

Pneumonectomy for Non–Small Cell Lung Cancer



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KEYWORDS

- Pneumonectomy • Multimodal therapy • Operative technique • Lung cancer
- Preoperative evaluation • Operative complications

KEY POINTS

- The diagnosis and management of lung cancer requires a multimodal approach that often involves surgical resection.
- Accurate preoperative staging is essential in selecting patients who would benefit the most from pneumonectomy.
- Pneumonectomy is usually indicated when tumors are centrally located, involving the hilum, or as part of a multimodal approach to locally advanced tumors.
- Pneumonectomy is a difficult and technically demanding operation associated with a high rate of perioperative morbidity.

INTRODUCTION

Lung cancer remains the most common cancer in the world, both in terms of new cases (1.8 million cases, 12.9% of total) and deaths (1.6 million deaths, 19.4%).^{1–3} The 2 major histologic types of lung cancer are small cell lung cancer (SCLC) and non–SCLC (NSCLC). SCLC accounts for 20% of all new lung cancer diagnoses.² Although SCLC is the more aggressive cancer, limited stage SCLC is usually responsive to systemic chemotherapy, with median survival rates of 18 to 36 months and 5-year survival of 20% to 25%.⁴ In contrast, NSCLC accounts for 80% of all new lung cancers and is amenable to surgical excision in select patients. NSCLC

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includes three major subtypes; squamous cell carcinoma (30%-40%), adenocarcinoma (25%-30%), and large cell lung carcinoma (<10%).⁵

A multidisciplinary approach to the diagnosis and management of lung cancer is essential to design a personalized treatment plan for each patient. The overall clinical status of the patient, pathologic subtype, and disease stage are all taken into account when designing the treatment plan.⁶⁻¹⁰ Staging is specifically important because the anatomic extent of the tumor has a significant impact on the treatment of choice and the final prognosis.¹¹ Original staging classifications were based on the TNM system dating back to 1944 and the multiple revisions of the staging classifications that have taken place since then.³ The most recent edition (seventh edition) of the lung cancer staging system has been defined by the International Association for the Study of Lung Cancer using a patient database of more than 100,000 patients. The next revision of the lung cancer staging system is slated to be published in 2016.³

Early and intermediate stage cancers (I and II) have in common the fact that a complete resection is achieved by anatomic resection, either lobectomy or pneumonectomy.¹² Locally advanced lung cancers (IIIA and IIIB) are also amenable to surgical resection in select groups using a multimodal approach to therapy.¹³⁻¹⁵ Pneumonectomy for non-SCLC is usually indicated when tumors are located centrally and invading vascular structures or the proximal bronchus, or when part of a multimodal approach to locally advanced tumors. Pneumonectomy, when part of a multimodal approach, has been shown to offer improved encouraging long term survival rates in selected patients with N2 disease.^{13,15-19}

Neoadjuvant chemotherapy and radiation are not recommended as treatment options for early to intermediate stage lung cancer.^{7,12} However, neoadjuvant chemoradiation has been shown as an effective tool to achieve regression of N2 nodes.²⁰ Adjuvant chemotherapy is recommended for stage IIA, IIB, and IIIA cancers, whereas adjuvant radiation therapy is currently only recommended for patients with N2 nodal disease to decrease local recurrence.^{7,12,21} Current data describe 5-year survival rates for stages I and II as 60% to 80% and 30% to 50%, respectively.^{8,22} The 5-year survival for stage III disease has been reported to be approximately 25% to 45% when using a multimodal approach to therapy.^{12,14,23-25} Accurate preoperative staging is essential in selecting patients who would benefit the most from a multidisciplinary approach to treatment of locally advanced disease that includes pneumonectomy.^{26,27}

PREOPERATIVE WORKUP

Staging

First, a complete history and a physical examination that focuses on performance status and weight loss as well as on identification of chest wall and lymph node involvement, and on signs of distant spread is performed. Next, a computed tomography scan of the chest and a PET/computed tomography scan are performed.²⁸⁻³⁰ These measures will rule out distant metastases, other than brain metastases. Patients without symptoms of headache and with a PET-negative mediastinum are unlikely to have brain metastases, so brain computed tomography scans or MRIs are not mandatory for preoperative staging. However, brain imaging should be included in the standard workup of those patients with locally advanced disease (stage IIIA or IIIB) or preoperative evaluation suggesting a high likelihood of nodal involvement to rule out brain metastases.

All patients with lung cancer should first undergo preoperative staging (**Box 1**). Candidates for pneumonectomy typically have large or central tumors and thus are likely

Box 1**Preoperative evaluation of potential pneumonectomy patients**

1. Complete history and a physical examination with focuses on performance status, weight loss, detection of chest wall involvement and detection of lymphatic or distant metastatic spread.
2. Imaging
 - a. Chest computed tomography scan
 - b. PET scan with or without brain MRI
3. Invasive Diagnostic Procedures
 - a. Mediastinoscopy/endobronchial ultrasound with transbronchial needle aspiration
 - b. Thoracoscopy

to have mediastinal metastases. PET scans are relatively sensitive for detecting mediastinal metastases; nevertheless, they are still not as accurate as mediastinoscopy and newer minimally invasive techniques for tissue acquisition like endobronchial ultrasound with transbronchial needle aspiration.^{31–34} Thus, we believe that tissue biopsy (either with endobronchial ultrasound, preoperative mediastinoscopy, or thoracoscopy), is indicated for patients who may undergo pneumonectomy, even if they have a PET-negative mediastinum.

Surgical Evaluation

Having mentioned the importance of surgical staging of the mediastinum, 2 other surgical evaluations should be considered in the preoperative workup of a pneumonectomy patient. Bronchoscopic evaluation of the airway will ensure that a patient with a hilar mass does not also have a contralateral endobronchial lesion. In the event the surgery is successful, a pneumonectomy would subject the patient to a difficult and possibly lengthy recovery with no impact on overall survival.³⁵ Thoracoscopic evaluation and staging of the pleural space has the potential to benefit patients undergoing pneumonectomy in multiple ways.³⁶ Thoracoscopy helps to identify pleural metastases that cannot be identified by conventional imaging techniques. Thoracoscopic nodal sampling or lymphadenectomy can evaluate suspicious nodes in patients who have not had tissue sampling and can also facilitate the sampling of nodes that are inaccessible to other biopsy techniques. Thoracoscopy can be used for surgical planning to determine the incision used for resection.

Cardiopulmonary Evaluation

Preoperative lung function is another valuable data point in the workup of a pneumonectomy patient. Patients with a preoperative forced expiratory volume in 1 second (FEV₁) of more than 2 L are considered eligible for pneumonectomy. For patients with a low or borderline FEV₁ it is useful to calculate the predicted postoperative lung function and diffusing capacity of the lung for carbon monoxide because these parameters were shown to correlate with postoperative complications after pneumonectomy.^{37–39} Patients with a predicted postoperative FEV₁ of more than 800 mL have been shown to have adequate pulmonary reserve to undergo resection in long-term follow-up.⁴⁰ Most patients requiring a pneumonectomy have obstructing cancers and are thus compensating for the loss of substantial lung function in the affected lung by depending primarily on the unaffected lung for respiration. Quantitative perfusion scanning (V/Q scan) has been used for more than 30 years to determine the relative contribution of each lung to the patient's total lung function and can be valuable when interpreting preoperative lung function studies.^{41,42} Cardiac evaluations

(ie, echocardiography, stress testing) and preoperative referral to a cardiologist should be performed in all patients. We routinely perform echocardiograms in patients with locally advanced disease to evaluate overall cardiac function and to assess any possible tumor invasion of the pericardium. Lower extremity duplex Doppler ultrasound to rule out deep venous thrombosis should also be considered in patients with locally advanced disease (Box 2).

TECHNIQUE
Left Pneumonectomy

While in the preoperative holding area, the anesthesia team places an epidural catheter for postoperative pain management. The patient is first positioned supine and intubated with a single lumen endotracheal tube and a bronchial blocker passed into the lung to be removed. Alternatively, a double lumen endotracheal tube, or the endotracheal tube can be purposefully main-stemmed in the bronchus of the lung to be preserved. To optimize the hemodynamic monitoring of the patient we routinely place a urinary catheter, an arterial line and a Swan–Ganz catheter. Once the anesthesiology team is ready, the patient is repositioned in the right or left lateral decubitus position. The lung on the side to be resected is occluded and positioning of the tube and blocker confirmed.

A muscle-sparing posterolateral thoracotomy skin incision is made. The latissimus dorsi muscle is divided and the serratus anterior muscle is retracted superiorly. The pleural space is approached via the fifth intercostal space (Fig. 1). Chest spreaders are placed to facilitate exposure. If needed the rib can be transected posteriorly. The chest is inspected for pleural effusion and the chest wall and lung are assessed for metastatic spread. Any suspicious tissue is sent for frozen section analysis. Next, the mediastinal pleura and inferior pulmonary ligament is divided circumferentially around the hilum using either scissors or electrocautery. Harvesting the lymph nodes in the aortopulmonary window gives better exposure to the proximal pulmonary artery. This technique must be performed carefully to avoid injuring the recurrent laryngeal nerve, which branches off the vagus nerve on the inferior surface of the aortic arch and then dives into the mediastinum immediately inferior and adherent to the arch (Fig. 2). The phrenic nerve should also be preserved, unless it is involved in the tumor. The phrenic nerve is at risk because it may abut the anterior aspect of the nodes in the anteroposterior window. Sometimes the vagus superior to the aorta or the recurrent nerve must be harvested if either is involved with the tumor. However, resection of these nerves will lead to vocal cord paralysis. Harvesting

Box 2
Preoperative evaluation of cardiopulmonary status before pneumonectomy
1. Complete pulmonary function testing with spirometry and diffusing capacity of the lung for carbon monoxide.
2. Quantitative perfusion scanning to evaluate lung function on each side.
3. Calculation of predicted postoperative forced expiratory volume in 1 second and diffusing capacity of the lung for carbon monoxide. Maximum oxygen consumption by exercise stress test.
4. Echocardiography.
5. Evaluation by cardiologist with or without referral for additional tests (stress test, stress echocardiography, left and right heart catheterization).
6. Lower extremity duplex Doppler ultrasound examination.

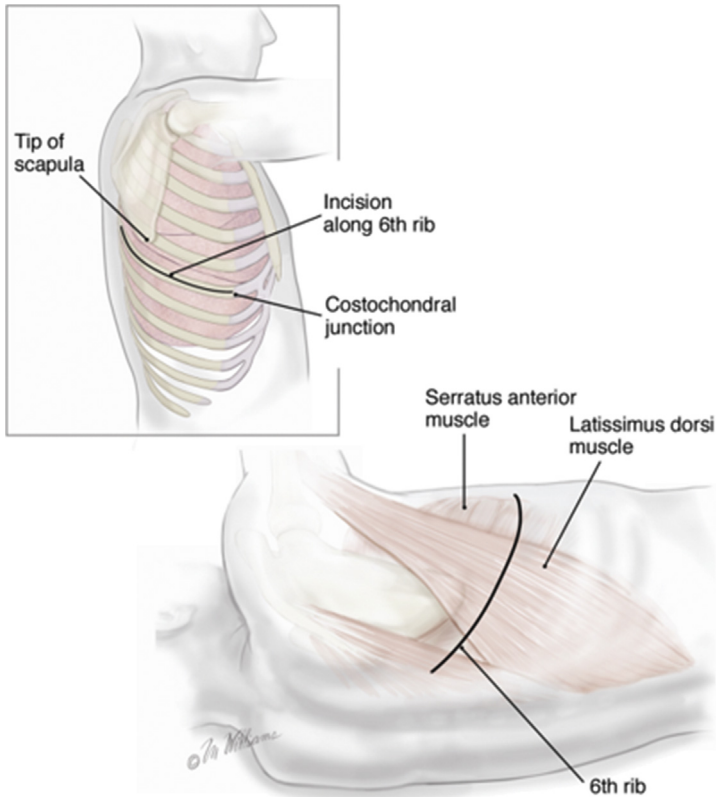


Fig. 1. A muscle-sparing posterolateral thoracotomy skin incision is made. The latissimus dorsi muscle is divided and the serratus anterior muscle is retracted superiorly. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

the subcarinal lymph nodes provides better exposure of the bronchus and also allows better palpation of the bronchus. Once the hilum of the lung is free, the pulmonary artery is dissected away from the superior pulmonary vein anteroinferiorly and the bronchus posteriorly (Figs. 3 and 4). In most instances, this can be done bluntly, before mobilization or division of the superior vein. Dissecting and dividing the vein first is an alternative in patients with inferiorly positioned artery or superiorly positioned vein.

The pulmonary artery should be occluded before its division to ensure that pneumonectomy will not cause right ventricular failure or pulmonary hypertension. Communication with the anesthesiologist is imperative after the artery is clamped to assess the systolic blood pressure and oxygenation and determine if the patient will tolerate pneumonectomy. If hemodynamic instability or hypoxia develops, the pulmonary artery catheter can be used to direct inotropic therapy, but in most cases, it is necessary to abandon the procedure altogether. Care should be taken during this maneuver not to “fracture” the pulmonary artery when temporarily occluding the vessel. (Digital occlusion may be preferable in this situation.)

Additional pulmonary artery length (to allow complete resection) can be obtained by using 1 or both of 2 maneuvers: dividing the ligamentum arteriosum while paying

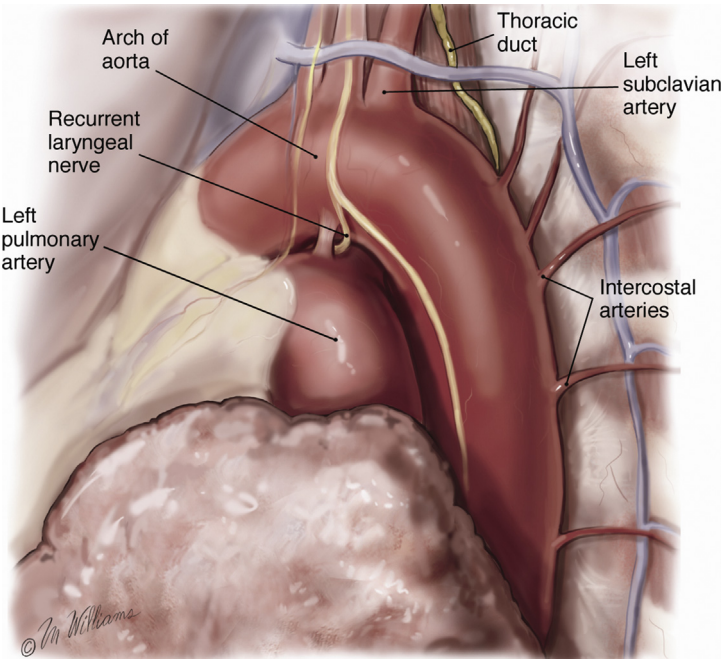


Fig. 2. When dissecting out aortopulmonary nodes, care must be taken to avoid injuring the recurrent laryngeal nerve, which branches off the vagus nerve on the inferior surface of the aortic arch and then dives into the mediastinum immediately inferior and adherent to the arch. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

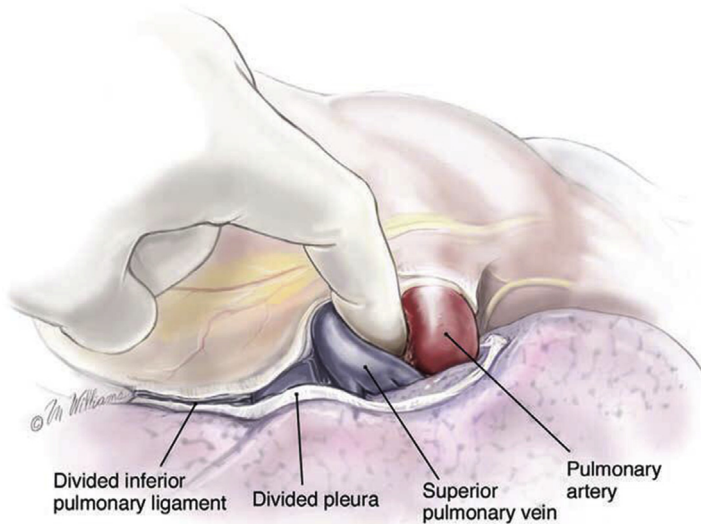


Fig. 3. The pulmonary artery is dissected away from the superior pulmonary vein. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

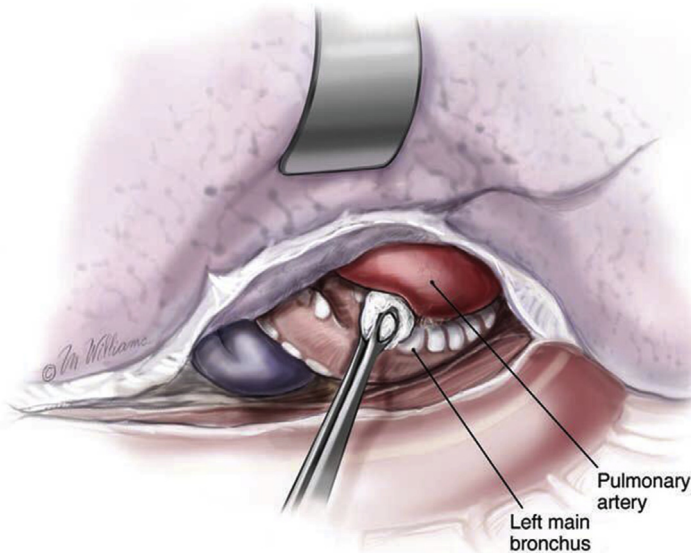


Fig. 4. The pulmonary artery is dissected away from the bronchus posteriorly. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

attention not to injure the recurrent nerve or opening the pericardium to identify a very short left main pulmonary artery within the pericardium. When entering the pericardium to access the pulmonary artery, it is essential to test clamp the artery before it is divided because the anatomy may be distorted by the malignancy, which can lead to inadvertent division of the main pulmonary artery and disastrous consequences.

The left pulmonary artery may either be divided with a vascular stapler (**Fig. 5**)⁴³ or it may be occluded with a proximal and distal vascular clamps and manually cut. The pulmonary artery stump is sutured with a double layer of 5-0 Prolene.⁴⁴ In some cases, a combination of these techniques may be required.

Next the pulmonary veins are identified and divided. If the tumor invades the pericardium, or if the pericardium has been opened to gain arterial control, the veins can be controlled and divided by extending the pericardial opening inferiorly, just posterior to the phrenic nerve. The pulmonary veins form a single branch as they enter the left atrium and can be divided at this level with any of the techniques described for the artery (**Fig. 6**). When dividing the veins outside the pericardium, the superior and inferior veins must be identified separately. The inferior vein begins at the superior edge of the inferior pulmonary ligament, and the superior vein is the most anterior structure of the hilum. These veins can be divided with vascular stapler loads or controlled with vascular clamps and oversewn with 4-0 or 5-0 Prolene.

Attention should be paid to delicately dissect the bronchus and maintain its vascular supply to decrease the chances of bronchial stump leak with its attendant dangers. The bronchus is usually the last structure divided. The lung is grasped and used to deliver the bronchus into the chest, with the goal of dividing the left main bronchus just distal to the carina, while leaving sufficient length to avoid tension on the closure. This maneuver can be facilitated by dissection of the subcarinal lymph node packet. Next, the anesthesiologist is asked to hold ventilation and to back out the bronchial

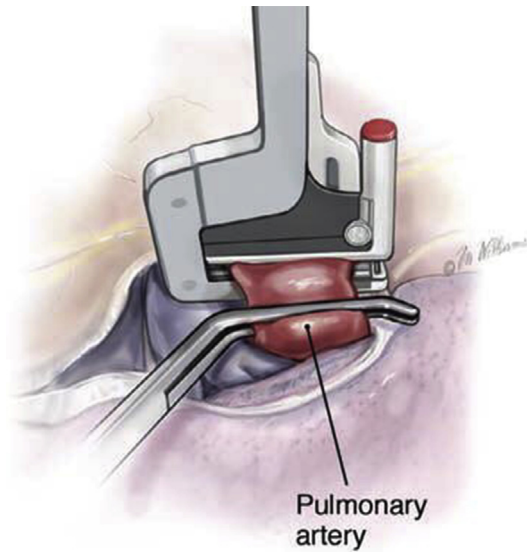


Fig. 5. The pulmonary artery is divided with a vascular stapler and a vascular clamp. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

blocker. The bronchial clamp or bronchial stapler is positioned across the bronchus to close it in an anterior-to-posterior fashion. If a stapler is used, the heavy load (green) or 4.8-mm stapler is chosen (**Fig. 7**). The anesthesiologist is then asked to ventilate the right lung to confirm correct positioning of the stapler. Once that is done and positioning of the stapler is indeed confirmed, ventilation is held again and the bronchus is closed and divided with the stapler.⁴⁵ The bronchus must be tested to

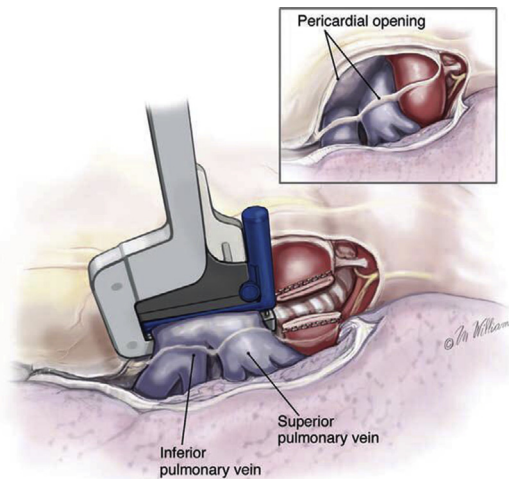


Fig. 6. The pulmonary veins form a single branch as they enter the left atrium and are divided at this level when favorable anatomy is present. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

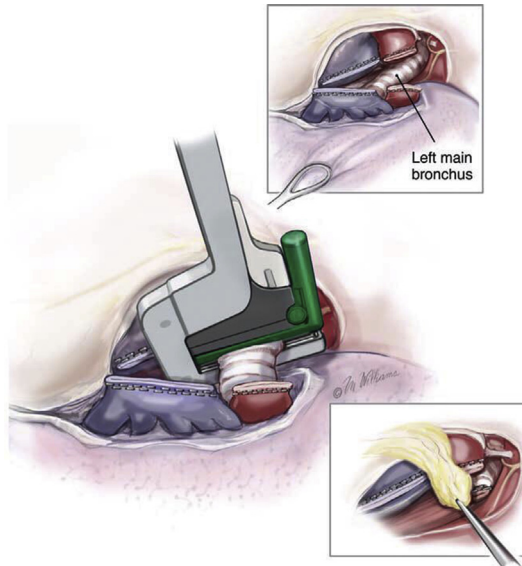


Fig. 7. The bronchus is usually the last structure divided with the goal of dividing the left main bronchus just distal to the carina. The bronchial clamp or bronchial stapler is positioned across the bronchus in an anterior-to-posterior fashion. If no leak is seen, the bronchus is covered with vascularized tissue. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

30 cm H₂O. If no leak is seen, the bronchus is covered with vascularized tissue. Whether an omental flap, a pericardial fat pad, a vascularized pericardium, or an intercostal muscle is used, it should be sutured either to the bronchus itself or to the tissues around the bronchus^{46–49} (**Fig. 8**).

Right Pneumonectomy

Patients undergoing right pneumonectomy are more likely to die from this procedure than left pneumonectomy patients, typically owing to the complications of recovering from surgery rather than the surgery itself.^{50,51} Consequently, for right pneumonectomy, postoperative management is crucial. As on the left side, a muscle-sparing posterolateral thoracotomy skin incision is made. The pleural space is approached via the fifth intercostal space and the chest cavity, chest wall, and lung are inspected for disease spread (see **Fig. 1**). The pleura around the hilum is divided and the inferior pulmonary ligament is taken down. For lesions in the hilum, dividing the azygos vein and harvesting the right paratracheal nodes first gives better exposure to the proximal pulmonary artery and proximal right mainstem bronchus (see **Fig. 8**). A patient who has had previous chemoradiation therapy or who has a history of granulomatous disease in the mediastinal lymph nodes often will have dense scarring between the posterior arterial plane and the anterior plane of the bronchus that will be encountered while dissecting the artery away from the bronchus and vein. Proximal control of the artery is needed when the surgeon encounters this situation.

Several maneuvers permit proximal control of the right main pulmonary artery; the simplest method is to divide the azygos vein and perform a right paratracheal node dissection. The proximal pulmonary artery can be approached by opening the

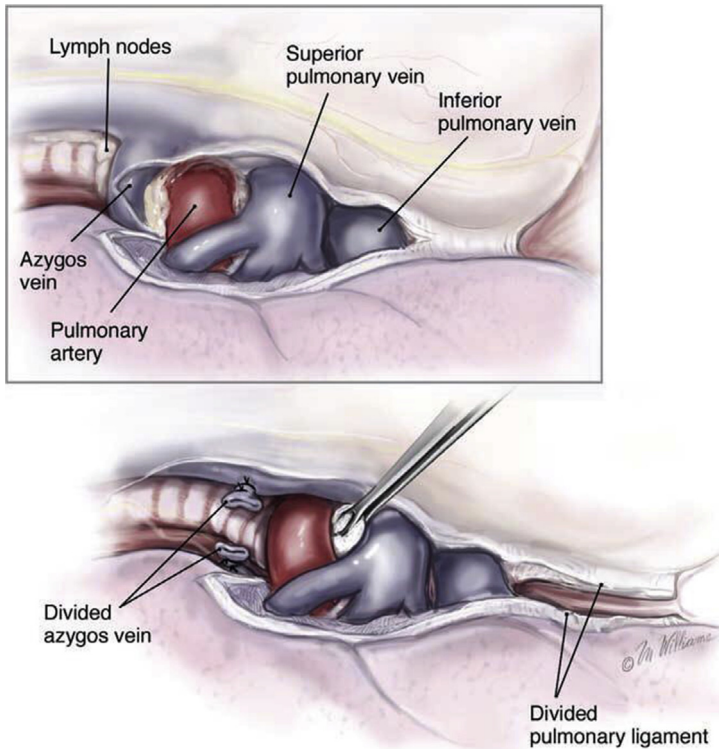


Fig. 8. For right-sided lesions in the hilum, dividing the azygos vein and harvesting the right paratracheal nodes first gives better exposure to the pulmonary artery and right mainstem bronchus. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

pericardium. Alternatively, the pulmonary artery can be identified medial to the superior vena cava, because the right main pulmonary artery is very long. The right pulmonary artery can be divided just after it crosses the aorta and the artery is then delivered back to the right hemithorax underneath the superior vena cava (**Fig. 9**). Notably, this approach markedly diminishes the chance of hemorrhage.

PERICARDIAL RESECTION AND RECONSTRUCTION

Pericardial reconstruction has been deemed necessary after pericardial resection during pneumonectomy, especially on the right side to prevent cardiac herniation.^{52,53} However, owing to our experience of having patients arrest even after left sided pericardial resection, we believe the determining factor is the extent of resection rather than the side. The only goal of reconstruction is to repair the pericardial defect in a manner that would prevent herniation. Limited resections (<2 cm) may not require reconstruction to prevent herniation. Yet, reconstruction may be helpful in preventing tachyarrhythmias and in avoiding cardiac irritation. Most surgeons use a nonabsorbable material like Gore-Tex (W.L. Gore and Associates, Flagstaff, AZ) mesh to reconstruct the pericardium, whereas others fill the defect with some of the vascularized tissue flap used to buttress the bronchus. A Gore-Tex patch should be sewn into place

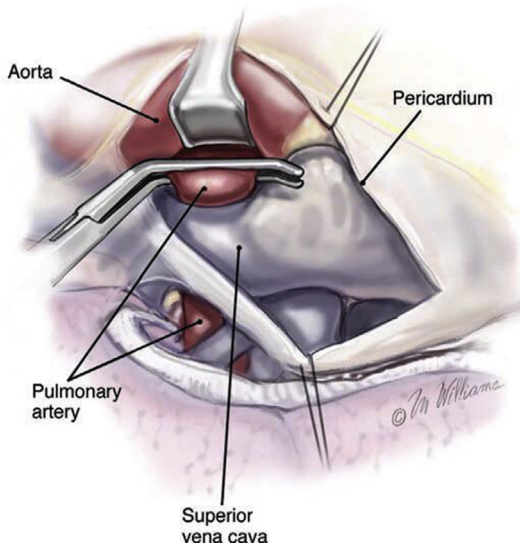


Fig. 9. The pulmonary artery is identified medial to the superior vena cava and divided just after its bifurcation and then delivered back to the right hemithorax underneath the superior vena cava. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

with interrupted sutures approximately 1 cm or more apart because the goal is to fix the patch in place and not to make it watertight (**Fig. 10**). This would avoid:

1. A state of positional pericardial constriction once the patient resumes upright position; and
2. Positional tension and narrowing of the superior vena cava as the patient changes positions.

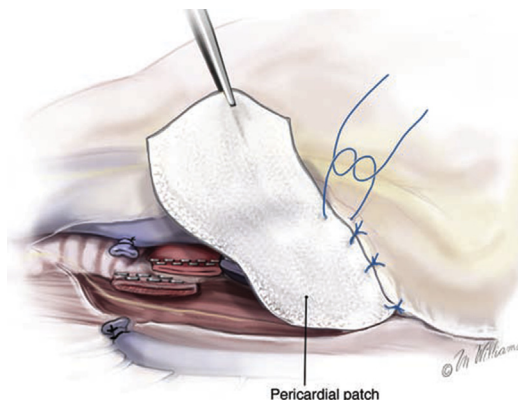


Fig. 10. The patch is sewn loosely into place with interrupted sutures approximately 1 cm or more apart. The desire is to fix the patch in place and not to make it watertight. (From Sugarbaker DJ, Bueno R, Colson YL, et al, editors. *Adult Chest Surgery*. 2nd edition. New York: The McGraw-Hill Company; 2015; with permission.)

PERIOPERATIVE MANAGEMENT

Postoperative management of the postpneumonectomy patient is beyond the scope of this article; however, some important points are worth mentioning. After pneumonectomy, and before leaving the operative theater, we place a 14-F red rubber catheter into the hemithorax and drain 500 to 1000 mL of air/fluid from the chest.⁵⁴ This helps to maintain a centered position of the mediastinum and allows for proper expansion of the contralateral lung. Serial chest radiographic monitoring and repeated drainage or insufflation of air is used to maintain proper positioning of the mediastinum in the first days after surgery.

A multidisciplinary team is essential to optimizing patient recovery in the perioperative period. Early mobilization after pneumonectomy has the known benefit of decreasing the risk of postoperative deep vein thrombosis, but also has the added benefit of contributing to effective pulmonary toilet and facilitating a shorter length of stay. Early extubation in the operating or recovery room is helpful at avoiding barotrauma to the staple line.

POSTOPERATIVE COMPLICATIONS

Pneumonectomy is a difficult and technically demanding operation associated with a high rate of perioperative morbidity.^{15,25,55,56} Over time, perioperative mortality from pneumonectomy has decreased to 3% to 10% at select institutions.^{57,58} This decrease is mainly attributed to increased awareness to the common postoperative complications and to improvement in the treatment provided these conditions. Good outcomes depend on a multidisciplinary team approach, awareness of the early signs of complications, and careful patient selection.

Careful preoperative patient evaluation will help to mitigate most of commonly encountered postoperative complications. Known risk factors for major postoperative complications include²⁶:

- Age greater than 70 years
- High American Society of Anesthesiologists physical status
- Chronic obstructive pulmonary disease
- Coronary artery disease

The most common complications experienced after pneumonectomy are atrial fibrillation and vocal cord paralysis.^{26,55,57}

Cardiac Complications

Atrial fibrillation

Atrial fibrillation has been reported to occur in up to 25% of postpneumonectomy patients and may manifest at any point during the postoperative hospital course.^{59,60} Risk factors contributing to atrial fibrillation include large volume shifts intraoperatively and postoperatively, age greater than 65 years, pericardial resection with or without reconstruction, and right-sided pneumonectomies.⁵⁹ In patients with strong risk factors for developing postoperative atrial fibrillation the American Association for Thoracic Surgery recommends continuing beta-blocking agents if previously taking them, magnesium supplementation, diltiazem in patients with no known heart disease, or amiodarone in patients with some history of heart disease.⁶¹ If postoperative atrial fibrillation should occur, treatment begins with optimizing fluid balance and maintaining a normal electrolyte profile. Hemodynamically unstable patients should be electrically cardioverted immediately, whereas hemodynamically stable patients can be treated with intravenous beta-blocking agents or calcium channel blockers to achieve a heart

rate of less than 100 bpm.⁶¹ A special mention should be made to anticoagulation of medically refractory atrial fibrillation after pneumonectomy. Because a postpneumonectomy patient can bleed almost their entire blood volume into the empty pleural space, any small bleeding vessel may lead to devastating consequences. Thus, consideration should be made to electrically cardiovert the patient in a timely manner. Notably, intracardiac thrombus formation should be ruled out before cardioversion.

Tamponade

Patients with symptoms of cardiac tamponade usually present with hypotension and increased filling pressures. This can be owing to a persistent pericardial effusion and/or a constrictive pericardial patch. A transesophageal echocardiogram can assess whether a constrictive effusion is present or whether the patch is too tight. Effusions are treated with either a pericardial window or a percutaneous drain.

Patch dysfunction

Constrictive patches require immediate reexploration and revision of the patch ensuring that there is a balance between the tension holding the patch in place and the laxity preventing restriction.⁵⁷

Cardiac herniation

Cardiac herniation after pneumonectomy is rare. Causes include a loose patch, not using a patch after pericardial resection, sudden changes in intrathoracic pressure, chest tubes on suction, or sudden high peak airway pressures during mechanical ventilation.^{55,62} An emergent thoracotomy is indicated should cardiac herniation occur. Once the patient is resuscitated, a return trip to the operating room should take place to wash out the chest and correct the underlying cause of the herniation. Special attention is warranted to make sure the pericardial patch is sewn to remaining pericardial tissue and not to weak tissue surrounding the pericardium.

Pulmonary Complications

Acute respiratory distress syndrome

Acute respiratory distress syndrome (ARDS) is a potentially fatal respiratory condition that presents with hypoxemia and stiff lungs.⁶³ It begins with alveolar capillary damage leading to increased endothelial permeability that results in the accumulation of protein rich fluid and neutrophils in the interstitium (fibroproliferative phase).^{63,64} Recently, the European Society of Intensive Care Medicine, the American Thoracic Society and the Society of Critical Care Medicine revised the definition of ARDS, known as the Berlin definition. The revised definition states that⁶⁵:

1. Symptoms must begin within 1 week of known insult or change in respiratory status
2. Bilateral opacities involving at least 3 quadrants, not fully explained by pleural effusions, atelectasis and nodules seen on chest radiography
3. Echocardiography or other objective test to rule out heart failure

The revised definition also clearly separates ARDS into mild, moderate, and severe according to the pulmonary arterial oxygen tension/fraction of inspired oxygen ratio while mechanically ventilated with a positive end-expiratory pressure of ≥ 5 cm H₂O.

ARDS occurs in 2% to 3% of postpneumonectomy patients with a distressing mortality rate of 50% to 70%.^{56,66–69} Current treatment strategies for ARDS are supportive and include lung protective ventilation, diuresis, fluid restriction, and prone positioning.^{63,70,71} The high mortality associated with ARDS highlights the importance of minimizing intraoperative and postoperative volume administration, and of perusing aggressive postoperative diuresis.

Empyema

Postpneumonectomy empyema occurs in 2% to 12% of standard postpneumonectomy patients and is usually associated with a bronchopleural fistula (BPF; addressed elsewhere in this article).⁷² Known risk factors include advanced age, postoperative pneumonia, diabetes, steroids, induction chemoradiation, and malnutrition.⁷² Treatment of postpneumonectomy empyema is time dependent. Early presentations (within the 1 month of pneumonectomy) can be managed safely with thoracoscopy, washout, debridement, and chest tube drainage of the hemithorax followed by postoperative antibiotic irrigation into the pneumonectomy space.⁷³ Patients who present months to years after pneumonectomy are treated with an open thoracostomy, long-term intravenous antibiotics, and eventual coverage using a pedicled muscle flap.

Bronchopleural fistula

BPFs are characterized by a direct communication between the trachea and the pneumonectomy space, with large fistulas leading to life threatening respiratory distress and sepsis. They occur in 1.7% to 11% of postpneumonectomy patients and mortality can be up to 40%.^{46–49,74,75} BPFs share many of the same risk factors as postpneumonectomy empyemas, except that earlier fistulas (within 1 week of surgery) are often associated with technical failure to close the stump, or extensive dissection of the stump leading to devascularization.

BPFs presenting in the first or second postoperative days often require early revision of the stump in the operating room. All BPFs and in particular those presenting more than 48 hours after the operation should be considered infected and require similar measures of action as postpneumonectomy empyema. We initially place a chest tube for immediate drainage, send cultures of the pleural fluid, and start broad-spectrum antibiotics. Next, we perform a thoracostomy with stump coverage to protect the remaining lung from exposure to the ongoing infection. At the same time, we do not hesitate to place a jejunostomy tube to aid in nutrition optimization if the patient is malnourished. Once the infection has resolved, the thoracotomy space is filled with a muscle flap; thoracoplasty has been used with some success by other groups.⁷⁶ Small BPFs may occasionally respond to therapy with sclerosing agents like ethanol or injection of a fibrin glue.^{77,78} As mentioned, BPF is a very serious and dangerous complication of lung resection in general and pneumonectomy in particular. Thus, BPF requires special attention from the surgical team and medical staff and only by careful attention to details and by repeated assessment of the patient can this situation be addressed properly.

Postpneumonectomy syndrome

Postpneumonectomy syndrome is a rare, late complication of right-sided pneumonectomy caused by severe shifting of the mediastinum to the right years after resection. The trachea is deviated to the right, causing the left mainstem bronchus to become impinged between the spine and the pulmonary artery. Tracheobronchomalacia occurs owing to the constant stretch and compression of the airway. Patients present with dyspnea, decreased exercise tolerance, and inspiratory stridor years after their pneumonectomy.⁷⁹ Treatment consists of filling the right hemithorax with an inert material (ie, acrylic balls) or using tissue expanders.^{79,80}

QUALITY OF LIFE

One of the first questions patients have after being diagnosed with lung cancer is what of quality of life they will have. Pneumonectomy has been portrayed as the procedure of last resort when all hope is lost. Patients have little to no expectation of any quality

of life and resign themselves to mental confinement by their disease. However, it is the duty of the surgeon to have an upfront and honest conversation with patients before surgery. Previous experience with pneumonectomy resulting in a poor quality of life was derived from inferior techniques and poor patient selection.⁸¹ Multidisciplinary teams, improved surgical techniques, and more accurate clinical staging have selected out patients who would benefit most from a pneumonectomy. Cerfolio and colleagues⁸² have recently looked at the quality of life experienced by patients after pneumonectomy and found that patients who have a good quality of life before surgery are likely to have a good quality of life after surgery. Age greater than 70 years and low preoperative quality of life were associated with poorer quality scores.⁸³ This is a significant change in the thought paradigm concerning pneumonectomy, where now the preoperative status of the patient drives the overall quality of life rather than burden of the surgery. As long as the surgeon performs a technically sound operation, there is no reason postpneumonectomy patients cannot go on to experience a good quality of life.

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