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REVIEW / DERLEME

Overview of indications for pulmonary sleeve resection

Pulmoner sleeve rezeksiyon endikasyonlarına genel bakış

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ABSTRACT

Pulmonary sleeve resection is a complex lung resection and reconstruction surgery mostly performed in patients with centrally located locally invasive lung cancers which often penetrate into central airways and vasculature. This approach was initially used for patients unable to tolerate pneumonectomies, while it is currently also being preferred in patients whose tumors are anatomically suited. Today, thoracic sleeve resections include a wide range of procedures ranging from bronchial and tracheal sleeve resections to carinal sleeve pneumonectomies. In this review, we discuss indications for various types of sleeve resection in the light of current literature.

Keywords: Carinal sleeve resection, double sleeve resection, indication, sleeve lobectomy, sleeve pneumonectomy, sleeve segmentectomy.

ÖZ

Pulmoner sleeve rezeksiyon, daha çok santral hava yollarını ve vasküler yapıları tutan lokal olarak ilerlemiş invaziv akciğer kanseri olan hastalarda gerçekleştirilen bir tür karmaşık akciğer rezeksiyonu ve rekonstrüksiyon işlemidir. Başlangıçta pnömonektomiyi tolere edemeyen hastalarda kullanılmasına rağmen, günümüzde anatomik olarak uygun tümörler için tercih edilen bir yaklaşım olmuştur. Günümüzde torasik cerrahide yalnızca bronşiyal veya trakeal sleeve rezeksiyondan karinal sleeve pnömonektomiye kadar geniş bir yelpazede sleeve rezeksiyon işlemleri uygulanmaktadır. Bu derlemede, sleeve rezeksiyon tipleri için endikasyonlar mevcut literatür ışığında irdelendi.

Anahtar sözcükler: Karinal sleeve rezeksiyon, çift sleeve rezeksiyon, endikasyon, sleeve lobektomi; sleeve pnömonektomi, sleeve segmentektomi.

Pulmonary sleeve resection is a complex lung resection and reconstruction surgery typically performed in patients with locally advanced lung cancers which invade central structures such as the main airways and vasculature. The term is used for a wide range of lung resection procedures where the affected part of the bronchus and/or pulmonary vasculature is excised together with the affected surrounding lung parenchyma, while preserving the unaffected lung parenchyma.

Compared to traditional pneumonectomies, pulmonary sleeve resection has increased patient survival, quality of life, and pulmonary function, while decreasing mortality rates. Indeed, it soon became clear that traditional pneumonectomies were a clinical condition in and of themselves with higher rates of postoperative complications and long-term adverse effects on lung function. This is why pulmonary sleeve resections were initially only used for patients who were unable to tolerate pneumonectomies, whereas they are currently the preferred surgical approach for any patients for whom the anatomical position of their tumor qualifies for this type of intervention. Sleeve resections are technically more demanding than pneumonectomy and are more prone to certain complications.[1-3]

Pulmonary Sleeve Resection Types

Standard sleeve resection refers to the type of surgery performed to remove a single lobe and part of the main bronchus. Following the resection, an anastomosis is created between the two remaining ends of the bronchus. Given its attempt to salvage the remaining unaffected lung parenchyma, sleeve resection

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can be also thought of as a type of autotransplantation. A similar procedure can be performed at the level of the pulmonary artery (PA) where it is referred to as bronchovascular sleeve resection or double sleeve resection. Finally, extended sleeve resection (ESR) refers to a bronchoplastic operation whereby additional wedge resections or segmentectomies are performed in the remaining lobes following the initial sleeve resection.[4-9] Types of ESRs have been described:

Type A involves resection of the right upper and middle lobes (with or without segment 6) and anastomosis between the right main and lower bronchi.

Type B involves resection of the right middle and lower lobes and anastomosis between the right main and upper bronchi.

Type C involves resection of the left upper lobe and lower lobe superior segmentectomy and anastomosis between the left main and basal segmental bronchi.

Type D involves resection of the left lower lobe and lingular segment and anastomosis between the left main and upper division bronchi.[3]

Anatomy

Surgical anatomy of tracheobronchial tree

The trachea extends from the cricoid cartilage down to the carina which is located approximately at the level of the fourth thoracic vertebra. At this point, it divides into the right and left main bronchus. The right main bronchus is located at the level of the trachea. Its length from the carina to the start of the upper lobe varies between 1.5 and 2 cm. The right main bronchus further divides into the right superior lobar bronchus proximally and the intermediate bronchus distally. The latter measures around 2 cm in length. Its presence on the right side provides a technical advantage for right-sided sleeve resections. The right middle lobar bronchus exits the intermediate bronchus anteriorly at the same level as the superior segmental bronchus of the right lower lobe which exits the intermediate bronchus posteriorly.[10-12]

The main left bronchus exits the carina at a more oblique angle than the right main bronchus. It measures between 4 to 6 cm in length and is therefore longer than the right main bronchus which measures around 1.5 cm. The longer length of the left main bronchus provides more surgical options when it comes to sleeve resections of the left upper lobe. However, the proximity of the aorta prevents the appropriate exposure for anastomosis. The left main bronchus extends posteriorly below the aortic arch to the left hilum where it divides into the left upper and lower bronchi. The absence of an intermediate bronchus on the left makes left-sided sleeve resections more tricky.[10] The left lower bronchus gives out its first segmental branch about 0.5 cm below the orifice of the left upper lobe.[11] Special care needs to be taken to preserve the left recurrent laryngeal nerve while performing bronchoplasties involving the left main bronchus. Indeed, this nerve loops posteriorly around the arch of the aorta close to the ligamentum arteriosum and ascends in the tracheoesophageal groove into the neck.[11,12]

Vascular and nervous supply of the lower trachea and bronchi

Bronchial arteries mostly arise from the anterior surface of the descending thoracic aorta or intercostal arteries. They travel along the membranous layer of the main bronchi and, then, dorsally along the lobar and segmental bronchi. There are typically two left and one right bronchial arteries. This is why ischemia of the right main bronchus is more common than its left counterpart. The bronchial artery on the right descends parallel to the azygos vein. Another characteristic of the bronchial vascular supply is the rich web of anastomoses that link it to the PA system. This web is particularly important at the level of the lobar and segmental bronchi. Indeed, the pulmonary vasculature supplies between 75 to 90% of the blood supply to the airways. Most of the venous drainage that comes from the bronchial arteries empties into the pulmonary veins; the remainder drains through the bronchial veins surrounding the segmental and subsegmental bronchi. These bronchial veins further drain into the azygos and hemiazygos veins.[11-13]

Pulmonary arterial system

The main PA starts as the pulmonary trunk from the pericardium of the right ventricle and runs superiorly and to the left. It divides into the right and left PAs below the arch of the aorta. The right PA extends toward the right, behind the ascending aorta and the superior vena cava (SVC) and in front of the carina. More than three-quarters of its length is located inside the pericardium. Lateral to the SVC, the right PA runs in front of the right main bronchus and gives off its first branch to the right upper lobe. Shortly after, it runs downwards in between the intermediate bronchus posteriorly and the superior pulmonary vein anteriorly as the interlobar PA. The latter, then, runs posteriorly behind the origin of the middle bronchus. At this point, it gives off one or two ascending arteries supplying the upper lobe behind the upper lobe and middle lobe arterial segments. The middle lobe and

the ascending arteries arise from the anteromedial and the posteromedial surfaces of the interlobar PA, respectively. More distally, the interlobar PA gives off a branch that supplies the apical segment of the lower lobe and eventually branches off into the various branches which supply the basal segments. The left PA is shorter than its right counterpart; it originates at the level of the ligamentum arteriosum and passes behind and downwards the descending aorta and above the left main bronchus. As the left PA covers 60 to 75% of the left upper bronchus, left PA resections are most commonly accompanied by left upper lobe sleeve resections.

Indeed, the PA is adjacent to the superior, posterior and inferior aspects of the upper lobe bronchus whilst anteriorly, it runs adjacently to the superior pulmonary vein. Its first branches, the apical and anterior segmental arteries originate from the anterosuperior aspect of the upper lobe bronchus and the posterosuperior aspect of the superior pulmonary vein. The interlobar PA gives off several branches during its course along the upper lobe bronchus. These are often found surrounded by lymph nodes, but their number and location vary from person to person. The most distal of these branches is the lingular artery which usually arises distally to or at the same level as the artery supplying the superior segment of the lower lobe. The lingular artery arises from the anteromedial surface of the interlobar PA, while the superior segmental artery arises from its posterolateral surface. The PA, then, continues anteriorly and branches off into arteries supplying the basal segments of the lungs.[11,14,15]

Patient eligibility and preoperative assessment

If obstructive pneumonia is present, it should be corrected prior to surgery. In such patients, the airway should be opened temporarily through endobronchial techniques such as laser therapy, cauterization, and pneumatic dilatation. Steroid treatment should be stopped prior to surgery and if any infection is present, it should be treated accordingly prior to planning a resection. Patients with bronchostenosis secondary to tuberculosis should undergo bronchoscopy to rule out any active disease. If the stenosis is thought to be due to tuberculosis, tuberculosis treatment is advised at least six months prior to surgery.[11]

A preoperative bronchoscopy assessment by a thoracic surgeon is essential before planning a sleeve resection. This is important to confirm bronchial infiltration. Indeed, only a fraction of cases would reveal a tumor intraoperatively limited to the outer bronchial wall which could not be observed during the preoperative bronchoscopic assessment. The key finding from the bronchoscopic assessment is the presence of any intraluminal tumor spread from the segmental bronchi into the lobar or main bronchial orifice. To assess tumor spread, mucosal biopsies should be taken both distally and proximally to the lesion. The presence of decreased bronchial wall mobility during breathing can be a sign of peribronchial tumor infiltration and warrants further radiological testing to assess tumor size.[11]

Radiological investigations should be conducted in addition to bronchoscopy to identify those patients who are surgical candidates. Non-invasive investigations such as computed tomography (CT) with a contract agent and positron emission tomography (PET) scans (for invasive cancers) are essential to visualize the potential for sleeve resection. Thus, an endobronchial lesion or one located in the main bronchus should be assessed to assess suitability for routine lobar resection or the need for pneumonectomy for complete resection. Endobronchial ultrasound can be used for staging, whereas mediastinoscopy should be performed in all cases of lung cancer. This procedure is also helpful for the anterior mobilization of the main bronchi and the trachea during bronchoplastic resections. Tumors having multiple N2 involvements are a contraindication for curative resections. In such cases, alternative treatments should be considered.[1,4]

Lung function tests should be performed to establish how well the patient would be able to cope with surgery. Pulmonary scintigraphy can provide further information. As there is always a risk to convert the surgery to a pneumonectomy, cardiac evaluation should also always be performed. Educating the patient with regard to postoperative physiotherapy and spirometry would aid in recovery. Preoperative consultation with the anesthetist to establish the operation and the type of intubation has shown to be beneficial for surgical planning.[4,11]

The level and extent of PA infiltration may not always be established with preoperative imaging. Angiography and magnetic resonance imaging (MRI) may provide important information to establish the level of vascular involvement. However, the latter is often only fully established intraoperatively. Inconsistencies between preoperative imaging and intraoperative findings can lead to inappropriate surgical indications, as the preoperative study may show more or less vascular involvement than it actually is. Establishing the right indication for surgery is even harder and more controversial following induction therapy. While

assessing preoperative CT, it can become very difficult to differentiate widespread desmoplastic reaction and fibrosis secondary to chemoradiotherapy from cancer tissue.[7,8]

Sleeve Resection Indications

Sleeve bronchial resection

While treating distal tracheal or centrally located benign endobronchial tumors, it is preferred to opt for bronchoplastic resection sparing the lung parenchyma rather than lobectomy, particularly in patients with poor lung function. In general, the main indications to perform this surgical intervention that excludes resection of the lung parenchyma include less malignant bronchial tumors such as typical carcinoid tumors mucoepidermoid carcinoma, and adenoid cystic carcinoma as well as benign conditions such as tuberculosis. Pure bronchial resection is not appropriate in patients with non-small cell lung cancer, as it is not possible to investigate intrapulmonary mediastinal lymph nodes.[16,17]

Sleeve lobectomy

Sleeve lobectomy can be performed in cases of lung cancer, bronchial carcinoid tumors other bronchial tumors trauma, or benign bronchial constrictions secondary to inflammatory conditions, airway problems following lung transplants, acute traumatic injury to the airways and malignancies lobar malignancies to the main bronchus. Around 6 to 8% of resections for primary lung cancers are sleeve resections.[18]

Typical carcinoid tumors are ideal for sleeve resections. These often have a limited amount of intrabronchial invasion and as such, the resection margins can be relatively close to each other. Long-term outcomes in this group are excellent. Patients with mucoepidermoid and cystic adenoid carcinomas are also good candidates for sleeve resections. In these cases, complete resection is required together with the associated lymph nodes. Other benign tumors that warrant preservation of the healthy lung parenchyma include hamartomas, large lipomas, schwannomas, and granular cell myoblastomas. Patients with bronchial or pulmonary Wegener granulomatosis or sarcoidosis can be also candidates for sleeve resection.[18]

Any lobe can be a potential candidate for sleeve resection, while the most common location is the right upper lobe. The reason for this is the presence of the intermediate bronchus in this anatomical location. The second most common location for sleeve resections is the left upper lobe. However, the presence of the aorta and the left recurrent laryngeal nerve makes the latter more difficult to perform.[11,12]

Early (Stage I-IIb) lung cancers and N0 and N1 nodal disease are typically considered good candidates for sleeve lobectomy. Furthermore, a select group of patients with single-station N2 disease with micrometastases can benefit from sleeve lobectomy following successful downstaging induction treatment using recent advances in preoperative neoadjuvant care.[1,3,11]

Advanced lung cancer patients, particularly those with T4 disease, are typically poor candidates for sleeve lobectomy. Involvement of the pleura, SVC, atrium, or transverse aortic arch is all contraindication, as well. Relative contraindications include disease spread to the pericardium, phrenic nerve, vagus nerve, and diaphragm. While the presence of a single N2 disease is not a contraindication *per se* to sleeve lobectomy, potential systemic disease recurrence indicates poorer long-term outcomes.[11,12]

The use of sleeve lobectomy was initially aimed at preserving as many healthy lungs as possible in patients with low-grade carcinoma or carcinoid lesions and benign bronchial stenosis. However, it then became clear that sleeve lobectomy was a good curative operative option for patients with lung cancer and poor lung function. Currently, surgeons opt for sleeve lobectomy over pneumonectomy even in patients with adequate lung function to reduce the rate of complication and improve the quality of life. In cases of invasive cancers, sleeve lobectomies are still being considered where it is thought that the surgical margins would likely be clear of disease and the resection can be successfully completed. Indeed, a positive surgical margin is a poor outcome. The use of sleeve lobectomy in N1 and N2 disease has been debated as in there is poor data in these cases to support an improvement in the survival rates and quality of life.[19,20]

Sleeve lobectomy is also indicated in patients with cardiopulmonary compromise. Typical indications in such patients where sleeve lobectomy is aimed at preserving the lung parenchyma include forced expiratory volume in 1 sec (FEV1) <50% of the predicted value and maximum voluntary ventilation <50% of the predicted value (Table 1).[11]

Extended sleeve lobectomy

Bronchoplasty usually requires anastomosis between the proximal main bronchus and the distal intermediary or lobar bronchus and is, thus, technically difficult. Only thoracic surgeons are able to perform

Table 1. Indications for sleeve lobectomy[11]

- Compromised patients unable to tolerate pneumonectomy
- Pulmonary malignant tumor
- A routine procedure for proximally located tumors
- Carcinoid tumors or benign lesions
- Pulmonary hypertension
- Benign or low-grade malignant tumors of the airway
- Inflammatory strictures
- Post-traumatic bronchial disruptions
- Treatment of bronchial complications
- Re-sleeve resection

anastomoses of distal segmental bronchi. This is known as ESR and was first reported in 1999. The definition of ESR is that of a bronchoplastic procedure which includes the resection of more than one lobe.[5,6]

Extended sleeve resection can be used to prevent lobectomy in locally advanced lunch cancer. Preoperative assessment should first be made and tumor spread and lymph node status confirmed. If N3 and M1 disease are present, ESR is not indicated. When N2 disease is histologically diagnosed, preoperative induction treatment is used including chemo-radiotherapy. Simultaneous reconstruction of the PA is not a contraindication for ESR. Prior to performing an ESR, the patient's ability to tolerate pneumonectomy should be established.[21,22]

Sleeve double resection

Its primary indication is direct tumor infiltration of the interlobar PA. Similarly, this technique can be used to treat extracapsular nodal extension into the artery. Following induction treatment, the PA can be affected in various ways including by the presence of tumor or desmoplastic reaction, scar tissue, or fibrosis. Such patients carry a higher risk of complications. Of all PA reconstructions, around 70% take place for left upper lobe tumors, and 20% for right upper lobe tumors. The remaining 10% include procedures that take place in the main PA and those bilateral procedures involving the lower lobes.[2,7,8,23]

Careful thought should be given to patients with lesions in the proximal end of the PA. Regardless of whether bronchial sleeve resection is performed or not, such patients can benefit from pulmonary arterioplasty. The extent of pulmonary involvement varies and, therefore, the reconstruction procedure can include surgical mesh, primary anastomosis, or interposition grafting.[18,24]

Sleeve segmentectomy

Sleeve segmentectomy can be used to treat low-grade malignant tumors and early-stage lung cancers located in the hilum. The most common type of bronchoplasty is the S6 (superior) segmentectomy, followed by lingular or upper segment resections. Most lung cancers cannot be totally resected in this way and sleeve segmentectomies are as a result rarely indicated, whereas the actual operation is fairly straightforward, and the healing of the anastomosis is easier compared to sleeve lobectomies. Indeed, there is less tension in the anastomosis and perfusion is better in both the pulmonary and the systemic circulation. The anastomosis is covered with a well-vascularized piece of lung tissue which also acts as a protective flap. Finally, the negative pressure within the lung parenchyma pulls the anastomosis outwards, thereby extending its diameter.[6,25]

Tracheal Sleeve Pneumonectomy, Tracheal and Carinal Resection

The most common indications for elective tracheal resection and reconstruction include constructions secondary to long-standing intubation, as well as benign and malignant tumors. In such tumors, surgical resection is often the main part of treatment. Both the trachea and the last third of the carina are particularly affected sites in cases of usually malignant primary tracheal tumors or lung cancer infiltration.[2,26]

In terms of operative technique, carinal resections can be performed as isolated carinal resections where both lung parenchymas are preserved, or as sleeve lobectomy or pneumonectomy where resection of the lung parenchyma and the carina is performed together (Table 2).[26,27]

Tracheal sleeve pneumonectomy is an extended type of resection for tumors affecting the carina and the lower part of the trachea and lung. The most common indication is non-small cell lung cancer (NCCLC), but others include other types of malignancies such as carcinoid tumors or cystic adenoid carcinomas. Tracheal sleeve pneumonectomy is often indicated for right-sided tumors. This is because left-sided tumors rarely extend to the carina. A safe resection margin between the left main bronchus and the lower trachea is considered to be around 4 cm. Mobilization of the left main bronchus upwards is limited due to the presence of the aortic arch and can result in excessive tension within the anastomosis.[28]

Invasion of the SVC, particularly if a superficial SVC resection is being performed, is not an absolute contraindication to surgery. Furthermore, the number

Table 2. Indications carinal resection and reconstruction[27]

Benign
• Fistula in the main bronchus following prior pneumonectomy (short bronchial stump)
• Esophageal-tracheal fistula in the carinal region
• Restenosis following segmental trachea resection
• Stenosis of the main bronchus opening following prior inflammation (in the course of tuberculosis, granulomatosis with polyangiitis, and etc.)
• Post-traumatic stenosis of the main bronchus
• Stenosis of the main bronchus opening in the course of mediastinal fibrosis
Malignant
• Primary lung cancer with isolated carina infiltration (Grade T4, most often originating from the upper right lobe)
• Low-grade tracheal tumors: adenoid cystic carcinoma, carcinoid tumor
• Sarcomas of the carinal region
• Recurrence after prior resection of lung parenchyma due to primary lung cancer (completion pneumonectomy)

of tracheal sleeve pneumonectomies related to SVC prosthetic graft replacement is limited and, thus, long-term outcomes in such patients have not been established yet.[28]

In conclusion, long-term outcomes of carinal resection in patients with bronchogenic carcinoma with N2 or N3 disease are poor. Therefore, the presence of positive mediastinal lymph nodes during mediastinoscopy is usually considered to be a contraindication for surgery. Induction therapy is advised in such patients. However, this can make surgery technically more difficult and is associated with higher postoperative mortality and morbidity rates in patients undergoing tracheal sleeve pneumonectomies. Preoperative radiation higher than 45 cGY is a relative contraindication for sleeve pneumonectomy and is even considered for some to be an absolute contraindication.[26]

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