscopic Esophagectomy with Intrathoracic Anastomosis

14

Yuqing Huang, Jun Liu, and Xianjun Min

Contents

14.1 Methods

Yuqing Huang and Jun Liu

14.1.1 Introduction

Minimally Invasive Esophagectomy (MIE) was first introduced in 2000 and has developed rapidly since 2012. The major challenge in MIE is the intrathoracic anastomosis that is still unresolved technical bottleneck. There are a variety of intrathoracic anastomotic methods applied in thoracoscopic and laparoscopic Ivor-Lewis esophagectomy: circular-stapled anastomosis with trans-oral anvil, intrathoracic anastomosis using a purse-string forceps, and hand-sewn combined with conventional stapled anastomosis. Here, we introduce a method of hand-sewn combined with conventional stapled anastomosis.

14.1.2 Technical Points

- **Patient selection**
  (a) Middle or lower esophageal carcinoma, or carcinoma in gastroesophageal junction.
  (b) Patients suitable for intrathoracic anastomosis
- **Preoperative examination**
  (a) Gastroscopy and pathologic examination
  (b) Enhanced chest CT
  (c) Radiography of the upper digestive tract
  (d) Assessment of patient status
  (e) Clinical stage of the tumor

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- **Anesthesia**
  (a) General anesthesia with double lumen endotracheal intubation
  (b) Laparoscopic or gastric and abdominal segment dissociation with open surgery
- **Positioning**
  (a) Supine abdominal operation with five abdominal incisions. One incision at the umbilicus and two at the umbilicus and the lateral border of the rectus abdominis muscle, 5–10 mm in length, two at both rib arches were 5 mm in length (Fig. 14.1). Or epigastric midine incision up to the sword and down to the umbilicus.
  (b) Patients are positioned on their left side for the thoracic portion of the operation, with a 1.5 cm incision at the anterior axillary line of the seventh intercostal space and the lower corner line of shoulder, and a 4–5 cm lesion at the anterior axillary line of the fourth intercostal space (Fig. 14.2)

Tips
There is no need to extend the previous operation window, nor add an additional incision, with only three conventional incisions required. The operation window is located at the anterior axillary line of the fourth intercostal space, which allows for dissociation of the diaphragm defect and suture fixation, as well as completion of the anastomosis at the proximal end of the esophagus and intrathoracic portion of the stomach.

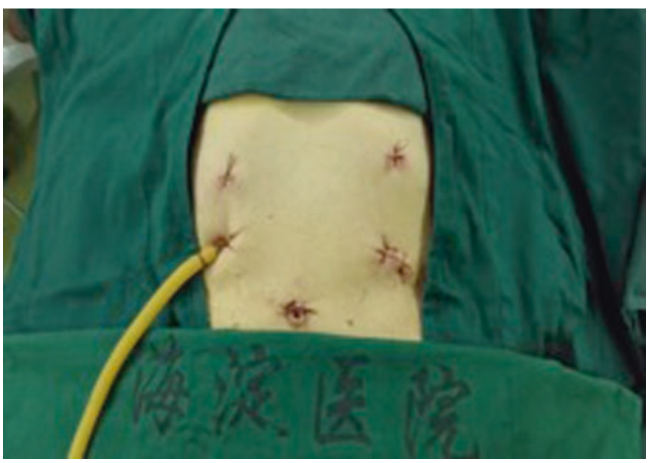

Fig. 14.1 Supine position with elevation of pelvic region, umbilical incision as observation port for laparoscope, incisions at the lateral border of the rectus abdominis muscle and both costal margin in midclavicular line as operation port

Fig. 14.2 Lateral recumbent position of thoracic operation, 1.5 cm incision at the anterior axillary line of the 7th intercostal space and the lower corner line of shoulder, and a 4–5 cm lesion at the anterior axillary line of the fourth intercostal space

14.1.3 Operation Procedure

- **Abdomen (description)**
  1. After achieving pneumoperitoneum and introducing a 30° thoracoscope, dissect the gastroepiploicasinistra, short gastric vessels, right and left gastric arteries with the surrounding fat, and lymph nodes using a LigaSure (our preference) or ultrasonic scalpel, while maintaining the right gastroepiploic artery. Simultaneously complete the lymphadenectomy.

> **Tips**
> The left gastric vessels can be ligated with a Hemo-lock or a 30 mm linear-cutting stitching instrument.

2. Dissect the stomach distal to the gastric antrum and proximal to the diaphragm, as well as the abdominal esophagus, and divide the diaphragmatic crura in order to expand the hiatus. Irrigate the abdominal cavity and place abdominal drainage tubes around the gastric wall; close the incision.

> **Tips**
> It is not necessary to make a separate incision to prepare the gastric tube, which is usually under the xiphoid process. We are more accustomed to preparing the gastric tube posteriorly, in the intrathoracic cavity.
>
> **Key point**: Divide the crura of the diaphragm as much as possible in the abdominal cavity, dissect the abdominal esophagus, and thus position the stomach in the thoracic cavity more conveniently.

- **Chest**

Dissect the esophagus in the left lateral position and make the intrathoracic anastomosis. Make a 1.5 cm small incision at the seventh intercostal space in the anterior axillary line, with the bottom angle of the shoulder as the observation port and the auxiliary operative port, and another 4–5 cm small incision at the anterior axillary line of the fourth intercostal space as the main operating port.

Use an electronic hook to divide the right inferior pulmonary ligamentand the mediastinal pleura along the posterior margin of the inferior pulmonary vein to the azygos venous arch. Dissect the seventh, nineth, and tenth lymph node groups. Dissect and ligate the azygos venous arch with a 30*2.5 Endo-GIA. Continue to separate the anterior esophagus and dissect the upper mediastinal periesophageal lymph nodes, taking care to protect the recurrent laryngeal nerve.

Dissect and completely separate the mediastinal pleura on the posterior wall of the esophagus along the anterior margin of the vertebral column. Pay attention to deal with the esophageal artery branches (we usually utilize electrocoagulation and titanium clips to ligate esophageal artery branches) during the lymphadenectomy.

Separate the entire esophagus circumferentially beneath the tumor (separate the esophagus above the tumor in carcinoma of the gastric cardia or near the gastroesophageal junction). Place and pull variceal bands to dissect the left side of the esophagus and tumor site, anteriorly to the anastomosis site. In the case of obvious tumor invasion, careful separation is required, with caution so as not to damage the azygos vein and intrathoracic duct.

Finally, fully dissect the esophagus beneath the tumor to the diaphragm. Completely relax the esophagus beneath the tumor and around the cardia with a 3–4 cm lateral incision made along the hiatus. Ensure that the stomach can be brought up to the thoracic cavity.

Approximately 5 cm above the tumor, using an endoscopic needle with a 2-0 silk suture, perform an esophageal purse-string suture with four to five stitches in total (Fig. 14.3).

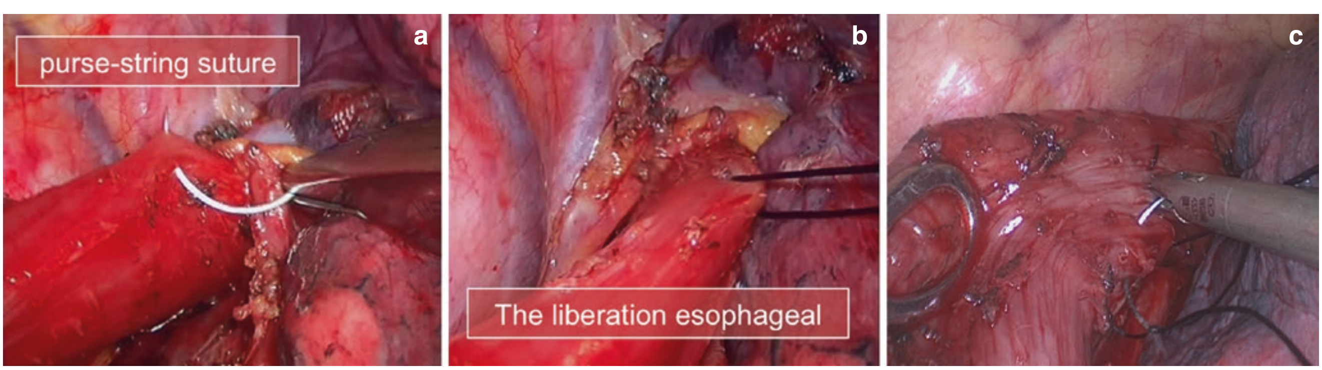

Fig. 14.3 Approximately 5 cm above the tumor, using an endoscopic needle with a 2-0 silk suture, perform an esophageal purse-string suture with 4–5 stitches in total (**a–c**)

Tips

Theoretically, a manual purse suture is difficult to perform; however, intraoperatively, the direction and angle of the dissected esophagus can be adjusted freely and is suitable for suturing. Especially with the posterior wall stitch, the suture line can be continued circumferentially to the front, and sutured counterclockwise around the esophagus. A traditional purse string forceps has a wide front plier head, which makes suturing and line packaging from the same incision different, considering the space limitations during intrathoracic anastomosis. As the operative window is already occupied by the purse string forceps, an additional incision is required to complete the suture. For surgeons experienced with laparoscopic suturing, an esophageal purse string suture is easy to perform.

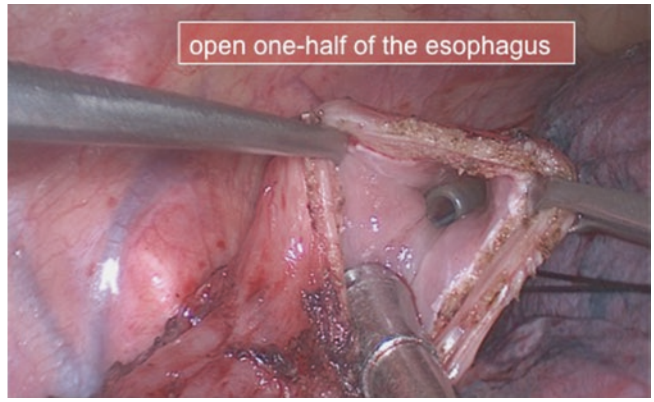

Fig. 14.4 Electrocoagulation is used to open one-half of the esophagus to expose the esophageal lumen at the bottom of the purse-string suture

At the bottom of the purse-string suture, electrocoagulation is used to open the entireone-third to one-half of the esophagus to expose the esophageal lumen (Fig. 14.4). Under endoscopy, the anesthesiologist slowly withdraws the gastric tube to 1 cm above the esophageal anastomosis, which is fully exposed to allow for examination of the condition of the esophageal mucosa. The stapler nail anvil needle holding forceps (patent product, ZL 2014 3 0122322.4; ZL 2014 2 0234093.X; PCT/CN/2014/088998) is then used to staple and the anvil is placed inside the proximal esophagus through the esophageal incision (Fig. 14.5), tightening and closing the purse-string suture (Fig. 14.6).

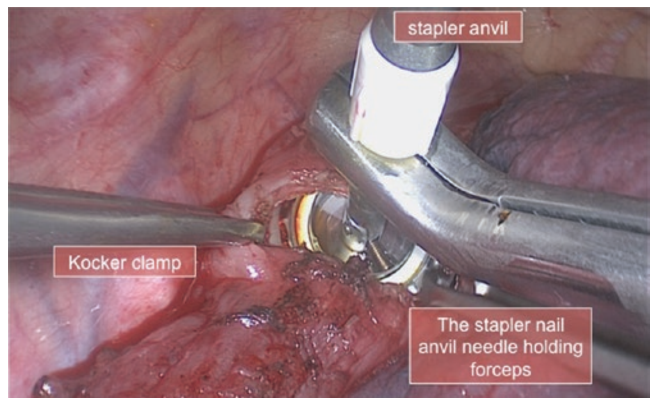

Fig. 14.5 The stapler nail anvil needle holding forceps (patent product, ZL 2014 3 0122322.4; ZL 2014 2 0234093. X; PCT/CN/2014/088998) is used to staple and the anvil is placed inside the proximal esophagus through the esophageal incision

Tips

The esophageal stapler anvil needle holding forceps (our independently patented product) can stably clamp the holding stapler anvil and easily feed the nail anvil into the pre-sutured purse suture due to its inclined angle.

A more important role of the holding forceps is that, during subsequent docking of the nail anvil and anastomotic rods, it can stably fix the nail anvil, allowing for accurate and easy docking of the nail anvil and anastomotic rods. This invention has significantly improved the performance of the anastomosis, which due to lack of specialized instrument, and intrathoracic anastomosis position, as well as the unfavorable operational angle between the operative port and auxiliary operativeport, avoiding secondary injury of the esophagus, stomach, and other organs in the intrathoracic cavity previously.

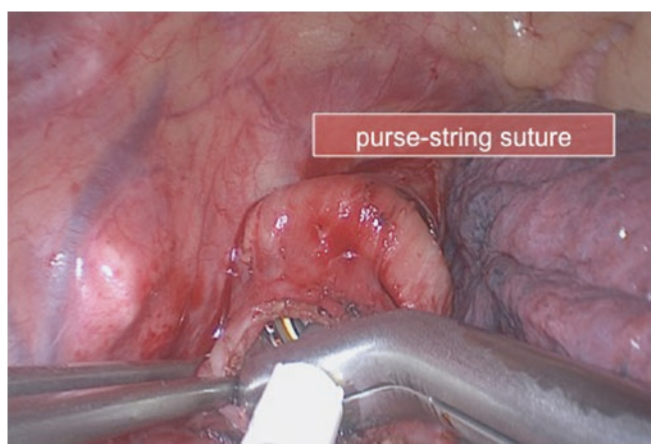

Fig. 14.6 Tightening and closing the purse-string suture

Use an electrocoagulation hook to divide the esophagus and close the end of the esophagus. Use two oval forceps from the main operative port and auxiliary operating port, to bring the stomach from the abdominal to the thoracic cavity.

Extract the esophagus from the main operating port and close the cardia with a Kocker clamp. Using a linear line cutting stapler along the distal end of the Kocker clamp, create the gastric tube; arotary nail box can be used based on the angle (Fig. 14.7a).

Tips

Preparation of the gastric tube: extract the divided esophagus and gastric fundus, which has been closed by a Kocker clamp. With the space for the anastomosis reserved, use a linear stapler to divide the stomach along the lesser curvature, beneath the cardia.

In the process of bringing the stomach up from the abdominal to the thoracic cavity, the oval forceps in the main port should retain the edge of the lesser curvature of stomach. Even though damage might occur, this damaged portion can be resected in the process of creating thegastric tube. The oval forceps in the assisting port should be used to gently retract the body of the stomach, while avoiding damage to the right gastroepiploic artery and gastric wall.

In addition, use a nail box of 2.5 mm thickness at the distal part of the omentum, close to the right gastric artery to prevent bleeding, due to insufficient closure of the right gastric artery (Fig. 14.7b). Examine the cutting edge to decide whether an embedding suture is needed.

After the completion of the gastric tube, open the clamp and release the open end. After aspiration of the gastric contents, a traction line was sewn at the 3 o'clock, 6 o'clock, and 12 o'clock positions; introduce the tube into the intrathoracic cavity. Place a long tissue clamp into the intrathoracic cavity from the scapular line incision, maintaining the 9 o'clock position of the gastric cross section. Place the anastomotic site into the gastric cavity from the broken end of the stomach. The operator should drag the traction line and move with the stapler at the same time to avoid prolapse of the stapling head (Fig. 14.8), piercing through the posterior wall of the gastric tube. Insert an oval forceps from the posterior incision

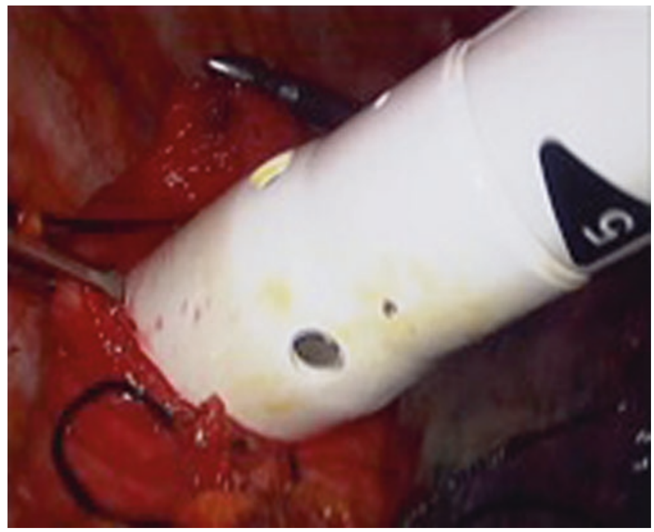

Fig. 14.8 Place the anastomotic site into the gastric cavity from the broken end of the stomach, piercing through the posterior wall of the gastric tube. Insert an oval forceps from the posterior incision to remove the puncturing head. Insert the nail anvil holding forceps from the posterior auxiliary operative port, fixing the anastomotic anvil and the operator should drag the traction line and move with the stapler at the same time to avoid prolapse of the stapling head

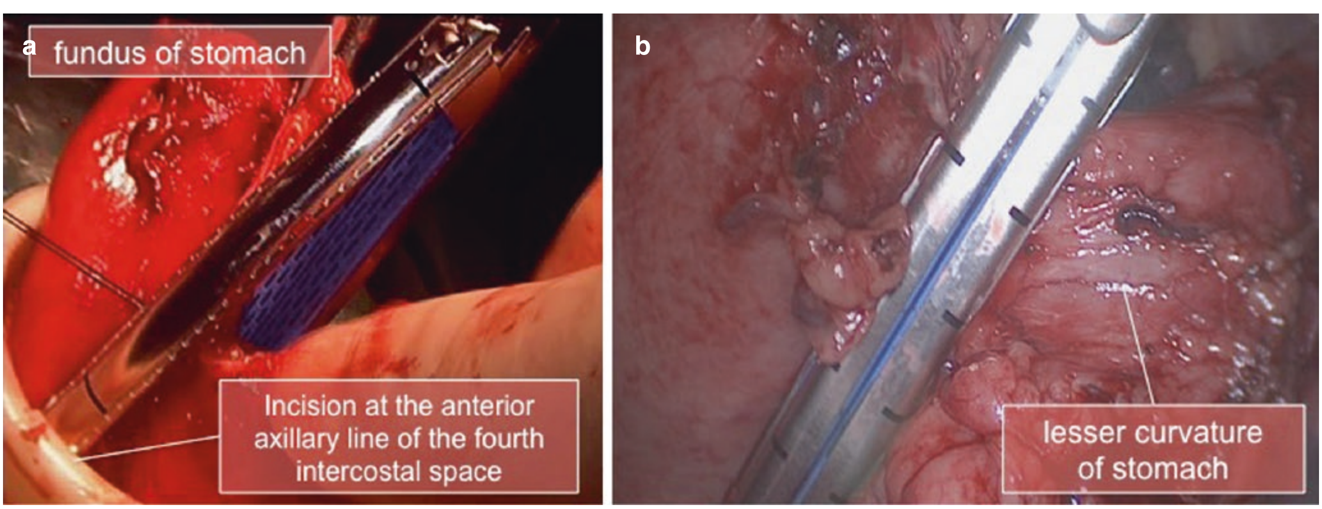

Fig. 14.7 Using a 3.5 mm thickness of linear line cutting stapler create the gastric tube; arotary nail box can be used based on the angle, a nail box of 2.5 mm thickness is used at the distal part of the omentum (**a**, **b**)

after successful puncture, with the puncturing head removed (Fig. 14.9). Insert the nail anvil holding forceps from the posterior auxiliary operativeport, fixing the anastomotic anvil, and closing it by rotating the instrument (Fig. 14.10).

After completing the anastomosis, examine if the stoma is complete and hemostatic through the thoracoscope. Replace the nasogastric tube into the stomach under endoscopic surveillance (Fig. 14.11). Utilize an oval clamp to stabilize the gastric tube while the anesthesiologist pulls it to prevent it from twisting in the oral cavity or esophagus.

Fig. 14.9 Insert an oval forceps from the posterior incision to remove the puncturing head

Properly affix the gastric tube after this has been confirmed. Pull the traction lines to lift the open end of the stomach, using the thoracoscope to examine form the main intercostal incision, and close the gastric incision using a 3.5 mm rotary staplers implanted through the seventh intercostal incision (Fig. 14.12). Use 2-0 needles with four strands to reinforce the suture of the muscular layer.

Tips
To close the gastric stump, use a linear stapler via the observation port at the anterior axillary line of the seventh intercostal space, in the same direction of the intrathoracic and gastric cavities; this method is easily performed and reliable.

Finally, an intrathoracic drainage tube was placed through the axillary midline incision at the seventh intercostal space, reaching the superior portion of the thoracic cavity to accompany and affix the thoracic stomach appropriately.

In the case of the mediastinal pleura openingin the opposite direction, it is recommended to maintain closed intrathoracic tube drainage.

Pull the traction lines to lift the open end of the stomach, using the thoracoscope to examine form the main intercostal incision, and close the gastric incision using a 3.5 mm rotary staplers implanted through the seventh intercostal incision.

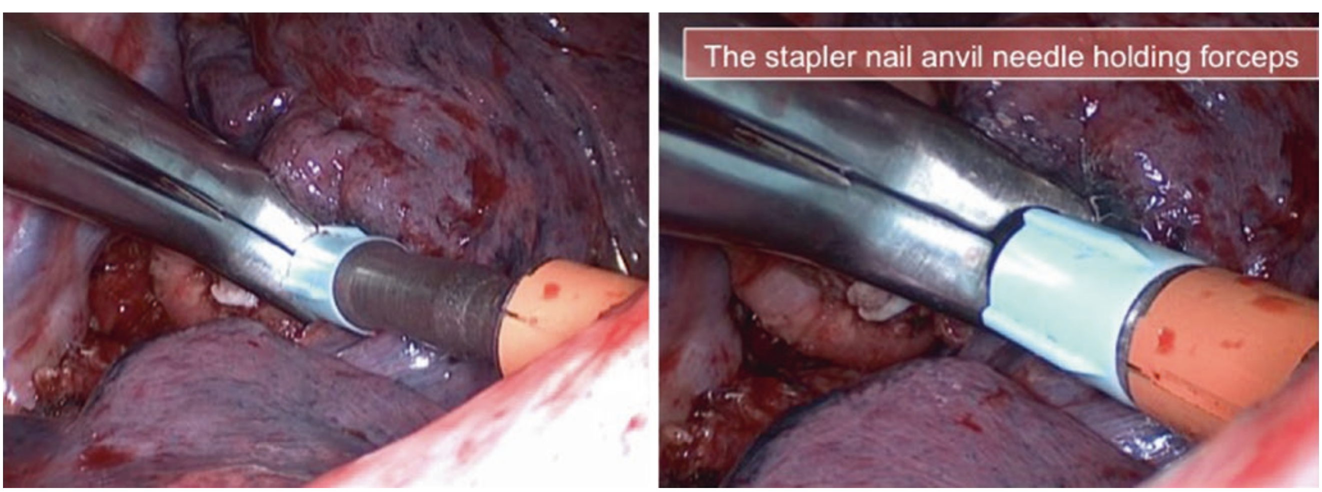

Fig. 14.10 Fixing the anastomotic anvil, and closing it by rotating the instrument

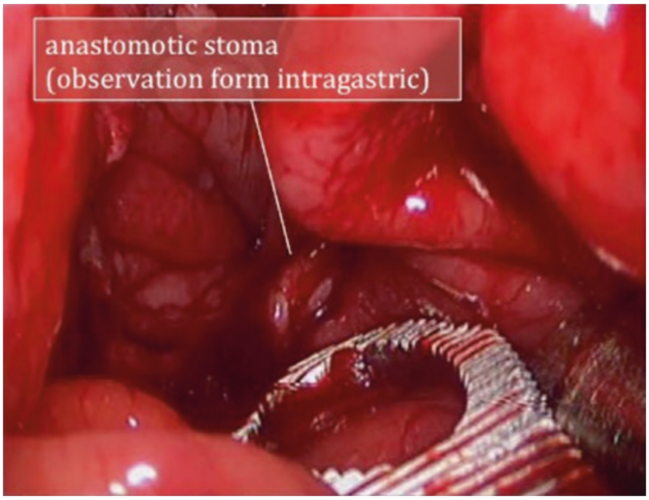

Fig. 14.11 Examine if the stoma is complete and hemostatic through the thoracoscope. Replace the nasogastric tube into the stomach under endoscopic surveillance

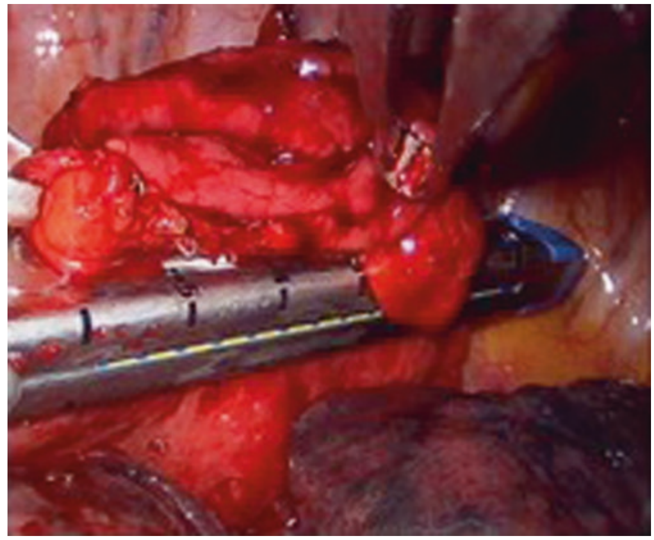

Fig. 14.12 Pull the traction lines to lift the open end of the stomach, using the thoracoscope to examine form the main intercostal incision, and close the gastric incision using a 3.5 mm rotary staplers implanted through the 7th intercostal incision

14.2 Results and Discussion

Jun Liu and Xianjun Min

With recent developments and progress in the use of endoscopic techniques, the application of minimally-invasive esophageal (MIE) resection surgery has gained a great deal of attention and been extensively explored [1]. MIE resection surgery has developed rapidly since the first successful laparoscopic resection of esophageal carcinoma reported by Luketetich in 2000 [2]. The McKeown method through the right chest-abdomen-neck, and the Ivor-Lewis method through the right chest-abdomen are the most representative approaches which have been explored and performed in many clinical centers [3–8]. These studies were first to demonstrate the advantages of MIE resection surgery, which include minimal invasiveness and high safety [1, 9, 10]. However, controversies involved in traditional esophageal resection are also present when patients are treated by minimally-invasive surgery of the esophagus, and involve decisions such as: whole or partial esophageal resection, intrathoracic anastomosis or cervical anastomosis, two-field or three-field lymphadenectomy. Various MIE surgical approaches still have not resulted in precise answers to these dilemmas, and more research and exploration are needed to solve these problems and improve techniques in order to perform safe and smooth MIE resection using existing equipment and technology.

The McKeown method can be used to treat esophageal cancer in different position of carcinoma. However, the incidence of postoperative complications such as anastomosis fistula, anastomotic stenosis and postoperative digestive dysfunction after cervical anastomosis is relatively high, and the neck incision also increases trauma and affects patients' postoperative appearance [11, 12]. The Ivor-Lewis method is mainly used inpatients with esophageal carcinoma in the middle and lower segments, or cardia cancer [13], treatment of which is characterized by anastomosis of the stomach and esophagus within the thoracic cavity, reducing the incidence of complications. However, procedures such as esophageal pouch suture, nail anvil, and even docking of nail anvil and anastomosis rod, which are essential for intrathoracic anastomosis, are still being explored. Therefore, in minimally-invasive esophagectomy, many problems still remain to be solved, with the question of how to achieve intrathoracic stomach and esophageal anastomosis being one of the major problems. Bypassing this technical difficulty by cervical anastomosis is a negative approach that should not be taken, considering either the profit of patients or the improvement of MIE technology. Therefore, it is expected that a variety of minimally-invasive attempts, which although not perfect, will jointly promote the maturity of MIE surgery.

In 2008, the Couviden company launched Orvil, providing a relatively safe and feasible method for anastomat anvil insertion, which is necessary for intrathoracic anastomosis, allowing the wide application of laparoscopic Ivor-Lewis thoracic anastomosis in Europe and the United States [14, 15]. The Orvil oral nail anvil conveying system, delivering the nail anvil to the esophagus from top to bottom through the connected gastric tube, which does not require apurse string suture ligation at the esophageal stump, achieves satisfactory anastomosis with a clear operation process. However, it is difficult to release the head of the nail during surgery, and the overlapping suture at the stomacan increase the risk of anastomotic fistula. In addition, the cost of this procedure is relatively high.

When trying different methods of intrathoracic anastomosis, it is common convention to use the conventional purse clamp first. After finishing the purse suture in thethoracic cavity through four incisions on the chest wall, thoracic anastomosis should be carried out using an ordinary anastomat [3, 16, 17]. A conventional purse clamp is inserted through the anterior axillary line operation hole to perform apurse suture. The nail anvil is then inserted and the conventional anastomatis inserted through the operation hole at the anterior axillary line or scapular line. The main limitation of this method is the limited chest space, making it difficult to complete a purse suture using an ordinary purse clamp. At the same time, due to the limited height of the purse string suture, the esophageal resection range is also limited. Other factors, such as the narrow intercostal space at the posterior axillary line and the relatively long distance to the top of the thoracic cavity, lead to difficulties in anastomat insertion and angle adjustment.

One way to avoid the use of a conventional purse clamp is to cut open the esophagus first, insert the nail anvil, and close the esophageal stump using a straight-line cutting stapler, before conducting the anastomosis. The disadvantages of this method are: first, the esophageal stump is put aside, forming a diverticulum; secondly, the stapled surface is too great resulting in overlapping staples near the stoma, which might lead to problems of blood circulation [18].

Another method is to abandon the conventional anastomat. Instead, after completely cutting off the esophagus, a straight-line cutting stapler should be used to cut open the side wall of the esophagus and the bottom wall of the gastric fundus, and close the gastric stump and the esophagus stump, completing anastomosis of the esophagus and stomach. Such a method simplifies the process of anastomosis, but changes the conventional ring shape of the stoma into a "T" shape [19]. This means that the width of the stomais not easily controlled, increasing the possibility of postoperative regurgitation; at the same time, due to the double crossed staples at the stoma, and the overlapping part of the suture at the distal end, there is the possibility of a fistula; in addition, since there is only limited tissue available in the esophageal wall, such a method may lead to postoperative esophageal stricture.

In this paper, we performed a manual esophageal purse suture under a thoracoscope. We cut open part of the esophagus at the bottom of the purse suture and inserted the anastomat nail anvil at the proximal end of the esophagus, which we then tightened using the purse knot. At this stage, we performed anastomosis after completely cutting off the esophagus. Although in theory a manual purse suture is difficult, in the actual operation, since the direction and angle of the esophagus can be freely adjusted after dissociation, which is very suitable for seaming, an esophageal pouch suture is still relatively easy for a physician skilled in the laparoscopic suturing technique. The stapler anvil-holding forceps, which were independently researched and developed by our center (patent product, ZL 2014 3 0122322.4; ZL 2014 2 0234093. X; PCT/CN/2014/088998), makes the nail anvil insertion of the esophageal pouch and the subsequent docking of the stapler rod and the nail anvil much easier and smoother, which greatly improves the accuracy and reliability of the surgical operation [20]. This method avoids the necessity for a difficult operation due to the use of a conventional purse clamp, but also retains the high quality anastomosis by conventional anastomat.

Another important procedure of MIE surgery is the preparation of a tubular stomach. Due to its many advantages demonstrated in most clinical studies, the preparation of a tubular stomach has become a routine procedure of MIE resection surgery [1, 12]. In early reports of MIE operations, the tubular stomach needed to be prepared after laparoscopic dissociation of the stomach, which had to be completed after dragging the stomach outside of the peritoneal cavity through a 5-cm incision at the midline of the upper abdomen [21], causing extra injury. Later, some physicians reported preparing a tubular stomach under a laparoscope using a straight-line cutting suture stapler [8, 16]. Due to the multiple entry points required for a linear cutting stapler, the laparoscopic pneumoperitoneum is severely disrupted, and exposure of the surgical field is poor, increasing the difficulty of operation and the operation time. As mentioned above, the method of preparing a tubular stomach within the thoracic cavity used in our center not only reduces the injury, but also facilitates the subsequent anastomosis operation, which has good reliability and practicability.

The exploration of minimally-invasive surgery will always be ongoing, so as to improve the standard of minimally-invasive techniques. Minimally-invasive techniques can only continue to improve with constant innovation of the concept, technology and equipment, when complying with the principle of diagnosis and treatment, ensuring the efficacy of treatment, and respecting the decision of patients.

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Laparoscopic Transhiatal Esophagectomy

15

Joerg Zehetner and John C. Lipham

Contents

15.1 Methods

15.1.1 Technical Points

The operation has three parts:

Part 1 is the laparoscopic mobilization of the thoracic esophagus through the hiatus.

Part 2 is the laparoscopic abdominal part, including mobilization of the entire stomach preserving the epiploic arcade, stapling of the left gastric artery, including an extensive lymphnode dissection, and the dissection of the hiatus.

Part 3 is the left cervical access to mobilize the cervical esophagus down into the thoracic inlet, dissection of the cervical esophagus, and then pulling down the esophagus into the abdomen.

Reconstruction is then performed by creating a narrow gastric tube (through mini-laparotomy) and assessment of perfusion, pull-up of the graft and anastomosis in the neck.

15.1.2 Anatomical Landmarks

Important anatomic landmarks are:

1. Gastroepiploic arcade (Fig. 15.1)
2. Left gastric artery (Fig. 15.2)
3. Hiatus with right crus and left crus (Fig. 15.3)
4. Aorta, Pleura, azygos vein, thoracic duct, right and left mainstem (Fig. 15.4)
5. Cervical esophagus, recurrent laryngeal nerve (Fig. 15.5)

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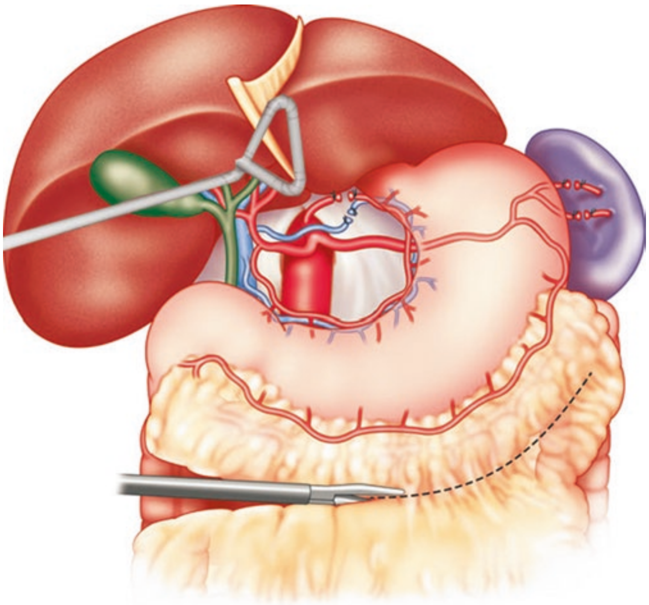
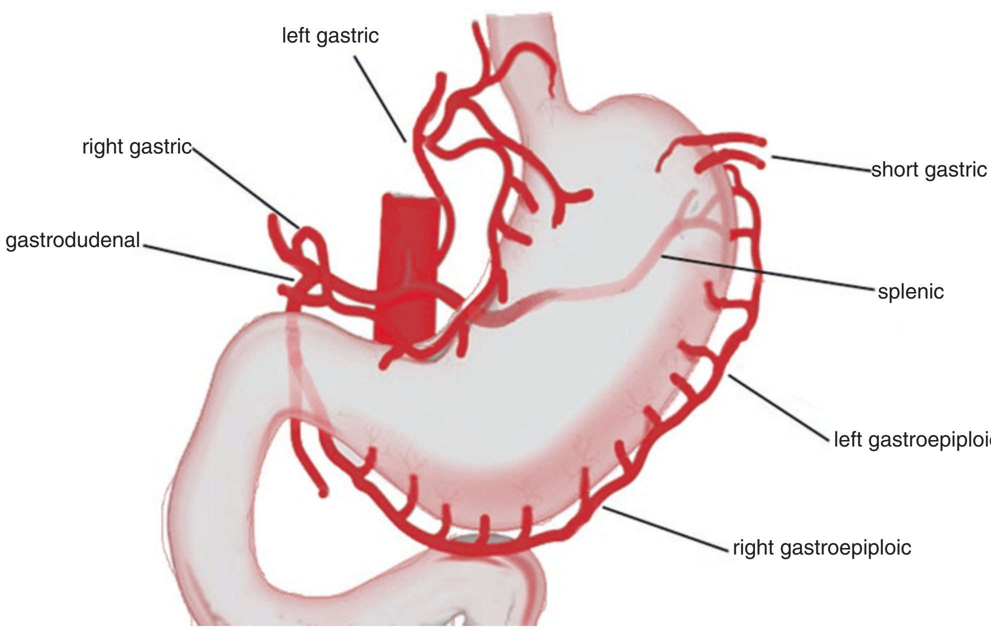


Fig. 15.1 The gastroepiploic arcade

Fig. 15.2 The left gastric artery. (Reprint with permission from Fisichella et al, Atlas of esophageal surgery, Springer, 2015)



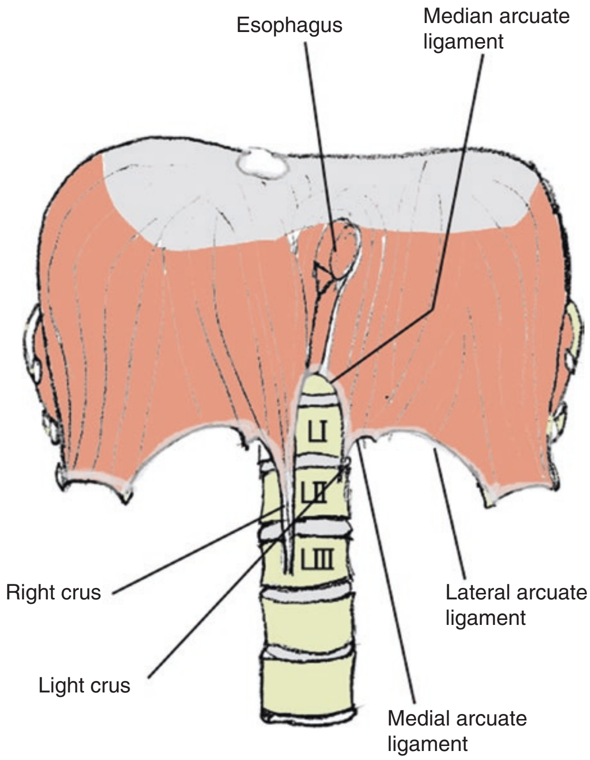


Fig. 15.3 Hiatus with right crus and left crus

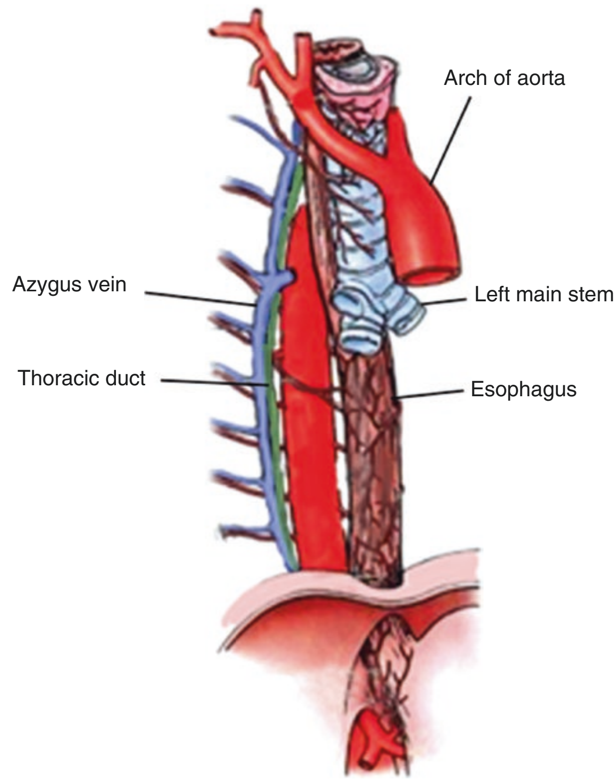


Fig. 15.4 Aorta, Pleura, azygos vein, thoracic duct, *right* and *left* mainstem

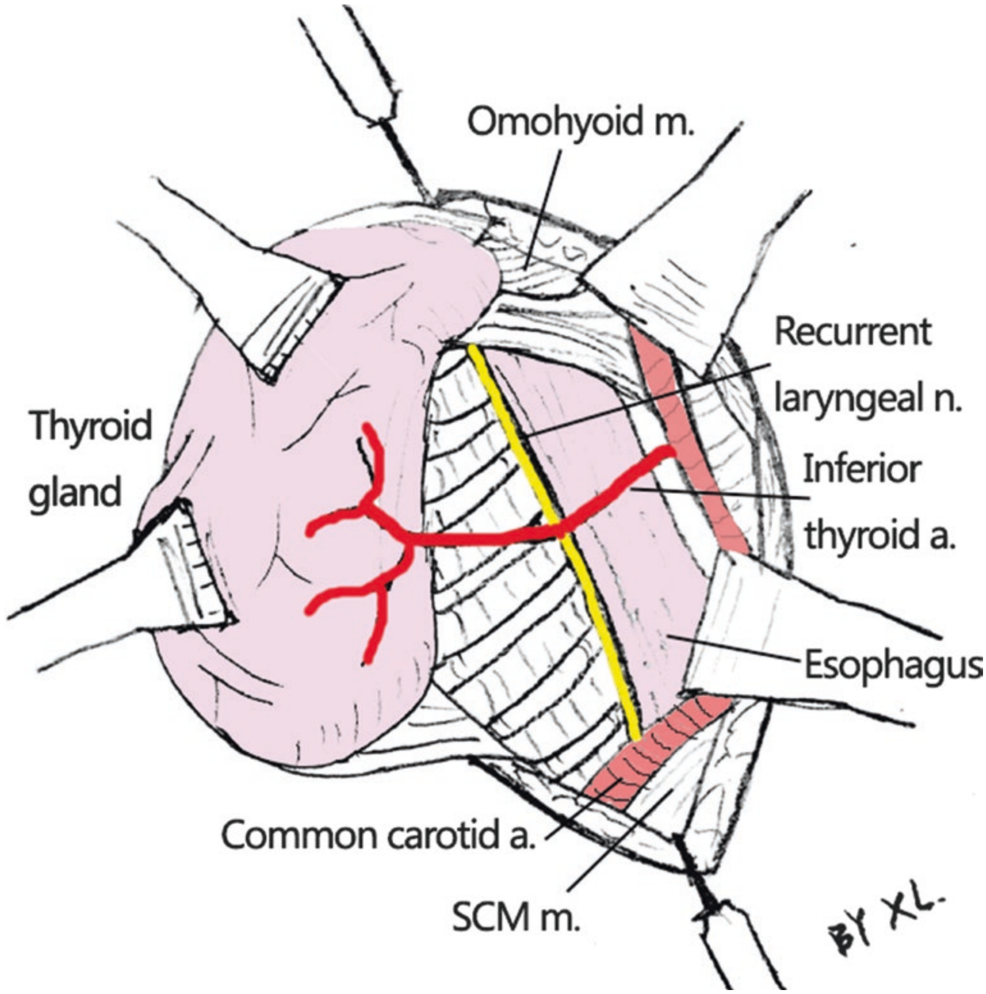


Fig. 15.5 Cervical esophagus, recurrent laryngeal nerve

15.1.3 Operation Step by Step

15.1.3.1 Positioning

Laparoscopic transhiatal esophagectomy is performed with the patient in dorsal lithotomy position, with the operating surgeon standing between the legs with assistants on either side.

The standard precautions for safe positioning are applied.

The patient has general anesthesia with endotracheal intubation, an arterial line for monitoring and either two large IV accesses or a central line (on the right side of the neck) (Fig. 15.6).

Establishing pneumoperitoneum and trocar positioning.

The pneumoperitoneum is established either with Veress needle, optiview trocar or Hassan technique. The location for the first trocar is similar to the Nissen fundoplication except that it is a horizontal incision in the midline, as this incision will be later extended to a mini-laparotomy to construct the gastric pull-up.

The further trocars are placed in the upper abdomen in a standard laparoscopic Nissen fundoplication configuration. A diagnostic laparoscopy is performed to rule out any peritoneal metastasis, distal disease or liver metastasis (Fig. 15.7).

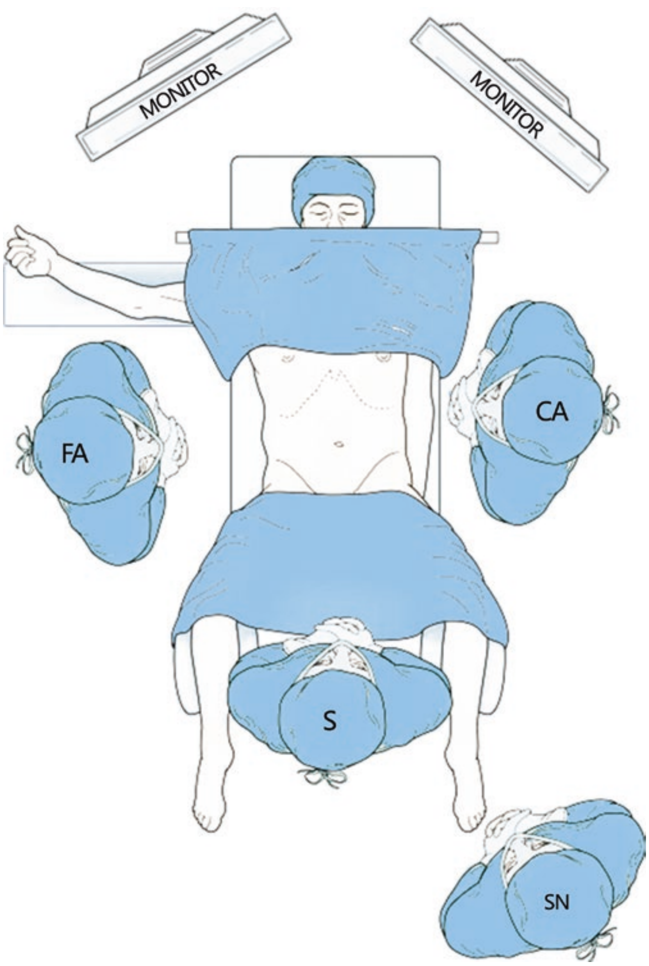


Fig. 15.6 Patient is in dorsal lithotomy position, with the operating surgeon standing between the legs with assistants on either side

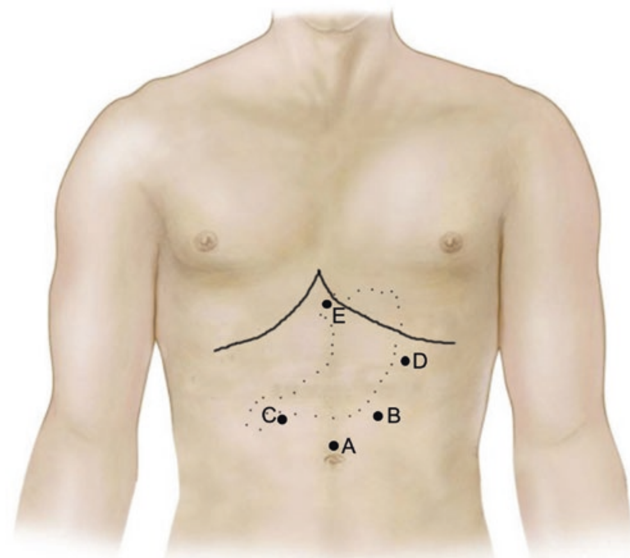


Fig. 15.7 Incisions or trocars placement

15.1.3.2 Part 1

The distal esophagus and all periesophageal tissue are then carefully mobilized and the dissection is extended proximally in a circumferential manner. This allows a first assessment of the resectability of the tumor. The operation can be still aborted after initial mobilization, if no safe plane can be encountered to either the aorta, or the pericardium, the airway or the inferior pulmonary vein. The pericardium is skeletonized anteriorly up to the carina. In a similar manner, the aorta is skeletonized posteriorly, and the parietal pleura laterally. The right and left crura are often incised to provide better exposure of the mediastinum (Fig. 15.8).

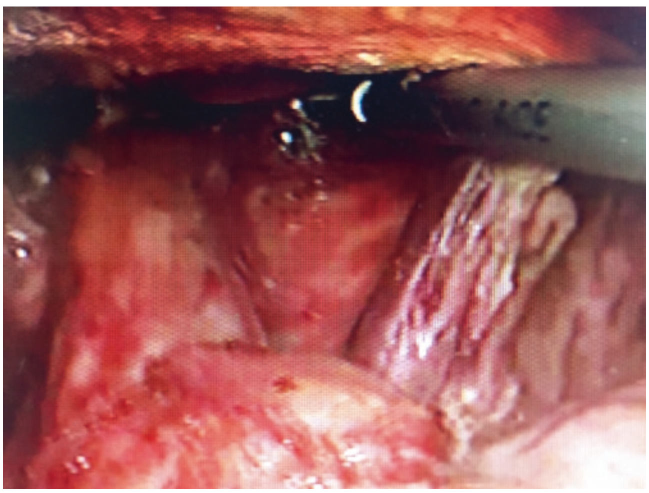


Fig. 15.8 Mobilization of the distal esophagus and all periesophageal tissue

15.1.3.3 Part 2

After completing this portion of the mediastinal dissection, the stomach is then mobilized preserving the epiploic arcade (Fig. 15.9).

This is best started midway by defining the omentum on top of the transverse colon, then close to the colon and up to the inferior border of the spleen the dissection is performed with a harmonic scalpel. Then, similar to the dissection of the fundus for a laparoscopic fundoplication, but this time instead of close to the stomach the dissection is performed close to the spleen (cave splenic artery). After opening the pars flaccida the lesser sac is entered, the left gastric artery identified and a lymphadenectomy of the celiac trunk is performed. The left gastric artery is stapled of with a vascular staple load (white) (Fig. 15.10).

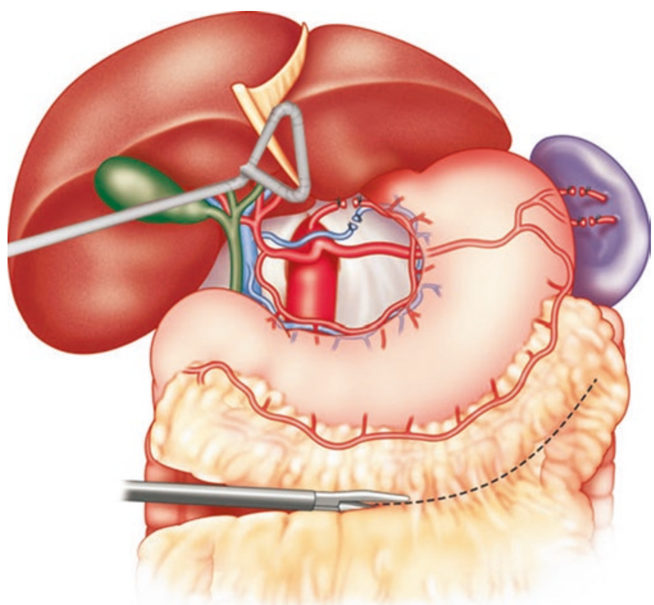


Fig. 15.9 The epiploic arcade should be preserved

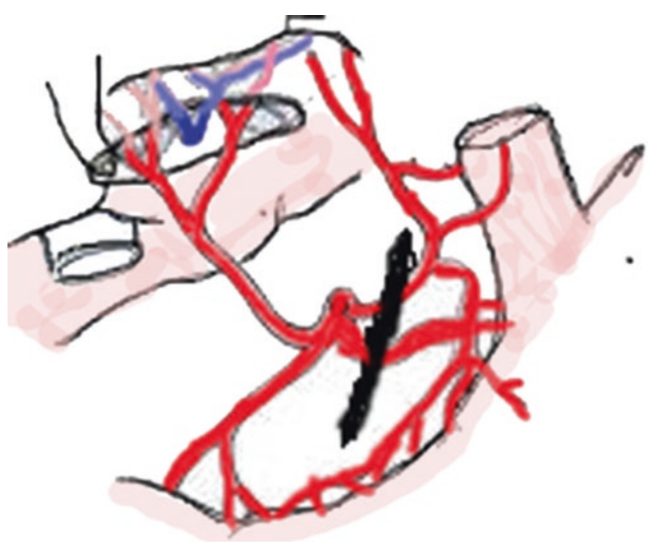


Fig. 15.10 The left gastric artery is stapled

15.1.3.4 Part 3

The cervical dissection is then performed through a left neck incision and the cervical esophagus is dissected down to the proximal extent of the previous mediastinal dissection.

The esophagus is then transected in the neck and removed transabdominally after the camera port is extended with a mini-laparotomy to 5 cm to accommodate the specimen. The stomach is then tubularized by sequential firings of a GIA 100 mm stapler, and the staple line is over-sewn to prevent lesions of the staple line when being pulled-up, as well as to prevent damage of the staple line to the airway or vascular structures in the chest. The perfusion of the gastric pull-up is then tested with laser-assisted angiography (Spy-System, Novadaq, Toronto), and the area of good perfusion marked with a stitch (Fig. 15.11).

A chest tube is then passed through the posterior mediastinum, attached to the gastric conduit, and gently withdrawn to pull the conduit up into the neck (Fig. 15.12).

Adequate vascular supply of the conduit and the esophagus is confirmed, and a single-layer interrupted hand-sewn anastomosis is constructed. Additionally, a jejunostomy feeding tube is routinely placed for post-operative nutritional supplementation. Pyloroplasty is not performed for any patients undergoing LTE.

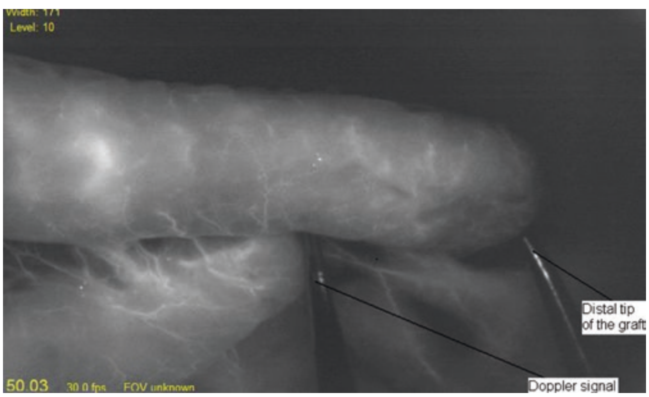


Fig. 15.11 Perfusion can be assessed with laser-assisted fluorescence angiography using the Spy-system (Novadaq, Toronto)

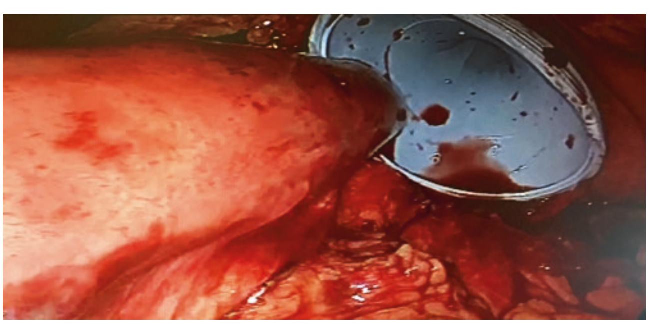


Fig. 15.12 Pulling up gastric conduit into the neck: the *top* of half of a bulb syringe connected to a chest tube is used to pull-up safely the gastric conduit

15.2 Results and Discussion

The laparoscopic transhiatal approach was first described by DePaula et al. in 1995, with several subsequent reports regarding this technique [1–3]. The transhiatal approach avoids the complications of directly accessing the thorax. For some surgeons this is a perceived lack of mediastinal exposure that could potentially compromise the radial resection margins and lymphadenectomy. Although there was initial concern over the oncological feasibility of minimally invasive techniques, a systematic review by Dantoc et al. reported higher median lymph node yield for MIE compared to open techniques (16 vs. 10), as well as no significant difference in 5-year survival [4].

In our recently published study we showed that laparoscopic transhiatal esophag -ectomy (LTE) had comparable results compared to open esophagectomies, but with the benefits of laparoscopic surgery [5]. In summary our study results: Charts were reviewed to identify all patients who had undergone LTE (33 consecutive patients) for esophageal cancer from a period of July 2008 to July 2012. Data were analyzed and compared to a historical cohort of esophageal cancer patients who underwent open transhiatal esophagectomy (OTE, 60 patients) and en-bloc esophagectomy (EBE, 139 patients) at the same institution from November 2002 to November 2009, to investigate perioperative outcomes, lymph node harvest, and overall survival.

Prevalence of comorbidities was significantly higher in the LTE and OTE groups than EBE ($p=0.01$), with a higher incidence in all subgroups except prevalence of diabetes.

Additionally, the percentage of patients with positive nodes was similar among all groups ($p=0.65$), although the number of lymph nodes resected was lower for the LTE group (22) than the OTE and EBE groups ($p<0.0001$). Recurrence was similar among all groups ($p=0.9$), with no significant differences between the ratios of systemic and locoregional recurrence between the groups ($p=0.24$). The LTE group had a conversion rate of 6.1 % (2/33), with one conversion being due to the inability to clearly identify the left gastric vessels due to adhesions. The other conversion was due to difficulty with port placement and maintaining proper insufflation secondary to a previous abdominal wall reconstruction.

The average operative time was similar among LTE and OTE groups (274 and 275.5 min), and significantly shorter than the EBE group (415 min) ($p<0.0001$). The presence of minor operative complications among the three groups was similar ($p=0.36$), but major complications (defined as those requiring intervention other than conservative management, a prolonged hospital stay, or any anastomotic complication) were significantly less common in the LTE group ($p=0.04$). The median LOS was significantly lower for the LTE group at 10 days, compared to the OTE and EBE groups, at 13 days and 15 days, respectively ($p < 0.0001$).

Median follow-up was 26 months (2–55 months) for the LTE group. Using the Kaplan-Meier method, overall survival was not significantly different between the groups, with a median survival at 24 months of 70 %, 65 %, and 65 % respectively ($p = 0.65$).

The number of centers employing MIE continues to rise, as well as the overall percentage of patients undergoing MIE compared to open repair [6]. Due to the difficulty of randomization, only one trial has been published to date. This study compared open transthoracic with minimally invasive transthoracic esophagectomy, showing lower rates of pulmonary complications and shorter hospital stay in the MIE group, with equivalent lymph node yield between the two arms [7].

In their selected series of LTE compared to laparoscopic and thoracoscopic two-field esophagectomy, Benzoni et al. showed shorter operative times, shorter ICU and overall stay, and a trend towards better survival in the LTE group [8]; although this was limited by a small number of patients.

15.2.1 Conversion Rate and Learning Curve

Depending on the type of MIE employed, conversion rates have been reported between 3 % and 18 % in the literature [3,5,9–12]. Although previous reports described problems with bleeding due to blunt dissection associated with the transhiatal approach, we experienced no such issues with hemostasis, as our conversions were due to aberrant anatomical considerations. Luketich et al. reported conversion rate of 4.5 % in their large series, with reasons for conversion from laparoscopy most commonly cited as adhesions, inadequate conduit length, tumor bulkiness, or need to better assess margins [13]. Some of the series report early conversions as part of the learning curve.

15.2.2 The Benefits of Laparoscopic Surgery

In our study the LTE group showed a significantly shorter operative time than the EBE group, and operative times are comparable to those reported in other recent series of laparoscopic and laparoscopic hand-assisted transhiatal esophagectomies [1,11,14,15]. Maas et al. showed similar operative times when comparing LTE and OTE (300 min vs. 280 min, $p = 0.11$). LTE also has the potential for shorter operative times compared to other MIE techniques utilizing thoracoscopy since these require intraoperative repositioning of the patient. Further, with improved visualization during a laparoscopic transhiatal approach, blood loss is minimized as there is less “blind” dissection associated with the open transhiatal approach.

The significantly shorter length of stay in our study for LTE is consistent with other reports of MIE [1,16]. Bernabe showed a shorter LOS for hand assisted LTE compared to OTE (9.1 vs. 11.6, $p = 0.037$) [17] with a similar reduction shown by Scheepers et al. [18] and Maas [19] In their review, Decker et al. reported median LOS of 11.5 days for all MIE techniques, vs. 15–19 days for conventional [19]. The LTE technique also causes less tissue trauma than traditional open techniques and three-field MIE approaches. Parameswaran et al. showed in their prospective longitudinal study that patients undergoing MIE began to recover within 3 months and return to baseline by 6 months, which was maintained at 1 year [20].

The transhiatal approach can potentially reduce complications by avoiding the atelectasis associated with thoracoscopy or thoracotomy. Although minor post-operative complications were similar among groups, major operative complications were significantly lower in the laparoscopic group. Hulscher et al. showed lower rates of pulmonary complications with the transhiatal approach in a randomized trial, presumably by obviating the need for single lung ventilation and direct thoracic access [21]. Other studies have reported lower rates of chest complications with MIE [20,22,23]. Maas et al. also showed a lower incidence, although not significant, of pulmonary and cardiac complications in their comparison of LTE and OTE [11]. Other comparative studies have shown 8–10 % complication rates for open and 7–8 % for LTE [24,25].

Higher leak rates with cervical anastomoses are widely reported [23,26], although a few have reported higher leak rates with thoracic anastomosis [9]. We perform only cervical anastomosis in conjunction with LTE, as we feel the potential increased risk of leak is offset by the ease in managing cervical leaks, compared to the often catastrophic consequences of thoracic leaks and associated mediastinitis. Our series showed no difference in leak rates and are consistent with others reported in the literature ranging from 7 % to 13 % [19] and that of Luketich et al. in their large series of MIE (11.7 %) [13] and Orringer et al. in their large series of THE (9 %) [27].

Shiozaki et al. report that performing the lower and middle portions of the mediastinal lymphadenectomy via the hiatus allows it to be approached along the appropriate anatomical layers, with good surgical views of the posterior and left mediastinum [28]. Our institution previously reported a survival benefit for patients with 23 or more LN resected [29], although it is unclear whether this benefit is due to stage migration or eradication of occult metastatic disease.

Recent studies have suggested that a less invasive and less radical operation is not necessarily a less curative one. In a randomized trial by Hulscher et al., there was no significant difference in the median survival, disease-free survival, and quality-adjusted survival between the groups [30]. The authors commented that long follow-up is needed to determine whether the possible survival benefit outweighs the increased morbidity associated with the transthoracic approach. Reports from our institution have shown improved survival and decreased local recurrence with more radical LN resections in selected series [31,32]. Recent reports comparing MIE to open techniques have shown at least equivalent survival. Dantoc et al. also reported no difference in overall 5-year survival between open and MIE, and although MIE showed better survival in earlier time periods, this was not born out when analyzed for stage [33]. Maas et al. showed no difference in overall and disease-free survival at 3 and 5 years in their study comparing LTE and OTE [11]. Others have suggested that survival may be improved with MIE. Montenovo et al. reported improved 5-year survival (63 % vs. 50 %) for laparoscopic-assisted THE compared to EBE [1], although there is no comparative data to substantiate this. The majority of recent publications and our own experience suggest MIE in general and LTE specifically has at least equivalent survival compared to open techniques.

15.2.3 Conclusion

Laparoscopic transhiatal esophagectomy has several advantages over open techniques for esophageal cancer resection. Operative mortality and reoperations are equivalent to open techniques, with lower major complication rates, less blood loss and shorter LOS. Laparoscopic transhiatal esophagectomy provides excellent exposure and yields an appropriate lymph node harvest and oncological resection with equivalent recurrence and survival rates. Laparoscopic transhiatal esophagectomy should be considered as a preferred approach to esophagectomy.

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16 The Prone Position for Esophagectomy

Hirokazu Noshiro and Masatsugu Hiraki

Contents

16.1 Methods

16.1.1 Patients

Distant metastasis, multi-organ involvement, enlarged and fixed cervical lymph nodes, and suggestive celiac lymph node metastasis on computed tomography, magnetic resonance imaging or fluorodeoxyglucose-positron emission tomography are considered indications of incurable disease. Contraindications for thoracoscopic or even conventional thracotomic esophagectomy are a tumor infiltrating other structures; impaired circulatory or pulmonary function; a concomitant serious medical disorder such as severe diabetes mellitus, chronic renal failure, or liver cirrhosis; and patient refusal to undergo thoracoscopic surgery. According to a randomized controlled study [1], patients with stage II or higher tumors should undergo chemotherapy or chemo-radiation therapy before surgery. The abdominal portion of the procedure is performed laparoscopically. The alimentary tract is reconstructed using a gastric conduit in all patients except those with a history of previous gastrectomy.

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16.1.2 Anesthesia and Patient Positioning

A double-lumen endotracheal tube for single-lung ventilation was previously used for general anesthesia, but bilateral ventilation using a single-lumen endotracheal tube has been employed in recent patients. The latter type of anesthesia is more advantageous during dissection along the left recurrent laryngeal nerve because the trachea is flexible even while the patient is intubated. In addition, more pulmonary function is preserved by partially bilateral ventilation during anesthesia, possibly preventing postoperative pulmonary complications.

The patient is initially placed in the prone position. The right arm only is raised cranially to expose the right axillar fossa, as in a swimming crawl. The face is directed toward the right to facilitate suction of the sputa by a bronchial scope and to avoid increasing the ophthalmic pressure (Fig. 16.1a).

16.1.3 Setting of Surgical Ports

All attendant surgeons stand on the right side of the patient at chest level and a high-quality video monitor is placed on the opposite side (Fig. 16.1a). A 12-mm blunt trocar is carefully inserted in the fifth intercostal space (ICS) on the lateral side of the right scapula to confirm the absence of pleural adhesion. Another three trocars are inserted under thoracoscopic

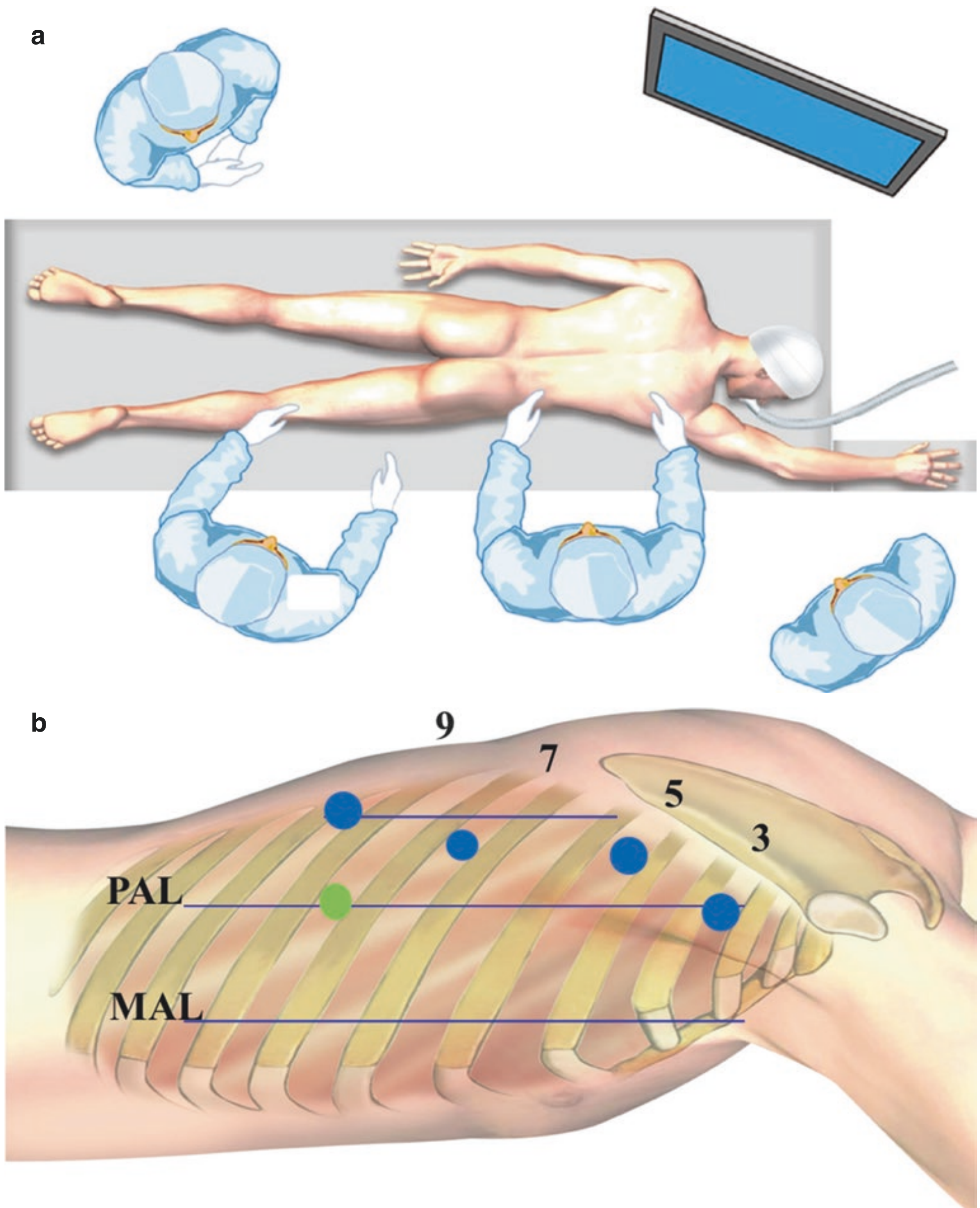

Fig. 16.1 (**a**) Position of the patient, surgeons and video monitor. (**b**) Sites of the four trocars. *Roman numerals* indicate the rib numbers. *MAL* mid-axillary line, *PAL* posterior axillary line

control: a 12-mm trocar in the ninth ICS on the scapular angle line for the thoracoscope during surgery, a 5-mm trocar in the seventh ICS behind the posterior axillary line, and a 12- or sometimes 5-mm trocar in the third ICS on the posterior axillary line. A 5- or 3-mm trocar in the eighth ICS on the posterior axillary line is added for dissection of the lower mediastinum if necessary (Fig. 16.1b). A smaller trocar is more advantageous for smooth movement of the forceps in patients with narrow ICSs, despite the fact that an endoscopic linear stapler or gauze cannot be passed through it. Carbon dioxide pneumothorax is achieved at a pressure of 8 mmHg (6–12 mmHg) to collapse the right lung and to expand the mediastinum in all patients. To maintain a clear operative fields, surgical mist or fog produced by energy devices must be removed using an exhaust pump.

16.1.4 Thoracoscopic Procedures

Our actual procedures in the prone position are basically the same as the conventional right thoracotomic open or thoracoscopic procedures in the left lateral decubitus position during three-staged esophagectomy for thoracic esophageal cancer [2]. The surgeon uses a grasper in the left hand and a monopolar or bipolar electrocautery, ultrasonic-activated device or tissue-fusion system in the right hand. First, the mediastinal pleura overlying the anterior aspect of the esophagus is opened. The pleura along the azygos in the middle mediastinum is cut, avoiding injury to the thoracic duct, and the pleura from the lower to upper mediastinum is then opened. The arch of the azygos vein is isolated and divided after ligation and clipping, and the posterior stump is sutured to the back to exposé the operative field around the right bronchial artery. The right bronchial artery is usually divided after the bifurcation of the third intercostal branch to expand the later operative views. However, in cases of salvage surgery for recurrent disease after chemo-radiation therapy with curative intent, the right bronchial artery must be carefully preserved to avoid tracheal or bronchial ischemia. Conversely, in such cases, the third intercostal branch must be divided to elongate the right bronchial artery for later assessment of the left aspect of the trachea.

The thoracic duct is usually preserved except patients with a stage T3 or higher tumor of the upper esophagus (Fig. 16.2). Keeping the preparation plane on the thoracic duct, mobilization of the esophagus can be performed in the upper mediastinum. However, the preparation plane is obscure around the azygos arch and right bronchial artery, where numerous nerve branches from the thoracic ganglia of the sympathetic nervous system cross the preparation plane. Thus, careful dissection in this area is necessary to avoid injury to the thoracic duct. In addition, some large collecting ducts that course from the esophagus or more anterior mediastinal organs and drain into the thoracic duct are often observed there. To obtain a safe circumferential surgical margin in patients with stage T3 or higher upper thoracic esophageal cancer, the thoracic duct is divided at the lower mediastinum and behind the left subclavicular artery and dissected as an attachment to the esophagus.

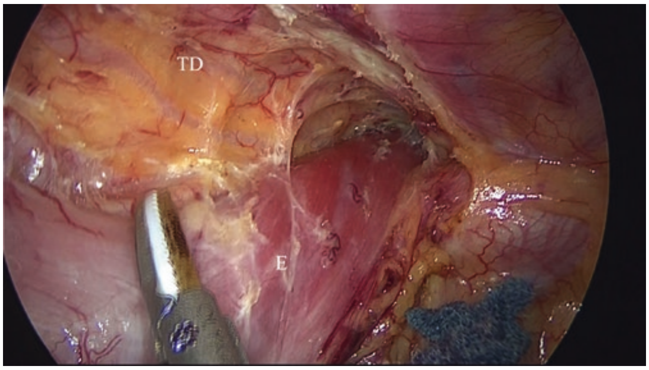

Fig. 16.2 View of the preserved thoracic duct at the upper mediastinum. *E* esophagus, *TD* thoracic duct

16.1.5 Dissection Along the Right Recurrent Laryngeal Nerve

Except for patients with upper thoracic esophageal cancer, pretracheal nodes are not dissected systematically because of the lower metastatic rate and lower effectiveness of dissection [3]. Therefore, the dissection is limited tithe posterior aspect of the right vagus nerve and around the right recurrent laryngeal nerve (RLN). The right RLN is identified and isolated around its bifurcation from the vagus nerve at the right subclavicular artery. Although many small vessels and nerves are involved in this region, careless use of energy devices should be avoided because of the risk of damaging the right RLN (Fig. 16.3a). On the right face of the trachea, the nodes along the right RLN must be dissected completely; portion of the pretracheal nodes is thus often dissected in this region. During this dissection, the vascular network on the cartilaginous portion of the trachea must be preserved to avoid impairing the blood supply to the trachea [4]. While some esophageal branches of the right RLN are divided, the lymph nodes around the right RLN can be dissected in an *enbloc* fashion nearly below the thyroid gland, which cannot be confirmed visibly during the chest procedures (Fig. 16.3b).

After dissection around the right RLN, a couple of esophagocardial branches of the right vagus nerve are divided after

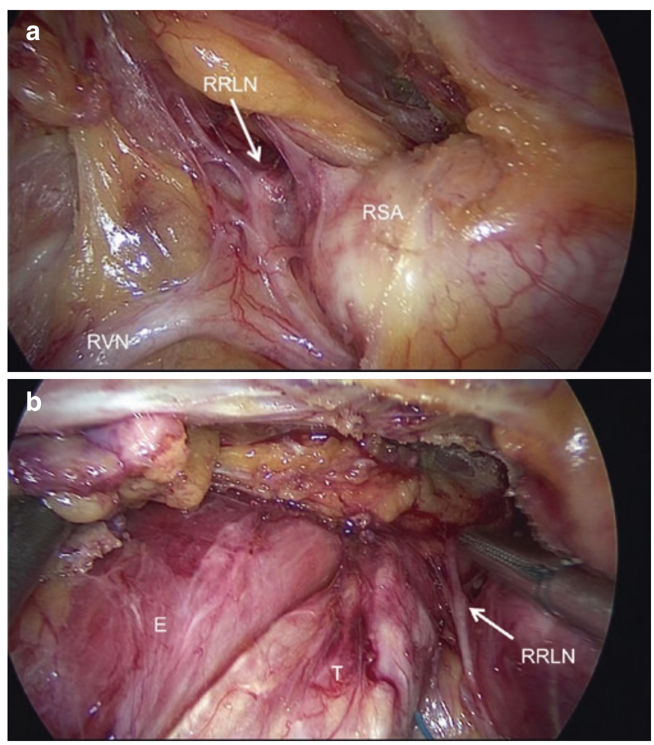

Fig. 16.3 Dissection along the right RLN. (**a**) View before dissection at the recurrent portion of the right RLN. (**b**) View after dissection toward the neck. *E* esophagus, *RRLN* right recurrent laryngeal nerve, *RSA* right subclavicular artery, *T* trachea, *RVN* right vagus nerve

the pulmonary branches of this nerve. Otherwise, sufficient counter traction cannot be obtained during the dissection around the right RLN. The preserved lower pulmonary branches are prepared and isolated from the subcarinal nodes and the nodes below the right bronchus, which will be dissected in a later step.

16.1.6 Dissection Along the Left Recurrent Laryngeal Nerve

This step is considered to be the most complicated procedures. After dissection along the right RLN, the esophagus is prepared from the membranous portion of the trachea, extending as far toward the cervical esophagus as possible. The trachea is strongly but carefully rolled back to the right and ventrally by a grasper holding a small piece of gauze to explore the left aspect of the trachea and the left bronchus (Fig. 16.4) [5]. During this manipulation, the use of a single-lumen endotracheal tube provides much better operative fields. After the esophagus has been released from the trachea toward the neck to allow the lymph nodes up to the thoracic inlet to be dissected, the tissue including the left RLN and lymph nodes is dissected just along the trachea and the left bronchus to create the ventral dissection border. The esophagus is strongly lifted posteriorly to facilitate pulling out the target tissue from the left aspect of the trachea. The posterior aspect, which is the left dissection border, is dissected on a vascular sheath of the dense connective tissue covering the aortic arch, left subclavicular artery and left carotid artery, which is supposed to be developed the pericardium caudally. This dense connective tissue includes a couple of superior cardiac branches of the sympathetic nervous system arising at the neck and running down along the left subclavicular artery. This tissue including lymph nodes and the left RLN, are recognized as a lymphatic chain on the vascular sheath overlying the aortic arch, subclavicular artery, and carotid artery. During isolation of the lymphatic chain to be dissected from the trachea and vascular sheath, the lymphatic chain should be attached with the esophagus to pull out the tissue on the left aspect of the trachea because of the esophageal branches of the left RLN. Next, the upper esophagus is mobilized circumferentially, and the esophagus is divided at a higher level of the aortic arch by linear stapling to facilitate subsequent lymph node dissection at the left aspect of the esophagus (Fig. 16.5). The tissue including lymph nodes and the left RLN attached to the

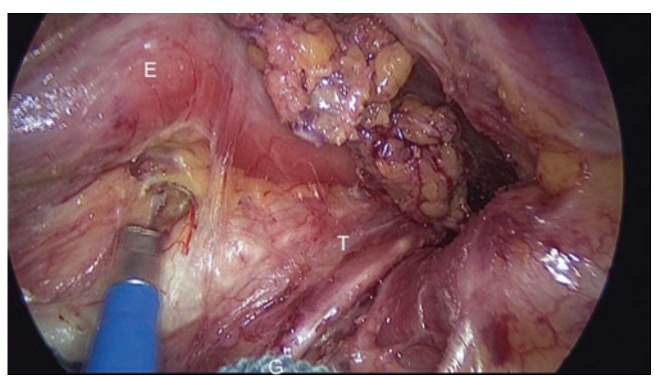

Fig. 16.4 Trachea is rolled back by a grasper with small gauze to explore the operative view around the left recurrent laryngeal nerve. *E* esophagus, *G* gauze, *T* trachea

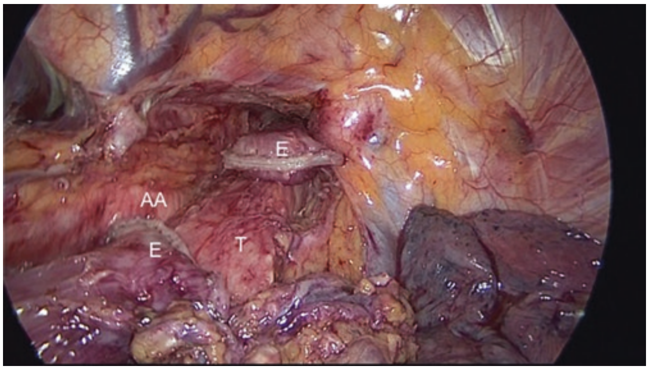

Fig. 16.5 Transection of the esophagus at the upper level of the aortic arch using an endoscopic linear stapler. *AA* aortic arch, *E* esophagus

divided proximal esophagus must be carefully detached from the esophagus, and the proximal esophagus is then fixed by suturing it to the anterior inner chest wall to facilitate exposure of the superior upper mediastinum between the chest and neck. Within the lymphatic tissue chain including lymph nodes and the left RLN, the left RLN can be easily identified without splitting the lymphatic chain only on the vascular sheath of the aortic arch because the RLN is embriologically descended concomitantly with the downward development of the aortic arch (Fig. 16.6a). In other words, the left RLN must be identified and isolated after splitting this lymphatic chain above the aortic arch toward the neck. Around the thoracic inlet, the lymphatic chain disconnected mainly to the pretracheal tissue and partially with the tissue along the neck portion of the left RLN and left supraclavicular tissue including the respective nodes [6]. Therefore, the ventral aspect of the left RLN has been considered to be important for dissection. Of course, complicated dissection procedures in this region can be performed during subsequent neck procedures. However, such dissection cannot be performed enbloc.

Dissection along the left RLN must be adequately performed according to the surgical anatomy described above. Dissection along the left RLN is carried out while some esophageal or tracheal branches of the identified left RLN are divided, and the dissection ends at the thoracic inlet. The left RLN is sharply isolated from the explored tissue without an electric device to avoid injury by electricity or heat, and the lymph nodes are consequently dissected in an *enbloc* fashion with the divided distal esophagus. The thoracic duct is also divided behind the left subclavicular artery at the thoracic inlet when it is excised. On the vertebral side of the posterior aspect of this dissection, a vascular sheath covering the aortic arch and left subclavicular artery is transected if the sheath has been prepared with the divided esophagus on the descending aorta at the posterior face (Fig. 16.6b).

Below the aortic arch, the recurrent portion of the left RLN also has a couple of esophageal branches, which are sharply cut. Lymph node dissection around the left RLN is then finished. During dissection below the aortic arch, one or two left bronchial arteries are identified and preserved on the face of the trunk of the right pulmonary artery (Fig. 16.7). This dissection is somewhat complicated. It is limited to the anterior aspect of the left vagus nerve, along the left bronchus, below the aortic arch and on the face of the pulmonary artery trunk. Using the same technique as that used for dissection around the left RLN, the right bronchus is adequately rolled back and the window below the aortic arch is opened widely.

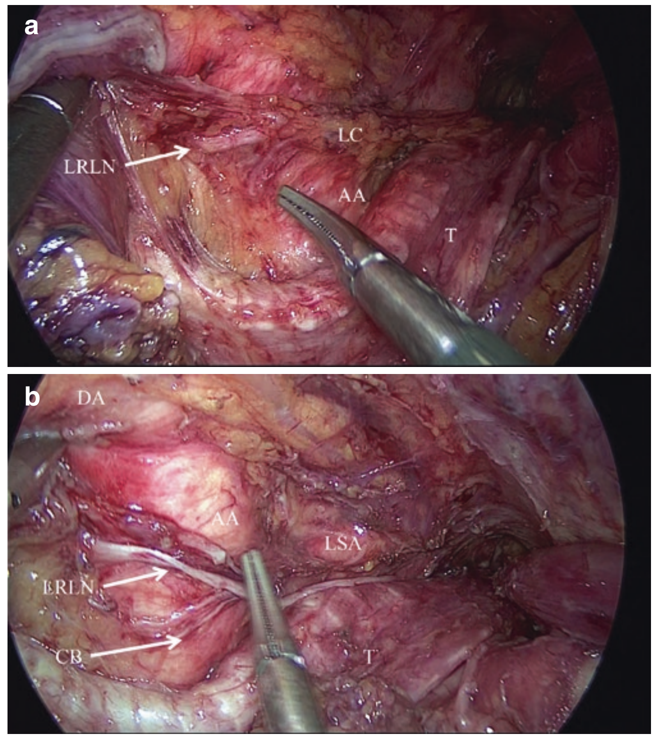

Fig. 16.6 (**a**) Isolation of the lymphatic chain around the left RLN and identification of the left RLN. (**b**) Dissection along the left RLN preserving the cardiac branches within the vascular sheath of the left subclavicular artery and the aortic arch. *AA* aortic arch, *CB* cardiac branches of the sympathetic nervous system, *DA* descending aorta, *LC* lymphatic chain, *LRLN* left recurrent laryngeal nerve, *LSA* left subclavicular artery

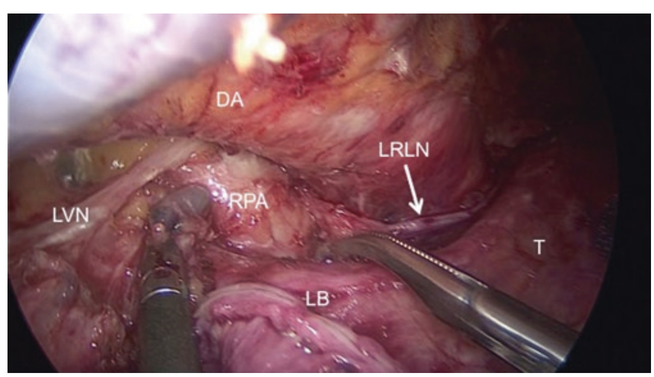

Fig. 16.7 Dissection below the aortic arch. *DA* descending aorta, *LB* left bronchus, *LRLN* left recurrent laryngeal nerve, *LVN* left vagus nerve, *RPA* right pulmonary artery, *T* trachea

16.1.7 Middle and Lower Mediastinal Dissection

Dissection along the left RLN and below the aortic arch is followed by dissection of the subcarinal nodes and nodes below the bilateral bronchi. The dissection extends from the right to left pulmonary hilum. When the right bronchial artery and pulmonary branches of the right vagus nerve are preserved, the procedures are complicated as mentioned above. The esophageal branches of the left vagus nerve are divided after the pulmonary branches. Around the left bronchus and left inferior pulmonary vein in the left pulmonary hilum, dissection must be carefully performed to avoid injury to these structures (Fig. 16.8). A proper dissecting plane comprising the pericardium, left pleura, descending aorta and diaphragm is then established to perform sufficient paraesophageal, middle and lower posterior mediastinal, and supradiaphragmatic lymph node dissection. Dissection is performed on the vascular sheath of the descending aorta without exposure of the adventitia of the aorta to avoid hemorrhage. In addition, the surrounding tissue on the face of the esophagus can be pulled out and dissected easily in this manner (Fig. 16.9). It is important to dissect the nodes below the left inferior pulmonary vein and along the left esophago-pulmonary ligament. In most cases, the left pleura is opened to facilitate dissection along the left esophago-pulmonary ligament and around the supradiaphragm region. In this situation, pneumothorax can influence the left lung ventilation, but the effects of this left pleurotomy on anesthesia are minimal or ignorable. Around the esophageal hiatus, dissection is carried out thoroughly on the bilateral crus preserving the sheath of the esophagus proper. Because both conjunctions of the bilateral crus are visible on the ventral and dorsal sides in all patients, the prone position is considered to provide the best operative view of the lower mediastinum (Fig. 16.10).

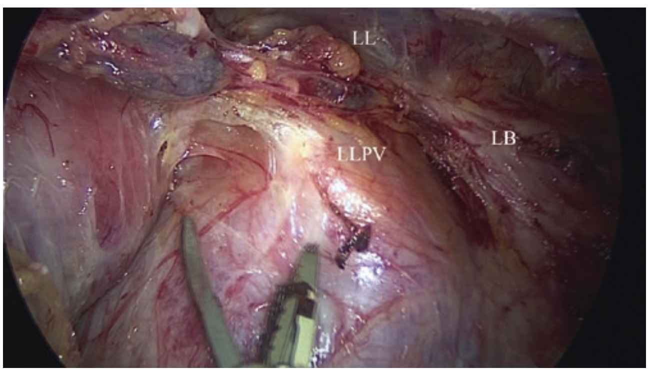

Fig. 16.8 Dissection in the middle mediastinum. *LB* left bronchus, *LIPV* left inferior pulmonary vein, *LL* left lung

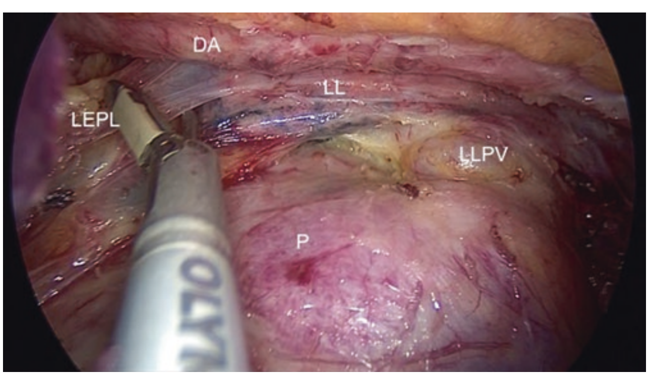

Fig. 16.9 Dissection in the lower mediastinum. *DA* descending aorta, *LEPL* left esophago-pulmonary ligament, *LIPV* left inferior pulmonary vein, *LL* left lung, *P* pericardium

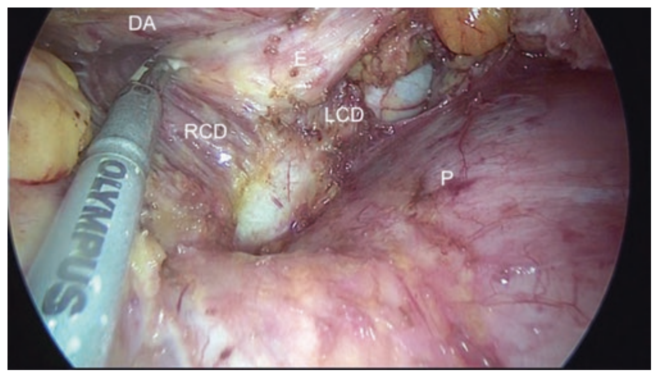

Fig. 16.10 Dissection around the esophageal hiatus. *DA* descending aorta, *E* esophagus, *LCD* left crus of the diaphragm, *RCD* right crus of the diaphragm, *P* pericardium

16.1.8 After Completion of Thoracoscopic Procedures

After thoracoscopic procedures have been completed, the divided distal esophagus is inserted into a vinyl bag to avoid spreading cancer cells. Both stumps of the divided esophagus are connected with a long string for the purpose of later reconstruction via the posterior mediastinal route. A chest tube is inserted in a standard manner. The patient is then placed in the supine position. Laparoscopic surgery using five ports is performed as in an abdominal procedure. The stomach is mobilized and the abdominal lymph nodes are dissected, and a gastric conduit is created extracorporeally through the small laparotomic incision at the umbilical port site. Reconstruction of an alimentary tract between the cervical esophagus and a gastric conduit pulled up through the posterior mediastinum is performed at the neck using the triangular stapling technique in our hospital [7]. Pyloroplasty is not performed and a feeding jejunostomy tube is not usually placed.

16.2 Results and Discussion

The results published in the literature, including our results, are summarized in Table 16.1. In spite of better operative exposure, the operative time in our previous series was not shortened. A long duration of time was required to preserve the mediastinal organs and structures, including recurrent nerves, bronchial arteries, thoracic duct, cardiac branches of the sympathetic nervous system and pulmonary branches of the vagus nerves. We recently began dividing the right bronchial artery to facilitate easier performance of the other procedures. As a result, the mean thoracoscopic time of our recent series was shortened by more than 70 min compared with that of the previous cases. Nevertheless, the operative time was still long because meticulous dissection along the RLNs was required. The numbers of retrieved mediastinal lymph nodes were correlated with the chest operative time of the thoracic procedure, as shown in Table 16.1.

Despite the prolonged operative time for thoracoscopic esophagectomy in the prone position, the estimated blood loss was lower. Blood loss is encountered secondary to either mediastinal dissection or injury to intercostal sites. Thoracoscopic surgery itself using four or five surgical ports can minimize damage to the chest wall. Furthermore, increased operative exposure and improved surgeon ergonomics in the prone position may allow for precise handling for dissection and hemostasis, resulting in less blood loss despite extensive dissection.

Mediastinal lymph node dissection is considered critical to ensure survival after radical esophagectomy. The average number of retrieved nodes in the current series was 27, which was nearly identical to that by open thoracotomic esophagectomy. This suggests that thoracoscopic esophagectomy in the prone position might be oncologically equivalent to open surgery and the left lateral decubitus position.

The incidence of respiratory complications when performing this procedure in the prone position was 15 %, equivalent to that in the left lateral decubitus position and lower than that in previous reports of open surgery [24, 25]. Minimized manipulation of the right lung as well as early recovery after thoracoscopic surgery prevented pulmonary complications. Because respiratory complications are the most common problem leading to prolonged hospital stay and postoperative mortality after thoracoabdominal esophagectomy, we expected that performance of a thoracoscopic procedure in the prone position would have a positive effect on the incidence of respiratory complications.

The overall 5-year survival rates of 74 patients with pStage I, II and III disease who underwent thoracoscopic esophagectomy in the prone position were 72.6 %, 73.9 % and 39.7 %, respectively.

Table 16.1 Studies investigating three-stage thoracoscopic esophagectomy in the prone position

Author	No. of cases	Conversion rate (%)	Thoracoscopy time (min)	Blood loss (ml)	No. of nodes (mediastinal)	Mortality (%)	Overall morbidity (%)	Respiratory morbidity (%)	Recurrent nerve palsy (%)	Anastomic leak (%)	Postoperation stay (days)
Dapri et al. [8]	15	6.7	75	700	4	0	40	13.3	20	26.7	14
Fabian et al. [9]	21	0	86	65	NA	5	48	8	0	4	10
Kuw] bara et al. [10]	22	5	196	50	20.5	0	27	5	22	14	16.5
Noshiro et al. [5]	43	0	307	142	27	2.4	34.9	11.6	14	7	NA
Feng et al. [11]	52	0	67	123	11.6	0	44.2	9.6	6	7.7	11.4
Yatabe et al. [12]	24	NA	247	209	NA	4	25	4	NA	13	23
Lienamn et al. [13]	25	0	90	300	9	0	64	28	0	8	11
Martin et al. [14]	36	5.5	240	200	NA	5.5	41	NA	NA	19	16
Palavielu et al. [15]	130	0	220	180	NA	1.54	20.76	2.31	1.54	2.31	8
Simithers et al. [16]	23	8	90	300	3	0	61	30	0	4	11
Simithers et al. [16]	309	3	90	400	4	2.3	62	26	2.6	5.5	13
Zingg et al. [17]	56	5.5	250.2	320	NA	3.6	34.5	30.9	NA	20	NA
Safranec et al. [18]	41	4.9	90	NA	NA	2.4	NA	14.6	17.1	17.1	11
Safranec et al. [18]	15	0	120	NA	NA	13.3	NA	40	20	20	14
Petri et al. [19]	46	2.2	NA	140	NA	4.4	37	15.2	2.2	13	15
Daiko et al. [20]	29	6.9	210	527	23	0	31	3	17	14	20
Biere et al. [21]	59	14	NA	200	NA	3	NA	12	2	12	11
Ozawa et al. [22]	30	0	260	NA	NA	0	27	NA	NA	NA	NA
Ozawa et al. [22]	30	0	203	NA	NA	0	13	NA	NA	NA	NA
Goldberg et al. [23]	42	NA	108	180	NA	4.8	71	NA	NA	9.5	8

NA not available

Esophagectomy via thoracotomy followed by cervical and abdominal procedures has conventionally been performed as the most curable operative procedure for treating invasive thoracic esophageal carcinoma. It allows for the most extensive lymphadenectomy for optimal management of the extremely aggressive characteristics of lymph node metastasis of the tumor [26]. In addition to the establishment of an effective surgical strategy, increased detection of early-stage cancer facilitated by the use of surveillance programs and advances in staging, patient selection, neoadjuvant therapy and intensive care methods have achieved a high 5-year survival rate [27, 28]. Despite improvements in the survival rate, however, the procedure is associated with significant operative morbidity and mortality rates owing to the extreme invasiveness of extensive dissection of the lymph nodes [29]. One of the most significant concerns regarding mortality is the development of respiratory complications, which occurs in up to 20–30 % of patients who undergo the conventional thoracotomic procedure [30]. Because the use of minimally invasive surgery reduces both pain and the systemic inflammatory response [31], minimally invasive esophagectomy was introduced in an obvious attempt to reduce the incidence of respiratory complications. A recently prospective randomized clinical trial by Biere et al. [21] compared minimally invasive surgery with open esophagectomy and showed the advantages of minimally invasive esophagectomy in terms of reducing postoperative pulmonary complications. According to the latest Japanese report in 2009 [32], the rate of thoracoscopic esophagectomy for esophageal cancer is approximately 20 %.

Thoracoscopic mobilization of the esophagus as part of a three-stage procedure was reported in the early 1990s [33]. This procedure was originally performed in the left lateral decubitus position. In 1994, Cuschieri [34] first reported thoracoscopic esophageal mobilization in the prone position in six patients. Because the proposed technical and physiological advantages of the prone position over the left lateral decubitus position are not fully understood, the technique has not become widespread among esophageal surgeons. Palanivelu [15] reported excellent surgical results based on their experience with 130 patients treated with thoracoscopic esophagectomy in the prone position in 2006. This stimulated new interest in this approach among many esophageal surgeons [35].

The prone position had many advantages over the lateral position. Enhanced visualization and improved ergonomics for surgeons may provide higher-quality mobilization and lymphadenectomy and appear to contribute to enhancement of the learning curve. First, similar to traditional laparoscopy, the surgeon can operate according to the parallel view of the camera. Second, the lungs are spontaneously dislocated from the operative field because of the effects of both gravity and pneumothorax, even without the use of one-lung ventilation. Third, exudate accumulates in the anterior chest apart from the operative field in the prone position. When traditional laparoscopic instruments are used, performing dissection is more ergonomic because both arms and hands of the surgeon are stable owing to the location of the port's entrance site at the surgeon's elbow level [36]. In the lateral position, the tension on the esophagus must be maintained against natural gravity to facilitate exposure for mobilization. The prone position provides better visualization in the subaortic arch and subcarinal and supraphrenic regions. The ease with which the prone position allows for good dissection around the RLN lymph nodes may also explain the technique's popularity among surgeons, given the proposed oncological significance of these lymph nodes [5]. The improved view and ergonomics may also reduce the incidence of complications, such as RLN palsy or tracheobronchial injury, which are known to be more common during minimally invasive surgery than during open esophagectomy [37]. Because of the enhanced operative view, the use of thoracoscopic surgery with fewer ports is enabled in the prone position [36]. This reduction in ports may contribute to decreases in postoperative pain and intercostal vessel and nerve injury.

On the other hand, this procedure is not established for use in emergencies requiring a thoracotomic procedure, such as massive bleeding [35]. Posterior thoracotomy is available; however, the ability to perform emergent thoracotomy is limited in the lower ICS, where the management of complications may be difficult if such complications occur in the upper mediastinum. Therefore, some authors have suggested that the prone position procedure should not be employed in patients with bulky tumors treated with preoperative chemoradiation [35] or large tumors adjacent to the aorta or tracheobronchus [10].

The oncological significance of the PP procedure is obscure owing to the short follow-up periods used in previous studies. Dapri et al. [8] reported that during a median follow-up period of 19.1 months (range, 1.5–34.0 months), seven (47 %) of 15 patients with a final pTNM stage 0 to III who had undergone the prone procedure died after a median period of 15 months (range, 1.5–23.0 months). Liebman et al. [13] found that 15 (60 %) of 25 patients treated with the prone technique developed recurrence of their cancer after surgery. The site of first recurrence was distant in 11 patients, locoregional in two patients and both distant and locoregional in two patients. The overall median survival was 32 months (range, 1–60 months). Martin et al. [14] reported that according to Kaplan–Meir survival analysis, the predicted 1- and 4-year survival rates among 34 study patients with invasive malignancy were 72 % and 44 %, respectively. Palanivelu et al. [15] showed that at a mean follow-up of

20 months (range, 2–70 months) in 130 patients, the 3-year survival rates of patients with stage I, IIa, IIb and III disease were 75 %, 50 %, 45 % and 18 %, respectively. According to Smithers et al. [16] and Zingg et al. [17], there are no differences in survival between patients treated with total MIE in the prone position and those treated with open esophagectomy when examined stage for stage when there are enough events to calculate a median survival rate.

Whether the prone technique is the best approach remains unclear, although the procedure is thought to have a number of theoretical physiological and ergonomic advantages for the patient and surgeon [38].

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Robotic Esophagectomy

17

Kemp H. Kernstine Sr., John K. Waters, Nabil P. Rizk, Inderpal S. Sarkaria, Christopher Scott, and Mark Onaitis

Contents

17.1 Robotic Esophagectomy: Rationale for Robotic Esophagectomy

Kemp H. Kernstine Sr. and John K. Waters

Esophagectomy is one of the more complex surgical procedures. Indications for esophagectomy include resection for cancer, severe esophagealdysmotility, reflux, trauma – i.e. perforation. For cancer, the goals are to remove involved or potentially involved adjacent tissue such as the periesophageal fat, nodes, and pericardium to achieve a negative margin (R0), to re-establish intestinal continuity, to assess the biology of the malignancy and response to induction therapy, and to minimize the disability from the procedure. Numerous approaches have evolved to accomplish these goals.

Open esophagectomy is comprised of four different procedures: McKeown or three-hole esophagectomy, the Ivor Lewis esophagectomy, the left sided approach esophagectomy and the transhiatal esophagectomy. The chest-based approaches have historically required large incisions for adequate visualization during the removal and reconstruction of the esophagus.

Minimally invasive esophagectomy has not enjoyed wide acceptance. Criticisms of the minimally invasive esophagectomy revolve around reported long operative times significant blood loss and high transfusion rates. Conversion to an open procedure rates are described at nearly 20 %. Some surgeons do not think there to be appreciable reduction in

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postoperative pain for patients undergoing minimally invasive esophagectomy. There are also reports of appreciable rates of postoperative complications, in particular pulmonary-related complications; concerns about the oncologic quality of the surgery, and patient quality-of-life after surgery.

The literature, however, does not support many of these criticisms. Six major analyses performed in the last 5 years provide evidence that minimally invasive esophagectomy is beneficial to patients. In 2009, Biere performed a meta-analysis comparing minimally invasive esophagectomy (MIE) to open esophagectomy [1]. In this study, there were 1061 patients assessed in one controlled trial and nine case-control studies. There did not appear to be any differences in the major morbidity or mortality rates. For MIE, there was a trend towards fewer anastomotic leaks, less blood loss, and a comparable number of lymph nodes harvested. The operative time was longer in the MIE group; however, the length-of-stay ranged between 9 and 16 days, not significantly different from the open group.

In 2010, Nagpal performed a random-effects model in a meta-analysis of 12 studies in 672 MIE and 612 open esophagectomies and found no differences in 30-day mortality with the MIE. Minimally invasive esophagectomy was also associated with less blood loss, shorter hospital stay, and fewer respiratory complications [2].

In 2011 and 2012, Biere et al. published results of a large multi-national randomized control trial, the TIME (Traditional Invasive *vs.* Minimally Invasive Esophagectomy) trial. In this study, 115 patients at five institutions in three countries were randomly assigned to either the open or MIE [3, 4]. There was a 9 % rate of pulmonary complications within 2 weeks of surgery in the minimally invasive group, compared to nearly 29 % in the open esophagectomy group ($p = 0.005$). In-hospital mortality was similar between the groups. The hospital stay was slightly longer for the open esophagectomy – 14 days – the MIE was 11 days ($p = 0.044$). For MIE, there was superior short-term quality-of-life compared with the open esophagectomy approach; 42 versus 36 ($p = 0.007$) and superior global health ($p = 0.020$). The complete resection rate and pathological staging was similar for both. Operatives times were longer for the minimally invasive approach 5.5 h versus 5 h for open esophagectomy ($p = 0.002$). Mean blood loss for the MIE was 200 mL versus 475 mL for the open esophagectomy ($p < 0.001$). The conversion rate from the minimally invasive to the open esophagectomy was 14 %. The anastomotic leak rate was similar between the two groups between 7 % and 12 %. Vocal cord paralysis was less common for the minimally invasive approach, 2 % versus 14 % ($p = 0.012$). The rate of reoperation and rate of pulmonary embolism was similar. In a smaller subset of patients from this study, 27 patients, half in the open and half in the MIE group, the MIE patients showed a 40–50 % reductions at the first postoperative week in the inflammatory mediators IL8, prolactin, and leukocyte counts ($p < 0.05$), which the investigators believed was correlated with fewer respiratory complications [5]. The HLA-DR expression, IL6 and CRP were similar. The same group reported the results of their patients at 1 year [6]. In this subset of patients, the quality-of-life physical component was also better for MIE compared to open esophagectomy, 50 vs 45 ($p = 0.003$). Global health was better as well, 79 for the MIE and 67 for the open esophagectomy ($p = 0.004$). Pain scores in MIE patients were less than half of the open approach patients at 6 weeks ($p = 0.002$) and 1 year ($p = 0.003$). Forty-four percent of the MIE patients were treated for anastomotic stricture and 39 % for the open esophagectomy. The overall survival at 1 year was 68 % for the open approach and 76 % for the minimally approach, where disease free survival was 59 % and 69 %, for the open thoracotomy and minimally invasive approach, respectively; none being statistically significant.

In 2012, Dantoc performed a systematic literature review and found that more lymph nodes were removed with the minimally invasive approach, 16 nodes removed compared with 10 for the open esophagectomy group ($p = 0.04$) [7]. In 2013, Uttley et al. published a systematic review of 28 studies, which did not include any randomized data [8]. It was found that operative mortality was similar between MIE and open esophagectomy – 2.4 versus 3.8 %, recurrence rate was approximately 24 % in the MIE group, length-of-stay in MIE was between 14 and 17 days. The complication profile of MIE patients was also further detailed tracheal perforation 2–7 %, damage to adjacent structures 5–7 %, anastomotic leak 10–11 %, chyle leak 3–4 %, wound infection 13–18 %, recurrent laryngeal nerve/hoarseness 10–13 %, pulmonary complications 7–10 %. MIE removed approximately 15 nodes.

In 2015, Zhou et al. found 48 studies that comprised 14,311 esophageal cancer patients [9]. Minimally invasive esophagectomy was associated with lower in-hospital mortality, 0.69 odds ratio. MIE was also associated with a reduced incidence of pulmonary complications, 0.73 relative risk, pulmonary embolism 0.71 and arrhythmia 0.79. There was no significant difference in the risk of anastomotic leak or gastric tip necrosis when MIE was compared to open esophagectomy.

As in other surgical procedures, smaller incisions lead to less trauma and less trauma appears to benefit patients. The clinical outcomes of MIE compared with the open esophagectomy appear to be relatively similar in early publications. But as the techniques and the technology have improved, MIE appears to show superiority to open esophagectomy.

An evolving question is whether the introduction of computer-assisted or robotic technology provides a better platform for minimally invasive esophagectomy. As with the open and MIE esophagectomies, there are many different ways to perform a robotic esophagectomy: McKeown or three-hole technique; Ivor Lewis technique or the transhiatal technique. For the McKeown and Ivor Lewis techniques, most reports to date use the robot to perform the chest portion of the procedure and perform the abdominal portion of the procedure by laparotomy or laparoscopy. These differences make it difficult to compare the robotic-assisted esophagectomy to the other techniques. In addition, for most of the past 15 years, there were too few robots, too little robotic operative surgical time available, insufficient technical support, and surgeon inexperience to understand the role of the robotic approach in the performance of an esophagectomy.

Theoretically, it made sense that 3-D visibility, the multiple arcs of rotation on the robotic arms, the ability of the surgeon to direct the view of the camera, and the ability to make intricate and complex moves in a small space would result in a significant advantage. All of these aspects would also result in minimal perturbation at the chest wall that would reduce post-operative pain, intraoperative bleeding, and postoperative dysfunction.

There are concerns with robot-assisted minimally invasive esophagectomy. In many facilities, robot time is a precious commodity. There are too few robots or relatively too many surgeons vying for the available robot time. The robot is expensive as is the equipment needed to support it. Training surgeons and surgical teams to manage the robot is expensive as well. Hospital administration and nursing teams must accommodate these intricacies and allow for the robotic team to operate most effectively. These issues make the robotic approach less attractive for most thoracic surgeons.

The most recent literature on robotic-assisted esophagectomy comes from a study published by Rurda et al. in 2015. In this systematic review of 16 articles in which a robotic esophagectomy was performed in 300 patients, it was found that the [10]. R0 rate was 77–100 % and between 18 and 43 nodes were resected. Visualization of the mediastinum was felt to be excellent. Blood loss was reported to be 100 ml or less. The complication profile was as follows: conversion rates 0–21 %, anastomotic leak rates 4–38 %, mortality 0–6 %. Length-of-stay was 7–21 days. These reported experiences were nascent in comparison to the open and MIE approaches and the approaches used – completely robotic, chest-only robotics and the McKeown, Ivor Lewis and transhiatal- make it difficult to make objective comparisons between robotic and minimally invasive esophagectomy techniques.

In our experience the non-robotic minimally invasive surgical approach has shortcomings. Wide resection can be compromised because of the lack of visibility and articulations necessary to perform a thorough lymphadenectomy within the mediastinum and the significant torque at the chest wall to obtain the best visibility increases the likelihood for postoperative discomfort. Robotic technology is relatively new and the equipment utilized to perform the procedure and our knowledge of it as it relates to the anatomy will evolve.

17.2 Robotic Esophagectomy: Methods

Nabil P. Rizk and Inderpal S. Sarkaria

17.2.1 Rationale

Since its introduction in the 1990's, a minimally invasive esophagectomy (MIE) has been very loosely defined. For instance, some MIEs incorporated a planned 'open' component (for example, a laparotomy, thoracoscopy, and cervical incision), while other MIEs included components which were performed minimally invasively, but at some point were then extended to an open approach for completion (for example, laparoscopic mobilization of the gastric conduit with a planned conversion to a 'mini' laparotomy to complete the transhiatal dissection and conduit delivery). These 'compromises' of a minimally invasive approach were done partly to address certain limitations inherent to the tools available in an MIE. Currently, the commonly accepted definition of a fully MIE is that no component of the procedure is performed in such a way that direct visualization of structures is required (other than the cervical component if done), with the possible advantage of minimizing the physiologic insults of open incisions. Using this more strict definition of MIE, it stands to reason that any tool which might improve the ability to perform such a complex operation, either thru better visualization or because of better instrumentation, would improve the conduct of the operation. Robotic assisted minimally invasive esophagectomy (RAMIE) was introduced to address both of these issues. For improved visualization, the robotic camera provides a three dimensional view of structures using a stable platform which is directly controlled by the surgeon. With regards to instrumentation, robotic instruments have two fulcrums of articulation, one at the entry point into the patient analogous to non-robotic MIE, but in addition, in most instruments, an additional 360° of articulation at the end of the instrument which results in significantly improved dexterity (Fig. 17.1). The limitations of the robotic approach include the lack of haptic feedback, requiring visual clues in order to compensate, the relatively greater importance of port positioning in order to allow instruments to work properly, and high fixed costs. Table 17.1 lists some of the published series in the literature in which the robot was used for various portions of the operation. It should be noted that the mortality and complications rates in these series are not dissimilar to published non-robotic MIE series. Ultimately, the value of the robotic approach will need to be assessed by comparing outcomes and costs to other approaches. The procedure described in this chapter is one that was developed using a four arm platform and two staff surgeons, one at the bedside and one at the console. Most procedures were done with an Ivor Lewis approach, although some were also performed as McKeown esophagectomies. Herein we describe only the Ivor Lewis approach. The technical components of the procedure have evolved with experience, and what we present in this chapter represents the most recent iteration; undoubtedly, in time more modifications will take place.

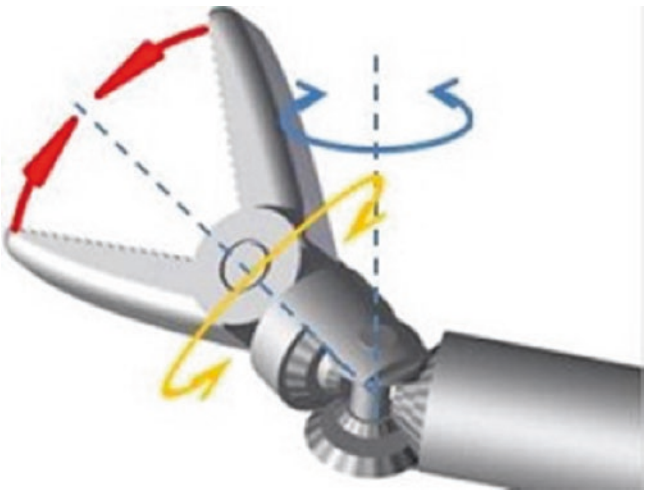

Fig. 17.1 360° of articulation of robotic instruments

17.2.1.1 Indications

The indications for a RAMIE Ivor Lewis are the same as for non-robotic approaches. Namely, the primary indication is malignancy, most commonly a distal esophageal and gastroesophageal junction adenocarcinoma. In patients with mid esophageal squamous cell carcinomas or in patients with more proximal involvement of adenocarcinoma or dysplasia, we have favored a RAMIE McKeown approach. Rarely, there are benign indications for a RAMIE Ivor Lewis, including end stage achalasia and a recalcitrant benign stricture.

17.2.1.2 Contraindications

If an Ivor Lewis esophagectomy is indicated, there are no absolute contraindications to a RAMIE approach. Occasionally, patients with extensive adhesions may not be amenable to any minimally invasive approach, although that determination is only made at the time of the attempted RAMIE.

17.2.2 Methods

Room Setup Viewed from the perspective of the anesthesiologist, the robot is placed on the right side of the room and the console with the camera screen and various energy sources on the left side. Initially the patient bed is placed in a neutral position for the intubation and any endoscopy components.

Table 17.1 Selected robotic esophagectomy series

	Total #	Approach	Robotic component	# of Lymph nodes	Morbidity and mortality
Kernstine [11]	14	McKeown	Chest (6)	18	29 %, 7 %
			Abdomen/chest (8)		
Boone [12]	47	McKeown	Chest (47)	29	NA, 6 %
Giulianotti [13]	5	NA	Chest (5)	NA	NA 40 %
Galvani [14]	18	Transhiatal	Abdomen (18)	13	50 %, 0 %
Kim [15]	21	McKeown	Chest (21)	38	52 %, 0 %
Weckslei [16]	11	McKeown	Chest (11)	23	NA, 9 %
Sarkaria [17]	21	Ivor Lewis	Abdomen/chest (21)	20	24 %, 5 %
Clark [18]	60		Multiple	NA	30 %, 2.4 %

17.2.3 Abdominal Phase

Positioning For this part of the procedure, the bed is turned 90° to the right as viewed from the anesthesia side (towards the robot). The patient is positioned with the right arm extended 45° on an arm board and the left arm is tucked by the side, with the body shifted such that the head is at the very top of the table and the right side of the body at the right edge of the table. This allows for optimal robotic arm use especially in tall patients, as well as appropriate use of the liver retractor. A foot board with padding is placed (Fig. 17.2).

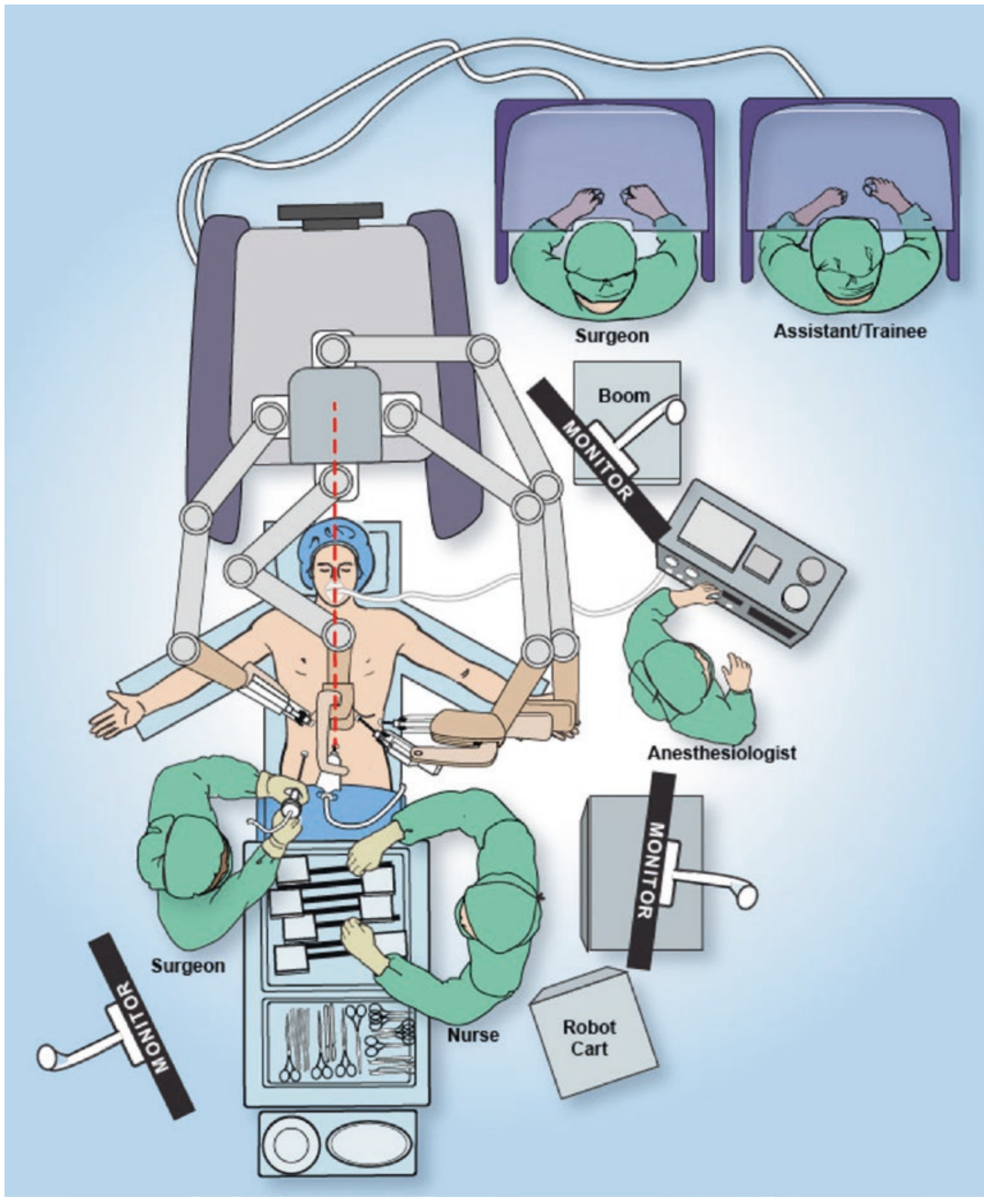

Fig. 17.2 Robot and patient positioning for abdominal portion of the procedure

Port placement The total number of ports placed for the abdominal phase is most commonly seven, and occasionally eight; four ports are for the robot, one for the liver retractor, and two to three for bedside retraction, suctioning, suture passing, and stapling. The initial port placed is a 12-mm mid-line immediately supra-umbilical camera port placed under direct vision, thru which a pneumoperitoneum is established with 15 mmHg of CO_2 pressure. A 12-mm 30° robotic camera is introduced, and the patient is placed in steep reverse Trendelenburg. Then, under direct vision, the additional ports are placed. Starting superiorly and on the left side, a left lateral 5-mm robotic port to be used for a grasper (Schertl Grasper, Intuitive Surgical) is placed about 3–4 cm below the sub-costal margin sufficiently lateral to be just anterior to the left colon (fourth robotic arm); a left mid-clavicular 8-mm port for the robotic ultrasonic shears (Harmonic Scalpel, Ethicon) is placed about 13–15 cm from the xyphoid (first robotic arm). Using these two ports and laparoscopic graspers, the hepatic flexure is retracted inferiorly and medially to expose the lateral most aspect of the right colon peritoneal reflexion immediately below the costal margin, where a 5 mm port is placed for the liver retractor (Diamond Flex, Snowden Pencer); the liver retractor is now placed under the left lobe of the liver and retracted anteriorly; a fourth 8 mm robotic port for a bipolar atraumatic grasper (Fenestrated Bipolar Grasper, Intuitive Surgical) is then placed in the right mid-clavicular area approximately 2–3 cm below the sub-costal margin (second robotic arm). We consistently place two additional bedside assistant ports on the right side at the level of the umbilicus, including a 5 mm port approximately 5 cm from the umbilicus and a 12 mm port approximately 10 cm from the umbilicus; lastly and occasionally (especially in obese patients), we also place an additional 5 mm port approximately 5 cm to the left of midline at the level of the umbilicus (Fig. 17.3a).

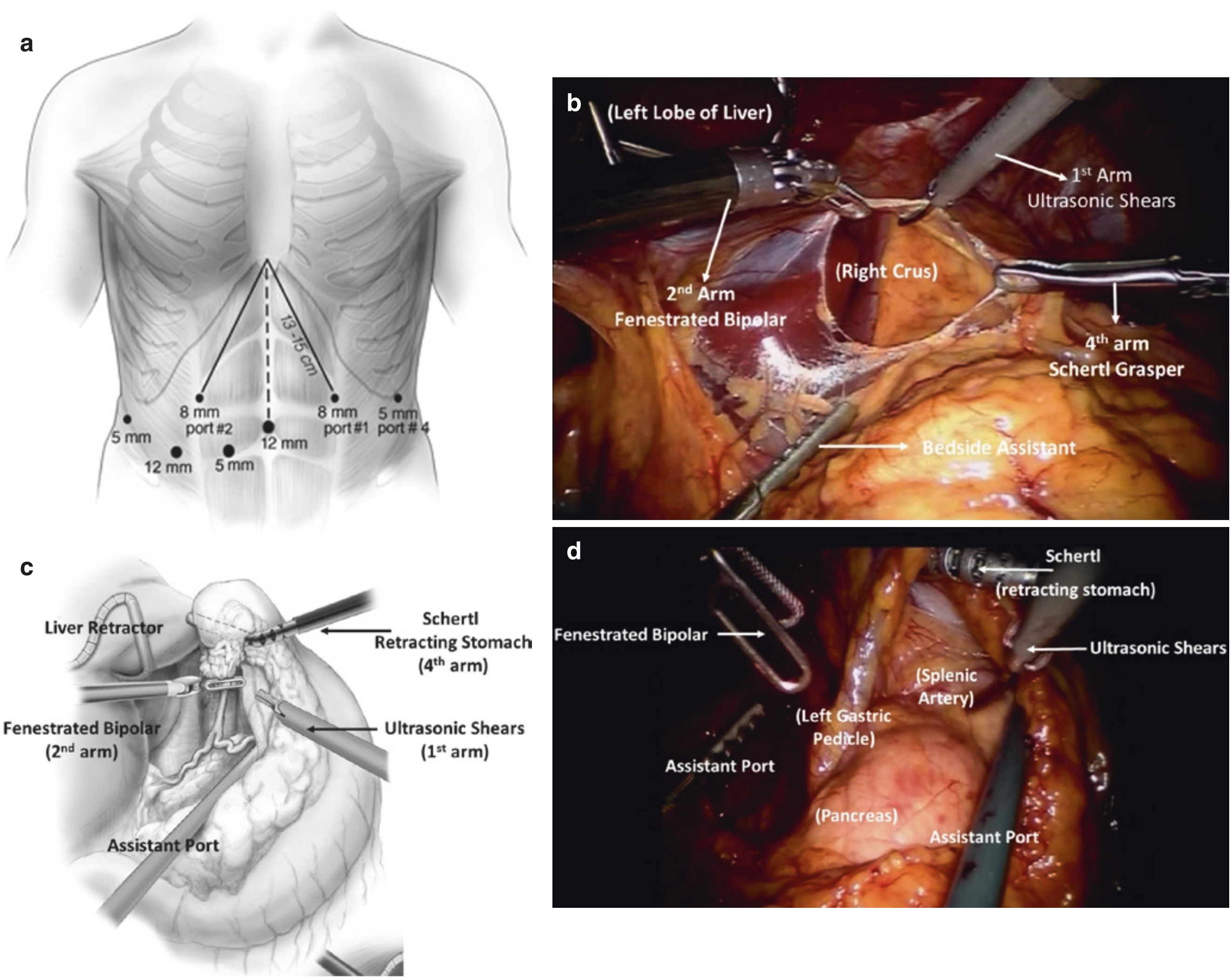

Fig. 17.3 (**a**) Placement of abdominal ports. (**b**) Initial dissection into the gastro-hepatic ligament after all the instruments are in position. (**c**) Initial exposure of the lesser sac via the right gastric side. (**d**) Dissection in the lesser sac via the lesser curve exposure

Hiatal and retro-gastric dissection After excluding any evidence of disease which would render the patient unresectable, the gastroesophageal (GE) junction is dissected off of the right and left crura laterally, and pericardium anteriorly with an en bloc resection to encompass all disease as needed, carefully avoiding entry into the pleural cavity which on occasion can cause hemodynamic instability and for which a tube thoracostomy might be necessary. The posterior aspect of the GE junction is then dissected off of the aorta, fully exposing the left and right crura, and thus fully mobilizing the GE junction. Attention is then turned to the retro-gastric component of the procedure which is accomplished initially thru exposure in the lesser sac from the lesser curve side. The stomach is retracted anteriorly and caudally using the Schertl grasper (fourth robotic arm), and with suctioning and additional exposure from the bedside assistant, the celiac axis, splenic artery, and common hepatic artery are skeletonized of their nodal tissue in an en bloc fashion. The left gastric artery and vein are then exposed and divided with an endovascular stapler. With continued retro-gastric exposure and anterior stomach retraction, we continue to dissect the most proximal aspect of the gastric fundus from its posterior and lateral attachments, ultimately exposing and transecting most of the short gastric arteries from the retro-gastric approach in the process (Fig. 17.3b–d).

Gastric mobilization The stomach is retracted to the right and caudally by the bedside assistant by grasping the gastric fat pad, thus exposing the greater curvature. The course of the right gastroepiploic artery and its termination can be clearly identified with this retraction, and any remaining short gastric arteries are divided using the ultrasonic shears. While maintaining this exposure, the lesser sac is entered thru a new window placed in the greater omentum at about the half way point of the extant of the right gastroepiploic artery. The schertl (fourth robotic arm) is then placed thru this window and is initially used to retract the greater omentum towards the left lateral abdominal wall. This clearly exposes the distal gastroepiploic artery, which is separated caudally from the omentum using the ultrasonic shears. Once this dissection is complete, the fourth robotic arm grasper is advanced behind the fundus to gently lift the stomach anteriorly, caudally, and towards the left; this clearly exposes the proximal extent of the gastroepiploic artery and any remaining retroperitoneal adhesions. With this view, the remaining stomach is completely mobilized to the level of the retro-pyloric position of the gastroepiploic artery (Fig. 17.4a).

Pyloroplasty Unlike our previously described procedure, we no longer routinely perform a gastric emptying procedure.

Gastric conduit formation The nasogastric tube is withdrawn to about 30 cm from the incisors. The stomach is positioned by using robotic fourth arm to grasp the tip fundus on the short gastric artery line and retracting caudally towards the left upper quadrant, and using the third robotic arm and an atraumatic grasper (Cadierre Forceps, Intuitive Surgical) to place downward traction on the antrum. An endovascular stapler is introduced thru the 12 mm port to divide the remaining lesser curve vasculature, sacrificing about three to four branches of the right gastric artery, while angling the stapler towards the incisura. The gastric tube is then fashioned using multiple firings of an endo-gastrointestinal stapler, creating a conduit approximately 5–6 cm in diameter. After completely separating the conduit from the GE junction, they are temporarily re-attached using a heavy suture while maintaining proper orientation, in anticipation of future delivery in the chest (Fig. 17.4b).

Feeding jejeunostomy We routinely place a feeding jejeunostomy. However, because of the positioning of the robot arms, it is technically not feasible to place a jejeunostomy robotically, so typically at this point we convert to a laparoscopic approach, and using the previously placed ports, place a feeding tube in the standard manner approximately 30 cm from the ligament of Treitz.

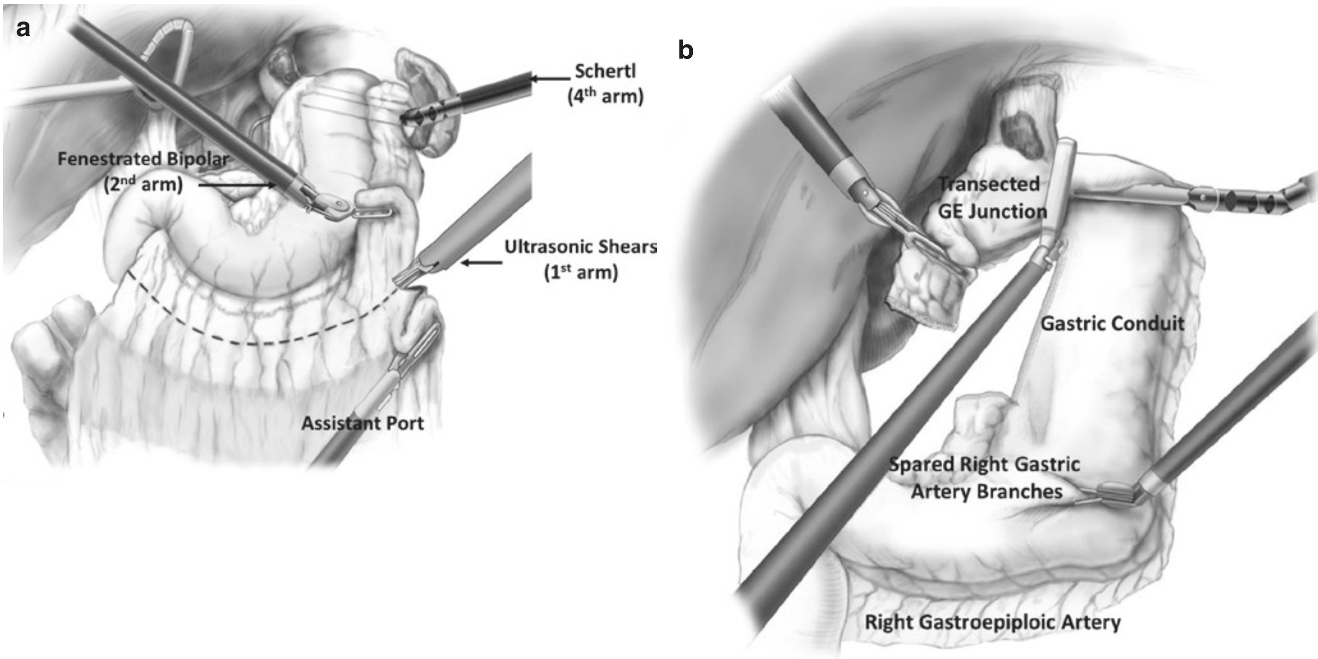

Fig. 17.4 (**a**) Competion of the mobilization of the greater curvature. (**b**) Creation of the gastric conduit

17.2.4 Thoracic Phase

Positioning For this part of the procedure, the bed which was oriented at 90°, is rotated back to about 70°. The patient is placed in a full left lateral decubitus position, and the bed is flexed. The right arm is positioned so that the patient's elbow is the least prominent possible (Fig. 17.5).

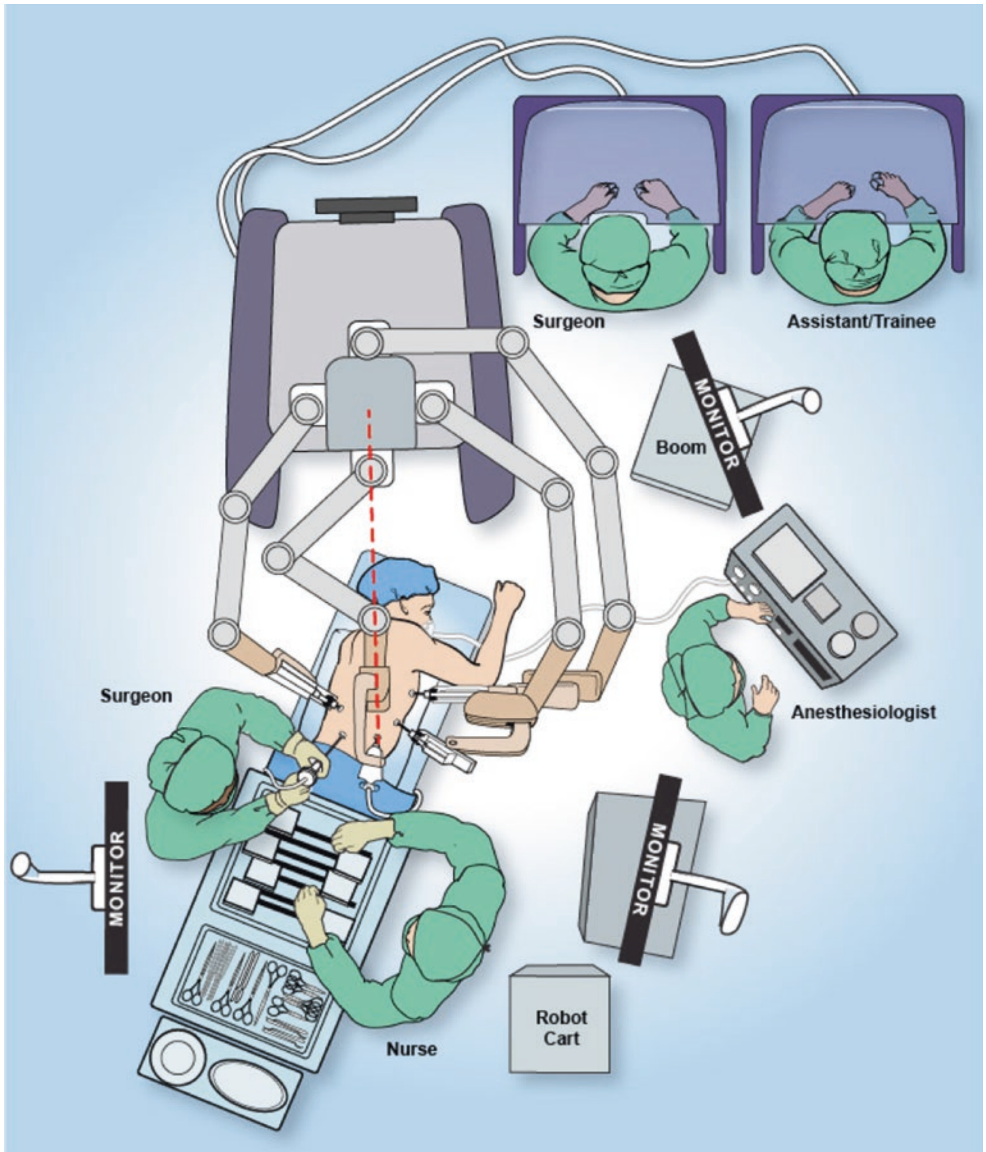

Fig. 17.5 Robot and patient positioning for chest portion of the procedure

Port placement A total of five ports are placed, four robotic and one assistant port. After right lung isolation, a Veress needle is temporarily placed into the chest at approximately the mid-scapula line in the fifth intercostal space for CO_2 insufflation to 8 mmHg. A 12 mm camera port is placed in the posterior axillary line in the ninth interspace. Under direct visualization, a 5 mm robotic port for the Schertl is placed in the third interspace in the posterior axillary line (fourth arm); an 8 mm robotic port for a spatula is placed in the sixth interspace between the mid and posterior axillary line (first arm); an 8 mm robotic port for the bipolar grasper is placed slightly posterior to the scapular tip at approximately the ninth interspace (positioned immediately above the GE junction) (second robotic arm); and a 12 mm assistant port is placed mid-way between the camera port and posterior robotic port, as low as possible and immediately above the diaphragmatic insertion, to be used for a suction irrigator, graspers, and staplers (Fig. 17.6a).

En bloc esophageal mobilization The thoracic component is performed essentially as an en bloc approach, with circumferential removal of all tissue off the pericardium and airway medially, and along the aorta and contralateral pleura posteriorly, from the level of the hiatus to the azygous vein. Above the level of the azygous, the dissection is maintained close to the esophageal wall. The initial dissection begins by mobilizing the inferior pulmonary ligament, then using the Schertl (fourth robotic arm) for anterior and superior lung retraction, followed by removal of the parietal pleura off of the vena cava and pericardium extending superiorly behind the inferior pulmonary vein up into the sub-carinal space as well as posteriorly to the level of the contralateral pleura. Minimizing the risk of thermal injury to the airway is critical at this point, especially as the dissection continues to the left mainstem bronchus. At this point the azygous vein is transected with an endovascular stapler. Posterior dissection is then begun along the pleura of the descending azygous vein, with careful identification and preservation of the thoracic duct (if injured, it should be ligated near to the hiatus). Dissection is continued posteriorly until the aortic adventitia followed by the contralateral pleura are identified, and continued inferiorly to the level of the hiatus. Most aorta-esophageal branches can be cauterized with the spatula, but some larger ones might require either clips or bipolar cautery. At the hiatus, the dissection should continue until both crura are completely exposed. Prior to introducing the stomach into the chest, the proximal esophagus should be dissected above the level of the azygous to the desired level of transection (based on both considerations of tumor location as well as expected conduit length). The GE junction along with the attached conduit are then pulled up into the chest. Once the previously placed stitch between the GE junction and gastric conduit is identified, the stitch is cut and the conduit is temporarily secured to the diaphragm with another stitch. The GE junction is grabbed with the fourth robotic arm and pulled laterally and superiorly as the remaining posterior mediastinal attachments are dissected to the level of the planned esophageal transection. The esophagus is the sharply divided with robotic shears thru the first port (Monopolar Scissors, Intuitive Surgical). The second robotic arm and port are removed and the incision is extended to about 4 cm in size, a wound protector is deployed, and the specimen is retrieved. The proximal margin is sent for frozen section (Fig. 17.6).

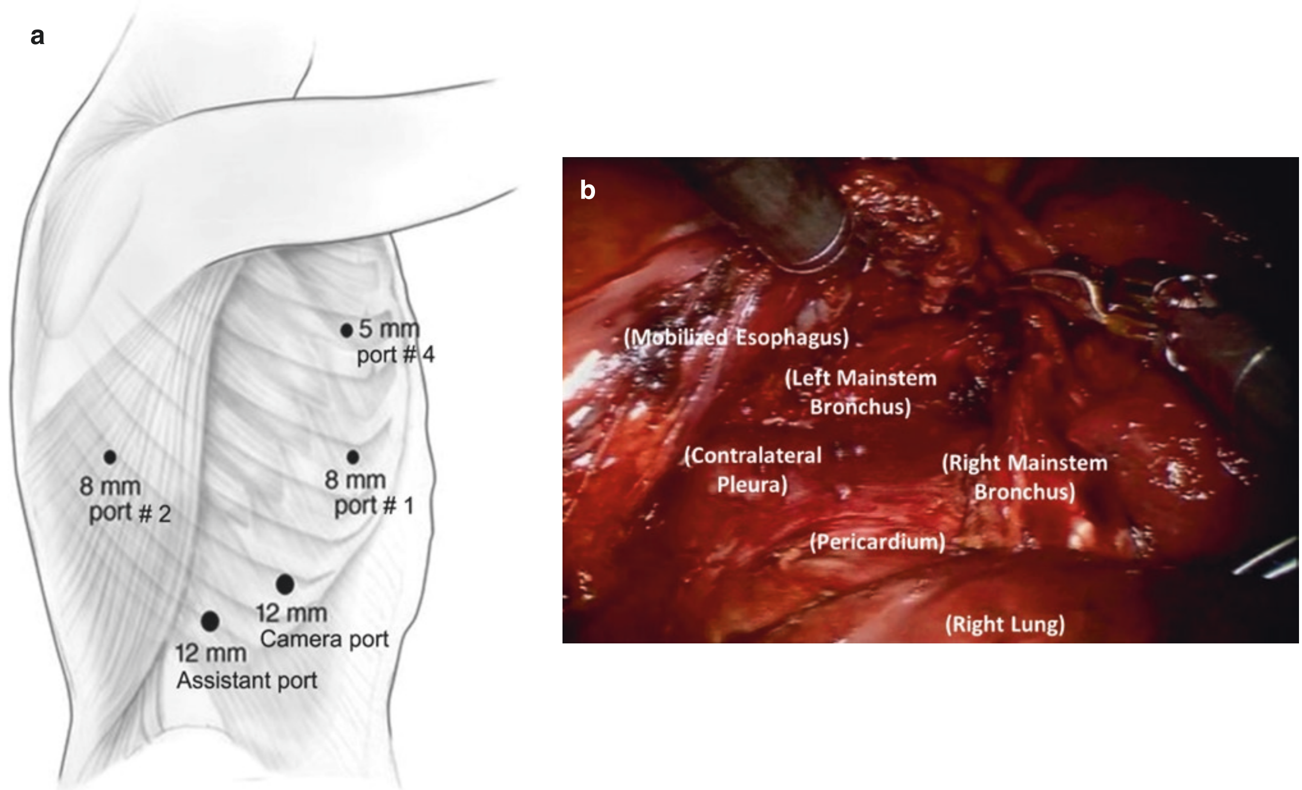

Fig. 17.6 (**a**) Placement of chest ports. (**b**) Mobilization of the esophagus en bloc with surrounding lymph nodes

Creation of the anastomosis The proximal esophageal lumen size is visually estimated, and typically a 28 mm anvil (DST EEA Stapler, Covidien Surgical) is introduced into the chest for later use. The second robotic port and robotic arm are placed back into the extended posterior incision. Large needle drivers are then placed on the first and second robotic arms. A running 'baseball' purse string stitch is then placed (0 Prolene SH Needle, Ethicon). The needle drivers are switched to a fenestrated bipolar in the second robotic arm and an atraumatic grasper (Cadierre Forceps, Intuitive Surgical) in the first robotic arm. The proximal esophagus is held open with the second and fourth robotic arms, and the Cadierre is used to grab the EEA anvil to position it into the open lumen. The first and second arm are then switched back to large needle holders, and the Prolene suture is securely tied. A second Prolene purse string suture is placed immediately proximal to the first one to reinforce the first one. The temporary diaphragm stitch to the conduit is now cut, and the rest of the conduit is delivered into the chest; this is best done using graspers from robotic arms one and two, carefully grabbing both sides of the stomach staple line (by not pulling the staple line apart, but rather approximating the two graspers) and pulling towards the lateral chest wall rather than apically. Slow gentle tugging invariably allows the conduit to be completely delivered into the chest as documented by identifying the first staple fire on the lesser curvature. Using the spatula and cautery in the first arm, a gastrotomy is made below the most proximal aspect of the staple line of a size sufficient to accommodate the EEA stapler. At this point, the bedside assistant grasps the distal aspect of the gastrotomy thru the 12 mm port site, and the first and fourth robotic arms grasp the gastrotomy opening at 3 o'clock and 11 o'clock, respectively. The second robotic port is removed, and the EEA stapler is introduced thru the wound and into the conduit. Once the stapler is safely advanced into the conduit, the fourth robotic arm releases the stomach and is replaced by a handheld grasper placed thru the second robotic port site by the bedside assistant (it is helpful at this point to have two bedside assistants, one for the two graspers and one for the stapler). The first robotic arm now also releases the stomach. At this point, thru the coordinated movements of the two bedside assistants, the stapler is further advanced into the conduit to a point as distal as possible to create a tension free, side stomach (on the greater curvature) to end esophagus anastomosis. While maintaining proper conduit orientation (staple line facing laterally), and while using the grasper on the first robotic arm on the anvil, the stapling device is deployed, coupled with the anvil (which is controlled by the first robotic arm), and fired. The stapler is then removed, the donuts examined for completeness, and the anastomosis is visually inspected thru the gastrotomy. The nasogastric tube is then advanced under direct vision, and the gastrotomy is closed with an endo-gastrointestinal stapler fired thru the 12 mm port, with the robotic first and second arm graspers holding both sides of the gastrotomy together. If there is sufficient omentum, it is placed between the anastomosis and the airway. We then place a Jackson Pratt drain posterior along the conduit up to the level of the anastomosis, exiting thru the 12 mm port. We also place a chest tube thru the camera port anteriorly to the apex (Fig. 17.7a–c).

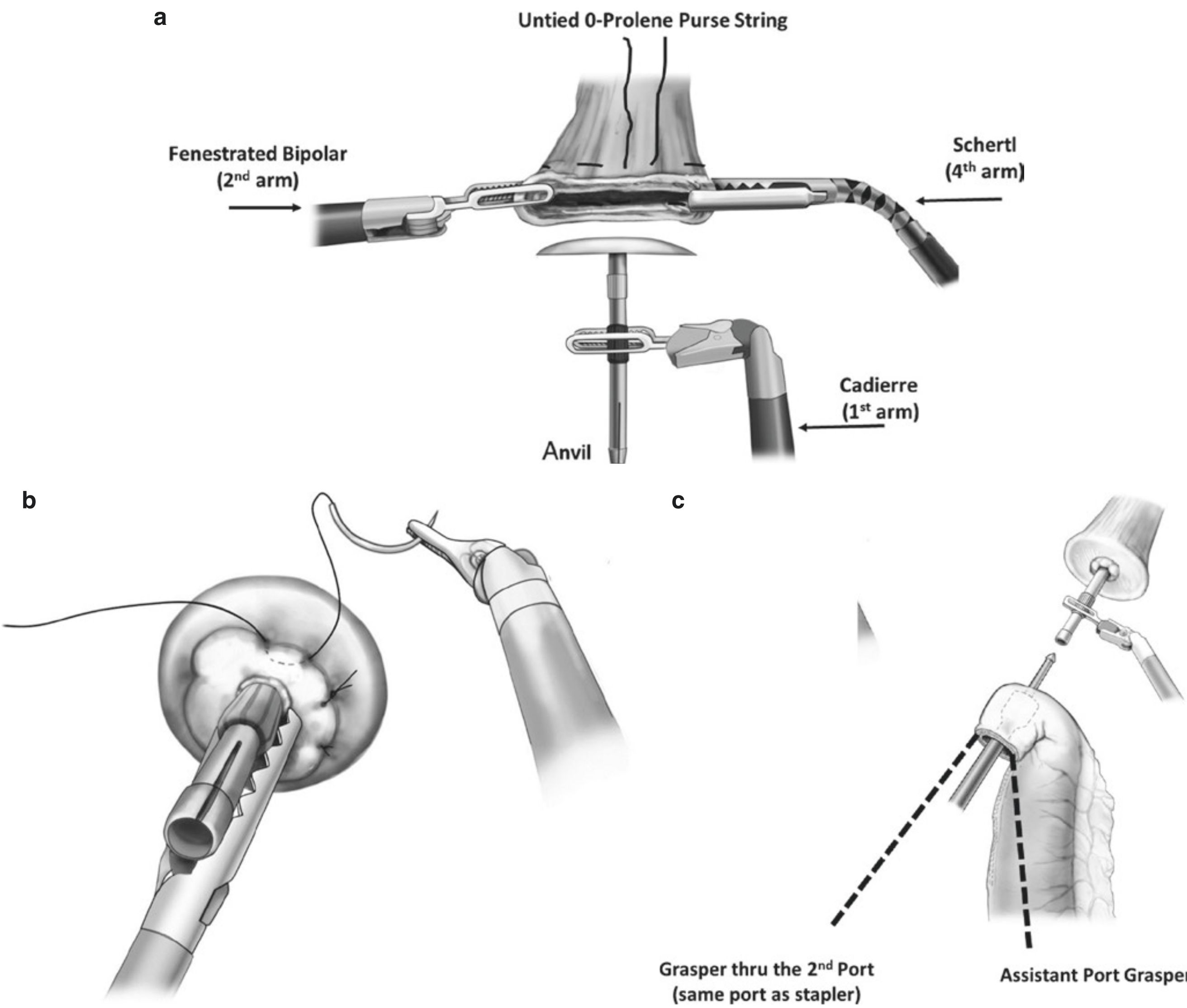

Fig. 17.7 (**a**) Following placement of pursestring suture, placement of the EEA anvil into the proximal esophagus. (**b**) Placement of the second pursestring suture after positioning of the anvil and tying of the first pursestring. (**c**) Creation of the end-to-end anastomosis

17.2.5 Results and Discussion

The overall number of published cases of robotic esophagectomy remains relatively small when compared to standard MIE and open esophagectomies. Therefore, long-term esophagectomy results regarding oncologic benefits are not yet available. Using the extent of lymphadenectomy as a surrogate for an adequate oncologic procedure (Table 17.1), however, one would expect outcomes to be equivalent, if not better than what has been published for other approaches. Likewise, in a prospective, non-randomized quality of life trial we performed which compared open esophagectomy (n = 100) to robotic esophagectomy (n = 62), short term mortality and morbidity rates were equivalent to the open approach, with the primary difference being a shorter length of stay in the robotic patients (unpublished study-Table 17.2). The complications which anecdotally (personal experience and communication) appear to be of greater concern during a RAMIE and following the procedure are airway injury and delayed intra-thoracic bowel herniation. We experienced three airway injuries during our initial 25 cases (none since). Two presented as broncho-enetric fistula during the initial hospitalization, and one presented with minimal symptoms about 2 months after the surgery. Of the two acute presentations, one died of sepsis, while the other required a complete diversion followed by a colonic interposition. The patient with the delayed presentation was managed successfully with a temporary esophageal stent until full healing. The likely cause of these three fistula was a thermal injury to the airway during the sub-carinal nodal dissection in addition to an anastomotic leak. The assumed source of the problem was the harmonic scalpel which remains hot after usage, and which has some radial thermal dispersion; we have since switched to either a bipolar instrument or a spatula with cautery with apparent success. A more insidious problem has been a delayed presentation (6–12 months) of bowel herniation, typically into the left chest, and typically asymptomatic. The incidence of this complication in our experience has been about 7.5 % (9/120). Once detected, we have routinely re-operated out of concern for potential strangulation. The re-operations were all done robotically. Intra-operative findings included minimal evidence of any adhesions, a widened hiatus, and the transverse colon and omentum herniated into the left chest. Reduction of the intra-thoracic contents was uncomplicated, requiring some cauterization to detach a few bands of adhesions. Once reduced, in most patients we were able to primarily re-approximate the crura with multiple sutures, and by also securing some of the hiatal sutures to the conduit. In some patients we also added a biologic onlay mesh onto the repair in order to re-inforce the sutures. The hernia repairs were successful in all but one patient in whom the bowel re-herniated.

Table 17.2 Association between complications and operative approach

	Operative approach		
Complication	Open (n = 102)	Robotic (n = 60)	*P value*
Technical[a] (Y)	12 (11.8 %)	8 (13.3 %)	*0.77*
Death (Y)	4 (3.9 %)	0	*0.05*
Worst grade (CTCAE v4.0)			*0.09*
0	28 (27.5 %)	22 (36.7 %)	
1–3	65 (63.7 %)	37 (61.8 %)	
4–5	9 (8.8 %)	1 (1.7 %)	
Cardiac (Y)	23 (22.6 %)	7 (11.7 %)	*0.08*
Respiratory (Y)	25 (24.5 %)	10 (16.7 %)	*0.24*
Urinary (Y)	17 (16.7 %)	5 (8.3 %)	*0.12*
Wound (Y)	5 (4.9 %)	3 (5 %)	*0.98*
Thrombotic/embolic (Y)	11 (10.8 %)	5 (8.3 %)	*0.61*

[a]Anastomotic leak, thoracic duct leak, recurrent nerve injury

17.3 Results and Discussion

Christopher Scott and Mark Onaitis

17.3.1 Results

The use of robotic technology in performing esophagectomy has many purported advantages extrapolated from experience using robot assisted surgery in other operations. These advantages include shorter hospital stays, reduced postoperative pain, less recovery time after surgery, improved visualization and more precise movements secondary to the wristed instruments. Disadvantages include increased operative times, surgeon and OR staff familiarity with the technology and the cost to acquire, maintain and store the equipment.

17.3.1.1 Operative Outcomes

The first published case report of a robot assisted esophagectomy appeared in 2003 in which the patient underwent a robot assisted transhiatal esophagectomy [19]. Since then, numerous retrospective studies have been published in the literature; there still does not exist any prospective randomized data comparing robot assisted esophagectomy to open or other minimally invasive techniques.

Morbidity and Mortality The morbidity and mortality results published in the retrospective series to date demonstrate comparable findings to previously published open and minimally invasive esophagectomy (MIE) techniques. One of the largest and most recent published series of robot assisted esophagectomy patients was reported by Puntambekar et al. in 2015 [20]. This series included 83 patients with esophageal cancer. They reported no treatment related mortality, the anastomotic leak rate was 3.6 % and the mean blood loss was 87 ml. Prior retrospective series [11, 12, 14, 15, 21, 22] have reported similar findings with mortality 0–6.4 %, anastomotic leak 9–33 % and mean blood loss 54–625 ml. By comparison, a large review of minimally invasive esophagectomy by videothoracoscopic/laparoscopic surgery yielded similar results with 1.7 % mortality and 5 % anastomotic leak requiring reoperation [23].

Operative Times There is a consistent trend in improving operative times with increased experience in robot assisted esophageal surgery. Cerfolio et al. described a series of 22 patients undergoing robot assisted Ivor Lewis esophagectomy. The median operative time was 556 min and this was reduced to 414 min for the last five cases of the series [24]. Similarly, de la Fuente et al. reported a series of 50 robot assisted Ivor Lewis esophagectomies [25]. The mean operating time was 445 ± 85 min. The authors noted a significant decrease in operative time as they gained experience with the procedure. The mean operative time for the first half of the cases as 479 ± 93 min and 410 ± 60 min for the second half of the cases. Furthermore, they found that there was no correlation between increased operative times and postoperative complications.

The trend of decreasing operative time with increasing experience was noted by other groups. Hernandez et al. demonstrated a continual and gradual improvement in their operative times in a reported series of 52 patients undergoing robot assisted esophagectomy; the mean operative time for the first 10 cases was 514 ± 106 min and 410 ± 58 min for the last 11 cases of the study [26]. The reduction in time with experience is also applicable to the time required to set up and dock the robot [20].

Nodal Harvest A major purported benefit of robot assisted technology in esophageal surgery is optimization of the mediastinal lymph node dissection by virtue of improved optics and increased complexity of motion with the wristed instruments. In a review of retrospective robot assisted esophagectomy series reporting more than 25 patients, the mean number of lymph nodes removed was 20–29 [12, 20–22].

When compared to contemporary MIE, the number of lymph nodes resected in the robot assisted is comparable. Weksler et al. reported a series of 43 patients in which 32 patients underwent MIE and 11 underwent robot assisted esophagectomy [27]. The median number of lymph nodes removed in the robot assisted patients was 19 vs 22 in the MIE group.

Length of Stay The hospital length of stay for MIE has been previously demonstrated to be reduced when compared to the open approach by 2–3 days [4, 28, 29]. The results for robot assisted esophagectomy are more widely varied, ranging from 9 to 22 days [11, 12, 20–22, 30]. Given the relatively small number of patients and retrospective nature of these reports, it is difficult to draw conclusions between MIE and robot assisted approaches. Table 17.3 summarizes the studies containing 25 patients or more who have undergone robot assisted esophagectomy to date.

Table 17.3 Studies of 25 patients or greater undergoing robot assisted esophagectomy

Author	N	EBL (mL)	OR Time (min)	Lymph nodes	LOS (days)	Death
Anderson et al. [21]	25	350 (100–1600)		22 (10–49)	11 (5–64)	0
Boone et al. [12]	47	625 (150–5300)		29 (8–68)	18 (10–82)	3
Dunn et al. [22]	38	97		20 (3–38)	9 (6–36)	0
de la Fuente et al. [25]	50	146	445	20	10.9	0
Abbott et al. [31]	134	150 (25–600)	407 (239–694)		9 (4–35)	2
Puntambekar et al. [20]	83	87 (50–200)	205 (180–300)	18 (13–24)	10 (10–13)	0

EBL estimated blood loss [median (range)], *OR* operating room time (range), *LOS* length of stay (range)

17.3.2 Discussion

Since the approval of the da Vinci Surgical System by the United States Food and Drug Administration in July 2000, the use of robot assisted surgery has significantly increased. The application of this technology has readily been adopted in certain procedures, such as robotic prostatectomy [32]. Other procedures, such as robot assisted esophagectomy have been slower to catch on. There have been a limited number of smaller retrospective case series reporting on the outcomes of robot assisted esophagectomy; currently, there are no published large prospective studies comparing robot assisted esophagectomy to MIE or open approaches. There is a prospective randomized single center trial underway of robot assisted esophagectomy vs MIE; the primary outcomes will measure overall complications [33].

Purported Advantages of Robot Assisted Esophagectomy The da Vinci Surgical System for robot assisted surgery employs optics with increased magnification and three dimensional imaging in a minimally invasive approach. Furthermore the wristed instruments allow for tremor filtration and a greater degree for freedom of motion, which may be maximally beneficial in a confined operative field. Additionally, seven degrees of motion are afforded by the robotic system: (1) in/out, (2) rotation, (3) pitch at wrist, (4) yaw at wrist, (5) pitch at fulcrum, (6) yaw at fulcrum and (7) grip strength [34]. These advantages have led pioneers in robot assisted surgery to question whether the technology could be applied to performing esophagectomy with superior nodal dissection, reduced blood loss and shorter length of hospital stay, while not compromising oncologic outcomes, morbidity or mortality.

The limited data that is available in robot assisted esophagectomy has attempted to address the morbidity/mortality, operative time, length of hospital stay, conversion to open rate, resection margin status and nodal harvest. These data have demonstrated that robot assisted esophagectomy can be performed with generally equivalent results to MIE. However, given the retrospective nature, these data should be considered with caution. Furthermore, it is necessary to realize that there is a steep learning curve with this technology and that optimal results were not achieved until a sufficient amount of experience was gained by the surgeon and operative personnel, specifically as it relates to operative times [20, 24, 25]. Hernandez et al. noted that for surgeons proficient in MIE, a significant reduction of operative time occurred after the completion of 20 cases and that operative complication rates remained low and unchanged regardless of the operative time [26].

Purported Disadvantages of Robot Assisted Esophagectomy With the introduction of new technology comes an inherent learning curve – this has been true for robot assisted surgery. Both the surgeon and OR staff require specialized training and it has been demonstrated that there is a steep learning curve with the initial cases. This is clearly represented by the reduction in operative times, not only from the surgeon's "hands on" time at the console, but also the set up and docking time for the robot by the OR personnel.

Furthermore, robot assisted surgery requires higher fixed costs when compared to MIE or open techniques. There is an initial fixed cost to acquire the robot, which can range from $1 million to $2.5 million, and then the cost of additional disposable instruments, maintenance and storage [35]. There is no cost comparison data for robot assisted esophageal surgery and the decision to pursue robot assisted surgery is largely a hospital-based, not payer-based, decision. As robot assisted technology continues to grow, this will need to be an area of continual assessment.

Conclusion Robot assisted esophagectomy is still in it's infancy. While there are many realistic advantages to robot technology in patients undergoing esophagectomy, the best we can say based on the available experience is that the robot assisted approach can be done comparably to MIE in the areas of morbidity/mortality, operative times, nodal harvest and length of stay. The steep learning curve, which is shorter for those proficient in MIE, and the cost of the technology may prohibit the widespread adoption for this application. Finally, there is no long term data on oncologic outcomes. Several studies have examined lymph node resection and R0 resection status as a proxy for cancer free survival, however, this has yet to be demonstrated definitively in the literature.

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Technical Notes

18

Lijie Tan, Chun Chen, Bin Zheng, Ke-neng Chen, and Xiaozheng Kang

Contents

18.1 The Alternatives of Grafts and Techniques in Reconstruction Following Esophagectomy

Ke-neng Chen and Xiaozheng Kang

Esophagectomy, mainly referred to sub-/total esophagus resection, is a major treatment for esophageal malignancies and some benign diseases of esophagus. The anatomically and physiologically unique characteristics of esophagus distinguishes esophagus from most solid organs such as liver and lung which need no reconstruction after partial resection, and from other parts of digestive tract such as large or small bowel which could obtain continuity through simple anastomosis due to their enough length. The importance of esophageal functions and its anatomic non-reproducibility make it difficult to reconstruct after esophagectomy. Due to the limited 25–30 cm of esophagus in length, grafts are needed to aid the completion of reconstruction. To date, the artificial esophagus that could be applied to reconstruction of esophagus is unavailable, and currently the accepted grafts for esophagus substitutions are, in order, stomach, bowel (including large bowel and small bowel) and skin flap transplantation in rare cases.

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18.1.1 An Overview of Surgical Reconstruction of Esophagus

In 1738, Gourand and Roland successfully took out the foreign body in thoracic esophagus of a patient but through cervical esophagus. About one and a half centuries later, in 1904, Sauerbruch completed thoractomy in an enclosed negative pressure container. The year after, Brauer and Petrson invented endotracheal positive pressure breathing system. Later on, in 1913, with the aid of endotracheal intubation positive pressure breathing system, Torek [1] performed transthoracic esophagectomy for the first time but without reconstruction, the patient survived for as long as 12 years with the nourishment through flexible hose connecting the cervical esophagus and the stomach. Two years before Torek's esophagectomy, Kelling successfully performed colon interposition for esophageal bypass, and Krischner successfully performed cervical anastomosis of esophagus and stomach in the year of 1920. Several years later, Okawa in 1933, Adams and Phemister [2] in 1938, successfully completed one-stage resection and anastomosis for lower esophagus. In 1941 the foregoer of esophageal surgery from China, professor Wu yingkai [3], in 1944 Garlok [4] from America, in 1948 Sweet [5], all of them reported successful intra-thoracic esophagectomy, respectively. Later on, the Ivor Lewis procedure [6], stomach mobilization via laparotomy and anastomosis via right thoractomy, introduced by Ivor Lewis in 1946 had since then been the mainstream esophagectomy in western society. In 1954, Mahoney and Sherman [7] jointly reported the outcome of esophagectomy with colon interposition. And in 1965 Brain [8] performed jejuna interposition for esophagus for the first time. In the year of 2003, Luketich [9] etc. established the position of minimally-invasive techniques in esophageal surgery, nevertheless, despite its merits of less pain and faster recovery, the principle of resection and reconstruction were not fundamentally changed.

18.1.2 The Objectives of Esophagus Reconstruction

Esophagus is a muscular conduit with about 25–30 cm in length. The most important physiological function of esophagus is to deliver masticated food to stomach for storage through swallowing act and preliminarily digest the food in it. Therefore, theoretically, any "tubular organs" that could meet the requirement is acceptable in esophagus reconstruction. Obviously, the most available and frequently used materials are other segments of gastric-intestinal tracts for auto-transplantation.

The esophageal mucosa is a friction-resistant but PH value-sensitive squamous epithelials, consisting of neutral or weakly-alkaline lumen. Unlike other segments of gastric-intestinal tracts that are enclosed by both three-layers of muscles (internal-circular muscle, musculus obliquus medius, external longitudinal muscle) and a layer of serosa, esophagus has no serosal layer other than the three-layers of muscles which transport food unidirectionally. The unidirectional muscle movement and the existence of upper and lower sphincter of esophagus could prevent the food and digestive juice from flowing into upper parts of GI or respiratory tract by regurgitation and aspiration. Therefore, it is not easy for a grafts-reconstructed esophagus to achieve such meticulous functions as a physiological esophagus.

18.1.3 The Alternative Grafts in Esophagus Reconstruction

Auto transplantation is divided into pedicle grafting and free grafting. For both of the two transplantation types, blood supply is of vital importance. Generally speaking, pedicle grafting is more convenient and simple. In contrast, free grafting is more difficult with higher technical requirements, which usually involve microsurgery techniques. Therefore, pedicle grafting becomes the mainstream in esophagus reconstruction. The alternatives of grafts depend on their availability and status of blood supply. Therefore, the distance between the target grafts and the esophagus bed, their length and blood supply together determined their sequence in reconstruction options. Obviously, stomach is the closest to esophagus bed anatomically with the most abundant blood supply, the six vessels of stomach are interconnected well and all could flow backward to any directions when other vessels are transected. That is to say, as long as one vessel remains intacted, the blood supply of stomach is guaranteed. The next comes to colon, although its distal location of the digestive tract seems to be far from that of esophagus which located at the top of digestive tract, in fact, the overlap of digestive tracts make the stereographic projective distance between colon and esophagus no farther than that between stomach and esophagus. More importantly, the left, middle and right vessel of colon interconnect well at the edge of colon and the connected vascular arch is almost equivalent in length with colon, these factors make the large bowel become the second choice in esophagus reconstruction. Unfortunately, compared to colon and stomach, small intestines are longer in length, but their lacking of equivalent-long vascular arch limited their applications in esophagus reconstruction.

18.1.4 Preoperative Evaluation Related to the Determination of Reconstruction Grafts

18.1.4.1 Barium Radiography

Barium radiography is technically simple and convenient. Double air-barium contrast examination of the upper digestive tract can estimate the length of the tumor, to clarify the adjacent relations between the proximal end of tumor and the surrounding structures such as the aorta arch, and the relations between distal end of tumor and the lesser curvature of stomach. Meanwhile, it could also offer an overall perspective of the substitute, this is extremely important for reconstruction by thoracoabdominal access or Ivor Lewis procedure. Barium colonography could help in identification of various diseases of the substitutive colons including cancer, giant diverticulum and congenital colon diseases that could affect colon interposition.

18.1.4.2 Endoscopy

Preoperative endoscopic examination could offer more detailed intraluminal information including the existence of multiple primary cancers or gastric ulcer, the functional status of pylorus, etc. If colon interposition is determined, then preoperative colonoscope is necessary to exclude colon polyps, occult colon cancer, colonic diverticulum or other colon diseases that could influence colon interposition.

18.1.4.3 Colonic Angiography

If stomach is chose, then it is unnecessary to perform angiography in that stomach is rich in blood supply. However, colon-angiography is usually recommended for western people for the following reasons: (a) aged patients often have arteriosclerosis, especially at the beginning of inferior mesenteric artery; (b) around 10 % of colon vessels have anatomical variation [10], including stricture at the beginning of inferior mesenteric artery, congenital absence of edge artery, disconnection between left and right branches of colonic middle artery and extremely short colonic middle arterial trunk; (c) to assess the status of key vessels in colon interposition, such as the ramus communicans status between left branch of colonic middle artery and ascending branch of left colon artery, the anatomic variation of right colon artery and the fragility of connection between right colon artery and middle colon artery or ileocolic artery. Therefore, the functions of angiography before esophagectomy with colon interposition are to help thoracic surgeons decide whether the colon of the patients is suitable for transplantation and which segment of colon is more appropriate to substitute esophagus according to vascularity. The explicit of these issues could help thoracic surgeons clearly decide the grafting sites of colon, so that intra-operative accident is avoided. For experienced clinicians, angiography could be performed through reverse implantation of femoral artery to inferior and superior mesenteric artery and celiac trunk, with high coefficient in safety and simple in procedure.

18.1.5 The Consideration of Surgical Access

Esophagectomy and reconstruction are two important components of esophageal surgery. The whole length of esophagus go through the three anastomic fields of neck, chest and abdomen, the resection and reconstruction of esophagus could share the common access, however, sometimes the two stages couldn't be performed through one incision, thus posture change is needed. For early stage esophageal cancer or Barrett's esophagus with high grade dysplasia (HGD) without lymphatic metastasis, the transhiatal procedure is acceptable by which abdominal and cervical incisions are enough to complete resection and reconstruction. Procedures vary according to pathology for locally advanced stage esophageal cancer. For esophagogastric junction adenocarcinoma which the eradication of the tumor seeks more sufficient distal margin and radical lymph node dissection in chest and abdomen, laparotomy and right-thoractomy are both needed; for squamous cell esophageal cancer located at upper and middle thorax, radical lymph node dissection of superior mediastinum and even the neck is emphasized. In this case, the cervical, thoracic and abdominal three-incision Meckown procedure is warranted [11], in which the esophagus is resected through right thoractomy, stomach is mobilized by laparotomy and the esophagus is reconstructed at the neck. Of course, for lower thoracic esophageal cancer, the one-stage surgery by single left thoractomy or left thoracoabdominal combined incision is also accepted. Currently, MIE, which is still developing, is no different from open surgery other than smaller incisions.

18.1.6 The Considerations of Conduit Pull-Up Route in Esophagus Reconstruction

The pull-up route in esophagus reconstruction include the followings: (1) through esophagus bed in the posteriormediastinum; (2) through retrosternal route in the anterior mediastinum; (3) through pleural cavity at the back of right hilum of the lung; (4) through subcutaneous tunnel in the front of sternum (which is poorly accepted due to cosmic reasons).

The posterior mediastinal route is universally accepted as the first choice for esophagus substitute pull-up to date [12–14]. The merits are as the followings: This way is corresponding with the physiological anatomy of esophagus, it is the shortest pull-up way and qualified not only with stomach but also colon interposition, especially following transhiatal esophagectomy. Transhiatal esophagectomy, which reserves the vagus nerve, reduces gastrointestinal complications including dumping syndrome and delayed gastric emptying and diarrhea, has now been widely applied to surgical treatment for benign diseases of esophagus including Barrett's esophagus with HGD or early stage esophageal intramucosa carcinoma without lymphatic metastasis.

When patients' condition couldn't tolerant thoractomy and esophagectomy, or the tumor can't be resected completely due to late stage, colon interposition is an alternative to relieve disphagia. In this case, retrosternal route is chose. Although retrosternal route is suitable for gastric or colon interposition, the application of this route is more common when colon is chose as the esophagus substitute. Compared to posteriormediastinum route, retrosternal route is not only longer in distance, but also has two angulations. The first angulation locates at the outlet of thorax, whereas the second locates at the joint of sub-xiphoid of sternum. Sometimes part of clavicular head and the forepart of first rib is resected to enlarge the outlet of thorax, so that the grafts and their blood supply vessels are free from depression. All the above factors are issues need attention in the maneuver of operation. Patients with a history of cardiovascular surgeries should avoid retrosternal interposition as long as possible, similarly, the application of retrosternal route in esophagus reconstruction would have some impact on future median sternotomy.

Pull up via pleura cavity at the rear side of right hilum of the lung is similar to pull-up through esophagus bed route. The pull-up route of grafts in reconstruction procedure after thoractomy are often located at the right thoracic cavity rather than esophagus bed.

18.1.7 The Consideration of Anastomotic Sites for Substitute-Esophagus

Cervical anastomosis is the only choice when transhiatal esophagectomy is performed, no matter stomach or bowel is chose to be the esophagus substitute. However, for transthoracic esophagectomy, both intrathoracic and cervical anastomosis are encountered according to circumstances. Generally speaking, the merits of cervical anastomosis are that it allows for longer esophagus to be resected, so that the proximal margin is more sufficient, which is recommended for the middle and upper esophageal squamous cell carcinoma that frequently occurred in Asian population; other merits include lower mortality due to easy-to-treat and mild presentations of anastomosis fistula and lower incidence of gastro-esophageal reflux. However, despite all the merits discussed above, cervical anastomosis has some drawbacks, including frequently occurred swallowing dysfunctions and even respiratory aspiration. Of course, the recurrent laryngeal nerve suffers a higher probability of being injured by neck maneuver. On the contrary, intrathoracic anastomosis yields fewer anastomosis fistula, lower swallowing dysfunction rate and less frequent respiratory aspiration. In addition, intrathoracic anastomosis is recommended for esophagogastric junction adenocarcinoma/lower esophageal cancer, which occur more frequently in western countries and require more sufficient distal margin. Moreover, intrathoracic anastomosis allows for more poorly blood-supplied tissues of gastric fundus to be resected.

18.1.8 The Key Procedures in Esophagus Reconstruction

The safety of esophagectomy is closely associated with postoperative complication especially anastomotic complications and with reconstruction technique following esophagus resection. The sequences in alternative of the substitutes are stomach (90 %), colon (when the stomach had been resected or abnormal), small intestine and skin flap transplantation. The prevention and treatment of anastomotic complications especially anastomosis fistula has always been a vital issue ever since the advent of esophageal surgery due to its importance and high incidence. The importance lies in that the beginning of the esophagus connects the laryngopharynx and down to abdominal cavity to connect with the stomach through posteriormediastinum, the whole length of esophagus go through the three anatomic sites of the neck, thorax and abdomen, with the major part in the thorax. Different from fistula of other segments of digestive tracts which only lead to systemic infection syndrome, the occurring of anastomotic fistula of esophagus usually involves the thoracic cavity contamination and infection which interferes the negative pressure of thoracic cavity, thus resulted in respiratory disorder and circulation unstability. The clinical ferocity of thoracic esophageal anastomosis fistula often threats the patients' lives; therefore, the gastric-esophageal anastomotic fistula is more important than anastomotic fistula at other sites of the digestive tract. On the other hand, the high incidences lies in that compared to other digestive organs, esophagus mainly consists of longitudinal muscle without serosal layer, thus when sutured, it suffers less endurement and poorer healing properties. The blood supply of esophagus is interrupted and has no trunk blood supply or interconnected communicating branches; therefore, ischemia of anastomosis in esophagus stump may occur if the esophagus is mobilized even a little bit longer. When anastomosis located in or adjacent to thoracic cavity, it suffers a high propensity of anastomotic linkage due to negative pressure inside the thorax. The grafts rose from abdomen to thorax or even the neck rely on only one vessel, this may easily lead to ischemia of the anastomosis region. All the above circumstances contributed to the occurrence of anastomosis fistula.

The complications of anastomosis fistula in esophagus reconstruction are associated with some other factors. Generally speaking, contemporary esophageal surgeons should have the following three specialities in order to prevent fatal anastomosis fistula, namely, "flexibility" in surgery procedures, "knowledgable" in mastering anatomic physiology of esophagus and esophageal diseases, and "technicality" in mastering esophageal operation skills. That is to say, the choice of esophagectomy procedure and the reconstruction modes should be made on the basis of individual patients and specific characteristics of the tumor, so that the treatment is more flexible and individualized. Moreover, a deep understanding and flexibly mastering diversified operation procedures are key factors of favorable clinical outcome. As to the regard of esophageal surgery, currently there is no one operation that fits all the patients. Experienced surgeons from large-volume clinical centers are safeguard of successful operation. Their mastering of all kinds of complications is not only of vital importance in preventing complications of anastomosis, but also unignorable in selecting appropriate treatment for individuals. Early recognition of the signs of some complications and accurately disposing in time is an important constitute in reducing the severity of complications. Ever since the advent of esophageal surgery in six decades ago, although significant progress has been made in prevention and treatment of anastomotic fistula, efforts are still in need to improve the outcome of esophagectomy and reconstruction in the long run, in which "emphasis on details, accuracy in procedure" has always been the important experience for the prevention and treatment of esophageal anastomotic fistula.

As to the regard of preventing and treating anastomosis fistula, the following aspects should not be neglected. (1) A deep understanding of the anatomy of esophagus is indispensible. Esophagus mainly consists of longitudinal muscles without serosa layer, and the blood supply are phased with a few communicating branches, therefore, both mechanical suture and manual suture require softness in procedure to avoid laceration and injury. The longer the esophagus freed, the easier the anastomotic procedure, however, this could also easily lead to ischemia, therefore, the balance of blood supply and feasibility of operation is emphasized; (2) The favorable vessels of grafts should be protected. Take stomach for instance, the right gastroepiploic artery is the only blood supply vessel of thoracic stomach which supplies blood to 60 % of stomach proximal to pylorus, whereas the other 40 % of stomach which is at the distal part of pylorus are supplied by submucosal small vessels. In this case, surgeons should prolong the thoracic stomach through favorable "gastric tube" reconstruction, and excise the fundus of stomach which is poor in blood supply, and then move the anastomosis towards the beginning of the right omentum vessel. More acid secretion surface being resected could reduce the clinical dangerous level of anastomotic fistula. And the clinical ferocity of intrathoracic gastric anastomotic fistula is positively associated with the amount of digestive juice entered into the thoracic cavity. The procedure of gastric tube resected half of the stomach tissue, reduces the acid secretion surface of the stomach, which is another factor for the reducing of the ferocity of anastomotic fistula. The reconstruction of "gastric tube" makes the lesser curvature side equivalent in length with the greater curvature side, so that the anastomosis and pylorus are on the same straight line, thus the issues of gastric retention and emptying dysfunctions are solved anatomically and dynamically, which further reduce the risk of anastomotic fistula. (3) To perform sufficient drainage for the mediastinum interval through which the thoracic stomach is lifted. Our conventional procedure is that start from the abdominal wall, pull up one drainage tube and thoracic stomach to anastomotic site at the same time, then pull out the drainage tube through abdominal wall, so that the mediastinum is sufficiently drained, the risk of mediastinum infection caused by effusion fluid is reduced, and finally, the risk of anastomotic-thoracic-gastric fistula is reduced. (4) The importance of early enternal nutrition. Jejunum ostomy or posput of nasal-duodenal nutritious tube is conventional after esophagectomy, so that postoperative enternal nutrition is guaranteed. Researches have found that the function of small intestine is recovered 12 h after surgery, therefore, enternal nutrition should be started within 24 h after operation due to the following reasons: to promote the functional recovery of gastrointestinal, to transport the intestinal contents downward, to protect the intestinal mucosa barrier, to prevent bacterial translocation, to balance the stress metabolites and to promote the anastomotic healing procedure. (5) Other traditional prevention measures include gently operate when freeing the grafts (stomach or intestine), avoid over malaxation of the gastric fundus, in order to avoid directly injury of the graft or the formation of venous thrombosis. The direction is of vital importance when pulling up the graft, in order to avoid twisting of the graft or blood-supplying vessels; assess the tightness of the thoracic entrance, if it is very tight, then free and cut off the substernal opisthodetic ligament, and cut off the clavicular head or sternoclavicular joint when necessary. Some scholars insist of conventional pylorus forming or pylorus myotomy despite the many controversies in this regard. Of course, patients' comorbidities preoperatively such as diabetes, malnutrition, atherosclerosishardening of the arteries should also be taken seriously. In addition, procedures like reinforcing perioperative management, early atelectasis after surgery, avoidance of hyoxemia and hypotention are all important measures in reducing the risk of anastomotic fistula.

18.1.9 Methods of Esophageal Reconstruction

(1) Esophagectomy with gastric conduit interposition; (2) Esophagectomy with colon interposition, including esophagectomy with right hemicolon, left hemicolon and transverse colon interposition; (3) Esophagectomy with small intestine interposition.

18.1.9.1 Esophagectomy with Gastric Interposition

Why Stomach Is the First Choice Substitute for Esophagus Reconstruction

The abundant blood supplies of stomach make it the first substitute in intrathoracic anastomosis. Before 1990s, gastric interposition following esophagectomy is completed by pulling up the whole stomach or the subtotal stomach to thorax or the neck. However, many problems lie in the whole gastric interposition for esophageal replacement: firstly, esophagectomy is a complicated procedure with significant morbidity and mortality ever since its existence. Once anastomosis fistula occurs following the whole gastric interposition for esophageal replacement, the gastric contents floods into the thorax, resulting in contamination and infection of the thorax, and leading to instability of respiratory and circulation system, which could be lethal. In terms of it, "nine deaths out of ten fistulas" is a common saying in the era of "esophagectomy with whole stomach interposition"; secondly, the whole gastric causes a series of pulled-up anatomical and physiological changes, which lead to emptying dysfunction, regurgitation, dumping syndrome and other symptoms of digestive, respiratory and circulating system (Fig. 18.1).

The anatomic and physical changes of the "thoracic stomach" are as follows: (1) Devascularization: under normal condition, the vessels of stomach not only offer blood supply for the stomach, but also immobilize the stomach in the upper abdomen, allows for normal functions of stomach; however, the gastric pull-up only reserves the right gastroepiploic artery, thus the blood supply of thoracic stomach is dramatically decreased; (2) Denervation: usually the vagus nerve is completely resected in esophagectomy, thus the myenteric nerve plexus is the only innervating nerve for thoracic stomach, which lead to pylorus emptying dysfunction; (3) Depositive pressure environment: the gastric pull up from positively pressured abdomen to the negatively pressured thorax could easily lead to gastric distension, therefore, the pressure in the stomach is directly correlated with the amount of food in the thoracic stomach; (4) The anti-regurgitation function of His angle is disappeared after surgery; (5) Acid-clearance dysfunction, mainly represented by hypokinesia of the remnant esophagus, is damaged; (6) Deendocrinization: Parts of the stomach motility promoting hormones are disappeared. From the above, especially in terms of their influences on long-term life quality of the patients, in clinical practice, it is generally accepted that "gastric interposition" is inferior to "colon interposition". Some believe that for larynx-preserving esophagectomy, colon interposition is more appropriate, whereas for laryngectomy, gastric interposition should be applied, in order to prevent respiratory aspiration and infections caused by regurgitation.

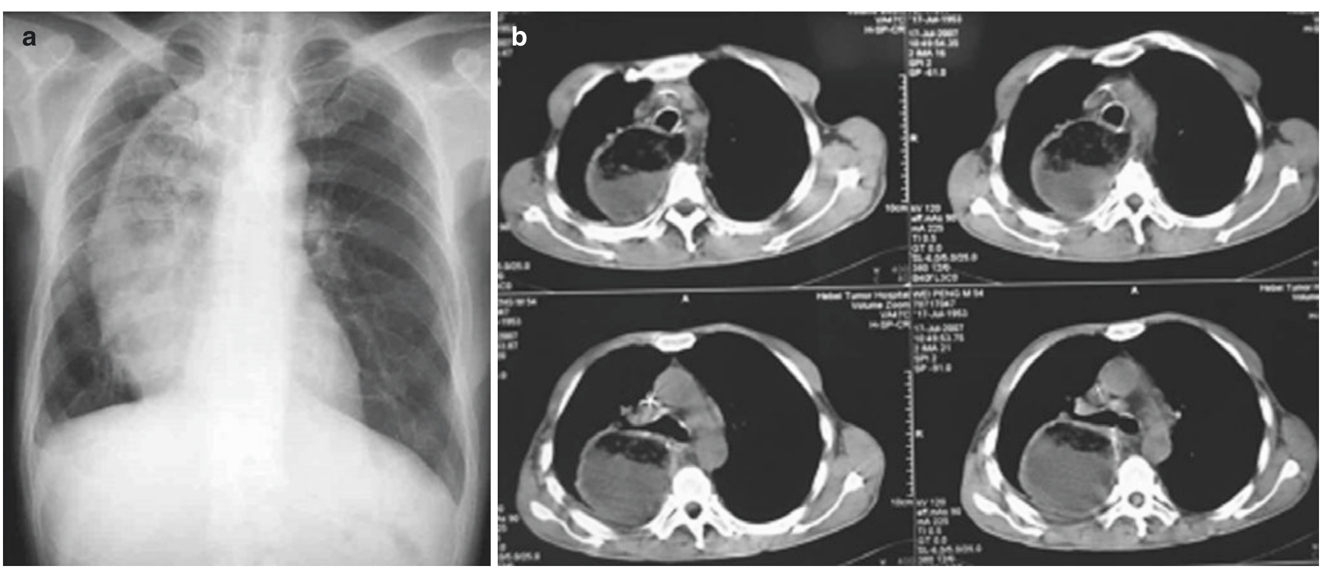

Fig. 18.1 In the early period, the whole stomach was used firstly for esophagus reconstruction. The disadvantages of the whole stomach were obvious. (**a**) The stomach occupied much more space in thoracic cavity; (**b**) Anatomical and physiological changes could lead to emptying dysfunction, regurgitation, dumping syndrome and other symptoms of digestive, respiratory and circulating system

The Refinement of Stomach Interposition for Esophagus: Gastric Tube

The history of gastric tube dates back to 1970s, when the length of "whole stomach" were not enough to reach the anastomosis in some cases, the surgeons then transversely cut and longitudinally sutured the lesser curvature to prolong the length of stomach, which might be the earliest gastric tube. However, to accurately understand the importance of gastric tube in esophagus reconstruction, not only basic theory and knowledge but also long-term life quality follow-up of the patients are needed [15]. From clinical perspective, "gastric tube" has some advantages comparing with "whole stomach", such as reducing postoperative fistula and improving functions of the thoracic stomach (Fig. 18.2).

Despite the long-existing debate about whether "gastric tube" or "whole stomach" interposition causes a higher incidence of fistula, it is well recognized that the anastomosis fistula of gastric tube bears less morbidity and mortality. The reasons are as follows: (i) the only blood supply vessel of thoracic stomach is the right gastroepiploic artery, which offers blood for 60 % of pylorus proximal stomach, the blood supply of the other 40 % stomach at distal side of pylorus is offered by submucosal small vessels. The poorly blood-supplied gastric fundus is removed during the gastric tube procedure, and the anastomosis as close to the initial part of right gastroepiploic artery, which can prevent gastric conduit necrosis to some extent; (ii) The severity of anastomosis fistula of intrathoracic stomach is positively correlated with the amount of gastric content. During the gastric tube interposition, nearly one-half of stomach is resected, thus the acid secretion area is reduced and the severity of fistula is accordingly decreased; iii. The gastric tube formation makes the length of the lesser curvature equivalent with that of the greater curvature, thus the anastomosis and pylorus are on the same line of gravity, which solves the problem of stomach retention and emptying dysfunction, and further decreases the risk of anastomosis fistula and its severity [16].

Dyskinesia of thoracic stomach: despite the ongoing controversies in terms of "gastric tube" and fistula, the functional preservation of "gastric tube" have been generally recognized and accepted. Whole stomach interposition renders faster functional recovery of gastric movement; however, the large volume and gastric distension make it difficult for the pressure in the stomach to be higher than that in the pylorus, which could easily lead to gastric dilatational retention, regurgitation and emptying dysfunction. In addition, the lengthy, lack of innervations and low-tensional greater curvature is more prone to be prolapsed, which could lead to the pyloric orifice locates higher than the lowest point of stomach, and acute angles could even be formed between the longitudinal axis of stomach and pylorus, all these circumstances could easily lead to emptying dysfunction of the thoracic stomach. The formation of narrow-body gastric tube makes the length of lesser curvature equivalent with that of greater curvature, so that the anastomosis and the pylorus are on the same line of gravity. Due to the restriction of the gastric tube, the intra-gastric pressure is higher than intra-pylorus, which improves the emptying. The distortion of the gastric conduit could occur in the procedure the whole stomach pull-up; this could easily lead to emptying dysfunction. Therefore, in terms of anatomic bionics, "gastric tube" is a better analogy to "esophagus", thus could reduce dyskinesia of thoracic stomach to the largest extent [16].

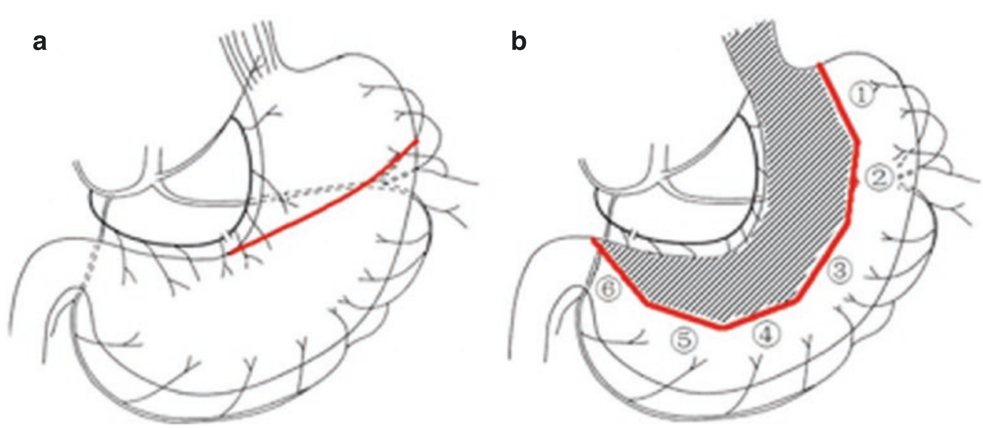

Fig. 18.2 The refinement of stomach interposition for esophagus – gastric tube. (**a**) The early gastric tube; (**b**) the narrow gastric tube

The Surgical Essentials in Gastric Interposition for Esophageal Replacement

The mobilization maneuver should be gentle in order to avoid injury of the stomach fundus and further thrombus formation. Attentions should be paid to the directions in the procedure of stomach pull-up, in order to avoid twisting of thoracic stomach or blood supply vessels. Preoperative management of comorbidities such as diabetes and malnutrition, intra-operative evaluation of outlet tightness of thorax and sufficient drainage of the mediastinal interval through which the thoracic stomach is pulled up and postoperative early enternal nutrition (12 h after the operation) and avoidance of early atelectasis, hyoxemia and hypotension are all necessary to guarantee the success of gastric interposition for esophagus.

Currently, the modern double stapling technique advances include the transition from hand-sewn to staple sutures, and from silk to absorbable material of better histocompatibility. Esophagectomy include “variability” in the wisely adoption of surgical procedure, “knowledge” in the esophagectomy and “technicality” of esophageal surgical approach. The choice of esophagectomy approach should depend on patients’ condition and tumor characteristics. There is no fit-for-all esophagectomy. High volume center with experienced surgical teamwork is the guarantee.

18.1.9.2 Colon Interposition for Esophagus

Colon interposition should be considered for patients with a history of gastrectomy or the wide extent involvement. Comparing with right hemicolon, the lumen is usually smaller. The distance between left hemicolon and esophagus is relatively shorter, and the available bowel tube of left hemicolon is with less anatomic variation. Noteworthy, inferior mesenteric artery is susceptible to arteriosclerosis; therefore, blood supply should be carefully evaluated before the procedure. The colon interposition is more suitable for distant inter-position (cervical or upper thoracic esophagus). For instance, when left hemicolon (isoperistaltic) is chose, its blood supply vessel is inferior mesenteric artery which flow through the ascending branch of left colonic artery; when antiperistalsis bowel is chose, then its blood supply is offered by middle colonic artery; when a short segment of colon is applied, then either transverse colon and middle colonic artery or splenic flexure of colon and left colon artery can be an alternative. As to right hemicolon, due to its variation of blood supply and poor flexibility, its application is restricted under the circumstances when other alternatives are all unavailable.

The colon with stenosis, extensive diverticulosis, or cancer is not suitable to be the esophagus substitute. Additionally, a past history of abdominal procedure makes the exposure and of dissection of vessels inadequate. As inferior mesenteric vein reflow into splenic vein, patients with a history of severe pancreatitis or other conditions are more likely to suffer from splenic venous thrombosis. Under these circumstances, the application of left hemicolon interposition carries a risk of inferior mesenteric venous thrombosis.

The essentials in operation are as follows: firstly, explore left hemicolon by middle laparotomy, then dissect left hemicolon and the peritoneal ligament alongside with the Toldt white line, identify the blood supply vessel of the left hemicolon by intra-operative diascopy, and temporarily clip the middle colonic artery and palpate the pulses of marginal artery; if the pulse couldn’t be ascertained, then ultrasonic Doppler transcriber should be adopted intra-operatively to evaluate the blood flow. Only when blood supply is guaranteed can esophagectomy be performed. Ligate and dissect mesenteric artery and middle colonic artery away from Drummond marginal artery (Fig. 18.3); finally, re-anastomose the remnant colon and close the peritoneum.

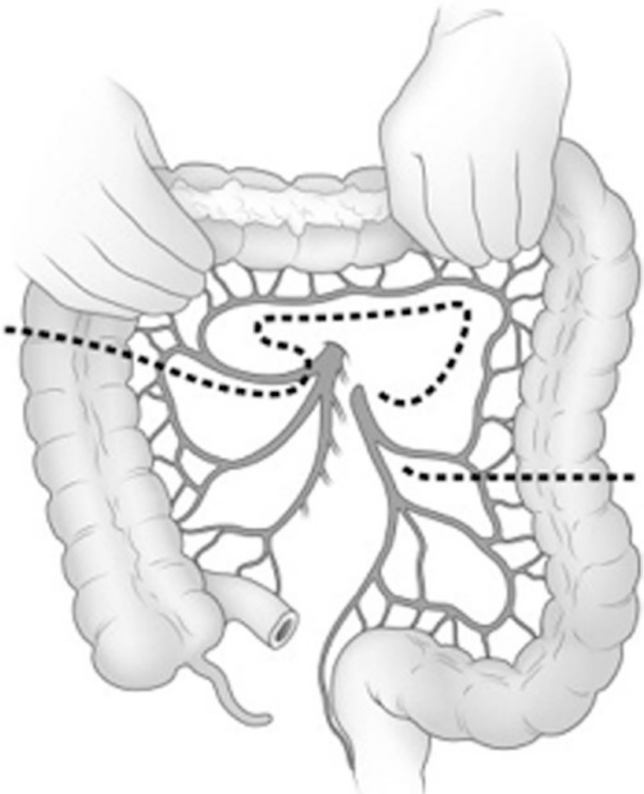

Fig. 18.3 The mesentery of the mobilized colon is transilluminated, revealing the mesenteric vessels. The *dotted lines* are the lines of division for a conduit based on the left colic artery (Modified from Sugarbaker and DeCamp [41])

18.1.9.3 Jejunum Interposition for Esophageal Replacement

Jejunum interposition for esophageal replacement is most commonly applied to substitute the distal esophagus, especially esophagus with benign diseases such as regurgitation. The methods of jejunum interposition are various, including free jejunum, pedicle jejunum or Roux-en-Y approach [17, 18] (Fig. 18.4). Usually, proximal jejunum and the first branch of jejunum branches from upper mesenteric artery is chose. The jejunum mesentery of asthenic patients is relatively longer, and sometimes it could reach the lower side of arcus aortae. The jejunum mesentery of child could even reach the cervical level of esophagus. Meanwhile, "enhanced charge", such as intrathoracic artery-jejunum artery anastomosis should be considered when replacing the substitute esophagus by the distant jejunum. In addition, jejunum interposition for esophageal

Fig. 18.4 Pedicle jejunum is ideally suited for distal esophageal replacement, especially esophagus with benign diseases such as regurgitation. Reprint with permission from Sellke, Nido and Swason, Sabiston and Spencer Surgery of the Chest, 2015, Elsevier

replacement requires the microsurgery double anastomosis technique for superior thyroid artery and superficial vein. Roux-en-Y method could be applied for distal esophageal cancer patients with a history of whole gastrectomy. This procedure usually harvest jejunum for 20–30 cm from the proximal side of Treitz ligament, then clarify the mesenteric arch by diascopy, clip the vascular branches and dissect them, and observe the serosal layer of jejunum for several minutes to exclude ischemia. Make a pathway or route between left colonic artery and middle colonic arteries to allow jejunum graft go through. Anastomosis should be located at distal end of upper esophagus after whole gastrectomy. The abdominal and lower thoracic esophagus has to be resected as esophagogastric junction involvement. The thoracotomy access usually between the sixth or seventh intercostals; if the length of jejunum is not long enough in the procedure of Roux-en-Y, then the previously procedure should be repeated to identify mesenteric arch and achieve the extra pedicled jejunum. The mobilization of the jejunum substitute helps to prevent the gastroesophageal reflux, but the risk of avascular necrosis and anastomotic complications may rise.

Other factors that may influence the choice of esophageal substitutes include: (1) past history of thoracotomy or laparotomy; (2) anatomic variation of the circulating blood supply vessels; (3) the physiological function changes of the substitute itself; (4) vascular anastomose techniques to improve the healing procedure of anastomosis (Fig. 18.5); (5) always of great importance – the experience of thoracic surgeons.

In conclusion, the blood supply of substitute, which comprise of arterial influx and venous efflux, is the key point during the esophageal reconstruction, regardless of the approach variation. The reliable blood supply is always the cornerstone of various anastomose.

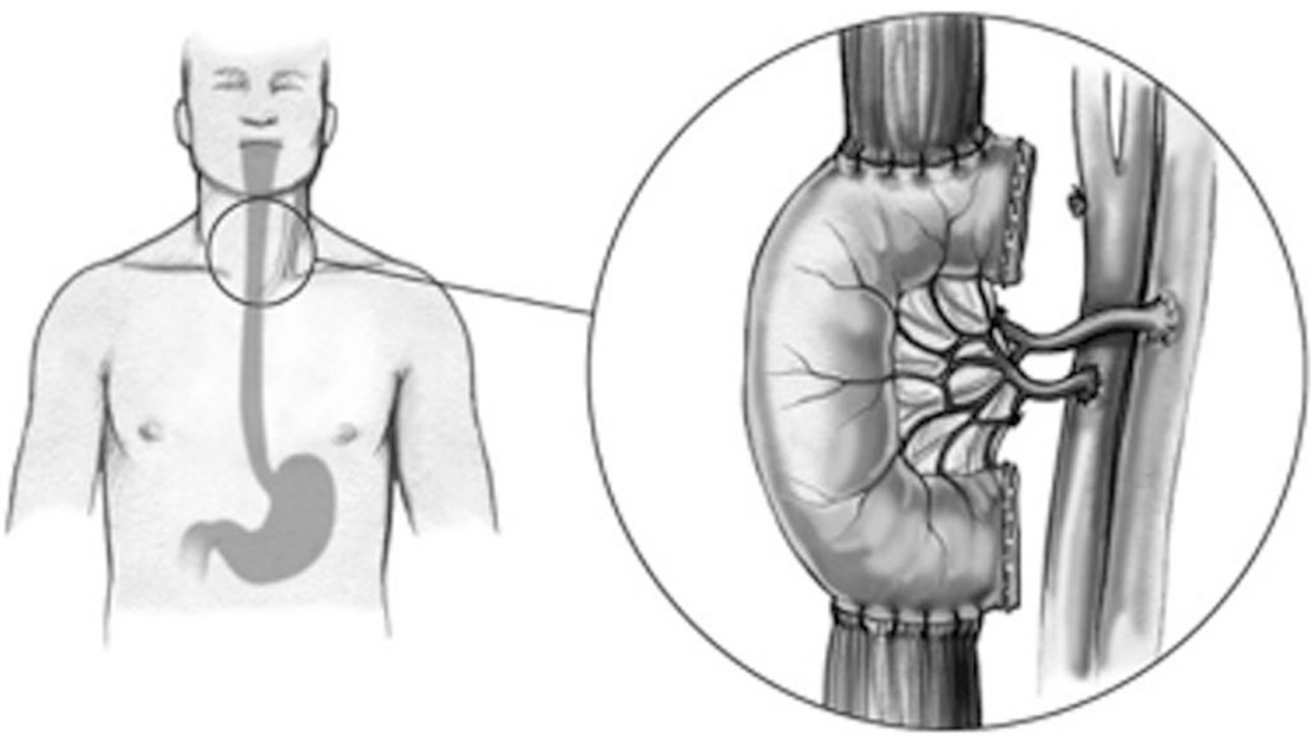

Fig. 18.5 Free jujunal interposition may be used where pedicled graft will not reach, such as in the proximal esophagus. The arterial and venous supplies are anastomosed to the carotid and jugular vessels under the operating microscope. A split-*thickness* skin graft covers the graft to allow inspection of graft viability in the perioperation period. Reprint with permission from Sellke, Nido and Swason, Sabiston and Spencer Surgery of the Chest, 2015, Elsevier

18.2 Tips and Tricks of Minimally Invasive Esophagectomy

Lijie Tan

Although surgical resection offers potential cure for esophageal cancer, its associated morbidity or mortality remain high following esophagectomy. Nowadays, with the rapid development of global economy, minimally invasive esophagectomy is world-widely favored with promising peri-operative results (Table 18.1). Therefore, it is of great importance to illustrate its tips and tricks with some useful suggestions for the green hands. In this section, the topic would be discussed into three parts: thoracic, abdominal and cervical reconstruction stage.

Table 18.1 The results from the comparison between open and minimally invasive esophagectomy

Variable	MIE(n = 444)	OE (n = 444)	P value
Respiratory complications	38 (8.6 %)	59 (13.3 %)	0.024
Pneumonia	29 (6.5 %)	44 (9.9 %)	
ARDS	9 (2.0 %)	15 (3.4 %)	
Circulatory complications	7 (1.6 %)	15 (3.4 %)	0.084
Heart failure	3 (0.7 %)	7 (1.6 %)	
Myocardial infarction	1 (0.2 %)	3 (0.7 %)	
Pulmonary embolism	1 (0.2 %)	2 (0.5 %)	
Severe arrhythmia	1 (0.2 %)	1 (0.2 %)	
Cerebrovascular accident	1 (0.2 %)	2 (0.5 %)	
Digestive complications	60 (13.5 %)	50 (11.3 %)	0.308
Cervical anastomotic leak	52 (11.7 %)	29 (6.5 %)	
Intrathoracic gastric conduit necrosis or intrathoracic anastomotic leak	4 (0.9 %)	15 (3.4 %)	
Delayed gastric emptying	4 (0.9 %)	6 (1.4 %)	
Operation-related complications	30 (6.3 %)	40 (8.8 %)	0.213
Postoperative bleeding	1 (0.2 %)	2 (0.5 %)	
Chylothorax	2 (0.5 %)	3 (0.7 %)	
Hoarseness	26 (5.9 %)	28 (6.3 %)	
Tracheal injury	1 (0.2 %)	1 (0.2 %)	
Wound infection	0	6 (1.4 %)	
Total major complications	135 (30.4 %)	164 (36.9 %)	0.039

18.2.1 Thoracic Stage in Minimally Invasive Esophagectomy

18.2.1.1 Position

Left lateral decubitus position is the primary option for the beginner. In the cases intra-operative conversion is planned, the thoracotomy could be easily performed. However, due to its compromised surgical view and inconvenience of lymphadenectomy, it is growing obsolescent.

Varieties of studies have indicated that prone position is a safe and feasible alternative to the conventional decubitus position. Compared with decubitus position, it provides better exposure around the left recurrent laryngeal nerve, which facilitates aggressive mediastinal lymphadenectomy during the operation. Besides, gravity ensures the lung and blood pools away from the operative field, which saved time from stretching or suctioning. Meanwhile, conversion to open surgery is inconvenient and difficult when unexpected emergencies occur.

Through the summary of the experience gained from the two surgical options above, a revised position:semi-prone position is applied in the surgeries (Fig. 18.6). Semi-prone position is valuable for the beginners and worth widely spreading.

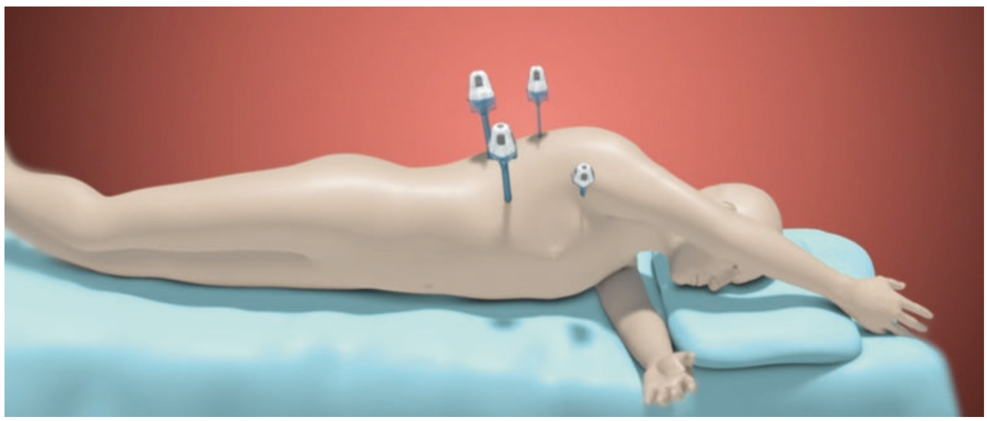

Fig. 18.6 Semi-prone position

18.2.1.2 Incision

Minimally invasive esophagectomy usually includes four to five small incisions. The incisions vary according to the habits and preferences of the surgeons. Despite such difference, bear one tip in mind that spaces be kept between these incisions in order to avoid the interruption of the operative instruments (Fig. 18.7).

Fig. 18.7 Thoracic incisions for minimally invasive esophagectomy

18.2.1.3 Esophageal Mobilization

Mobilizing esophagus is critical in thoracic stage. We summarize eight remarkable points in this process.

1. Not all the thoracic adhesions are required to convert to open surgery. In our experience, majority of the adhesions can be separated under thoracoscopy, which is even easier to deal with than thoracotomy.
2. It is necessary to isolate and ligate the azygos vein when mobilizing the esophagus, with which right bronchial arteries company (Fig. 18.8). Therefore, special attention should be paid to separate these vessels clearly in case of bleeding.
3. On the anterior side of the esophagus, suction device is suggested when dividing the esophagus from the trachea. Care must be taken to avoid the damage to the membranes of trachea and main bronchus when dividing the area of the tracheal bifurcation.
4. Attentions should be taken to protect the pulmonary branches of the vagus nerve, and the remaining branches could be dissected below the level of the azygos vein arch. Protecting pulmonary branches was reported to minimize the pulmonary complications following MIE.
5. When mobilizing the lower thoracic esophagus, switch the thoracoscope to the upper port, while operative instruments is introduced through lower port. In this way, the procedure goes more comfortable and convenient in operating.
6. The esophageal arteries are the branches found between aorta and esophagus. Hem-o-lock can be used to ligate these large vessels, and then shear it off. In this process, coagulation hook is not suggested for fear of damaging aortic walls, which may cause delayed hemorrhage by heat conduction.
7. Superior esophageal triangle and the esophageal bed behind aorta arch are the places where iatrogenic injury to the thoracic duct. Here the thoracic duct should be identified and carefully preserved. If injuring the thoracic duct negligently, ligate it from the lower level without hesitation.
8. Don't try to explore or expand the hiatus during the thoracic stage, leave it in the abdominal stage.

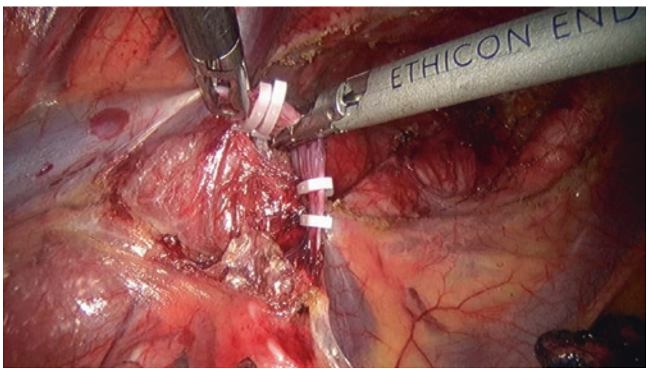

Fig. 18.8 Isolate and ligate the azygos vein

18.2.1.4 Mediastinal Lymphadenectomy

Esophageal cancer is reported to be invasive to the para-esophageal lymph nodes, especially the lymph nodes along bilateral recurrent laryngeal nerves (RLN). Therefore, lymphadenectomy of thoracic cavity stresses on these areas. Dissection of subcarinal and RLN lymph nodes are relatively difficult using thoracoscopic instruments. Four tricks are listed to help facilitate the procedure:

1. Once radical surgery is guaranteed, lymphadenectomy is carried out along the right recurrent laryngeal nerve by opening the mediastinal pleura above the azygous arch. Identify the right recurrent laryngeal nerve arising from the right vagus nerve in the initial site of the right subclavicular artery (Fig. 18.9) and preserve the branches to the inferior thyroid vessels. Do not touch the right RLN when dissecting the lymph nodes in this area.
2. When performing lymph node dissection along the left RLN, the endotracheal cuff is temporarily deflated to facilitate ventral retraction of the trachea. Then the tissues below aorta arch would be exposed and left RLN can be identified when trachea is pulled anterior gently (Fig. 18.10), the lymph nodes along the nerve should be dissected using endoscopic scissor. If enlarged lymph nodes were not observed, do avoid excess exploring would lead to lower incidence of hoarseness post-operatively.
3. Avoid extensive application of energetic instruments, such as harmonic scalpel, coagulation hook, when performing lymph nodes dissection along the bilateral RLNs. Energetic instruments would cause injury to the nerves via heat conduction.
4. Subcarinal lymph nodes dissection is performed after mobilization of the thoracic esophagus. Bronchial artery could be found under or around the carina, which required special care during the dissection. Additionally, instrumental damage should be avoided to the membranous trachea, which would lead to severe trachea-pleural fistula, post-operatively.

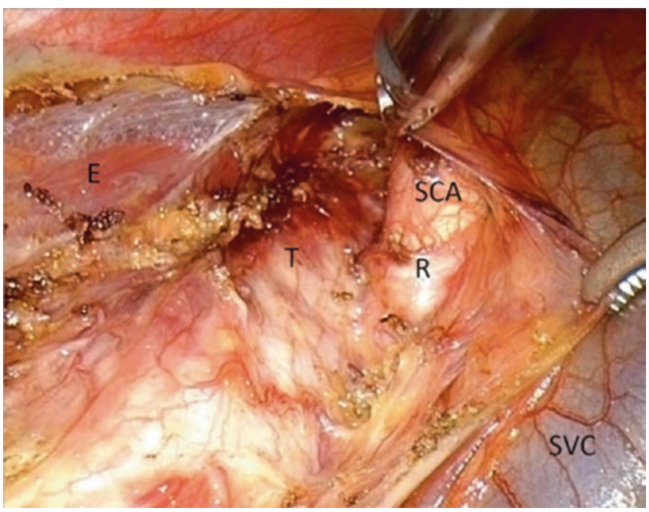

Fig. 18.9 Lymphadenectomy of the right recurrent laryngeal nerve area. *E* esophagus, *T* trachea, *SCA* subclavian artery, *R* right recurrent laryngeal nerve, *SVC* superior vena cava

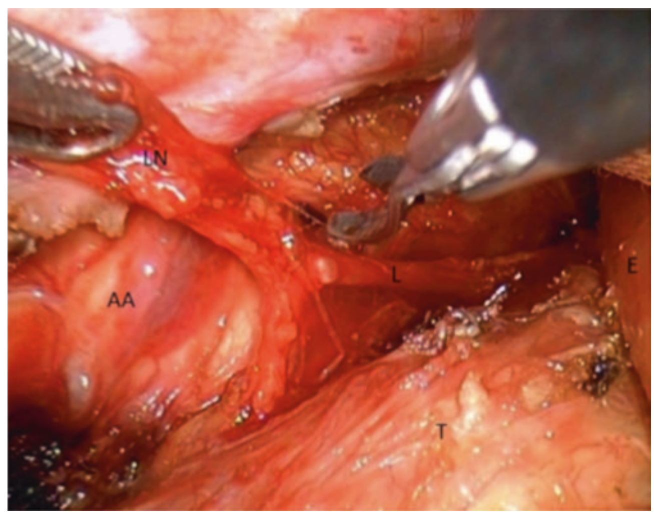

Fig. 18.10 Lymphadenectomy of the left recurrent laryngeal nerve area. *E* esophagus, *T* trachea, *AA* aortic arch, *L* left recurrent laryngeal nerve, *LN* lymph node

18.2.2 Abdominal Stage in Minimally Invasive Esophagectomy

18.2.2.1 Position

Supine position is generally applied during the abdominal surgery. The patients' posture could be adjusted with patient's legs closed and the laparoscope-carrier stands on the left side of the patient, or with legs open and the laparoscope-carrier stands between legs, which is more flexible and provides more space to adjust the laparoscope. Surgeons can select either position at their wills.

18.2.2.2 Incision

Abdominal incisions are usually set in accordance with gastrointestinal surgery (Fig. 18.11). Where to make incisions in the abdominal wall has reached a conclusion though it may have a bit differences from individual to individual. According to our own experience, one port had better be made just below the xiphoid process, through which instrument is put into the abdominal cavity to pull the liver and expose the stomach.

Fig. 18.11 Abdominal incisions for minimally invasive esophagectomy

18.2.2.3 Stomach Mobilization

Gastric mobilization is a routine procedure and we summarize six points according to our own experience.

1. Separating the greater omentum from the stomach till the pylorus can provide enough length of the stomach and reduce the proximal tension of the esophagus after anastomosis.
2. Attention should be paid to protect the right gastroepiploic artery. Dissecting gastrocolic ligament should be placed at least 2 cm from the hemal arch along the greater curvature of the stomach. Another suggestion is given by some surgeons that dissect the gastrocolic ligament along the colon. It not only avoids injuring hemal arch, but also resects the great omentum as much as possible to achieve radical effect.
3. Sometimes, there are severe adhesions between the stomach and the spleen, so clean them up in caution in case of damaging the spleen and vessels. If it is not easy to perform, we had better dissect the gastrohepatic ligament at the lesser curvature of the stomach first, then lift the posterior wall of the stomach and separate the spleenogastric ligament.
4. The steps in dealing with left gastric vessels and large short gastric vessels are critical in abdominal stage (Fig. 18.12). For left gastric vessels, double ligate them with hem-o-lock. For short gastric vessels, the small ones are cut off by ultrasonic shear coagulation. As for large ones, make use of hem-o-lock if necessary.
5. Cut off crus of the diaphragm partly to prevent gastric tube from constricting by hiatus (Fig. 18.13).
6. Abdominal organs may herniate into thoracic cavity if hiatus is enlarged excessively. Therefore, widen the hiatus properly.

18.2.2.4 Peri-stomach Lymphadenectomy

After gastric mobilization, lymph node dissection along the celiac and gastric vessels is performed. We suggest the surgeon stand on the left of the patient, the assistant on the right, so the assistant can pull the stomach to the right posterosuperior side to expose the celiac, gastric, common hepatic and splenic arteries, which make it easier for the surgeon to eliminate the lymph nodes along these vessels.

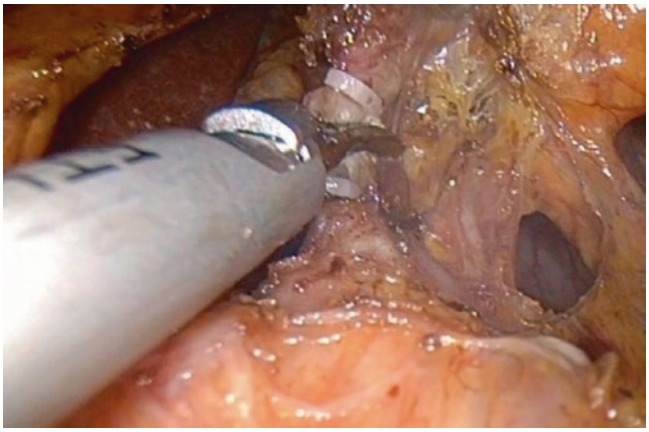

Fig. 18.12 Double ligation of left gastric vessels with hem-o-lock

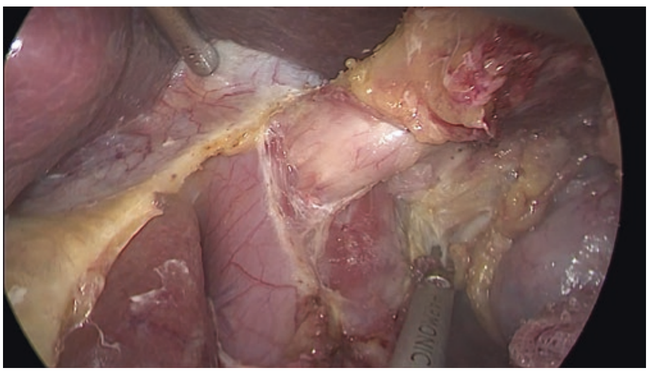

Fig. 18.13 Cut off crus of the diaphragm partly to prevent gastric tube from constricting by hiatus

18.2.3 Gastroesophageal Reconstruction

18.2.3.1 Gastric Conduit

Gastric conduit has advantages over whole stomach (Fig. 18.14). Firstly, gastric tube is longer, and the prolonged gastric conduit, applied as the esophageal substitution, results in lower tension to the proximal esophagus after the anastomosis. Secondly, the lymph nodes along the lesser curvature can be dissected radically, which conforms to the principle of tumor excision. Thirdly, it is small in size, which has lower compression to the lung and the heart. Therefore, patients' qualities of life would be improved.

Four points would be critical in making gastric conduit.

1. The tubulization has a linear and oblique resection on the upper part and from right to left of the lesser curvature to the summit of the fundus. In this process, the assistant spreads out the stomach so as to adjust the cutting route and master the length of the conduit.
2. The resection starts under the first three collateral branches of the left gastric artery with preservation of blood supply from the two proximal branches of right gastric artery. The cutting route varies according to the width of the conduit.
3. Although reports have indicated that a narrow gastric tube improves gastric emptying in a flow-visualization model, the narrow may have a poor blood supply and increase the rate of anastomotic leakage. So it is necessary to keep a proper width.
4. It had better suture the cutting margin of the conduit again to strengthen its stability. The cutting line of the gastric conduit is embedded by interrupted seromuscular suturing.

18.2.3.2 Mediastinal Routes of Reconstruction

Retrosternal route and esophageal bed are two ordinary routes in reconstruction. It has been suggested that a retrosternal route of reconstruction causes the conduit to travel a greater distance with a larger tension and a more tortuous course that may result in distortion of veins causing congestion. Additionally, the manubrium compresses conduit causing chronic hypoxia of anastomotic stoma. These two factors lead to a compromising anastomotic integrity. Nowadays, the posterior route is more commonly utilized in modern practice due to the added benefit it confers of permitting a thoracic lymphadenectomy. However, retrosternal route is an ideal choice for tumors invading adjacent tissues.

These two methods are both effective and safe for digestive tract reconstruction, and proper choice should be made according to the patients' conditions.

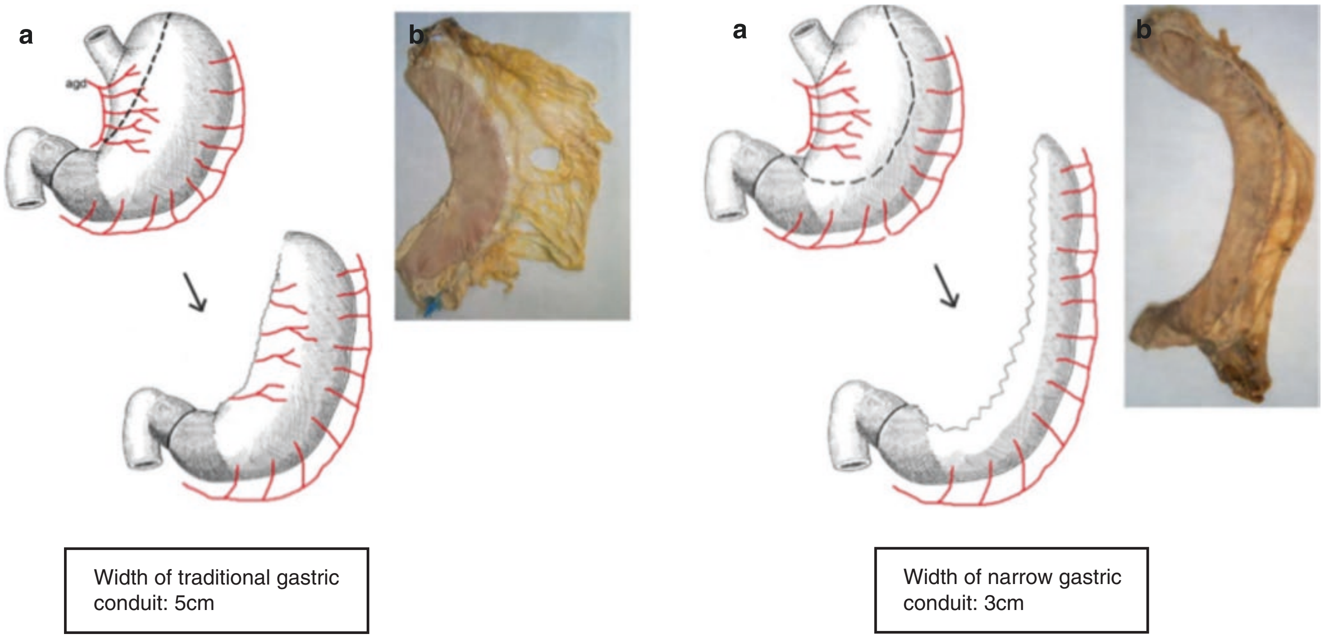

Fig. 18.14 The comparison between gastric conduit and whole stomach

18.2.3.3 Tips for Minimizing Anastomotic Leakage

There could be a number of contributors to the anastomotic leakage following MIE. While the role of blood supply would play the key role in the gastroesophageal reconstruction. As per the previous studies, the tips were summarized as follows:

1. Generally, the mobilization of the whole stomach would be favored, so that enough conduit length would be guaranteed with relatively low anastomotic tension.
2. Preserve the first branch (at least) of the right gastric artery, and the blood supply to the anastomotic site would be better preserved.
3. Prevent torsion of gastric conduit during the gastric pull-up, and avoid iatrogenic injury to the right gastroepiploic arch.
4. Make sure that different layers of esophageal stump and gastric tube were met and anastomosed. After finishing the anastomosis, take careful examination of anastomotic integrity (Fig. 18.15).

Fig. 18.15 Examination of anastomotic integrity

5. The anastomotic site should be close to the right gastroepiploic arch with sufficient blood supply to the anastomotic stoma.

18.2.3.4 Laparoscopic Jejunostomy

A jejunal feeding tube is placed under laparoscope during the abdominal stage. Before the tube introduction, the proximal and distal ends of jejunum should be confirmed. The continuous fluid injection to the jejunum would facilitate the insertion of feeding tube due to the peristalsis of the bowel. Besides, do make sure there is no obstruction or twist in any part of the bowel after the feeding tube placement.

In addition to the tips mentioned above, the following suggestions could be helpful during the practice of minimally invasive esophagectomy:

1. Set norms and standards of minimally invasive esophagectomy. The qualified surgeon learns the new surgical option by different ways, such as watching videos, simulated trainings, and animal experiments, under the direction of superior doctors.
2. Good candidates at the beginning. Those with clinically staged T_1-$_2$ N_0 M_0 tumors and without severe comorbidities are usually favored. More strict inclusion criteria would lead to less intraoperative emergencies, as well as postoperative complications.
3. Routine protocol works. The protocol usually read simply: (1) Assessment (of resectability), (2) Ligation (of the azygos vein), (3) Mobilization (of the esophagus), (4) Dissection (of the lymph nodes), (5) Check (of the thoracic duct and blood point), (6) Insertion (of the chest tube).
4. Listen to the MDT. The MDT would have included anesthetist, surgeon. The members that cooperate with each other for a long time are familiar with each other. They can discover problems and then solve them, which shortens the learning time in a sense.

18.3 Perioperative Management

Chun Chen and Bin Zheng

18.3.1 Preoperative Preparation

18.3.1.1 Nutrition

Preoperative nutritional repletion remains controversial. Preoperative assessment of nutrition cannot be done with any one simple test. Albumin and body mass index (BMI) are the wildly used index to evaluate nutrition status [19]. However, a study has reported that albumin and BMI had no relationship with postoperative complications [20]. A study included 400 cases also showed that BMI was not associated with postoperative complications [21]. The reasons of these results might be the albumin was influenced by the inflammation factors and acute reactive protein. And protein and BMI may be related with the postoperative complications, only combined action with other factors, such as age, exercise, etc. [22, 23] The better assessment is weight loss or the degree of muscle reduction [24]. Despite this difference, the goal for preoperative preparation of the patient is to maintain nutrition at all possible costs to prevent additional weight loss before operation and to schedule the procedure as soon as the patient is prepared.

18.3.1.2 Preoperative Pulmonary Exercise and Training

If surgical intervention is elective, a short period of preparation (preferably 3 weeks) may be beneficial if directed at improving the patient's physical status and specifically at pulmonary preparation, conditioning exercises, and nutrition [25]. Debigare and associates [26] studied preparation for lung volume reduction procedures. Because many patients traveled a great distance, the investigators devised a home exercise training program that included incentive spirometry, muscle exercises, and aerobic training. It began with detailed teaching and follow-up and was ensured through weekly phone calls and a diary filled out by each patient. As a result, there was a significant increase in the 6-min walk test, quality-of-life perception, peak work rate, peak oxygen consumption, endurance time, and muscle strength; it was therefore concluded that such training was beneficial when time permits a delay in the timing of the operation.

18.3.1.3 Smoking Cessation

Smoking cessation has always been considered an important issue in preparation for an operation. However, the evidence shows that the effects of cigarette smoking cessation are controversial.

Verra and associates [27] studied the cilia of human individuals who were smokers, ex-smokers, or nonsmokers. They noted that the percentage of axonemal ultrastructural abnormalities was higher in smokers and ex-smokers than in nonsmokers or control subjects, a condition that seemed to persist long after smoking cessation. The axonemal ultrastructural abnormalities were polymorphic, characteristic of acquired ultrastructural changes. These results suggest that chronic smoking may induce an increased number of abnormal cilia, which may lead to impaired clearance of mucus. Andersson and associates [28] studied bronchoalveolar lavage fluid from former smokers and found that Clara cell secretory protein was increased in smokers and remained elevated for up to 12 months after smoking cessation. Some data suggest that cessation of smoking leads to higher postoperative complications. This is based on the fact that patients have increased secretions early after cessation. Barrera and colleagues [29] studied smokers undergoing thoracotomy at Memorial Sloan-Kettering Cancer Center. They found no difference in pulmonary complications among recent quitters versus continuing smokers. Only patients with >60 pack-years and those with a significantly reduced diffusion capacity had higher risks of pulmonary complications. The investigators concluded that it was safe to quit at any time before operation.

Despite the lack of firm evidence, it is still recommended that patients quit smoking for as long as possible prior to operation.

18.3.1.4 Drinking

According to a recent World Cancer Research Fund report [30], alcohol is considered a "convincing" risk factor for esophageal carcinoma. Alcohol causes chronic irritation and inflammation of the esophageal mucosa, consequently induces a series of molecular change, and trigger carcinogenesis [31]. Alcohol may promote the development of specific types of esophageal carcinoma, and it is possible that alcohol influences the behavior and course of the disease and has an effect on outcomes. There is a positive synergistic effect of alcohol and tobacco use for esophageal carcinoma. The observed combined effect of the two factors is almost double [32]. Preoperative alcohol control should be emphasized to reduce mortality of esophageal carcinoma [33].

18.3.1.5 Medications

Preoperative medications should be continued up to the time of operation. The only exceptions are anticoagulant medications. Patients on warfarin, low-molecular-weight heparin, unfractionated heparin, or clopidogrel should stop their medications long enough prior to the procedure that the effects of these drugs are minimal. Cessation of aspirin is an individual preference. For pulmonary and esophageal surgery, there is no evidence that aspirin increases bleeding. There is also no evidence that the addition of preoperative short-term bronchodilators changes operative outcomes.

18.3.2 Postoperative Management

18.3.2.1 Postoperative Nutrition

Postoperative nutrition support helps to improve the nutrition status of patients and reduce the postoperative complications. Enteral nutrition feeding is the first choice after the operation, which is associated with less complication, more convenient and safer, compared with parenteral nutrition feeding. After the operation, it's better for these diets, both parenteral and enteral, included amino acids (arginine and glutamine), lipids (omega-3 fatty acids), micronutrients (vitamines C and E) and nucleotides. Soon after the implementation, some authors observed their encouraging influence on the outcome of surgery [34]. Common enteral nutrition routes included oral route, nasal tube, tube after gastrostomy, tube after jejunostomy and so on. Early oral feeding is associated with good gastrointestinal function recovery [35], which is commonly used for minimally invasive endoscopic surgery. The recent studies have reported the application of early oral feeding to the rapid rehabilitation of conventional esophageal surgery [36]. Tube set after jejunostomy, which is most wildly used feeding route, needs invasive surgery. However, it can avoid reflux and aspiration, can be used for long retention time and can be well tolerated. Several studies indicated that early enteral feeding could improve the nutrition status of the patients and reduced the postoperative complications [37, 38]. Another study also reported that early enteral feeding could reduce the length of stay in intensive care unit [39]. Based on these evidence, if it is possible, it recommends that do early enteral nutrition feeding within 24 h postoperatively. For patients having esophageal resection, enteral nutrition feeding should be initiated early with saline at 10 mL per hour. If tolerated overnight, full-strength feedings can be substituted and increased every 8 h until the patient's feedings reach a calculated goal. When the enteral nutrition can not meet the nutritional needs, the combine use of both enteral nutrition and parenteral nutrition can also effectively reduce the complications after the operation.

18.3.2.2 Pulmonary Rehabilitation

In the early postoperative course, the most significant potential complication following surgery is pneumonia. A significant risk factor for the development of pneumonia is atelectasis. This is a common problem following the surgery and seems to be minimized only with the patient's help. Several techniques for the prevention of atelectasis have been tried and investigated over the years. Varela and colleagues [40] found that routine use of pulmonary physiotherapy compared with incentive spirometry alone reduced postoperative complications such as pneumonia and atelectasis and also reduced hospital costs, based on a decreased length of hospital stay. Though the minimally invasive surgery can reduce the injury of the patients, the most effective approach to the prevention of atelectasis is still preoperative home exercises with coughing/deep breathing and possibly incentive spirometry and continuation of the same exercises with adequate pain control following operation. Because the nursing and other professional staff are stretched thin and can provide only sporadic attention, families are encouraged to support the patient's efforts on a regular basis during waking hours.

18.3.2.3 Chest Drainage Systems

Though surgeons now have several different options for draining the chest, especially in minimal invasive surgeries, most surgeons still place one tube anteriorly and one posteriorly in the chest. The tubes are attached to a drainage system that permits one-way drainage only, with a portion of the device set up to collect fluid.

Regardless of types of chest tubes and the use of suction, the drainage tubes must be assessed at least daily for patency, function, air leakage, and drainage. Inspection of the tube and drainage system for clots or blockages assures patency. Obstructions are removed by "stripping" the tubing. This is accomplished by occluding the tubing and pulling it away from the patient to produce a local suction effect. If this does not work, a balloon-tipped catheter may be passed up the tubing to remove the clot, or a suction catheter may be used for the same purpose. Air leakage is assessed by observing the water-seal chamber on the drainage device. Air leakage should first be assessed off suction at quiet respiration. Next the patient is asked to cough and the chamber is observed. Finally, the patient may be placed back on suction if suction is being employed, and the chamber again observed. Drainage should be measured daily.

In planning the removal of a chest tube, the drainage must significantly decrease to levels acceptable to the surgeon. Although exact numbers are not scientifically verified for the amount of pleural fluid produced per day while a chest tube is in place, a convenient number is 100–250 ml per day.

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Index

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