Pulmonary resection has been established as the treatment of choice for localized non–small-cell bronchogenic carcinoma in the healthy patient. Usually this entails lobectomy, but in certain circumstances, particularly when the tumor extends beyond the lobar bronchial orifice into the main bronchus, standard lobectomy will not accomplish a complete resection. Although pneumonectomy has traditionally been the alternative in this circumstance, sleeve lobectomy (lobectomy that involves resection of a segment of the main bronchus in continuity with that lobe) represents another logical option. Early reports of sleeve lobectomy in lung cancer proposed this technique as a compromise procedure in those patients whose pulmonary reserve was poor and insufficient to tolerate pneumonectomy. However, subsequent published data have established that sleeve lobectomy in lung carcinoma is associated with lower morbidity and mortality than pneumonectomy (and, in fact, approaching that of standard lobectomy), a cure rate equivalent to that of pneumonectomy, and preservation of lung function commensurate with the conservation of lung parenchyma in the operated hemithorax.

The first description of conservative resection of the bronchial tree was by Sir Clement Price-Thomas. In his report, Price-Thomas lamented having performed a left pneumonectomy in a young patient with a left upper-lobe bronchial adenoma in 1946. Therefore, in 1947, he performed a right upper-lobe sleeve lobectomy in a young royal air force cadet who would have been discharged from military service had he undergone pneumonectomy. Interestingly, Price-Thomas did not report these achievements until 1955. Subsequently, there were other instances of sleeve resection for benign disease in the late 1940s and early 1950s. Sleeve lobectomy for lung carcinoma was promoted in the United States by Paulson et al., mainly as a compromise procedure. In recent years, the notion of sleeve lobectomy in bronchogenic carcinoma has gained popularity, and in contemporary series, this procedure comprises 5% to 10% of elective lobectomies for lung carcinoma.

Patient Selection and Preoperative Evaluation
Traditionally, sleeve lobectomy for lung cancer was only proposed for patients who were elderly, or who had poor pulmonary function, notably where the predicted postoperative forced expiratory volume in 1 second (FEV₁) was less than 1 L. Essentially, these circumstances indicated situations in which pneumonectomy, the most common alternative to standard lobectomy, posed a very high risk. Although these continue to constitute solid indications for sleeve lobectomy, sleeve resections should also be considered in virtually any situation that is anatomically favorable. These may be summarized as the following: (1) bronchoscopic evidence of endobronchial tumor extending to or beyond the lobar bronchial orifice into the main bronchus; (2) the presence of metastatic peribronchial (lobar) lymph nodes infiltrating the bronchial wall at its origin; (3) or the finding of a positive bronchial margin after an apparently straightforward standard lobectomy. The preoperative bronchoscopy is one of the most important parts of the evaluation, suggesting the possible need for sleeve lobectomy. The bronchoscopic findings should be carefully reviewed in conjunction with the computed tomographic (CT) scan of the chest.

Ultimately, the suitability of sleeve lobectomy is confirmed at surgery. In addition to preoperative verification of the above favorable anatomic features, sleeve lobectomy is feasible only when the bronchial and vascular structures to the remaining lobes or segments are free of disease. Therefore, the presence of bulky peribronchial carcinoma enveloping the main bronchus or invading the pulmonary artery, or the finding of metastatic lymph nodes adherent to the pulmonary artery within the fissure are contraindications to pursuing a sleeve lobectomy. In these circumstances, pneumonectomy is the procedure of choice.

Patient evaluation begins with a careful clinical assessment, including history and physical examination. Clinical evaluation seeks out symptoms or physical signs suggestive of metastatic carcinoma. Clinical evaluation also assesses the patient’s cardiopulmonary status by questioning for symptoms of cardiac disease and regarding exercise tolerance.

Other imaging studies to achieve distant staging are occasionally indicated. These include CT or magnetic resonance scanning of the brain and radionuclide bone scanning. Because previously published reports failed to support the cost-effectiveness of routine multi-organ
staging scans in lung cancer, these additional studies are only obtained if there are clinical features raising concern about brain or bone metastases.

If the patient has symptoms consistent with coronary artery disease, a documented previous myocardial infarction, or an abnormal electrocardiogram, then formal cardiac evaluation is indicated before thoracotomy and pulmonary resection. All patients should undergo preoperative pulmonary function testing with careful attention to the FEV₁ and arterial blood gas obtained on room air. Despite the fact that the planned procedure may be sleeve lobectomy, operative findings may dictate the necessity for pneumonectomy, and therefore, the preoperative evaluation should be conducted with this in mind. Thus, if the preoperative FEV₁ is significantly less than 2 L, or if the predicted postoperative FEV₁ is less than or equal to 1 L, then quantitative ventilation-perfusion scintigraphy is necessary to evaluate the suitability of pneumonectomy in this patient. Typically, the presence of significant obstructive atelectasis or pneumonitis on the side of the carcinoma will result in the preponderance of both ventilation and perfusion being distributed to the contralateral lung.

It is the investigator’s preference to use cervical mediastinoscopy in virtually every case of known or strongly suspected lung carcinoma. However, left anterior mediastinotomy, to evaluate subaortic (level 5) lymph nodes is used selectively. This selective approach is based on the data from Patterson et al., which shows a more favorable survival rate for completely resected left upper-lobe carcinomas in which the only site of mediastinal spread was the subaortic nodes. Therefore, if the cervical mediastinoscopy shows no evidence of superior mediastinal lymph node metastases, left anterior mediastinotomy should be performed only if the technical feasibility of resection is in question. It is preferable that the mediastinoscopy be conducted under the same anesthetic as the thoracotomy and sleeve resection. This is performed to avoid the fibrosis and fixation that can develop around the proximal main bronchi within 1 to 2 weeks of cervical mediastinoscopy with an associated loss of mobility. This concern applies more to right upper-lobe tumors than to left-sided tumors.

A very important part of the preoperative preparation of the patient for surgery is the bronchoscopic evaluation of the tumor and of the remainder of the lung. The diagnostic and therapeutic significance of this evaluation is shown in this next case. The posterior-anterior (PA) and lateral chest radiograph of a patient ultimately found to be a suitable candidate for left upper-lobe sleeve lobectomy is shown in Figure I. The patient underwent thoracic surgical evaluation approximately 2 weeks after this radiograph was obtained. At the time of this evaluation, the patient was experiencing increasing shortness of breath and also fever, chills,
and purulent and bloody sputum. By this time, the patient’s chest radiograph showed further volume loss and obstructive pneumonitis of the left lung (Figure II). Appearance of selected cuts from the chest CT scan are shown in Figure III. Addition of rigid bronchoscopy allowed coring out of the majority of the endobronchially visible tumor. This served to confirm that the tumor did in fact originate in the left upper lobe, and that the lower lobe was free of disease. More importantly, a large amount of purulent secretions were cleared from the left lower lobe by resolving the bronchial obstruction. This led to considerable improvement in the chest radiographic appearance (Figure IV), and was associated with significant clinical improvement. This sequence of radiographs serves to underscore the importance of relieving obstruction of the bronchus to the lobes being preserved. Relief of obstruction, along with the institution of appropriate intravenous antibiotics and chest physical therapy, will minimize the incidence of postoperative pneumonia and other septic complications.

Fig II. PA chest radiograph of the same patient obtained at the time of thoracic surgical evaluation, approximately 2 weeks after the radiograph shown in Fig I. The patient presented with features of shortness of breath and cough, which were productive of blood stained purulent sputum. Note once again the large left hilar mass, now with worsening opacification of the left lung and further volume loss in the left hemithorax, with leftward mediastinal shift.
Fig III. Images from chest CT scan examination of this patient. (A) Hilar mass causing cutoff in the distal left main bronchus, associated with left upper lobe collapse and significant left-sided volume loss. (B) is the next most caudal cut. This shows similar findings, but also shows a patent left lower lobe bronchus. The mass protrudes from the atelectatic left upper lobe into the distal left main bronchus.
Fig IV. PA chest radiograph of the same patient after undergoing rigid bronchoscopy and core out of the obstructing bronchial mass. Note the improved expansion of the left lung, the patent air column within the left bronchial tree, and the return of the mediastinal structures to the mid-line.
Before entering the operating room, the patient has had placement of a lumbar epidural catheter for postoperative pain control. After completion of the cervical mediastinoscopy, the endotracheal tube is replaced with a left endobronchial (Robert Shaw) tube. Other monitoring modalities include a radial arterial line and Foley catheter. A standard posterolateral thoracotomy incision is made and the chest is entered in the fifth intercostal space. A short plug of the posterior aspect of the sixth rib can be excised to improve the exposure. Although standard lobectomies for small peripheral carcinomas can be routinely accomplished through limited muscle sparing incisions, it is preferable to adhere to the standard posterolateral thoracotomy approach for sleeve lobectomy because of the superb exposure it affords.
Once the thoracotomy is completed and proper exposure is afforded by placing the chest retractors, the inferior pulmonary ligament is divided. A careful inspection is made to verify the absence of any intrathoracic metastatic spread on the visceral or parietal pleura. The posterior mediastinal pleura is opened in a cephalad direction beginning at the inferior pulmonary vein. This is continued so that the pleura is completely opened within the concavity of the aortic arch. A systematic sampling of lymph node stations is then commenced. This includes sampling of nodes from the inferior pulmonary ligament (level 9) and also from the subaortic space (level 5). Care must be taken in the subaortic space to avoid traction or cautery injury to the left recurrent laryngeal nerve. All sampled lymph nodes are sent for frozen section analysis.
The pulmonary dissection attempts to achieve complete isolation of the arterial, venous, and bronchial structures to the upper and lower lobes. The pulmonary artery is identified and its perivascular plane is entered. The dissection is then carried down the major fissure exposing the upper lobe branches of the pulmonary artery. The branches to the lower lobe (superior segmental branch and basilar trunk) are also identified.
(A-B) All upper lobe arterial branches are then divided between 2-0 silk ligatures. Occasionally, a bulky central left upper-lobe tumor, metastatic or granulomatous involvement of the peribronchial lymph nodes, will encroach on these upper lobe arterial branches. In these circumstances, the left main pulmonary artery must be isolated at the site of exit from the pericardium. The pulmonary artery is then clamped proximal and distal to the site of tumor or nodal adherence.
A tangential excision of its wall may be necessary. The resultant arterial defect is then repaired directly with a continuous suture of 5-0 Prolene (Ethicon, Inc, Somerville, NJ), or alternatively with a pericardial patch secured in place with continuous 5-0 Prolene.
The superior pulmonary vein is isolated and divided between applications of the vascular stapling device. Any residual incomplete major fissure is completed at this point using the linear stapling instrument. The left upper lobe is now pedicled only on its bronchus. At this point, the procedure has been identical to that of standard lobectomy. Careful inspection and palpation of the origin of the upper lobe bronchus will confirm the feasibility of sleeve lobectomy. All interlobar lymph nodes in the crotch between the upper and lower lobe bronchi (level 11) are excised and submitted for frozen section analysis. Similarly, nodes are sampled along the course of the left main bronchus. This includes left tracheobronchial angle lymph nodes (level 10) and also subcarinal lymph nodes (level 7). Once the frozen section result has confirmed absence of lymph node metastases, the sleeve resection and anastomosis are undertaken.
Division of the bronchus is performed using a scalpel to ensure a neat transection site. The initial transection is in the distal left main bronchus several millimeters proximal to the upper lobe origin. The lumen is then carefully inspected to verify a tumor-free proximal bronchial margin. Using a small Yankauer suction tip passed down into the lower lobe bronchus, the site of distal bronchial transection is selected. In a similar manner, the bronchus is transected distally with a scalpel, and the adequacy of the distal margin is evaluated grossly. If grossly the proximal and distal margins seem satisfactory, preparations are made to begin the bronchial anastomosis. The sleeve lobectomy specimen is submitted for frozen section evaluation of the proximal and distal bronchial margins.
It is essential that the bronchial anastomosis be created without tension. In this regard, the inferior hilar release is an important component of the procedure. The pericardium around the inferior pulmonary vein is completely incised in a U-shaped manner. This facilitates upward mobility of the left lower lobe, and allows the hilum to come up by 1 to 2 cm.
The bronchial anastomosis is then created using a series of interrupted 4-0 Vicryl sutures (Ethicon, Inc, Somerville, NJ) passed through mineral oil. (A) Sutures are placed precisely approximately 2 mm apart and 2 mm from the cut edge of the bronchus. (B) Distance between sutures on the proximal and distal bronchial margins should be determined according to any size discrepancy between the two lumens. Any significant size disparity can subsequently be accommodated for with the highly pliable membranous bronchus.
Creation of the anastomosis is facilitated by the forward retraction of the pulmonary artery, therefore, that the bronchial anastomosis is created behind the artery. (C) After careful and sequential placement of all the sutures, the bronchial edges are gently approximated without tension and the sutures are tied. The anastomosis is immersed in warm saline, and manual ventilation of the left lung is commenced; it should be air tight despite 20 cm–water-sustained manual pressure.
The bronchial anastomosis is always wrapped with a pedicle of healthy tissue. In a left upper-lobe sleeve lobectomy, a very convenient pedicle is the anterior pericardial fat pad. This fat pad is harvested beginning near the diaphragm and staying anterior to the phrenic nerve. It is mobilized in a cephalad direction so that it remains pedicled proximally. This flap of tissue has sufficient bulk and mobility to wrap it around the bronchial anastomosis without difficulty. It is then tacked loosely into place with interrupted 4-0 silk sutures.

The procedure has essentially been completed. Verification of negative proximal and distal margins must be confirmed before the patient is awakened from the anesthesia. After securing proper hemostasis and irrigation of the chest with warm saline, two 28F chest tubes are positioned appropriately within the pleural space. The thoracotomy is then closed in standard fashion, using number 2 Vicryl (Ethicon, Inc) for pericostal sutures, number 1 Vicryl in the extracostal muscle layers, 2-0 Vicryl in subcutaneous tissues, and 4-0 Vicryl for subcuticular skin closure.
**Postoperative Care**

Data from previous publications have suggested the development of ipsilateral lung dysfunction after sleeve lobectomy in animals\(^6\) and humans.\(^7\) This lung dysfunction is associated with secretion retention, and manifests also with impaired gas exchange. For this reason, several previous investigators have recommended the liberal use of periodic bedside fiberoptic bronchoscopy in the routine postoperative care of the sleeve lobectomy patient.\(^8\) However, with modern techniques of anesthesia, perioperative pain control, and intensive physical therapy, the care of the sleeve lobectomy patient does not differ substantially from that of the patient undergoing standard pulmonary lobectomy, and routine fiberoptic bronchoscopy is not necessary. Intravenous fluids are limited on the night of surgery and are stopped the next morning when oral intake is resumed. Supplemental oxygen is administered by nasal prongs, and then weaned as tolerated, based on clinical status and pulse oximetry. Pain control is achieved through a lumbar epidural catheter placed preoperatively. This epidural catheter is retained for 48 to 72 hours postoperatively, and then removed and replaced with a patient controlled analgesia pump or oral analgesic tablets. Physical therapy, consisting of chest percussion and postural drainage, is commenced the morning after the procedure, and ambulation is begun the afternoon of the first postoperative day. Chest tubes are maintained at \(-20\) cm of water suction and converted to water-seal drainage when no air leak is discernable. The chest tubes may then be removed when fluid drainage is also minimal. The significant majority of patients are ready for discharge from the hospital by the 4th or 5th postoperative day. Fiberoptic bronchoscopy (under topical anesthesia) should be performed to inspect the anastomosis before hospital discharge. At this point, the anastomosis should show evidence of satisfactory healing. Although there may be minimal fibrinous exudate along the suture line, there should be no mucosal slough or separation noted. The 4-month-postoperative chest radiograph of the patient depicted earlier (Figures I-IV) is shown in Figure V. The bronchoscopic appearance of the well-healed bronchial anastomosis after left upper-lobe sleeve lobectomy in this patient is shown in Figure VI.

Fig V. PA chest radiograph of the same patient obtained 4 months after left upper-lobe sleeve lobectomy. Final pathology report showed this to be a moderately differentiated adenocarcinoma with negative lymph nodes. The chest radiograph is satisfactory, and shows good expansion of the left lower lobe.
Fig VI. Bronchoscopic appearance of the well-healed bronchial anastomosis after left upper-sleeve resection in the same patient.
COMMENTS

When used for appropriate indications, sleeve lobectomy achieves excellent results rivaling those of pneumonectomy with respect to operative mortality and late survival. Available data also show that sleeve lobectomy is superior to pneumonectomy by virtue of its preservation of lung tissue.

Tedder et al presented a collective review of 1,915 bronchoplastic procedures for malignancy reported between 1980 and 1992, and evaluated 30-day mortality, the complication rate, and late survival. They noted a 30-day mortality of 62/1,125 sleeve lobectomies, or 5.5%. In a report dealing with their institutional experience with 145 sleeve resections for carcinoma, Van Schil et al reported a 4.8% operative mortality. Similarly, Gaissert et al summarized the Massachusetts General Hospital experience with 72 sleeve lobectomies for lung cancer spanning 3 decades, and reported a 4% operative mortality. These figures compare favorably with the 6.2% operative mortality for elective pneumonectomy in lung cancer, as reported by the Lung Cancer Study Group in 1983. In the report by Tedder et al, the main sources of morbidity after sleeve lobectomy for carcinoma were pneumonia, persistent atelectasis, and anastomotic stenosis (Table 1). Bronchovascular fistula is a rare yet lethal complication of sleeve lobectomy, and was reported in 2.5% of the cases that comprised their collective review. The creation of a tension-free bronchial anastomosis and wrapping the anastomosis with a pedicle of healthy tissue remain the best maneuvers for avoidance of this dreaded complication.

The adequacy of sleeve lobectomy as a cancer operation in bronchogenic carcinoma must also be evaluated. In their collective review, Tedder et al found local recurrence to be reported in 84 of 673 sleeve lobectomies (12.5%). Gaissert et al reported local recurrences in 10 of 69 sleeve lobectomies (14%). The 5-year survival in the collective review by Tedder et al was 245/614 (40%). However, when late survival was stratified by stage, it was found to be 63% for stage I, 37% for stage II, and 21% for stage III. Tedder et al point out that only approximately one third of the patients who comprised this collective review were staged preoperatively. Therefore, the predicted 5-year survival for standard lobectomy, if corrected based on the percent-age of patients staged preoperatively, was 58% for stage I, 37% for stage II, and 22% for stage III. Similar survival rates have been reported by other authors. Van Schil et al reported a 59% 5-year survival rate after sleeve lobectomy in stage I lung cancer, and 42% in stage II. Gaissert et al similarly noted a 57% 5-year survival after sleeve lobectomy in stage I and 38% in stage II. As expected, the presence or absence of lymph node metastases profoundly affected late survival in all of these studies, and in the collective review by Tedder et al, 5-year survival after sleeve lobectomy for N0 lung cancers was 60%.

Another important aspect of sleeve lobectomy for bronchogenic carcinoma is the preservation of lung parenchyma that would otherwise be sacrificed if the alternative standard procedure, pneumonectomy, were performed. Unfortunately, there has been rather scanty documentation of the preservation of pulmonary function after sleeve lobectomy. This may be partly related to the fact that the greatest increase in implementation of this procedure has occurred only within the past decade. Gaissert et al used pulmonary function testing and quantitative ventilation-perfusion scintigraphy before and after sleeve lobectomy for lung cancer to evaluate this issue. From their review of 72 sleeve resections, 16 patients had postoperative spirometry (at a mean interval of 3.5 years after sleeve lobectomy) in addition to the routine preoperative spirometry. These investigators also used the preoperative quantitative ventilation-perfusion lung scan to predict the postoperative FEV1. In general, comparison of the observed to the predicted postoperative FEV1 yielded comparable values, with a correlation coefficient of 0.87. The predicted values tended to exceed the observed values by only about 15%. In their study, eight patients underwent postoperative quantitative ventilation-perfusion lung scintigraphy, at a mean interval of 4.5 years after sleeve lobectomy. Mean perfusion of the operated side was 35%, and mean ventilation was 44%. These impressive results support the notion that functional outcome is superior after sleeve lobectomy as compared with pneumonectomy in lung cancer patients.

In conclusion, sleeve lobectomy has recently gained significant popularity as a surgical option for patients with bronchogenic carcinoma. Although it was originally proposed as a compromise procedure for patients with poor pulmonary reserve, the available modern

### TABLE 1. Morbidity After Sleeve Lobectomy for Bronchogenic Carcinoma

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frequency (%)</th>
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<tbody>
<tr>
<td>Pneumonia</td>
<td>9.9</td>
</tr>
<tr>
<td>Atelectasis</td>
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<tr>
<td>Anatomostic Stenosis</td>
<td>4.8</td>
</tr>
<tr>
<td>Bronchopleural Fistula</td>
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<tr>
<td>Bronchovascular Fistula</td>
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<tr>
<td>Pulmonary Embolism</td>
<td>2.3</td>
</tr>
<tr>
<td>Empyema</td>
<td>2.0</td>
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</tbody>
</table>

NOTE. Taken from collective review of 1,915 reported sleeve resections for lung cancer by Tedder et al.
data support its use whenever the anatomic location of the tumor or involved lymph nodes are favorable. Recent series show that sleeve lobectomy is associated with a lower operative mortality compared with pneumonectomy in a similar group of patients. Available data also show that late survival after lung cancer resection by sleeve lobectomy is comparable with that for similarly staged tumors treated by standard lobectomy. With modern techniques of anesthesia and perioperative care of the pulmonary resection patient, the management of the patient undergoing sleeve lobectomy does not generally pose any unusual difficulties. Careful preoperative evaluation and attention to selected key technical aspects of the operation will minimize the incidence of serious perioperative complications and ensure a good late functional result.

REFERENCES


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