Lobectomy

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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

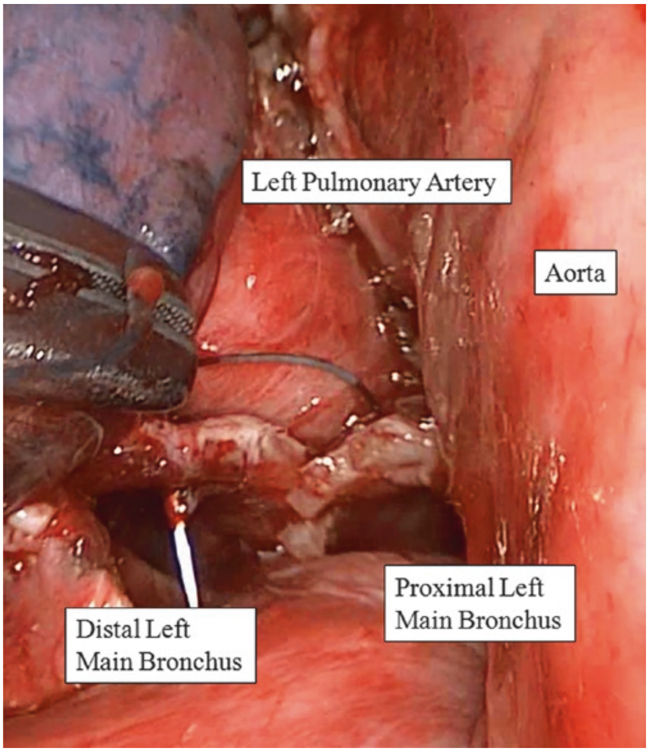

Fig. 4.1 Left bronchial sleeve resection for carcinoid (without parenchymal resection)

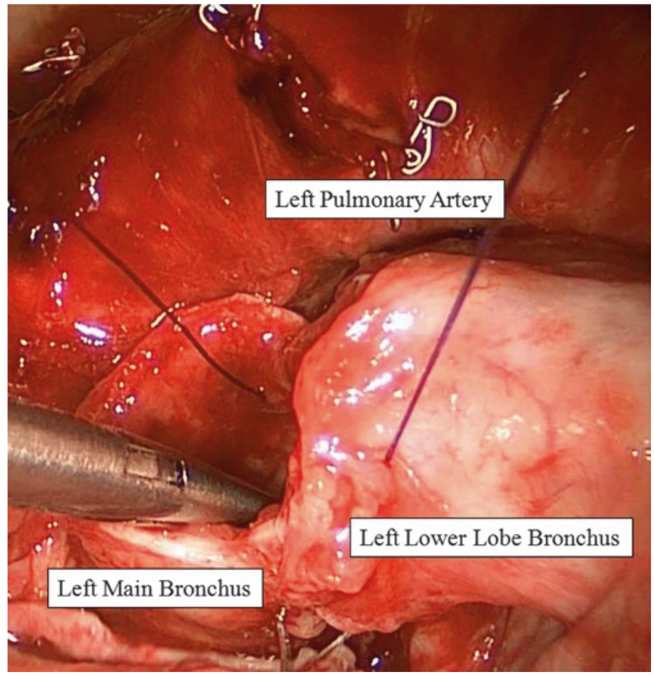

Fig. 4.2 Left sleeve upper lobectomy for lung cancer

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).

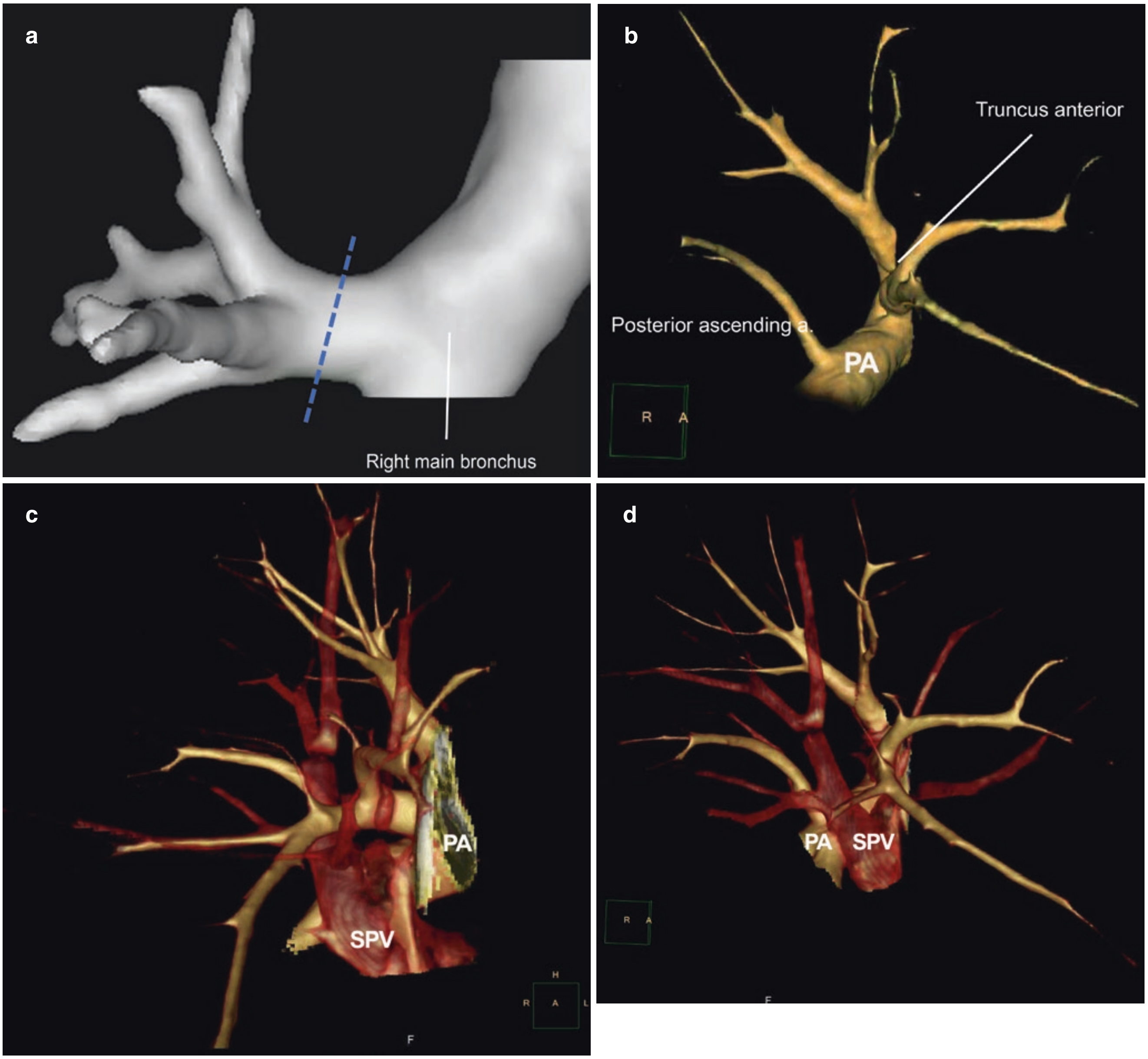

Fig. 4.3 Anatomical landmarks. (**a**) Upper lobe bronchus (*anterior view*). (**b**) Upper lobe arteries (*right lateral view*). (**c**) Relationships between arteries and veins of the right upper lobe (*anterior view*). (**d**) Relationships between arteries and veins of the right upper lobe (*right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

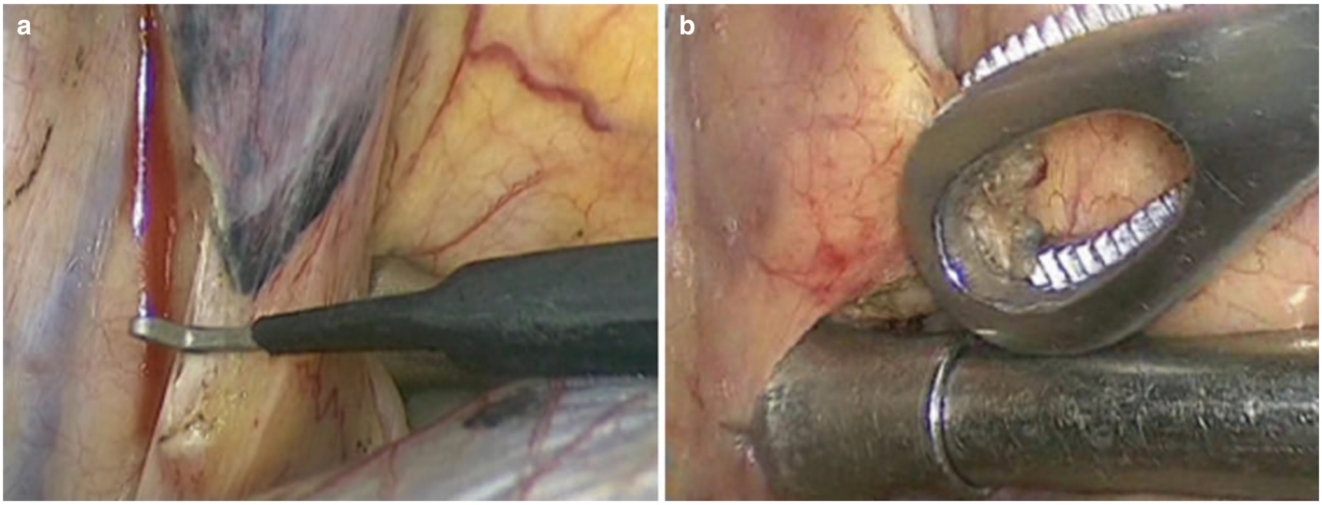

Fig. 4.4 (**a**) Dissect the pulmonary ligament. (**b**) Resect the group 9 lymph nodes

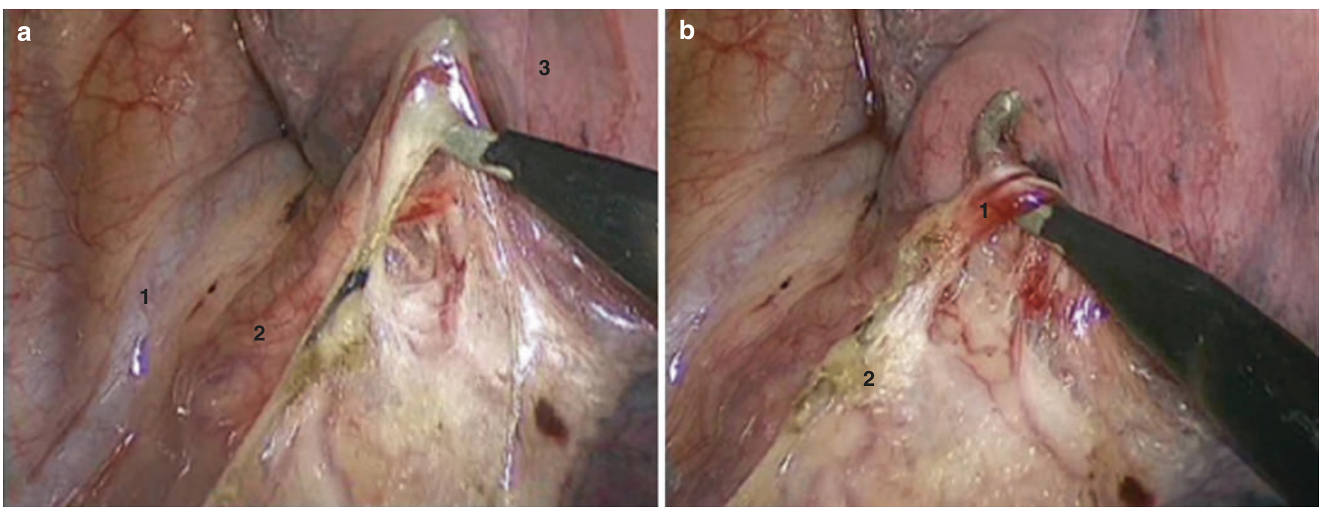

Fig. 4.5 (**a**) Open the posterior mediastinal pleura. *1* Azygos vein. *2* Right main bronchus. *3* Right upper lobe. (**b**) Dissect and cut off the bronchial arteries. *1* Bronchial artery. *2* Right main bronchus

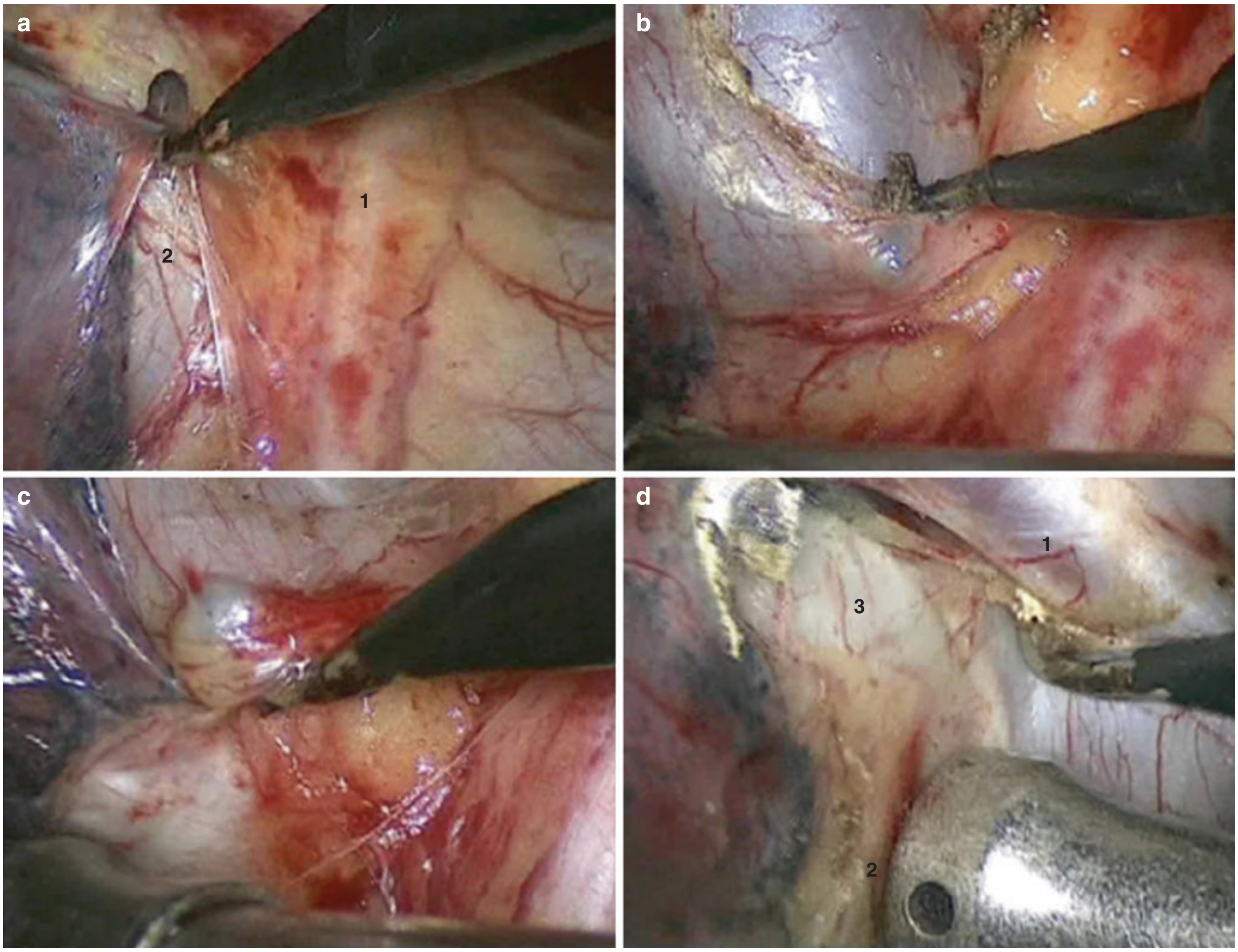

Fig. 4.6 (**a**) Open the anterior mediastinal pleura between superior pulmonary vein and phrenic nerve. *1* Phrenic nerve. *2* Superior pulmonary vein. (**b**) Dissect the superior pulmonary vein. (**c**) Dissect the superior pulmonary vein. (**d**) Dissect between the superior pulmonary vein and middle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

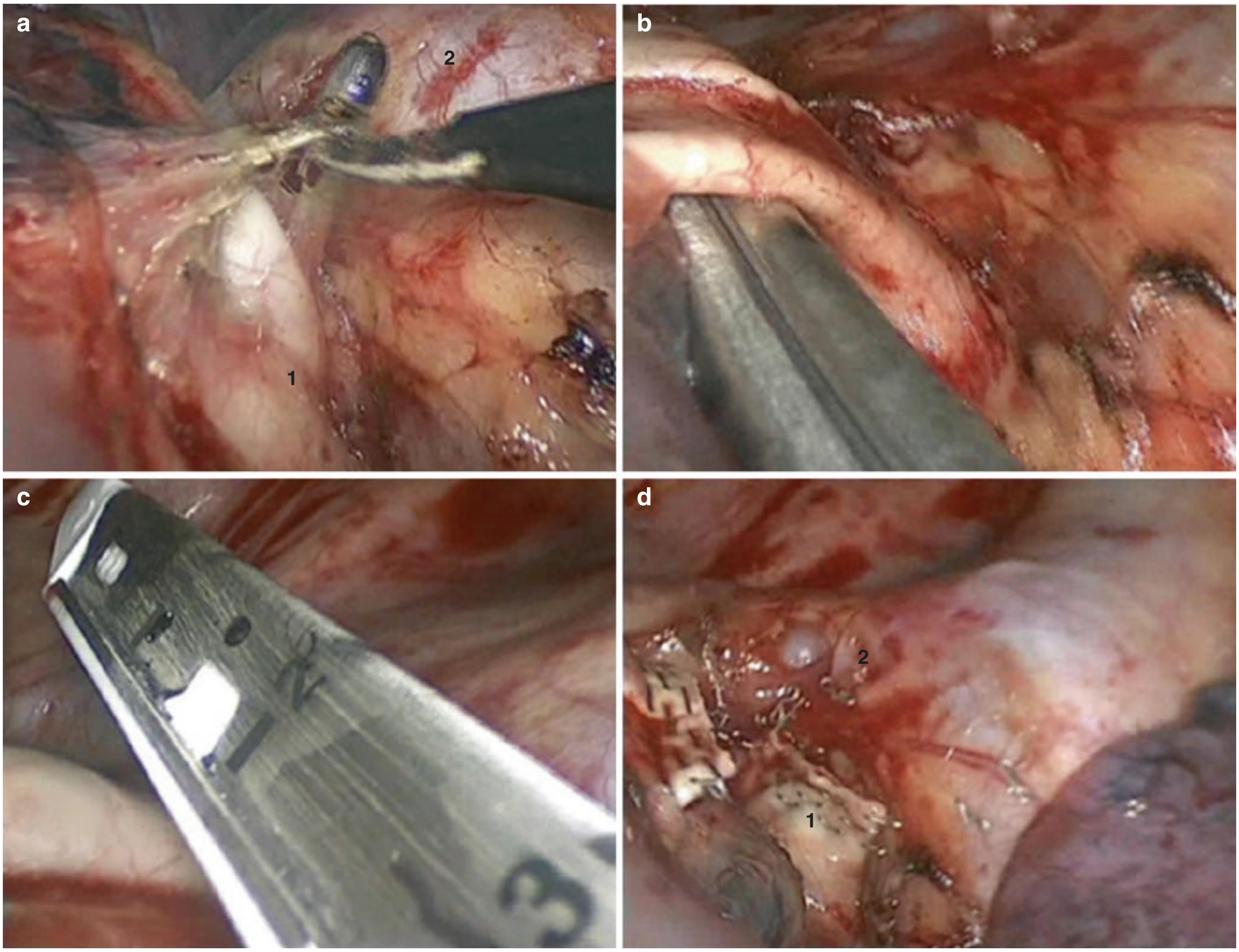

Fig. 4.7 (**a**) Dissect the truncus anterior. *1* The truncus anterior. *2* Arch of azygos vein. (**b**) Dissect the truncus anterior with curved forceps. (**c**) Cut off the truncus anterior with stapler. (**d**) The truncus anterior after cut off. *1* The truncus anterior. *2* Arch of azygos vein

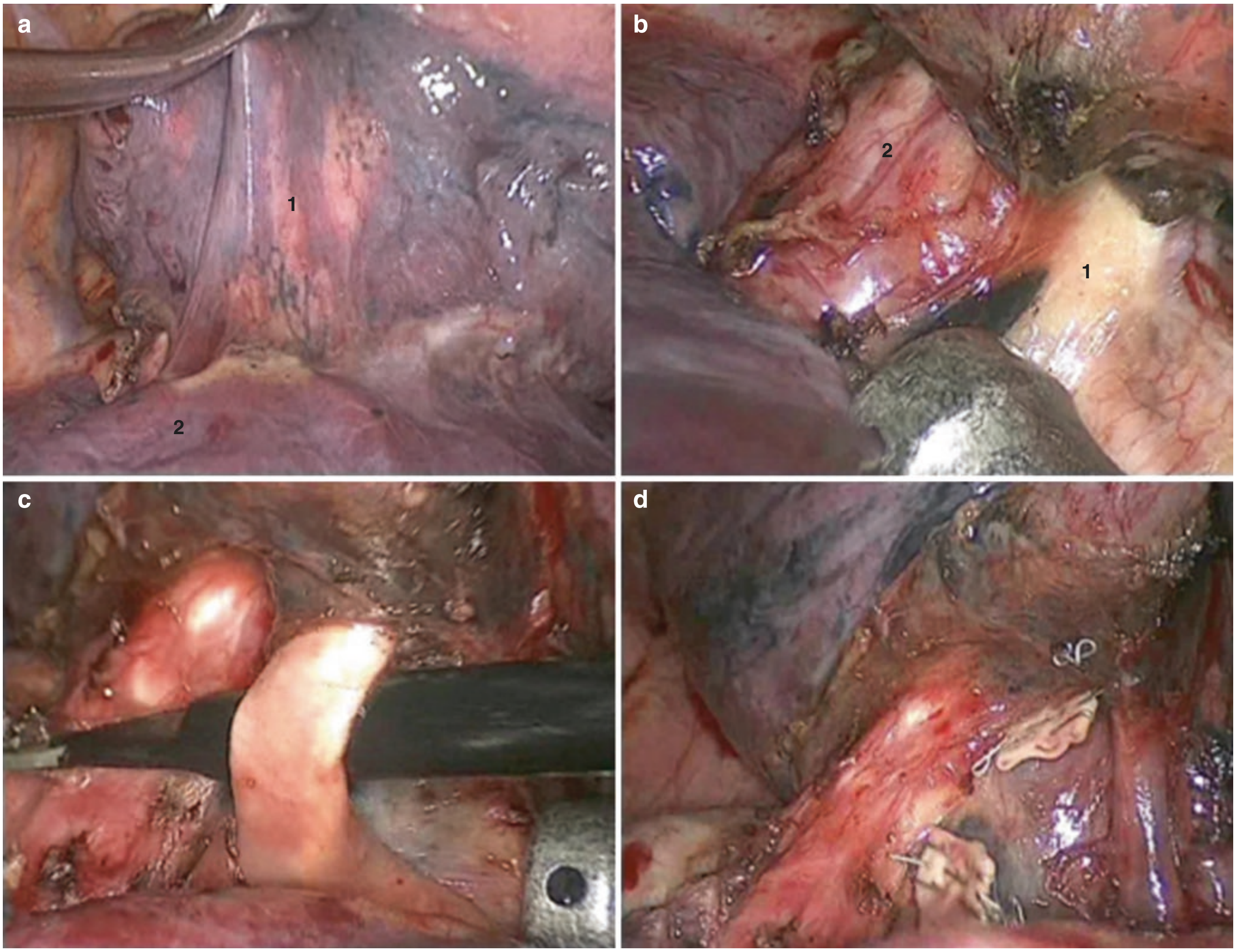

Fig. 4.8 (**a**) Retract the right upper lobe to the apex of lungs, and expose the posterior part of the major fissure. *1* RUL. *2* RLL (**b**) Divide the posterior part of the major fissure. *1* Ascending branches. *2* RUL bronchus. (**c**) The ascending branches to the upper lobe are dissected. (**d**)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

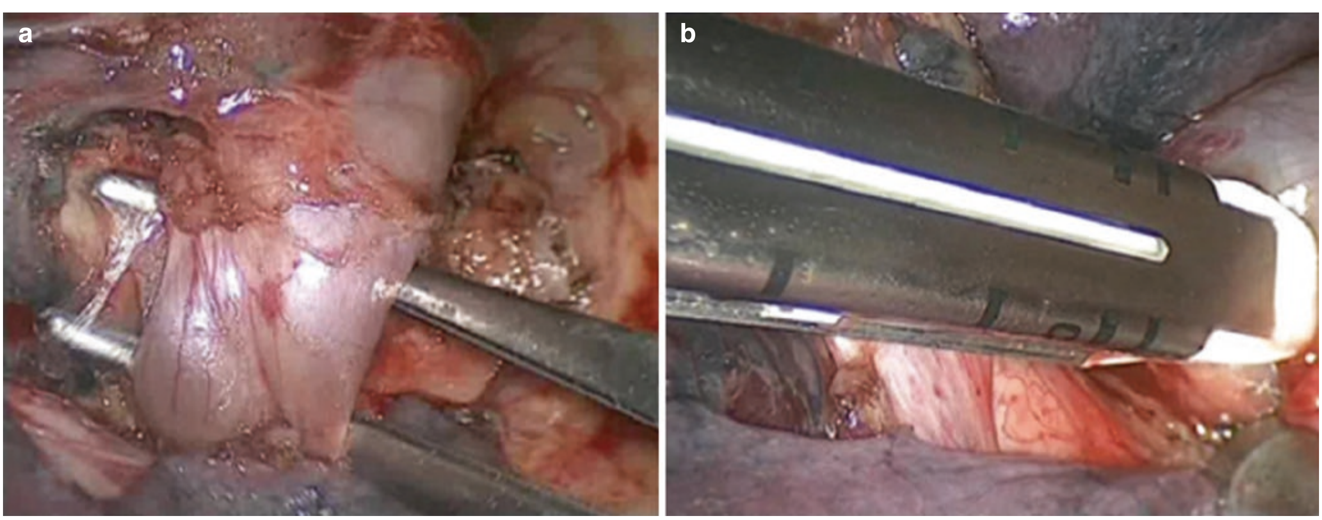

Fig. 4.9 (**a**) Divide the superior pulmonary vein by a right angle clamp. (**b**) Cut off the superior pulmonary vein by endo-stapler

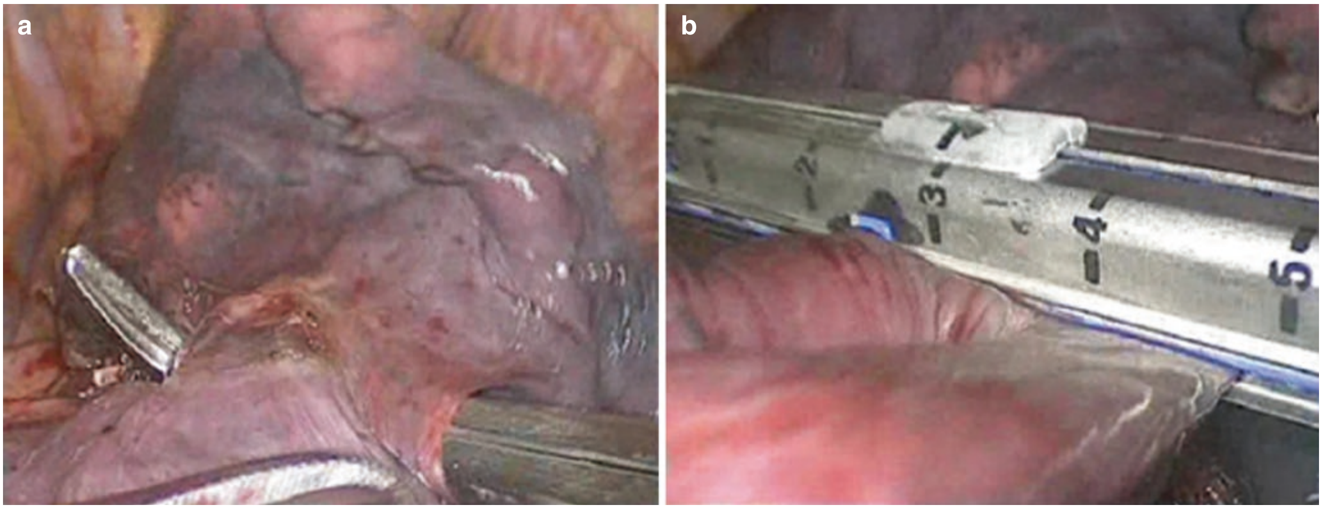

Fig. 4.10 (**a**) Divide the minor fissure using "tunnel" method by a right angled clamps. (**b**) The minor fissure is divided by stapler through the tunnel

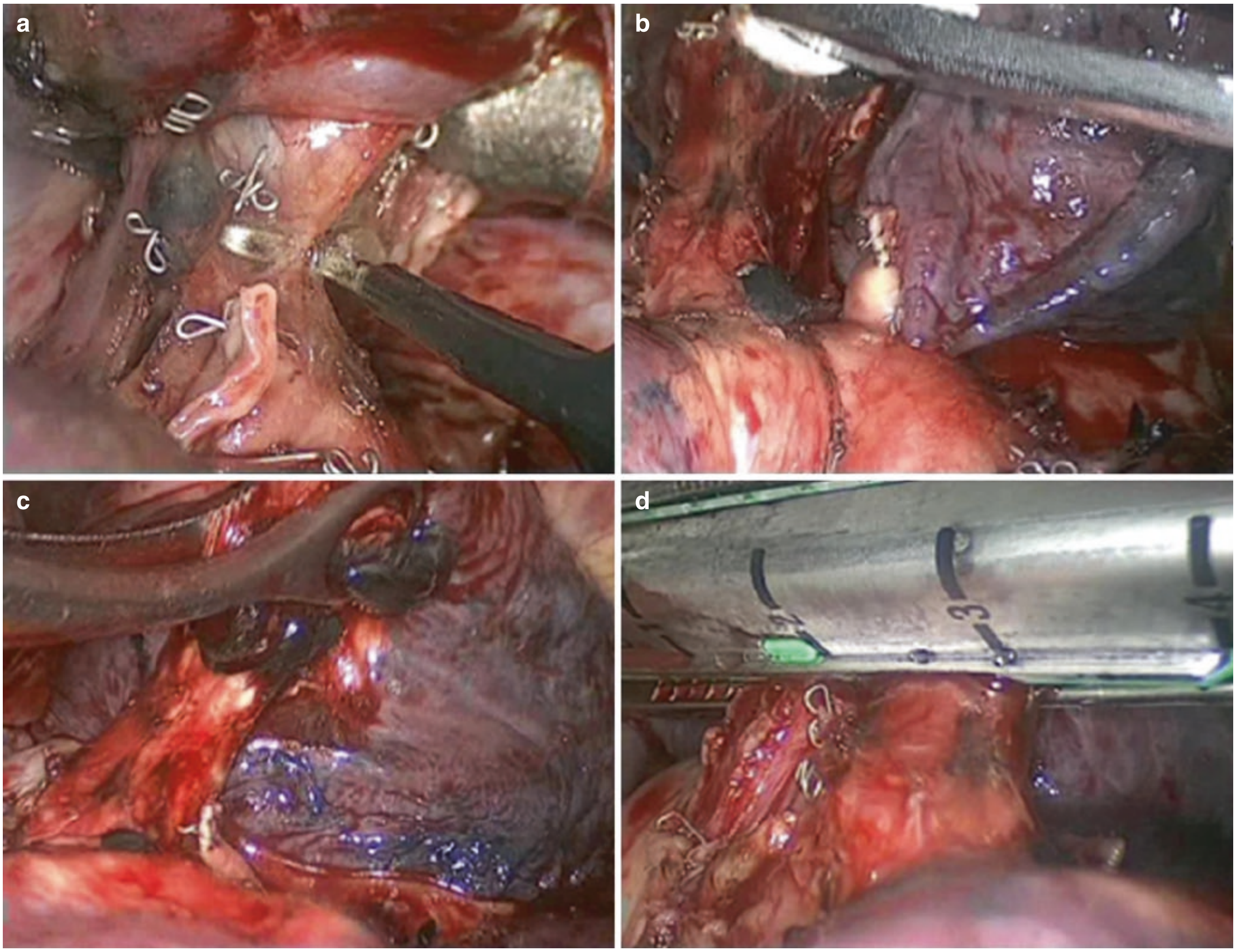

Fig. 4.11 (**a**) The upper lobe bronchus is dissected by electric hook. (**b**) The upper lobe bronchus is dissected by an endo-peanut. *1* Upper lobe bronchus. *2* Main pulmonary artery. (**c**) The lymph nodes are dissected by oval forceps. (**d**) The upper lobe bronchus is cut off by stapler

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).

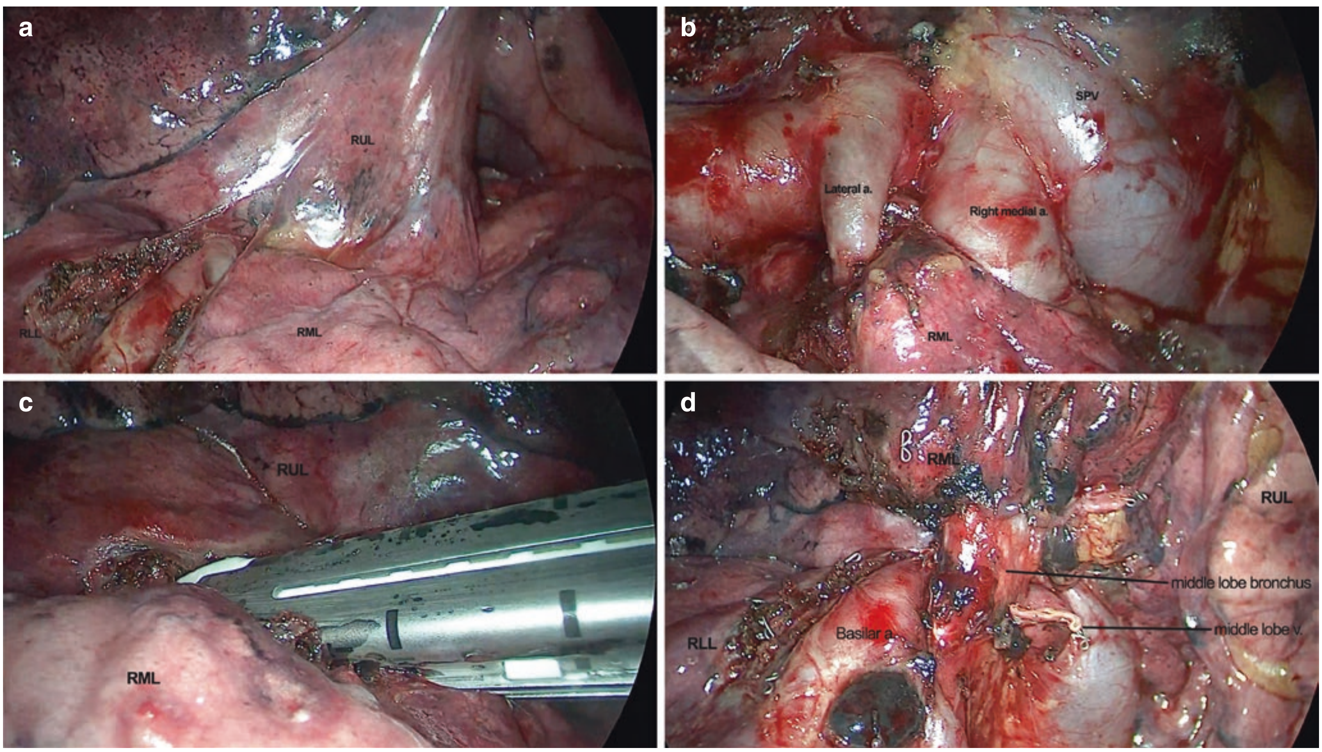

Fig. 4.12 Well differentiated fissure: (**a**) Before dissection. (**b**) After dissection of the horizontal fissure. (**c**) Ligation of the middle lobe artery. (**d**) Exposing the bronchus

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.

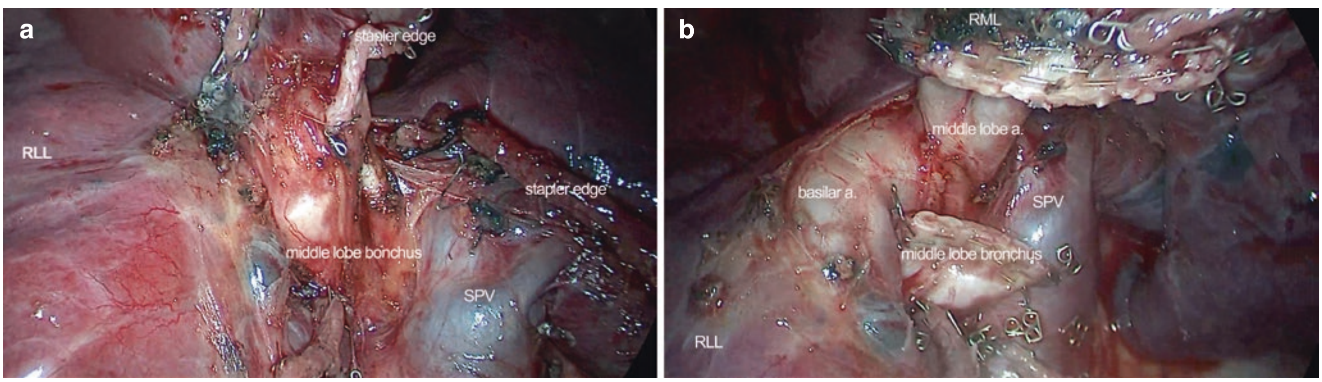

Fig. 4.13 Poor differentiated fissure: (**a**) Ligation of the bronchus. (**b**) Exposing the artery

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.

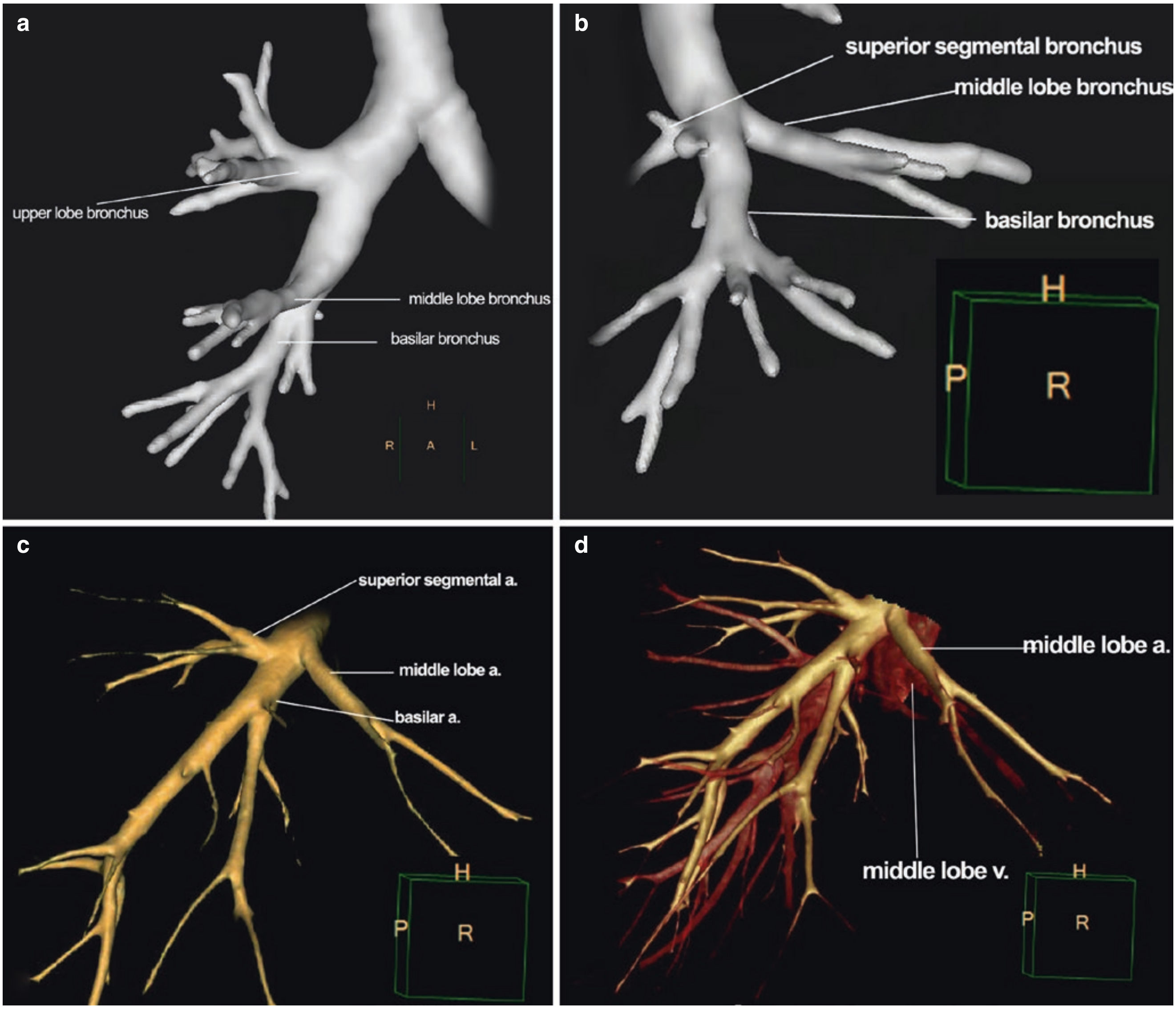

Fig. 4.14 Anatomical landmarks of right middle lobe: (**a**) Middle lobe bronchus (*anterior view*). (**b**) Middle lobe bronchus (*right lateral view*). (**c**) Middle lobe arteries (*right lateral view*). (**d**) Relationships between arteries and veins of the right middle lobe (*right lateral view*)

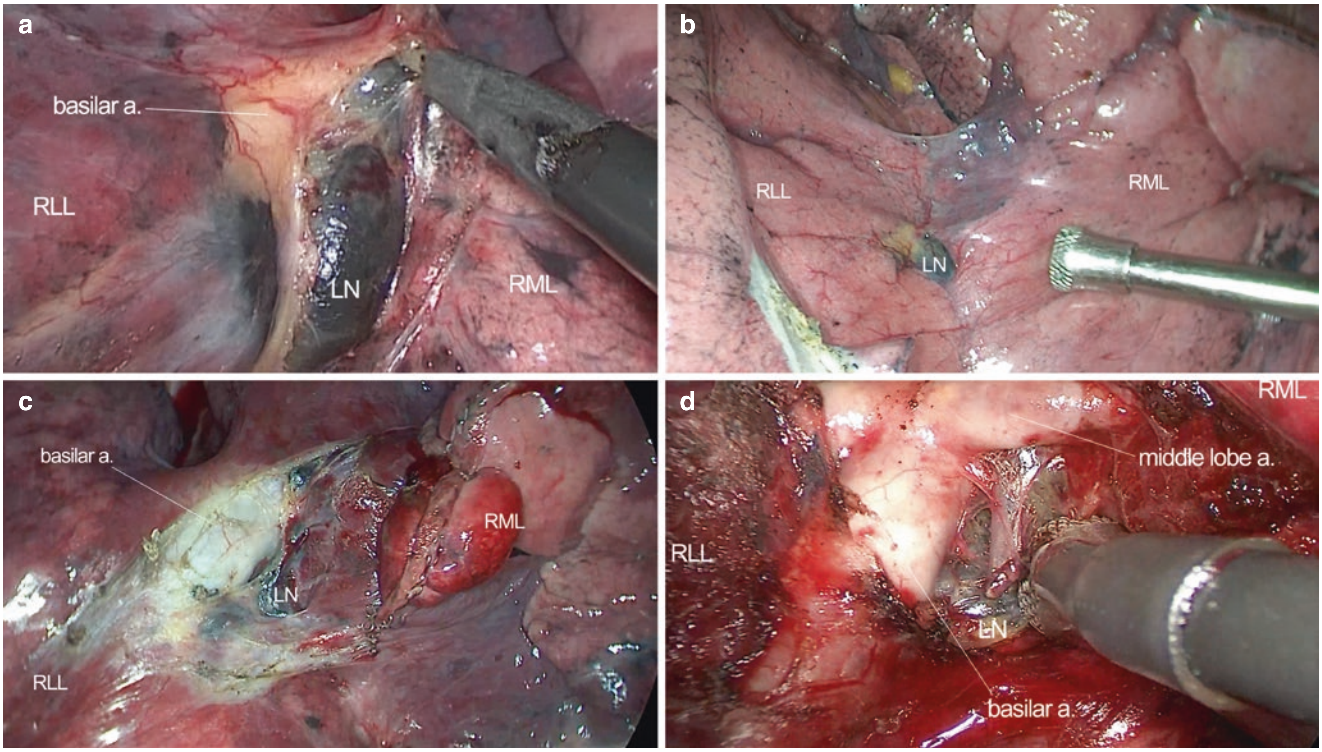

Fig. 4.15 Ligation of the vein: (**a**) An angled clamp is used to clear a path through the tissue posterior to the vein. (**b**) Ligation with a staple

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

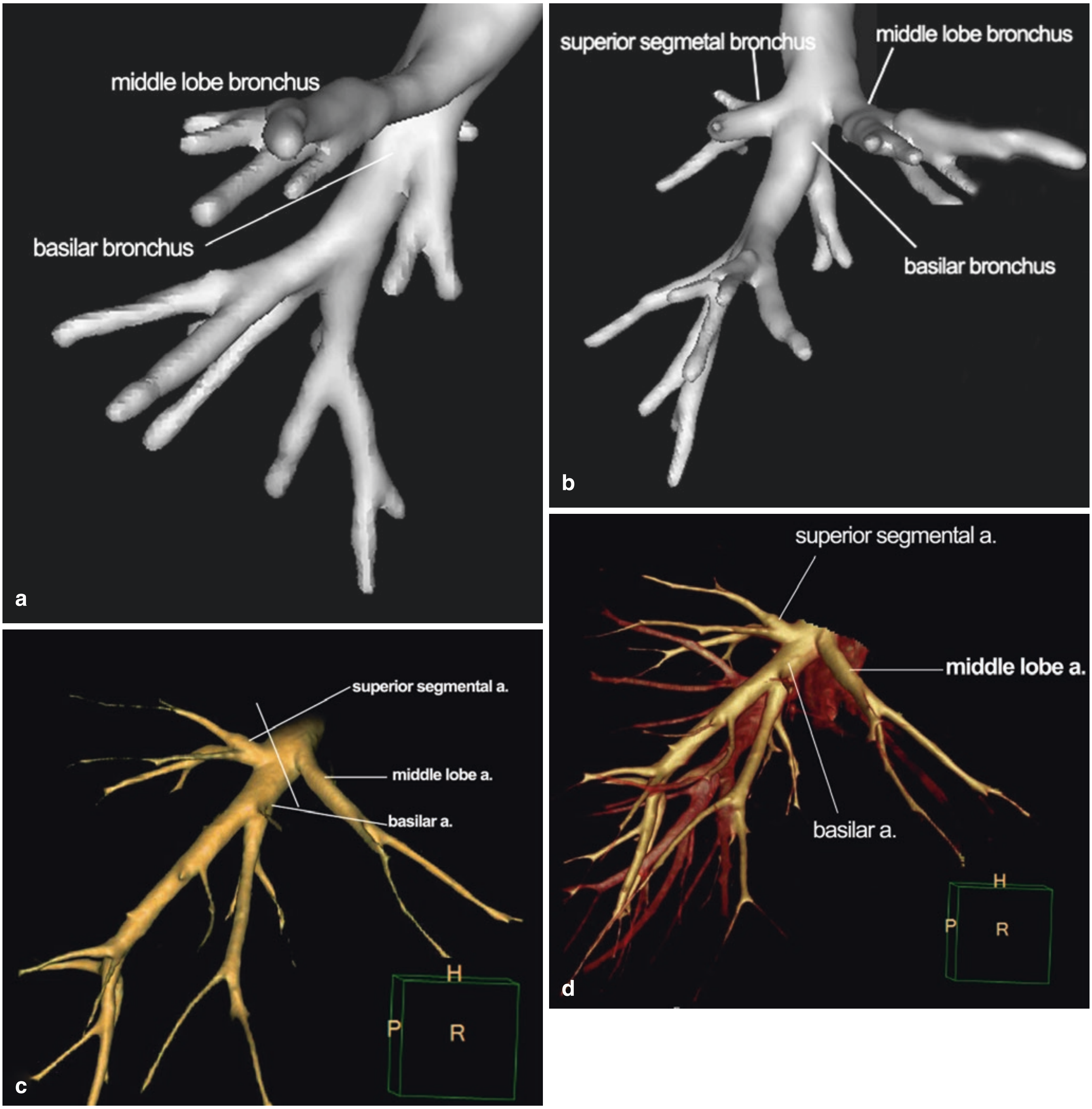

Fig. 4.16 Anatomical landmarks of right lower lobe (**a**) Lower lobe bronchus (*anterior view*). (**b**) Lower lobe bronchus (*right lateral view*). (**c**) Lower lobe arteries (*right lateral view*). (**d**) Relationships between arteries and veins of the right lower lobe (*right lateral view*)

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.

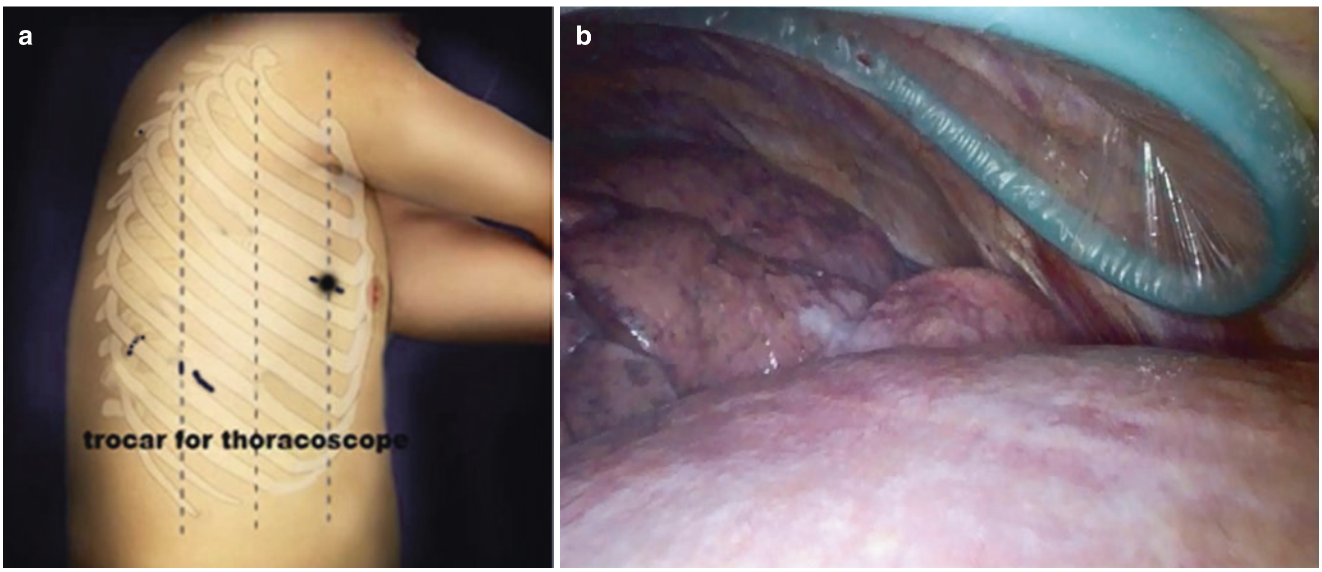

Fig. 4.17 (**a**) Three incisions: 1 anterior, 1 posterior, and 1 inferior. (**b**) Wound protector for retraction of wound edges

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

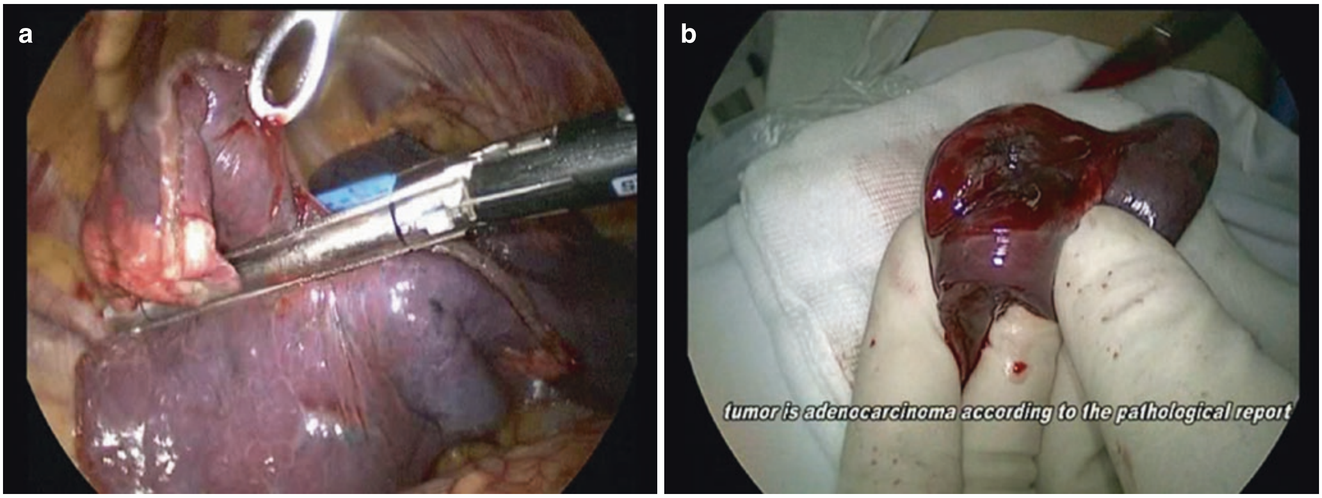

Fig. 4.18 (**a**) Wedge resection. (**b**) Frozen section demonstrated adenocarcinoma

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.

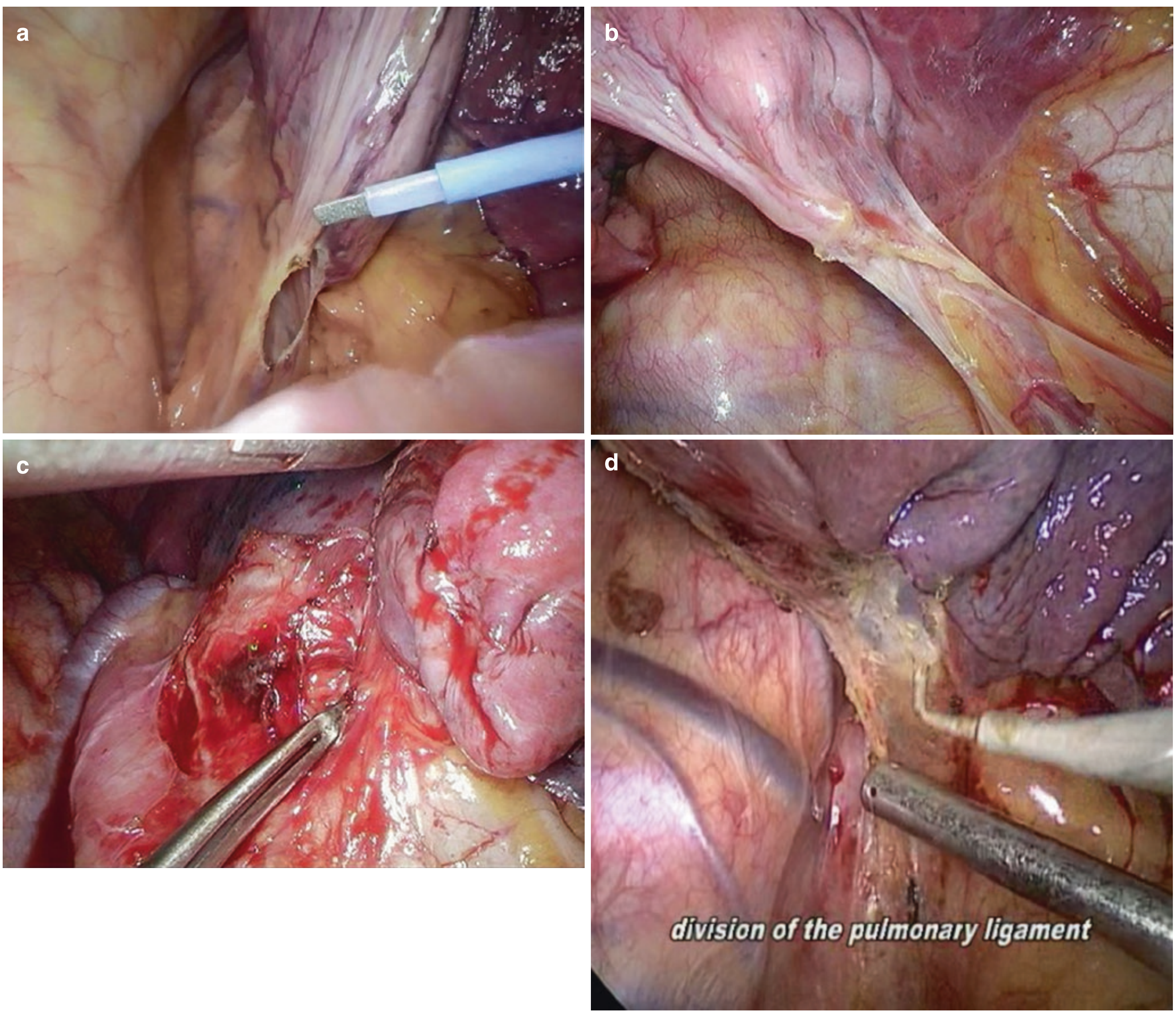

Fig. 4.19 (**a**) Retract the lung laterally to put the ligament on tension. (**b**) Incise the inferior pulmonary ligament sharply. (**c**) Extend the hilar pleural incision posteriorly up to the level of the azygos vein. (**d**) Remove the level 9 lymph nodes

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).

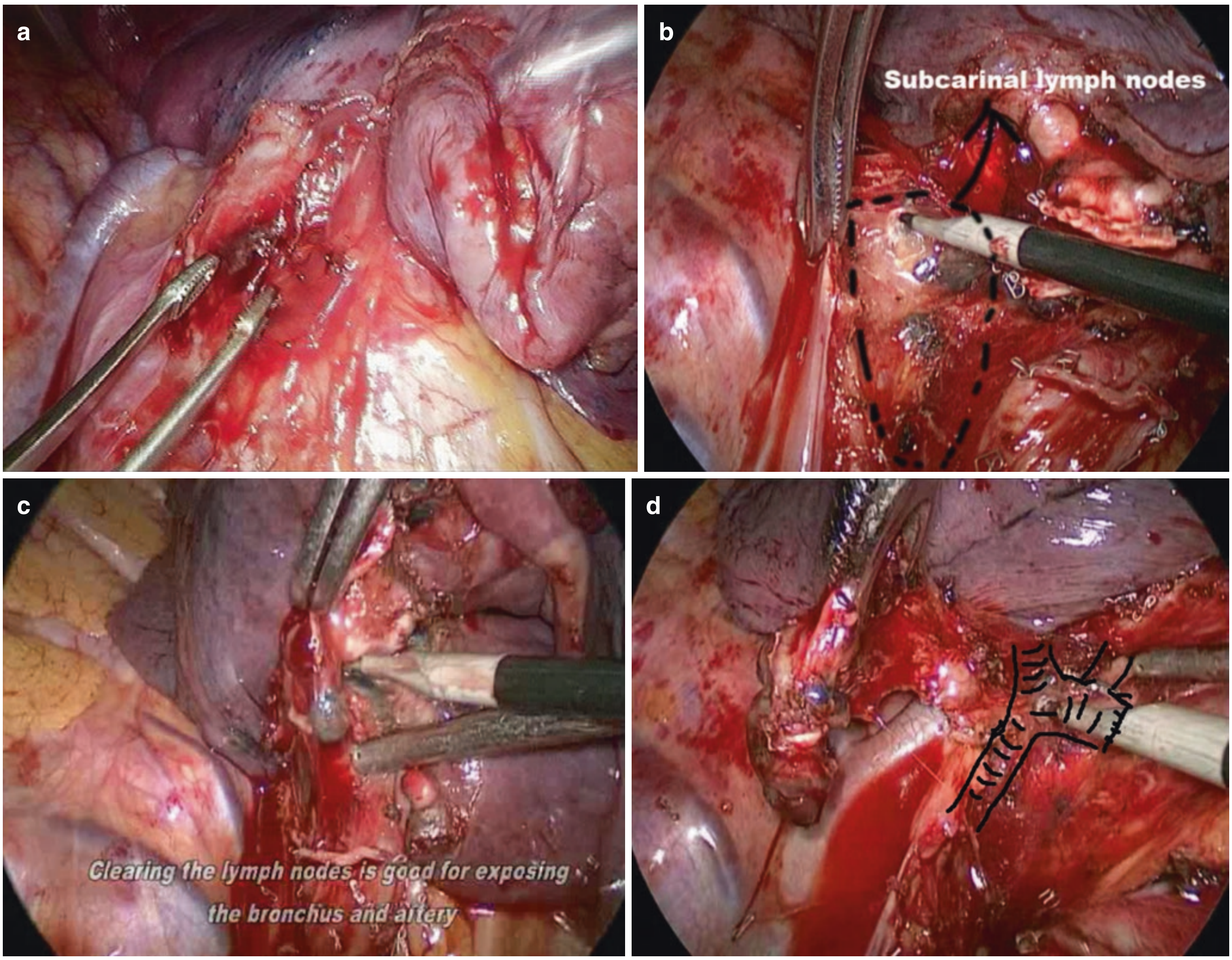

Fig. 4.20 (**a**) Exposing the subcarinal space to facilitate the node dissection. (**b**) Boundaries of the station 7 lymph nodes, including the right main stem bronchus, pericardium, esophagus, inferior pulmonary vein, carina and left main stem bronchus. (**c**) Performing the subcarinal lymph node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

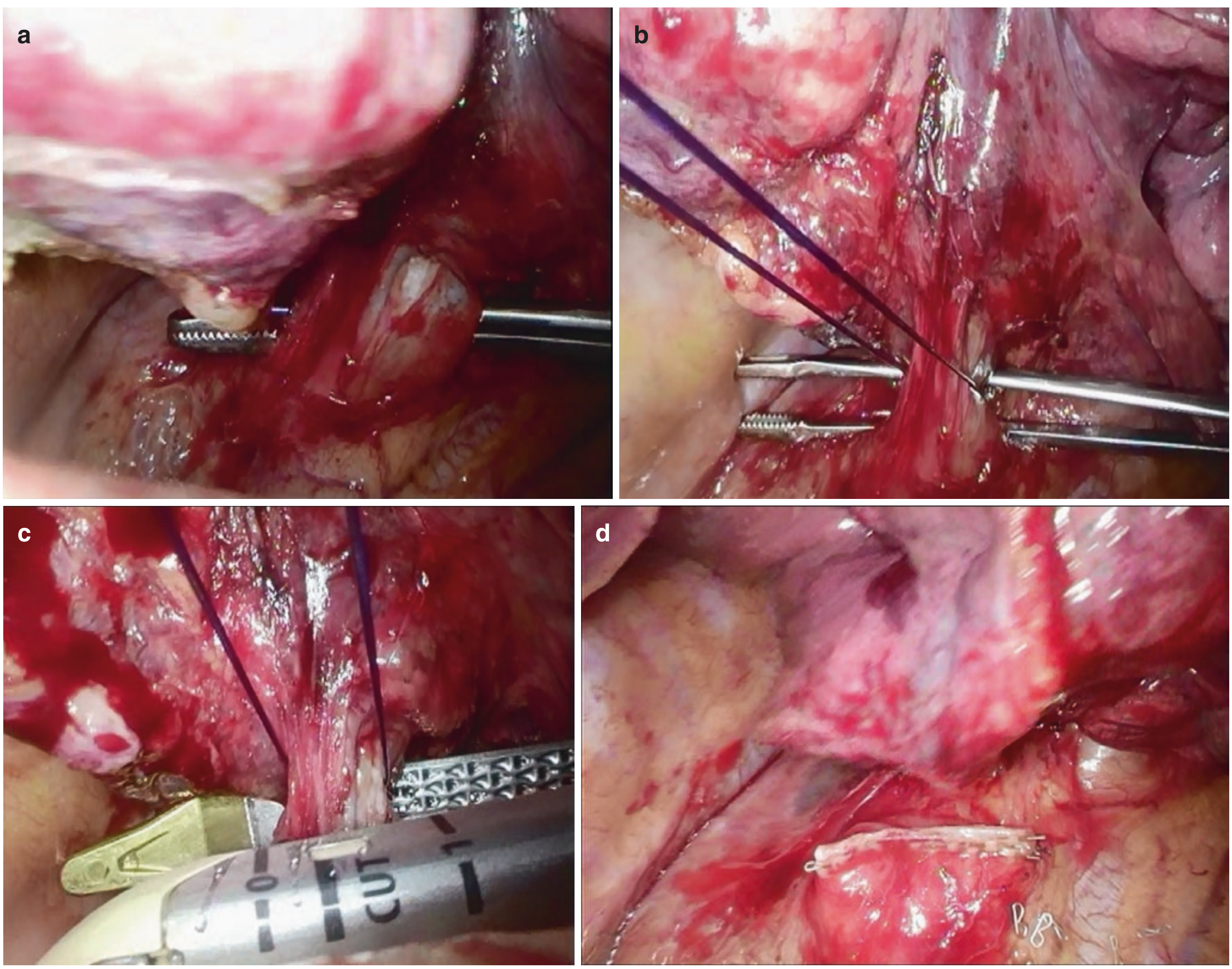

Fig. 4.21 (**a**) Dissecting the space between the vein and lower bronchus. (**b**) Encircling the vein with a ligature. (**c**) Passage of the stapler anvil behind the vein. (**d**) The stump of the vein, after division

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.

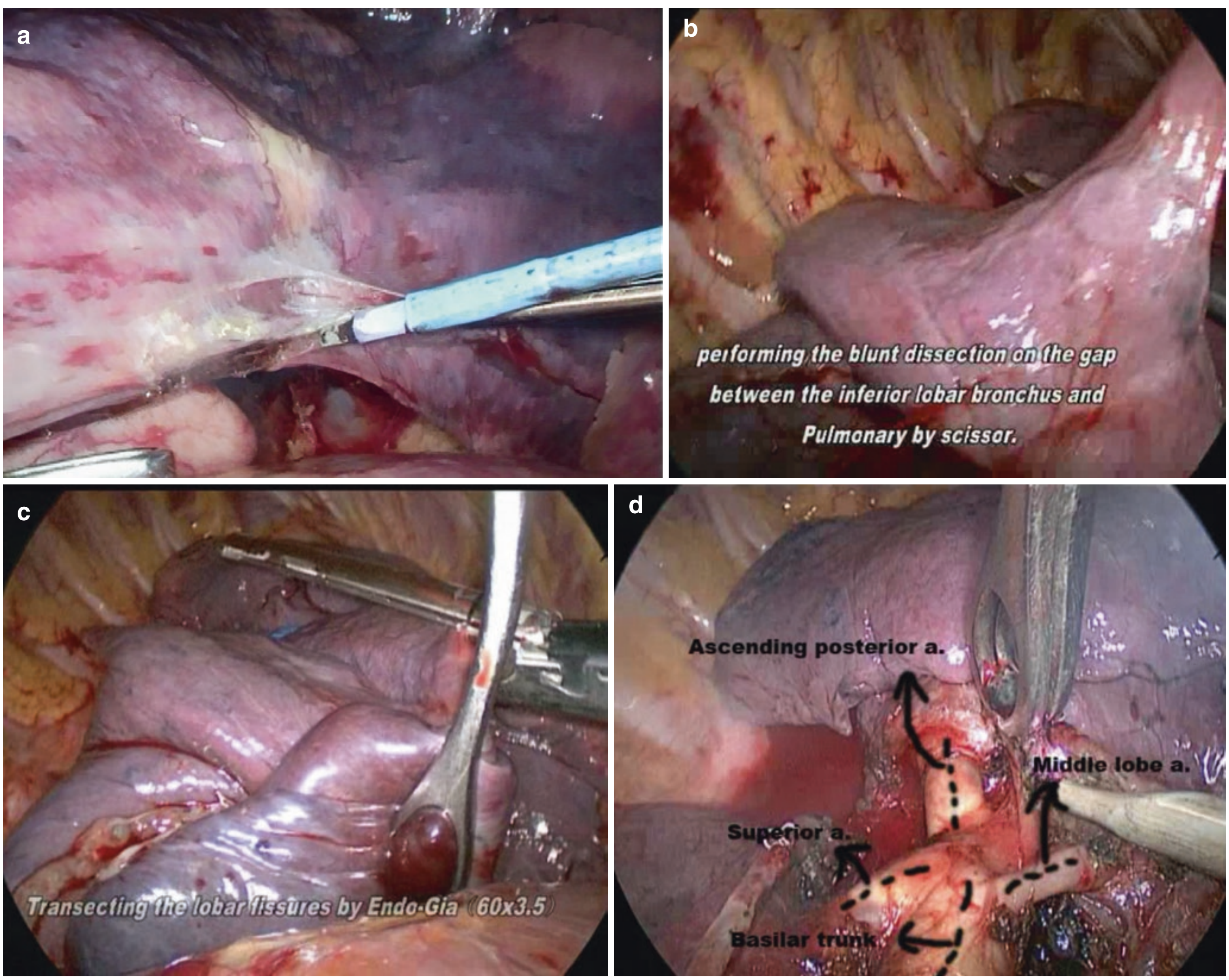

Fig. 4.22 (**a**) Initiating dissection of the fissure at its thinnest point. (**b**) Creating the tunnel. (**c**) Division of the fissure using a stapler. (**d**) Exposure of the branches of the pulmonary artery after division of the fissure

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.

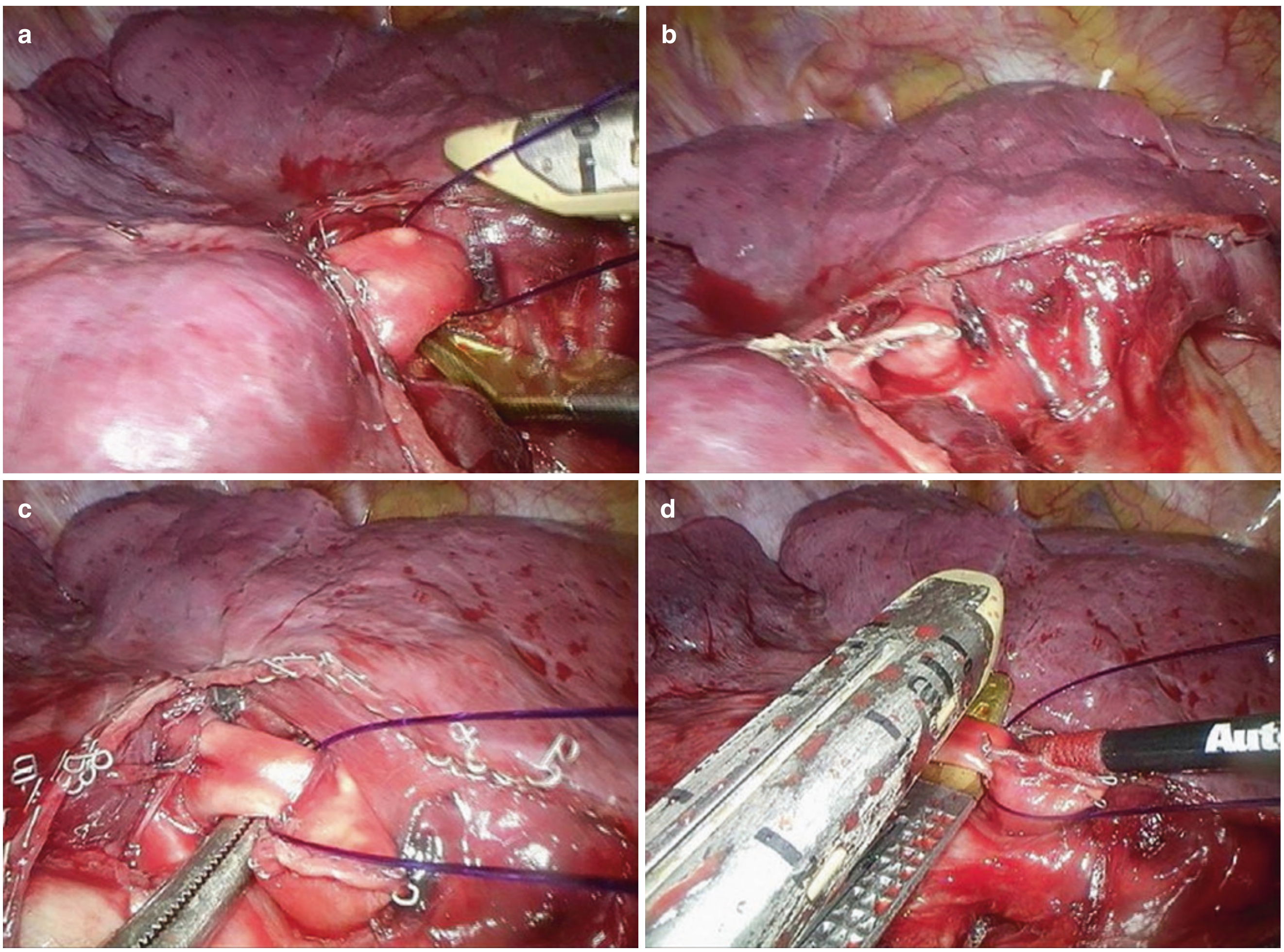

Fig. 4.23 (**a**) Isolation of the basilar artery. (**b**) After division of the basilar artery. (**c**) Isolation of the superior segmental artery. (**d**) Division of the superior segmental artery

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

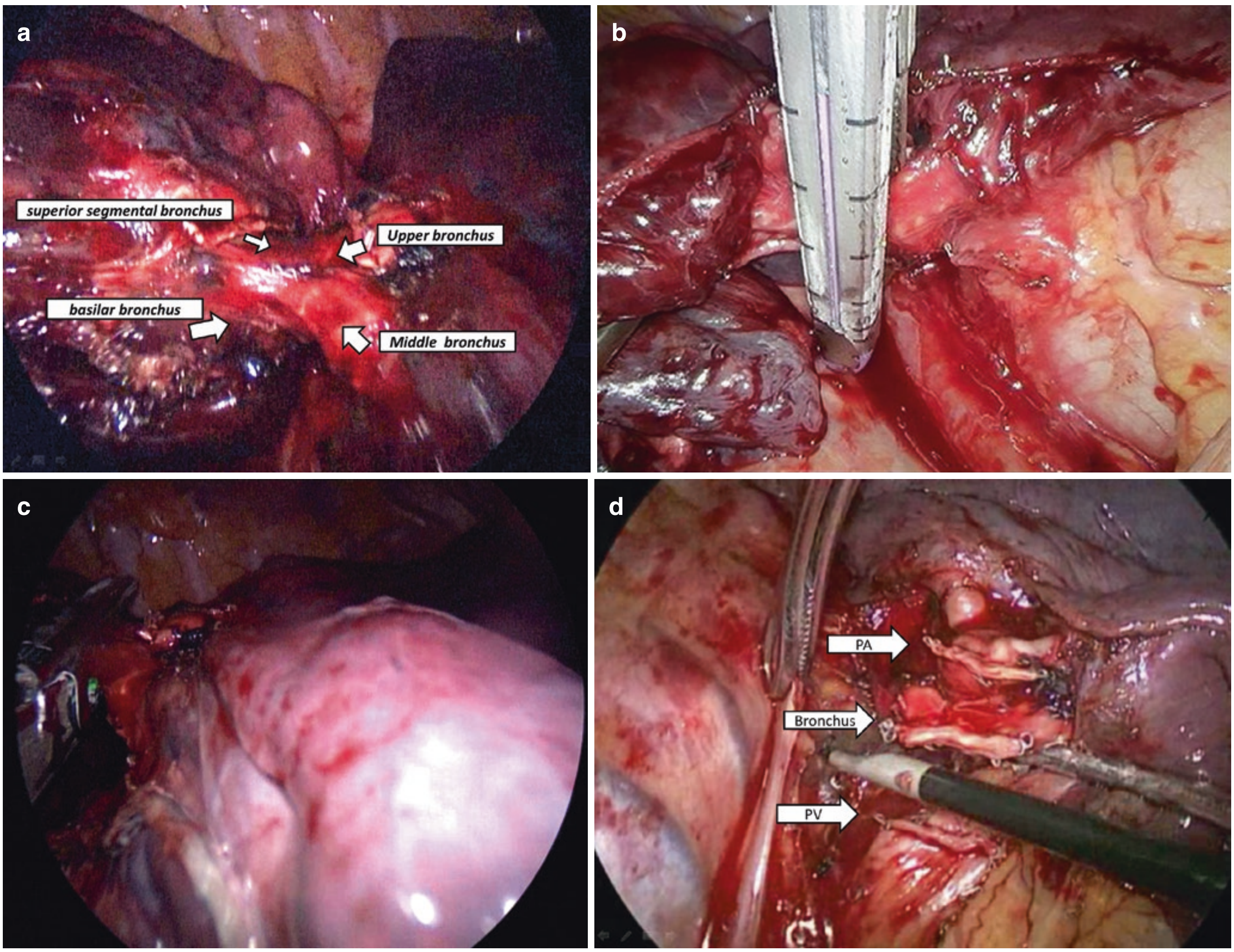

Fig. 4.24 (**a**) Identification of the branches of the bronchus. (**b**) Division of the bronchus. (**c**) Confirmation of ventilation to the middle lobe. (**d**) The stumps of the divided bronchus, artery and vein are shown

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).

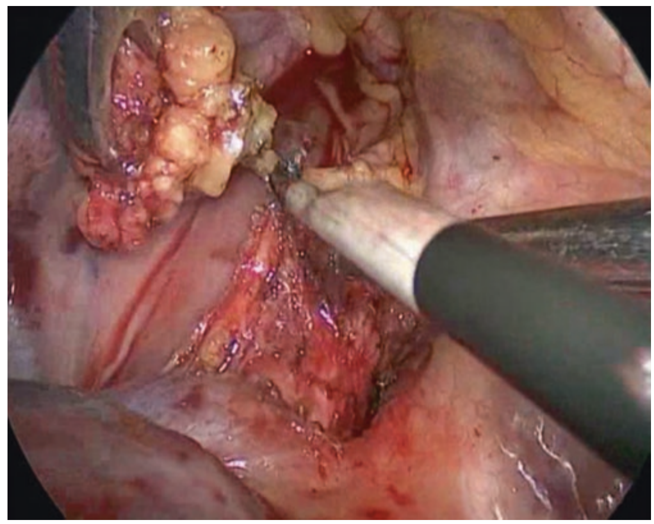

Fig. 4.25 The station 2R, 4R lymph nodes are dissected en-bloc

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).

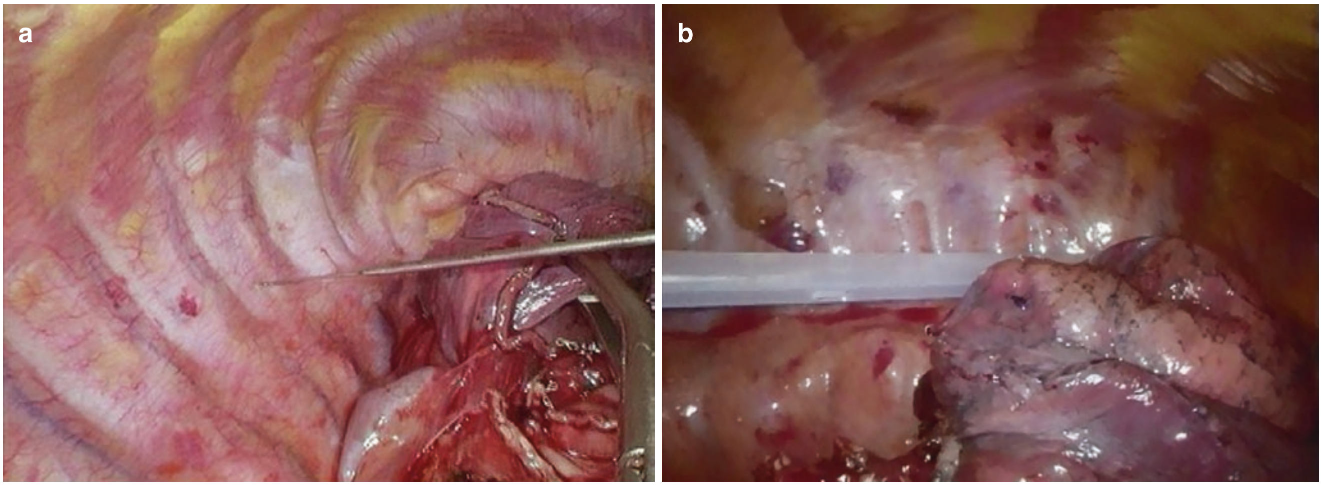

Fig. 4.26 (**a**) Intercostal nerve blocks. (**b**) *Placement of a* 28 Frchest tube

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).

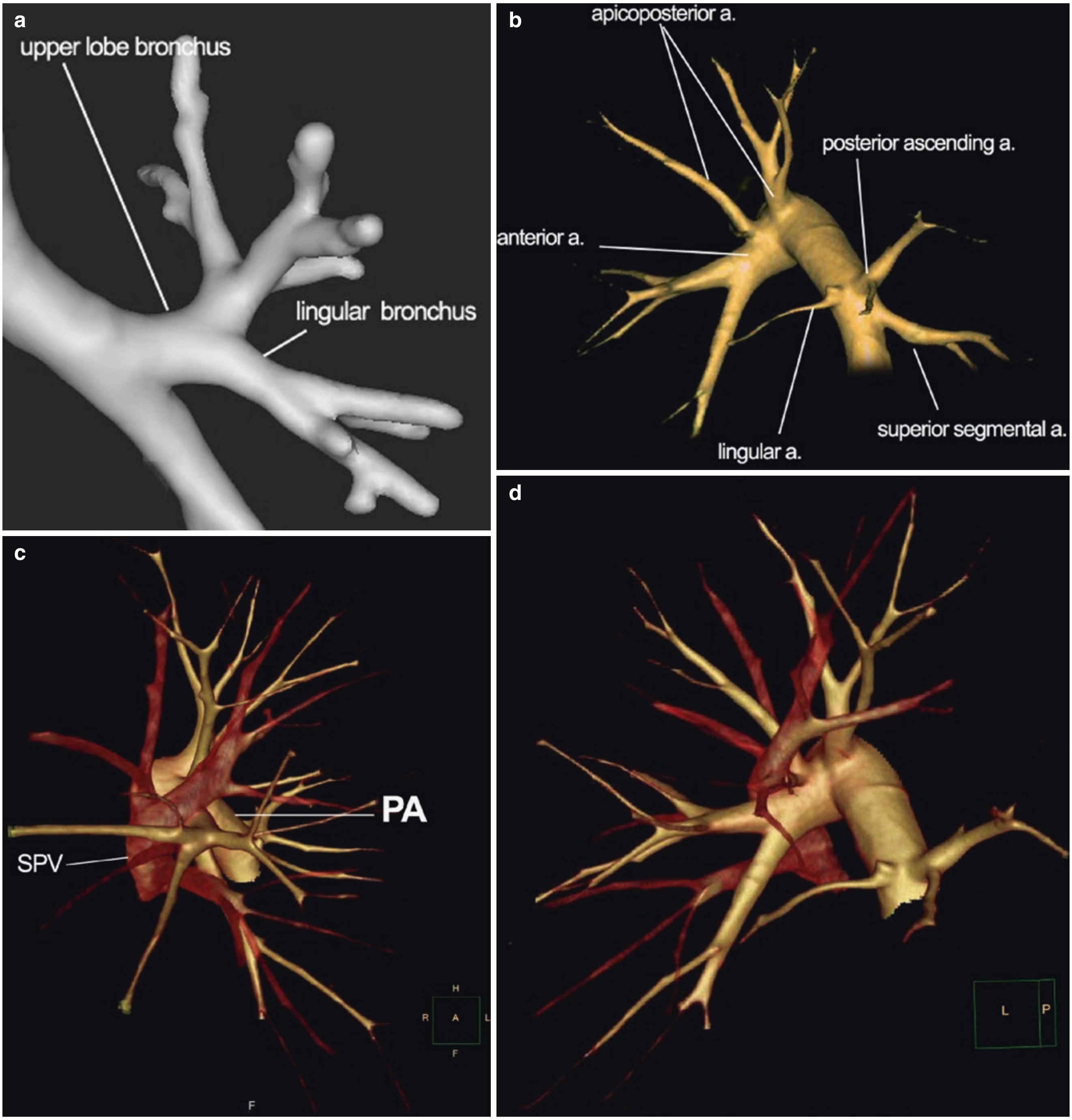

Fig. 4.27 Anatomical landmarks of left upper lobe: (**a**) Upper lobe bronchus (*anterior view*). (**b**) Upper lobe arteries (*left lateral view*). (**c**) Relationships between arteries and veins of the right lower lobe (*anterior view*). (**d**) Relationships between arteries and veins of the right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

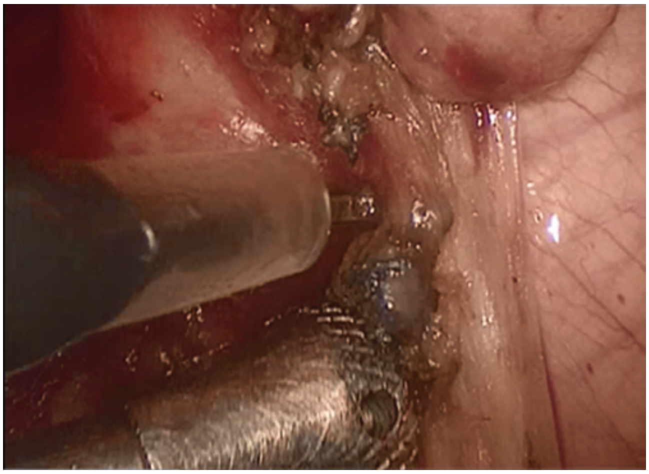

Fig. 4.28 Dissecting the pulmonary ligament, and resecting the group 9 lymph nodes

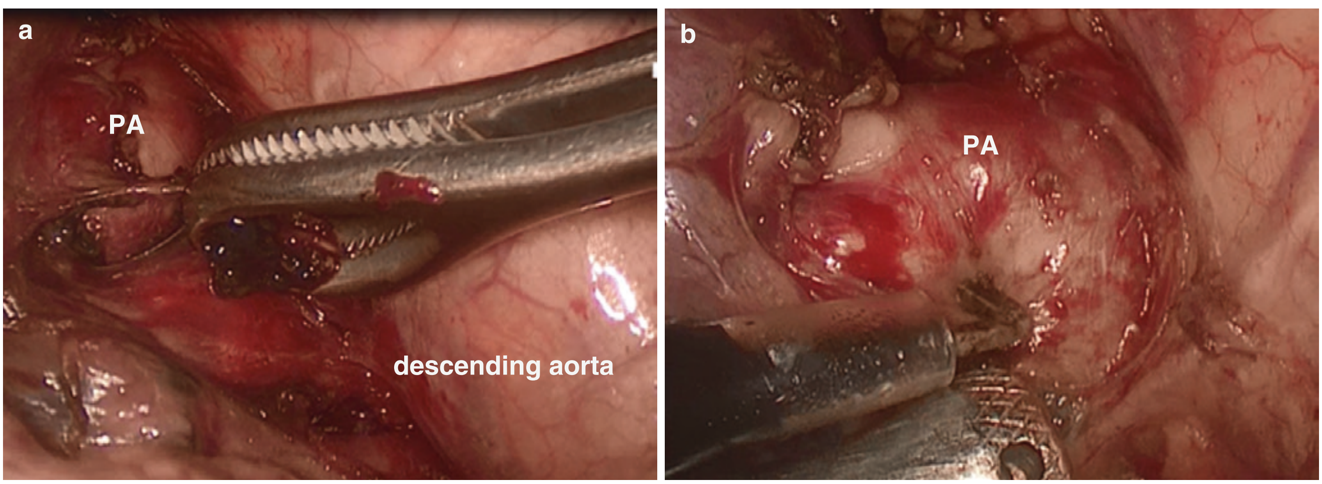

Fig. 4.29 (**a**) Dissecting the lymph nodes on the pulmonary arterial trunk. (**b**) Dividing the vagina vasorum of left pulmonary arterial trunk

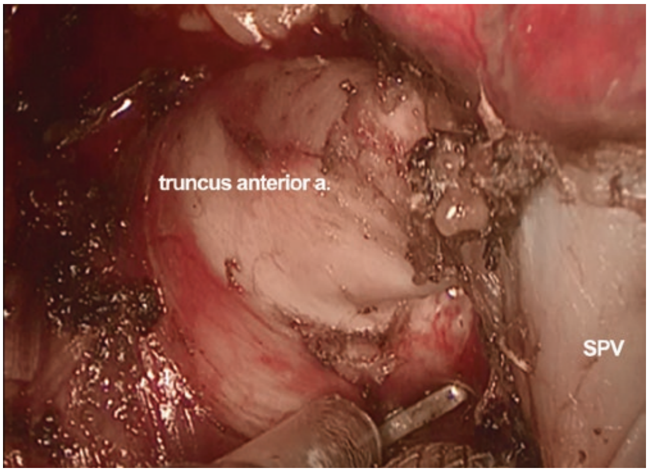

Fig. 4.30 Dividing the truncus anterior artery

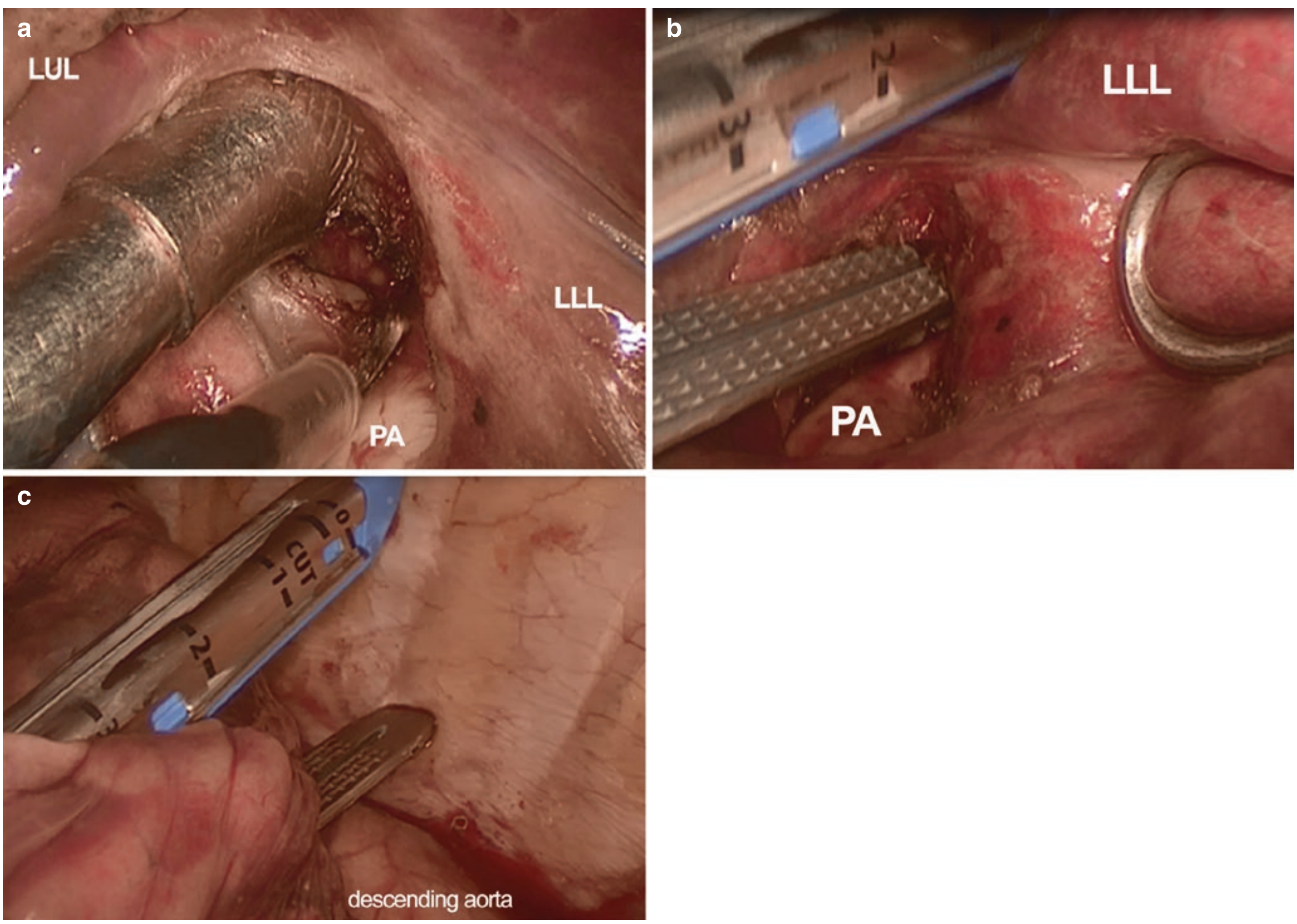

Fig. 4.31 (**a**) Dividing the fissure until the pulmonary arteries are exposed. (**b**) Making an artificial "tunnel". (**c**) Stapling the posterior portion of fused fissure

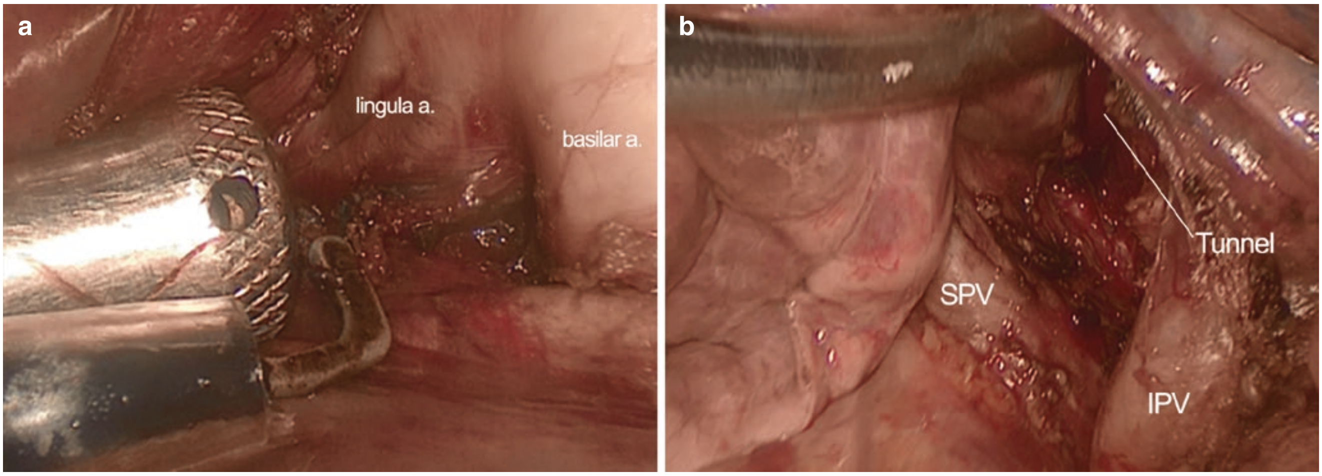

Fig. 4.32 (**a**) Anterior part of the oblique fissure, arteries exposed in last step. (**b**) Another "tunnel" made from anterior hilum

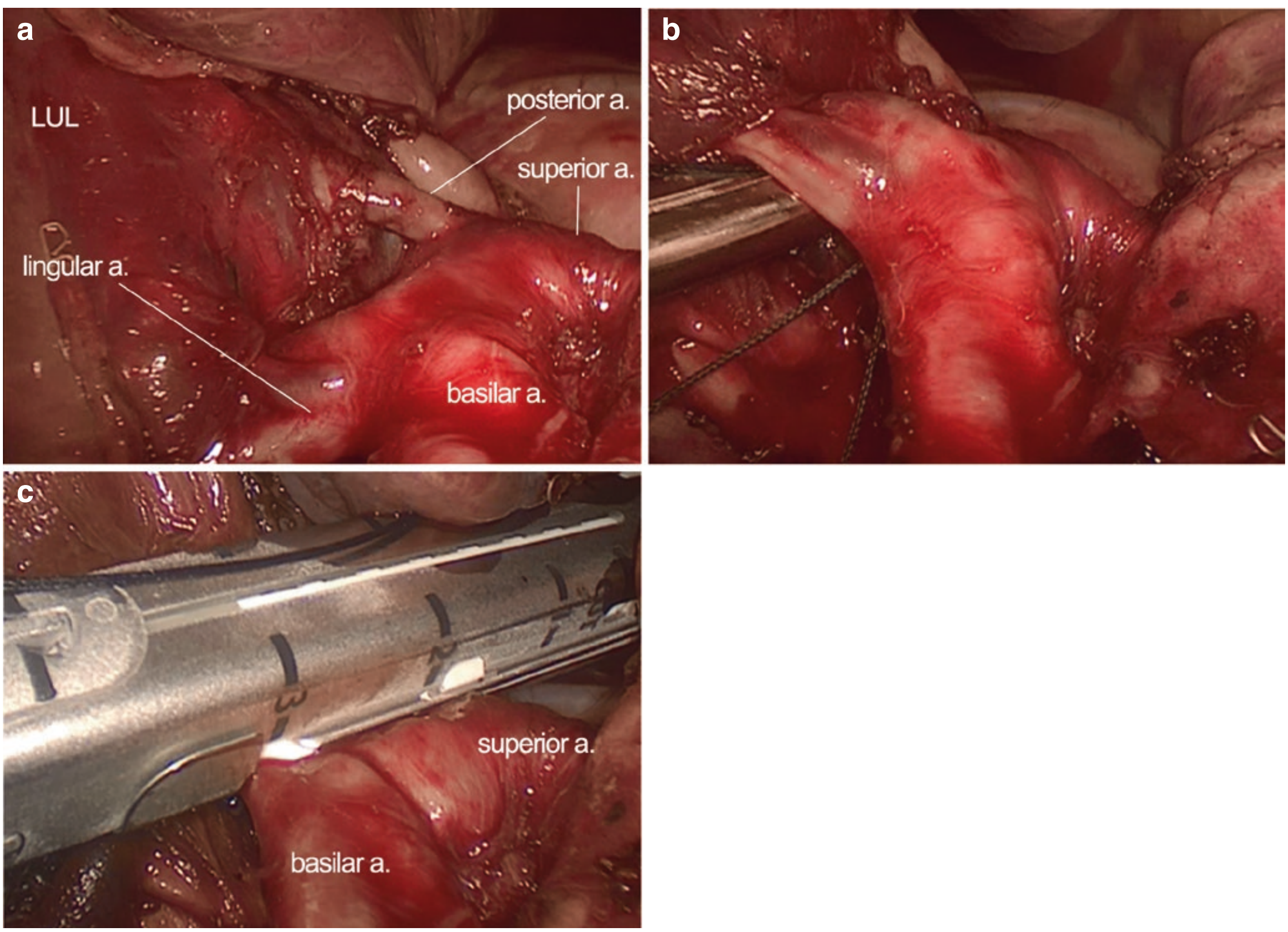

Fig. 4.33 (**a**) The well exposed pulmonary arteries. (**b**) Dividing the posterior ascending arteries. (**c**) Cutting off the posterior ascending arteries

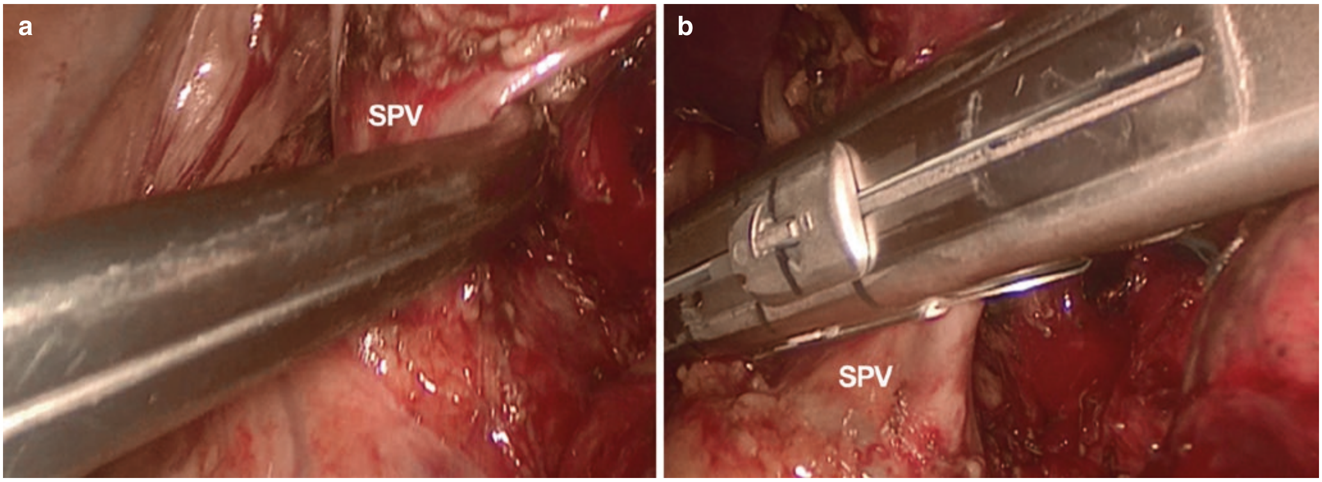

Fig. 4.34 (**a**) Dividing the superior pulmonary vein. (**b**) Cut ting off the pulmonary vein

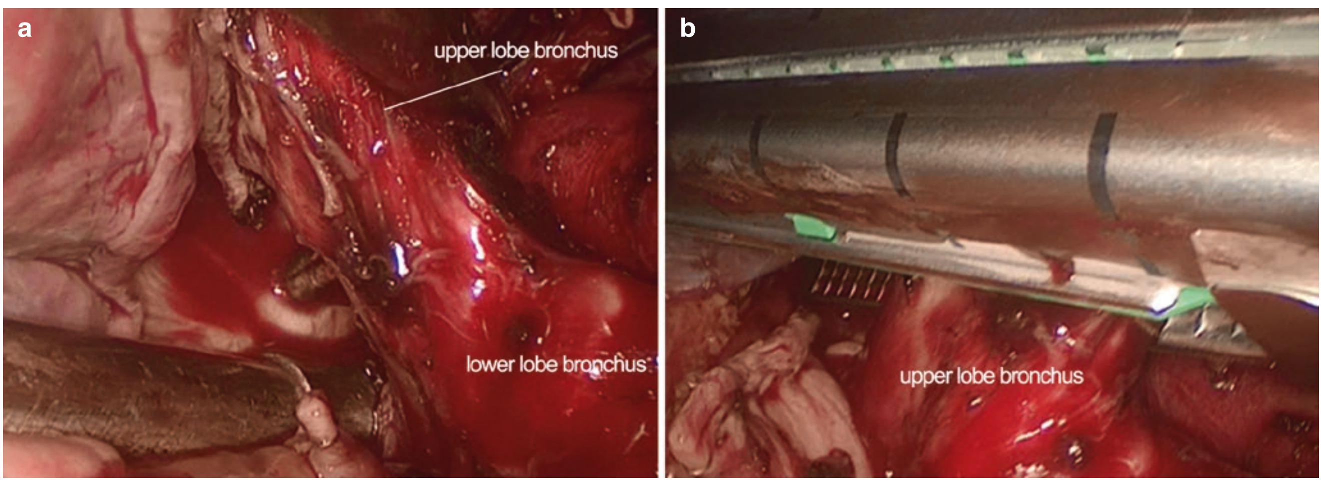

Fig. 4.35 (**a**) Dividing the upper lobe bronchus. (**b**) Cutting off the bronchus

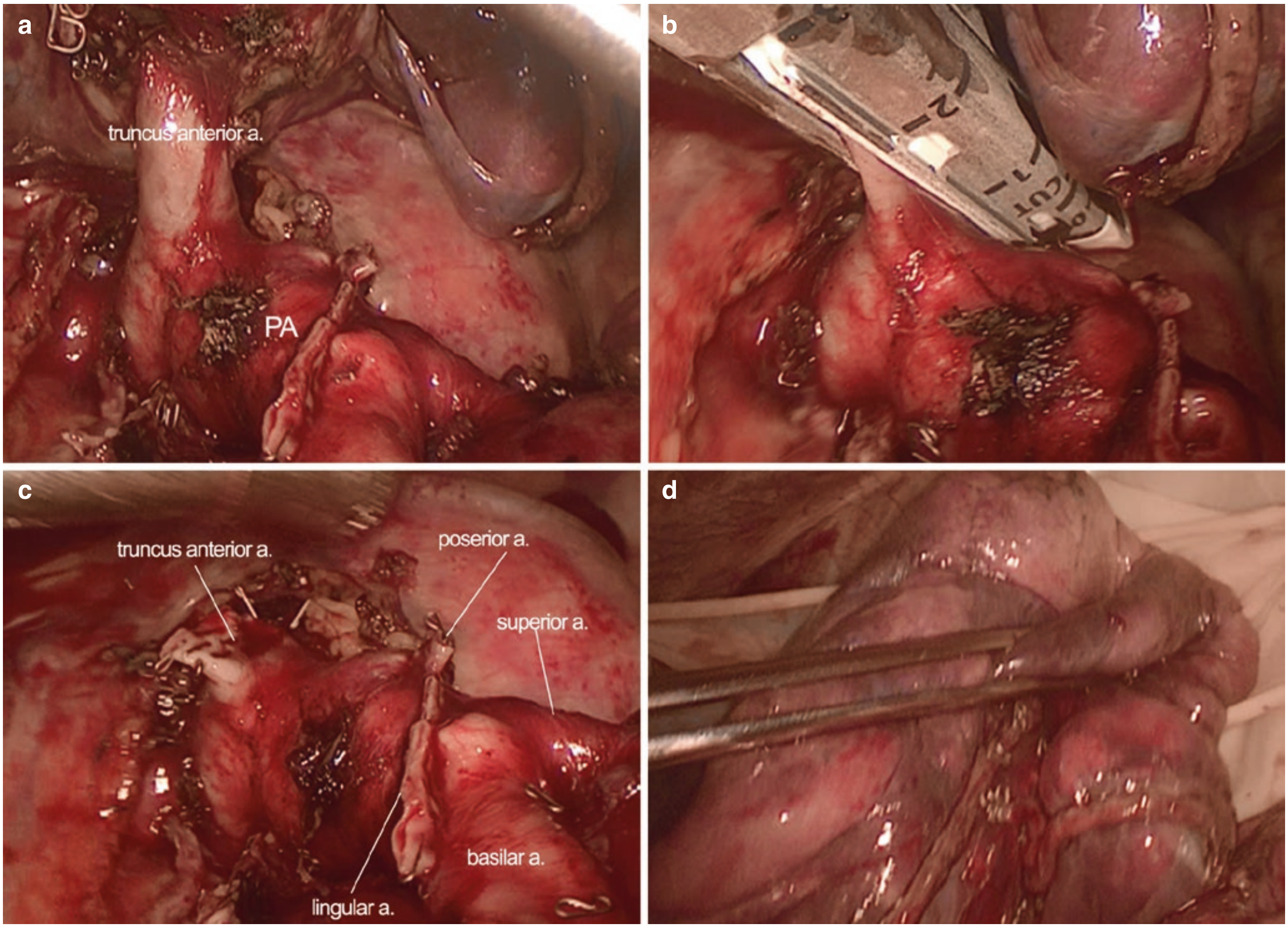

Fig. 4.36 (**a**) Dissecting the truncus anterior. (**b**) Cutting off the truncus anterior artery. (**c**) View of the arterial stumps. (**d**) Extracting the resected lobe by a sterile glove

4.6 Left Lower Lobe

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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).

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

8. Pull the LLL toward the apex and staple the inferior pulmonary vein by endostapler (Fig. 4.45).
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).

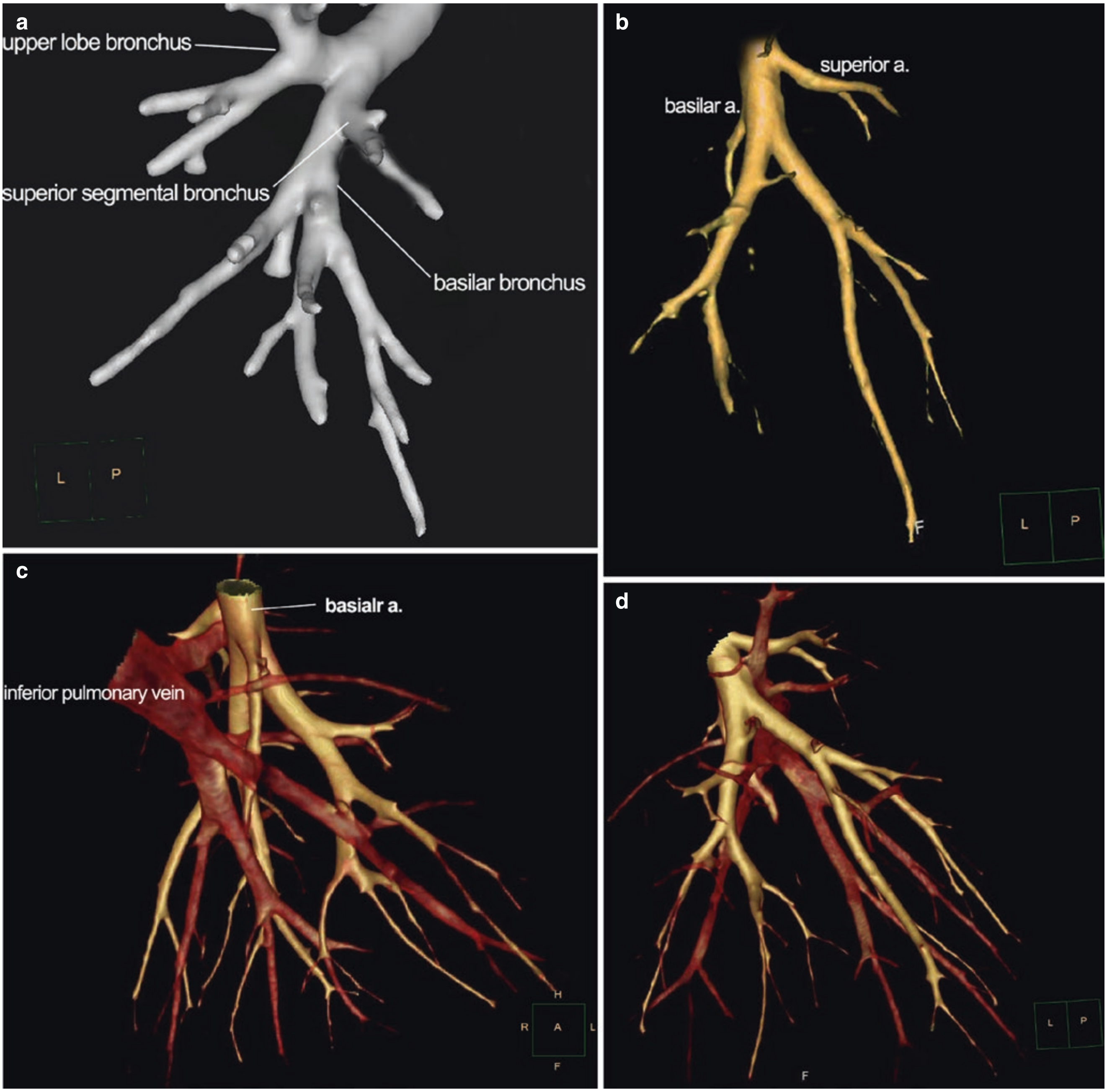

Fig. 4.37 Anatomical landmarks of left lower lobe: (**a**) Lower lobe bronchus (*left lateral view*). (**b**) Lower lobe arteries (*left lateral view*). (**c**) Relationships between arteries and veins of the right lower lobe (*anterior view*). (**d**) Relationships between arteries and veins of the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

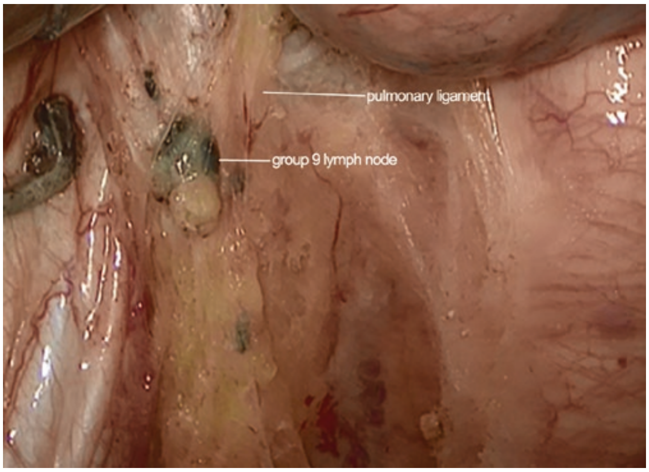

Fig. 4.38 Dissecting the pulmonary ligament, and resecting the group 9 lymph nodes

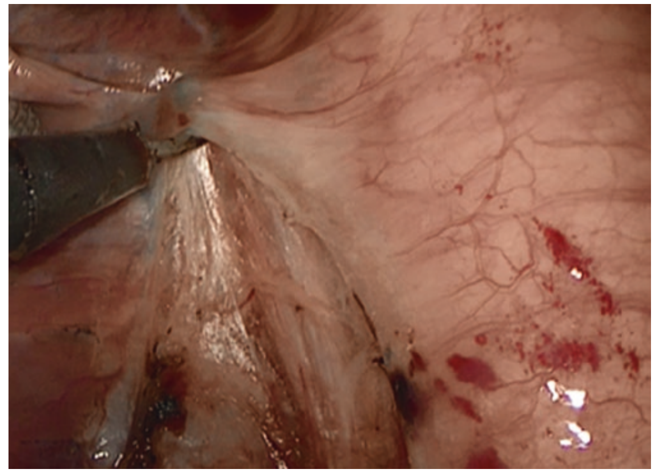

Fig. 4.39 Dissecting the posterior mediastinal pleura

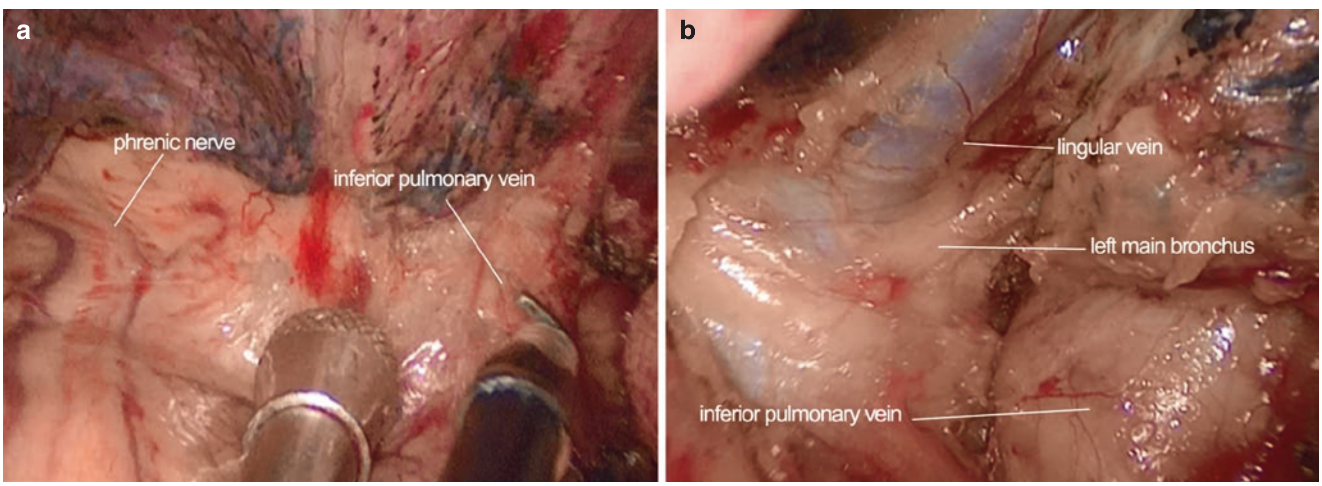

Fig. 4.40 (**a**) Dividing the anterior mediastinal pleura. (**b**) Anterior hilum between superior and inferior vein

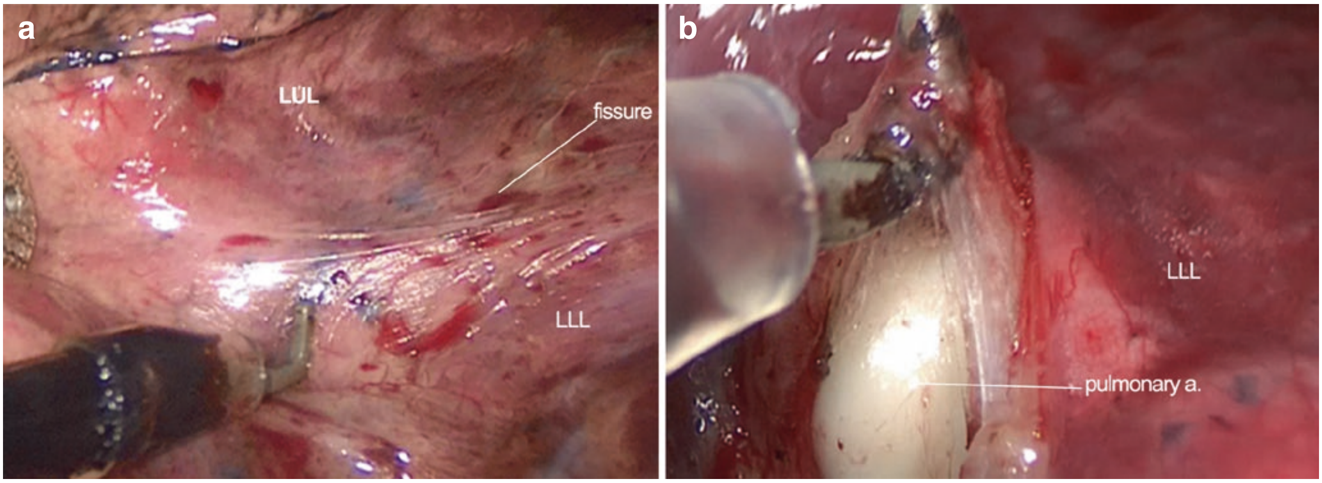

Fig. 4.41 (**a**) Dividing the fused fissure. (**b**) Exposed pulmonary artery

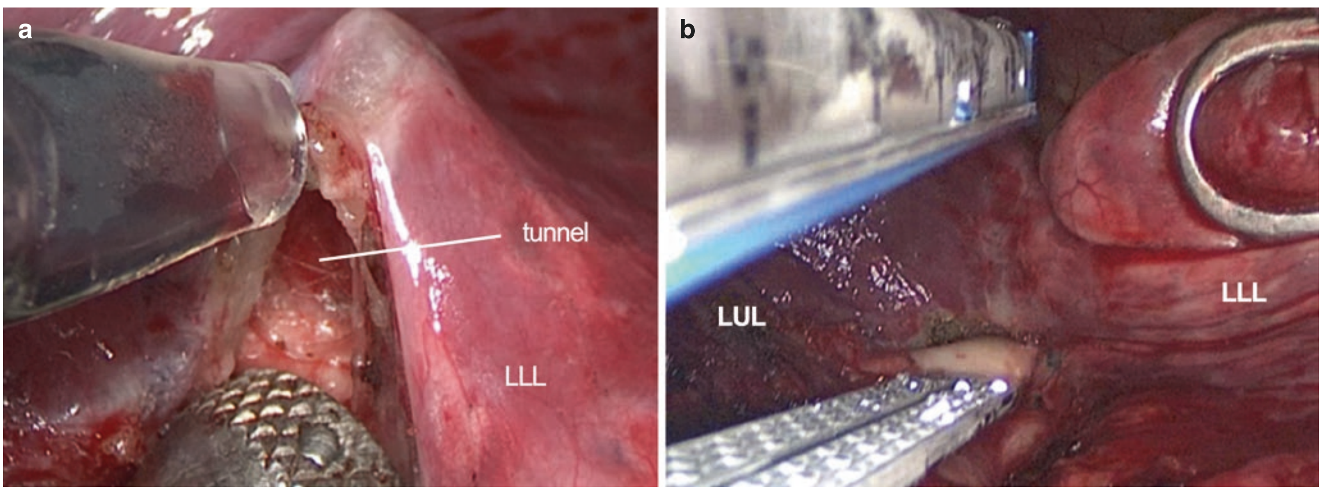

Fig. 4.42 (**a**) An artificial interlobar "tunnel" is set up. (**b**) Stapling the posterior portion of fused fissure

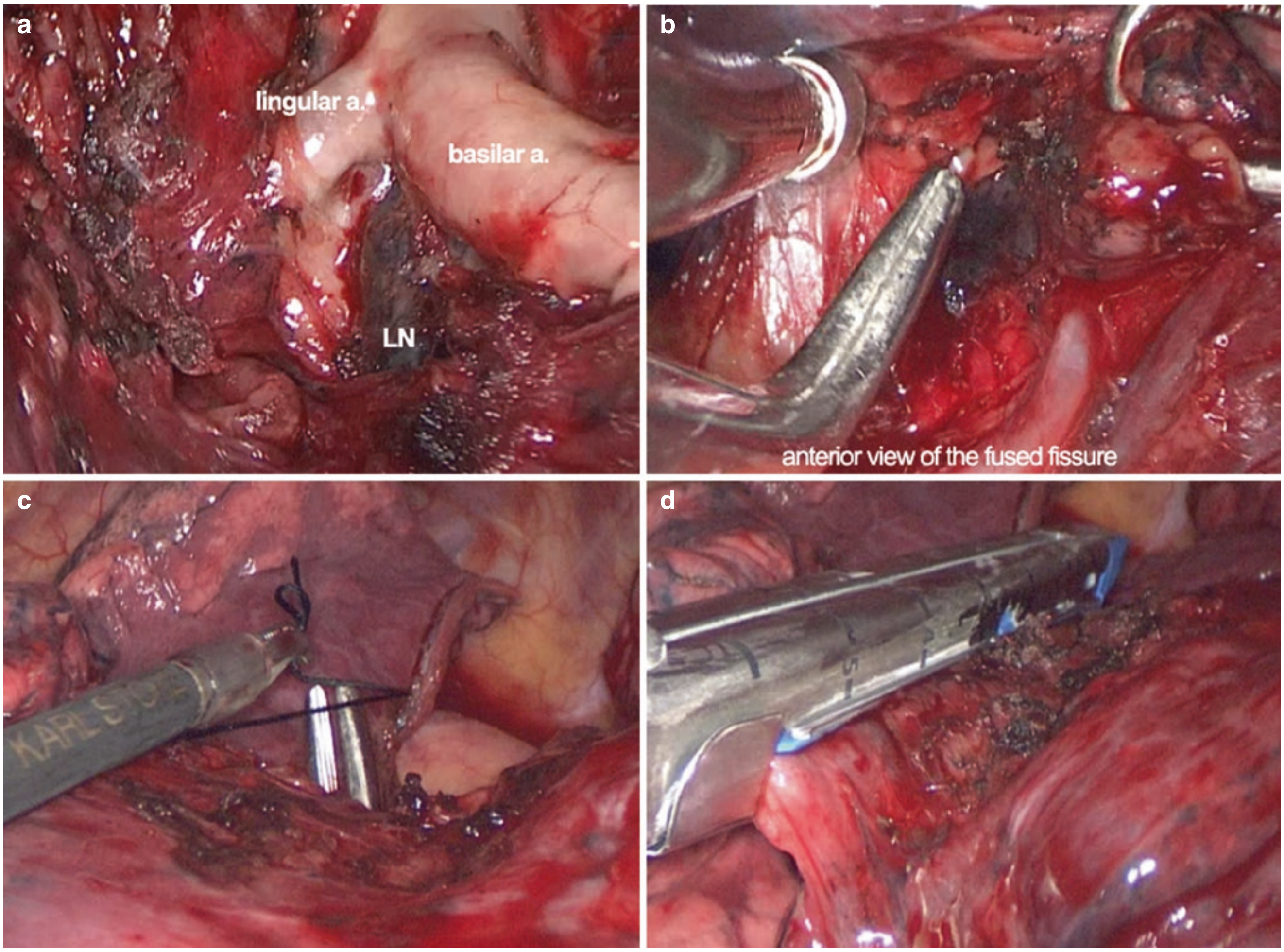

Fig. 4.43 Dividing the anterior portion of the fissure

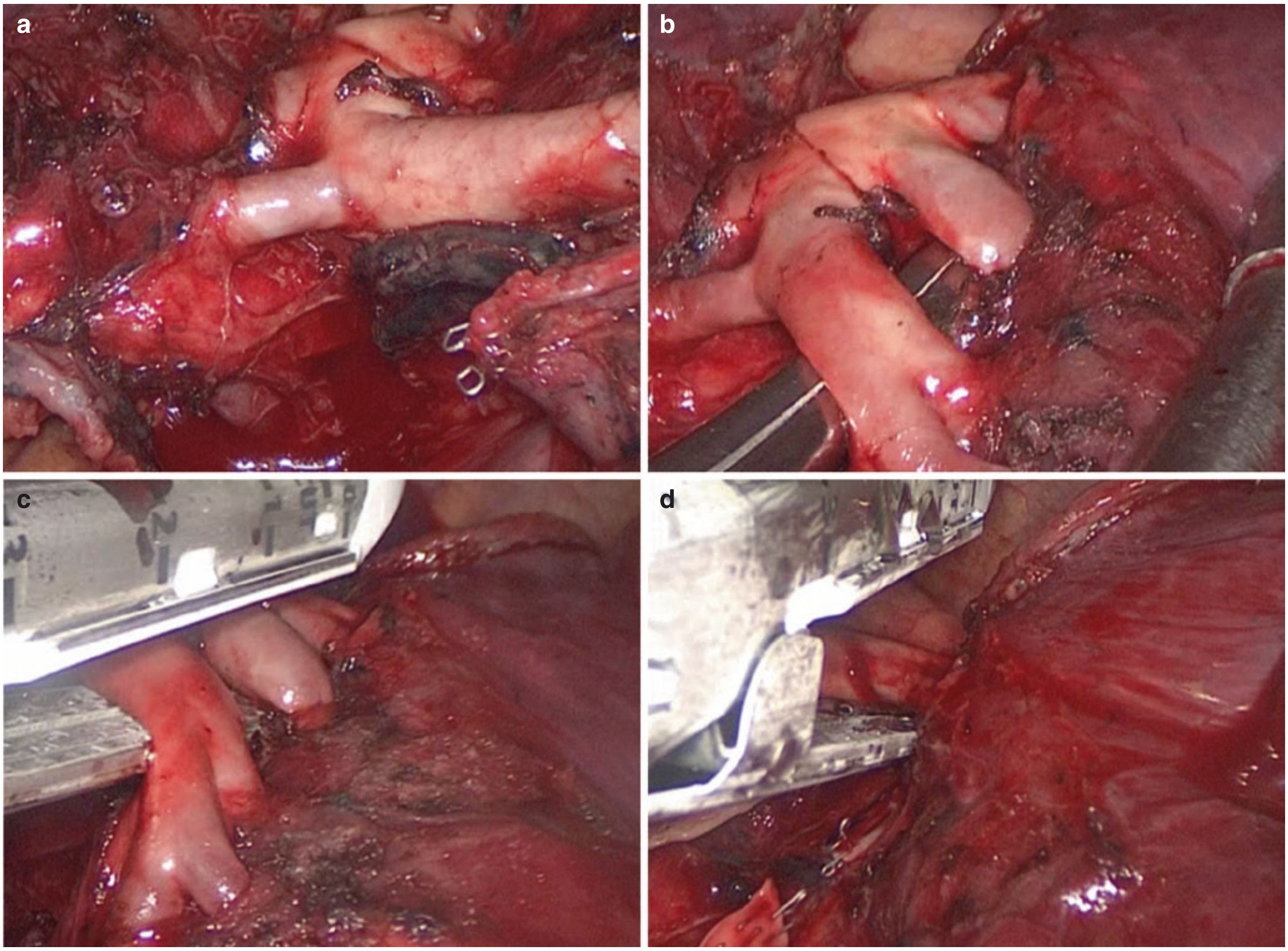

Fig. 4.44 (**a**, **b**) The well exposed pulmonary arteries. (**c**, **d**) Cutting off the basal trunk and superior segmental artery separately or together

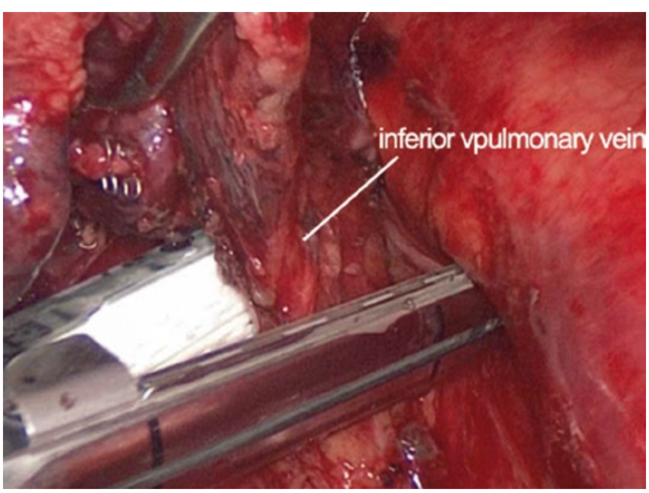

Fig. 4.45 Cut ting off the pulmonary vein

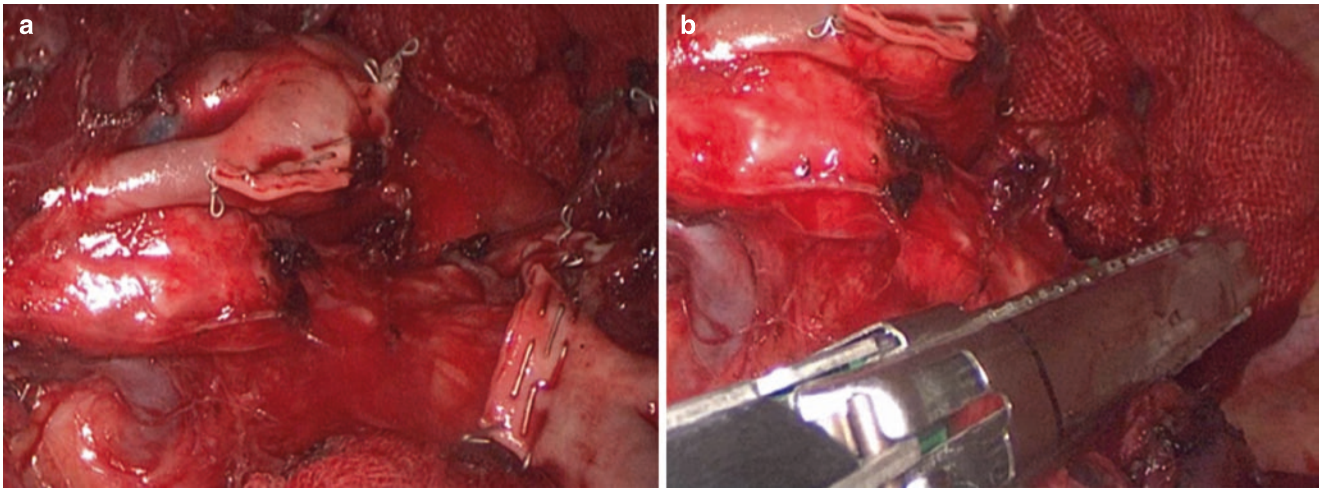

Fig. 4.46 Cut ting off the lower lobe bronchus

4.7 Results and Discussion

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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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