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REVIEW / DERLEME

Carinal sleeve resections

Karinal sleeve rezeksiyonlar

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ABSTRACT

Carinal resections are frequently performed for carinal tumors. Resection of the carina due to distal tracheal tumors may be required, and the extension of main bronchial tumors to the carina may lead to carinal resection. This is one of the rarely performed operations in thoracic surgery, which is technically challenging and has a high complication rate. In the early series, perioperative mortality rate was reported as 29% and the five-year survival rate as 15%. Due to its technical difficulties and high complication rates, it is performed only in certain centers. In this review, we discuss techniques related to carinal sleeve resection and prognostic factors in the light of literature data.

Keywords: Carinal sleeve resections, non-small cell lung cancer, sleeve resections.

ÖZ

Karinal rezeksiyonlar sıklıkla karinal tümörlere bağlı olarak uygulanmaktadır. Distal trakeal tümörlere bağlı karina rezeksiyonu gerekliliği doğabileceği gibi, ana bronş tümörlerinin karinaya uzanımı da karina rezeksiyonu ile sonuçlanabilir. Göğüs cerrahisinin teknik açıdan zorlayıcı, komplikasyon oranı yüksek, nadir uygulanan ameliyatlarındandır. Erken serilerde perioperatif mortalite %29 ve beş yıllık sağkalım oranı %15 olarak bildirilmiştir. Teknik açıdan zorluğu ve yüksek komplikasyon oranları nedeni ile yalnızca belirli merkezlerde uygulanabilmektedir. Bu derlemede, karinal sleeve rezeksiyona ilişkin teknikler ve prognostik faktörler literatür verileri eşliğinde irdelendi.

Anahtar sözcükler: Karinal sleeve rezeksiyonlar, küçük hücreli dışı akciğer kanseri, sleeve rezeksiyonlar.

The first successful carinal resection and lateral resection were performed by Belsey[1] in 1946. In 1950, the first carinal sleeve pneumonectomy was performed by Abbott.[2] Carinal resections are frequently performed due to carinal tumors. Resection of the carina due to distal tracheal tumors may be required, and the extension of main bronchial tumors to the carina may lead to carinal resection. This is one of the rare operations in thoracic surgery, which is technically challenging and has a high complication rate. Despite the high complication rate, operable patients should be surgically evaluated, as their acceptable mortality and one-year survival rate are as high as 87.5% compared to resectable tumors.[3] Carina resections due to benign causes are much less common. Carina resections can be performed due to hamartomas, bronchopleural fistulas, and inflammatory causes. Table 1 shows the most common causes in patients undergoing carina resection.

In the early series, perioperative mortality was reported as 29% and five-year survival as 15%.[4] Developments in the fields of anesthesia, surgery, and oncology, as well as increasing knowledge and experience, mortality rates in the current literature are much lower and survival rates are much higher than those for resectable tumors. Due to its technical

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Table 1. Indications for carinal resection

Malignant	Benign
Squamous cell carcinoma	Main bronchial fistulas
Adenoid cystic carcinoma	Inflammatory strictures
Adenocarcinoma	Hamartoma
Carcinoid tumors	Secondary to trauma
Large cell carcinoma	

difficulties and high complication rates, however, it is not suitable for use in all centers.

Preoperative Evaluation

Approach to tumors with carina involvement has similar characteristics to those for tracheal tumors. Therefore, carinal tumors can be considered a subset of tracheal tumors. The presence of carcinoma in the carina, such as in the heart, great vessels, esophagus, vertebrae, and trachea, can be classified at T4 in the Tumor, Node, Metastasis (TNM) staging system. Lymph node invasion and the presence of distant metastases are the most important markers for prognosis in carina tumors.

Symptoms can occur in a wide time frame in carina tumors. Non-specific complaints such as cough and shortness of breath are common, and symptoms such as wheezing and hemoptysis due to central airway obstruction can quickly a lead to diagnosis. Complaints such as cough and dyspnea may be mistaken for asthma. Therefore, there may be a delay in diagnosis. In addition, these patients receive long-term corticosteroid treatment with a preliminary diagnosis of asthma.[5] Due to treatment-resistant asthma or other causes, the diagnosis is usually made through thoracic computed tomography (CT).

Patients in whom carcinoma resection is planned should be well selected. Medical history of the patient should include the question of whether corticosteroids are being used and, if the patient smokes, it should be discontinued. The patients should be also evaluated from a cardiac perspective, and their pulmonary function should be assessed and their residual lung volume calculated. In our previous study on carinal sleeve resections, patients with a forced expiratory volume in 1 sec (FEV1) value above 40% were considered suitable for surgery.[6] Comorbidities and nutritional status of patients should be evaluated. The patients should be informed about the surgery to be performed, and the use of the chin suture should be explained. It should be remembered that one of the key factors in the success of surgery is patient compliance.

The main imaging modality used in diagnosis is thoracic CT. It provides valuable information on many issues, such as the location of the tumor, the width of resection to be performed, the extramural spread of the tumor, positive suspicious lymph nodes, and the presence of additional pathology. When possible, three-dimensional reconstruction images patterned after images from CT also contribute to surgical planning (Figure 1). In addition to carina involvement, resection of the carina is also required for main bronchial tumors that are less than 1 cm from the carina.[6] The carina is the most rigid cartilaginous structure in the tracheobronchial system. Pneumectomy near the carina increases the risk of bronchopleural fistula due to this stiffness. As with lung cancer, positron emission tomography (PET)/CT and cranial magnetic resonance imaging (MRI) should be used to evaluate for distant metastases in cases requiring resection of the carina.

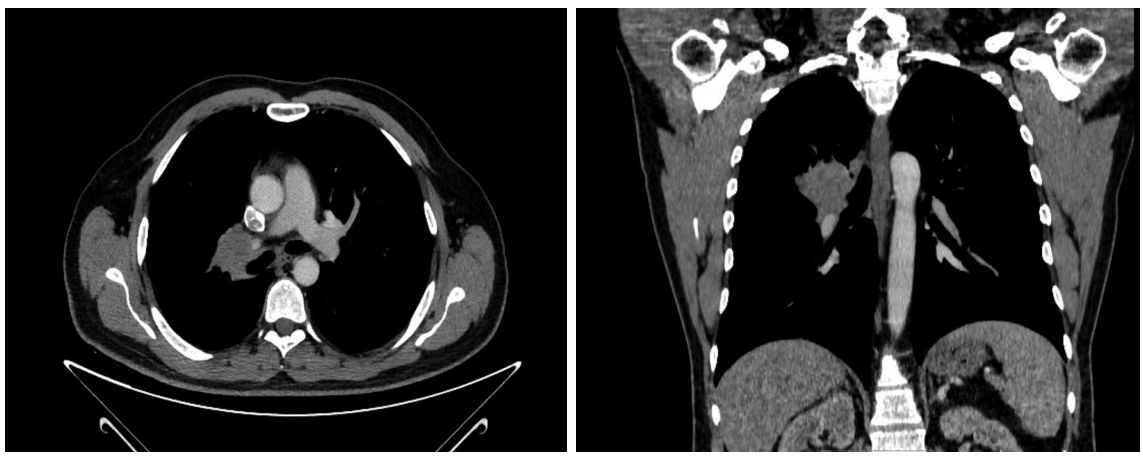

Figure 1. Thoracic computed tomography image of the patient with a lung tumor invading the right carina.

Fiberoptic bronchoscopy (FOB) is one of the main examination methods in preoperative evaluation (Figure 2). It is of utmost importance for both the diagnosis of the lesion and the length of the segment to be resected. Some authors have suggested achieving negative margins with multiple sampling from the surgical margin away from the tumor and proposed that the resection width should be measured according to these margins.[7] In case of obstructive lesions, rigid bronchoscopy should be performed prior to surgery to improve the patient's condition, as well as to identify the length of the segment to be resected preoperatively.

The two most common pathologies in carinal tumors are squamous cell carcinoma (SCC) and adenoid cystic carcinoma (ACC). The most important issue in resection planning for both SCC and ACC is reaching the negative surgical margin. However, wide resections performed to reach the negative surgical margin lead to tension and complications in anastomosis. Mitchell et al.[8] reported that anastomotic tension could occur in end-to-end anastomoses longer than 4 cm. Anastomotic complications also increase postoperative mortality. The benefit of incomplete resections is controversial. Grillo and Mathisen[9] reported that the surgical margin and lymph node positivity had a negative impact on survival in SCC of the trachea. They defined surgical margin negativity as 1 cm distance of the tumor from the surgical margin. For ACC, Honings et al.[10] concluded that incomplete resection was associated with lower survival, whereas Maziak et al.[11] reported that there was no significant survival difference between complete resection and incomplete resection. Adenoid cystic carcinoma exhibits submucosal and perineural spread, and it is often difficult to achieve a negative surgical margin. In addition, there is often an invasion of adjacent organs, particularly esophageal muscle layer involvement, which is frequently encountered. The effect of surgical margin positivity and the presence of lymph node metastasis on long-term survival with palliative treatment is more absolute than that of bronchogenic carcinomas. Honings et al.[10] reported that the factors that positively affect postoperative survival at ACC are negative surgical margins, negative adventitial margins, no extramural spread, no perineural spread, and no lymph node positivity. In addition, the mean survival was found to be 17.7 years, and they recommended long-term follow-up to provide survival analysis after ACC. Although there are publications reporting that the presence of mediastinal lymph node invasion in ACC has a negative effect on survival, there are also publications arguing that lymph node metastasis is not a contraindication.[12-16] In addition, Gaissert et al.[17] suggested in their writings that although the surgical margin remained positive in selected patients with ACC, surgery should be performed in experienced surgical centers. In SCC, lymph node metastasis is considered a poor prognostic factor for survival, and the presence of mediastinal lymph node metastasis is considered a surgical contraindication.[13]

Furthermore, PET/CT is an important guide in the evaluation of mediastinal lymph nodes. Histopathological confirmation should be performed in patients with suspected positive lymph nodes on

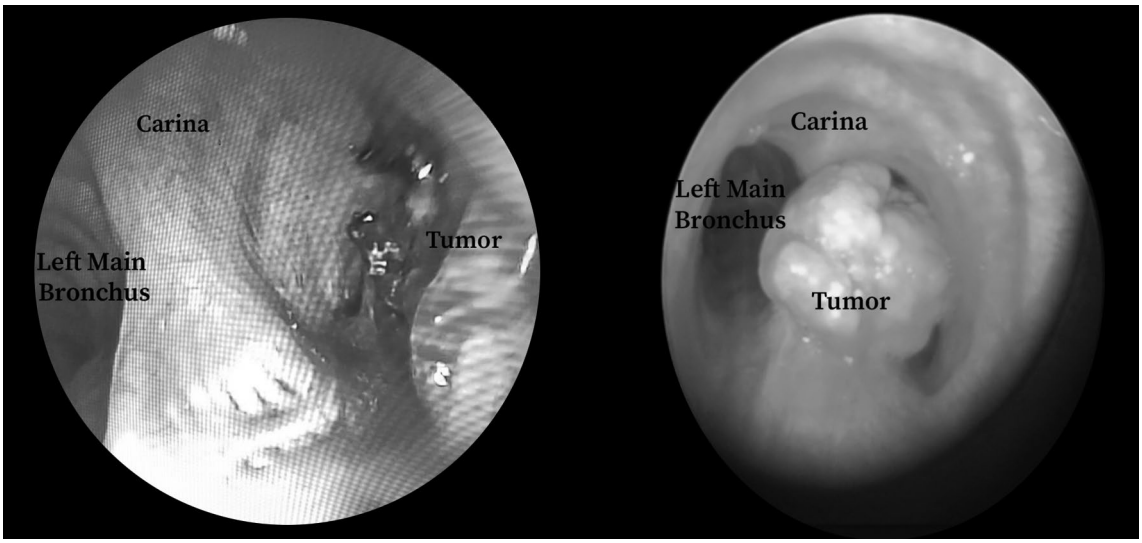

Figure 2. Endobronchial tumor image at the level of the carina in fiberoptic bronchoscopy.

PET/CT. In our opinion, TNM staging should be also applied in carina resections; therefore, patients with lymph node metastases should receive neoadjuvant chemotherapy or receive palliative treatment. Therefore, suspicious lymph node involvement on PET/CT should be investigated by endobronchial ultrasound (EBUS). Patients with positive lymph nodes on EBUS should be evaluated for neoadjuvant therapy, and eligible patients should be re-evaluated with mediastinoscopy after neoadjuvant therapy. Mediastinoscopy should be performed, even if the lymph nodes in PET/CT are negative. Mediastinoscopy can also provide information about the invasion of the tumor into the carina. The algorithm for preoperative evaluation of cancer patients with planned resection of the carina is shown in Figure 3.[6]

Anesthesia Management

A successful carina resection depends on the cooperation of the anesthesia team and the surgeon. The main goal of the team should be to extubate the patient while still in the operating room. To control postoperative pain, an epidural catheter should be inserted before the procedure. After total intravenous anesthesia, the patient was intubated, and a nasogastric tube was placed. There are different opinions about the intubation tube. Some authors prefer extraluminal tubes with a single lumen, usually No. 7,[8,15] while some authors consider using double-lumen tubes appropriate.[6,7] Double-lumen tubes are large and inflexible. In addition, tumors located in the carina may have difficulty in adjusting tube position and proper placement. Thus, double-lumen tubes are less preferred by surgeons.

Fluid loading and barotrauma should be considered during surgery. In addition, high oxygen concentrations, multiple collapses and re-expansion, hypoperfusion, and hypoxic pulmonary vasoconstriction should be avoided. High-frequency jet ventilation can be used in patients who cannot tolerate intermittent ventilation, but it should be noted that it is a predisposing factor for acute respiratory distress syndrome (ARDS). Cross-table ventilation equipment should be checked for sterility before resection. Once airway resection is initiated, the lung not to be resected is ventilated with a sterile endotracheal tube and a sterile connecting tube passing through the surgical site. The orotracheal intubation tube is used during the placement of the. An intermittent ventilation technique is applied while placing anastomotic sutures. After completion

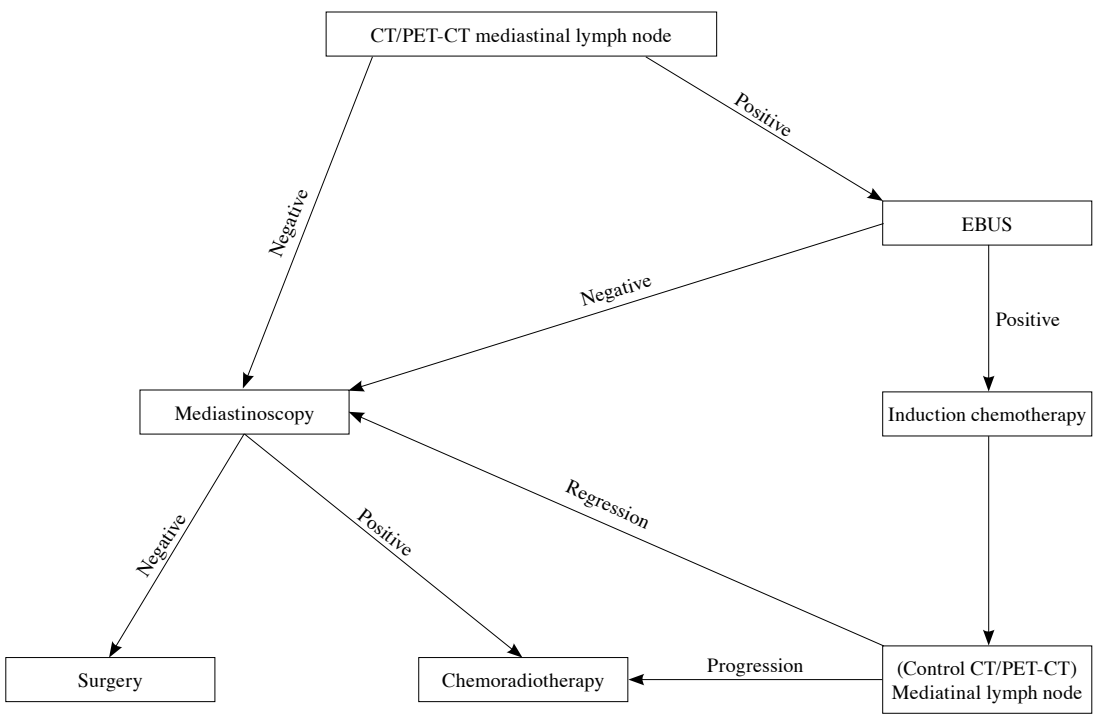

Figure 3. Preoperative evaluation algorithm in patients with planned carina resection.
CT: Computed tomography; PET: Positron emission tomography; EBUS: Endobronchial ultrasound.

of the end-to-end anastomosis, the orotracheal tube is advanced distal to the anastomotic line, and continental ventilation is provided for the end-to-end anastomosis. However, for end-to-side anastomoses in which the right interlobar bronchus or lower lobe bronchus is anastomosed to the left main bronchus, it should be kept above the anastomotic line, and the lungs ventilated with low volumes. Following the completion of the anastomosis, the pressure is gradually increased, and the anastomotic leak is investigated. Cardiopulmonary bypass is often not required. Although resection of the carina under spontaneous ventilation is rare, it can be used in patients with a poor general condition in the literature.[18,19]

Operational Management

Mediastinoscopy

In the literature, mediastinal lymph node invasion has been reported between 4 and 27% of carcinomas.[16,20-22] Mediastinoscopy should be performed concurrently with resection in patients with planned carinal resection. Mediastinoscopy performed in a separate session leads to scar tissue formation and complicates resection. The main indication for mediastinoscopy is tumor staging. Lymph nodes are harvested, and staging is performed by freezing section. Mediastinoscopy performed in the same session offers several other advantages. Releasing the pre-tracheal fascia allows it to be mobilized to the upper airways of the trachea. The recurrent laryngeal nerve can be mobilized and removed from the surgical site. Extramural spread of the tumor and invasion of surrounding tissue are noted. Involvement of the esophageal muscle layer and superior vena cava (SVC) are not contraindications for resection.

Incision

Right posterolateral thoracotomy from the fourth or fifth intercostal space provides the best view and mobility for the carina. To access the carina with left thoracotomy, the aortic arcus and left pulmonary artery must be mobilized, and the angle of view is limited. To reach the carina with median sternotomy, the ascending aorta should be retracted to the left, the SVC to the right, and the right main pulmonary artery to the apex depending on the patient. Depending on the surgeon's preference, one of these incisions may be used to reach the site of the tumor or the carina. For larger resections, a bilateral thoracotomy or clamshell incision may be used. In recent years, with the increasing experience with video-assisted thoracoscopic surgery (VATS), carina resections have been also performed using VATS.[23]

Mitchell et al.[8] reported that they frequently used right thoracotomy in carina resections and argued that the angle of view of median sternotomy was limited and could only be used for simple carina resections. Porhanov et al.[21] performed sternotomy in the majority of patients. However, it was difficult to reach the posterior hilum while performing left carinal pneumonectomy with sternotomy, the heart became too suspended and, therefore, arrhythmias and hypotension developed. The fact that it is difficult to reach the carina with left thoracotomy, that bilateral thoracotomy causes severe pain and respiratory depression, and that the clamshell incision is both cosmetically poor and difficult to use in individuals with obesity makes VATS a more useful option in this field. For left carinal pneumonectomy, right thoracotomy followed by pneumonectomy with left VATS or carina resection with VATS may be a solution to this technical problem.[24]

Release maneuvers

The purpose of the release maneuvers is to reduce anastomotic tension. All release maneuvers must be performed before starting the resection. For resections up to 4 cm, the opening of the pre-tracheal fascia and U-shaped release of the hilum and neck flexion are sufficient to reduce anastomotic tension. For resections larger than 4 cm or in cases where anastomotic tension persists despite these maneuvers, techniques such as the circular release of the hilum, pericardiophrenic release, and binding of traction sutures can be used.

By opening the pre-tracheal fascia with the help of mediastinoscopy, tracheal mobilization and left main bronchial mobilization can be achieved. In hilar release maneuvers, both inferior pulmonary ligaments are separated, and release is achieved through a U-shaped incision at the level of the inferior vein. Circular-shaped release of the hilum provides more mobility, but may damage the posterior lymphatic and vascular system connections. The effect of laryngeal dislocation on the mobility of the carina plane has not been demonstrated.[25] Neck flexion and maxillary suturing both reduce anastomotic tension and avoid early anastomotic complications by preventing the patient from extending the neck in the postoperative period. Grillo[26] reported that a 4.5-cm tracheal resection could be only performed with neck flexion. Chin sutures are removed within seven to 14 days postoperatively. Pericardiophrenic release is performed by detaching the pericardium from the diaphragm from anterior to posterior between the two phrenic nerves.

Resection

In the right thoracotomy approach, the right lung is effaced and retracted anteriorly. To increase the angle of view, the pleura is opened, and the azygos vein is transected. In median sternotomy, large vascular structures are removed from the operative area using a Thompson retractor, and the carina is reached. However, problems of venous return with excessive retraction of the SVC, decreased cardiac output with excessive retraction of the ascending aorta, and problems of ventilation-perfusion incompatibility with excessive retraction of the right main pulmonary artery may be encountered. In the left thoracotomy, the aortic arch and the left main pulmonary artery should be released, and the left recurrent laryngeal nerve should be protected.

After reaching the carina, the abdomen is retracted, sparing the left recurrent laryngeal nerve. The resection site is determined by palpation and/or FOB. Extensive dissection and skeletonization of the airway are not recommended, since it disrupts the supply to the anastomosis. In addition, aggressive lymphadenectomy has been reported to disrupt the nutrition of the anastomosis.[27] However, this approach may overlook micrometastases and cause a central tumor to be incorrectly staged. The trachea and both main bronchi are suspended with tape. If a parenchymal resection is to be performed, parenchymal resection is performed first. Then, traction sutures are placed two rings away from the area to be resected in both the main bronchi and trachea. In general, 2/0 atraumatic absorbable sutures are preferred as traction sutures. Ventilation is discontinued, and the intubation tube is withdrawn to the level of the proximal trachea. After the transection of the trachea, the right and left main bronchus is transected according to the resection and reconstruction to be performed. It is not recommended to enter the airway with the cautery, as it may become inflamed due to the high oxygen concentration. In addition, as it may impair the healing of the anastomotic line, as little cautery should be used around the anastomosis as possible. Division should be performed with the help of a scalpel. After the removal of the piece, the right or left main bronchus is ventilated with a sterile cross-table device. Before examining the microscopic surgical margin with a frozen-section from the piece, the piece should be evaluated with regard to the macroscopic surgical margin and radial margins. In cases where the surgical margin is positive, another ring is excised and the negative surgical margin is attempted. In ACCs, it can be sometimes difficult to achieve a negative surgical margin. Therefore, resection should be performed to avoid anastomotic tension, and it should be remembered that positive surgical margins have good results with adjuvant therapy. In case of positive radial margins, major resections involving the surrounding tissue should be performed, if necessary (Figure 4).

Reconstruction

The main goal of reconstruction is to provide a well-vascularized, non-stressed anastomosis. While performing anastomosis, attention should be given to diameter mismatch and tracheobronchial angles. The part with a larger diameter in diameter mismatch-usually the trachea-is shaped and narrowed according to the part with a smaller diameter. Diameter reduction can be performed by suturing the membranous part. Another method is the application of anastomosis by advancing the narrow part with the telescope method into the large part. A mismatch of the tracheobronchial angle is not always visible from the outside. Therefore, it would be useful to perform FOB after anastomosis.

Suture material and suturing techniques used in anastomosis vary according to surgeon preference. In general, 3/0 or 4/0 polyglactin (Vicryl), polydioxanone (PDS), or polypropylene sutures can be used continuously or intermittently.[6,21,28-31] The membranous face continent and cartilage ring

Figure 4. Cross-table lung ventilation image in right carina resection.

Figure 5. Intraoperative view after the anastomosis is completed in carina resection.

part can be sutured intermittently. Although it is recommended to tie the sutures outside the lumen, it has been reported that there are no problems in the lumen of absorbable sutures.[32] The use of a lubricant while using Vicryl sutures may reduce tissue trauma. It is recommended to begin the anastomosis from the membrane side. Then, the cartilage side is sutured, and the anastomosis is completed. When necessary, traction sutures are tied together to reduce anastomotic tension (Figure 5).

Several options are available for reconstructing the carina. The reconstruction technique described by Barclay et al.[33] in 1957 has been the most commonly used technique for many years. Mitchell et al.[8] used 15 different techniques in carina reconstruction. Fifteen different techniques for reconstruction of the abdomen are shown and described in the following figures (Figures 6 and 7).

Probably, the most important point to be considered in an end-to-side anastomosis is that the opening planned for anastomosis should be completely surrounded by a cartilaginous part to ensure rigidity. The membranous part should not be included in the end-to-side anastomosis. Mitchell et al.[8] suggested that end-to-end anastomoses should be applied to end-to-end anastomoses at least 1 cm away. However, anastomosis of the right intermediary bronchus or right lower lobe bronchus to the trachea may lead to tracheobronchial angle problems and drainage problems of the anastomosed lobe. In this case, the technique described by Miyamoto and published by Yamamoto et al.[28] can be used.

In the Miyamoto/Yamamoto technique, carina resection including the right upper lobe, trachea, and

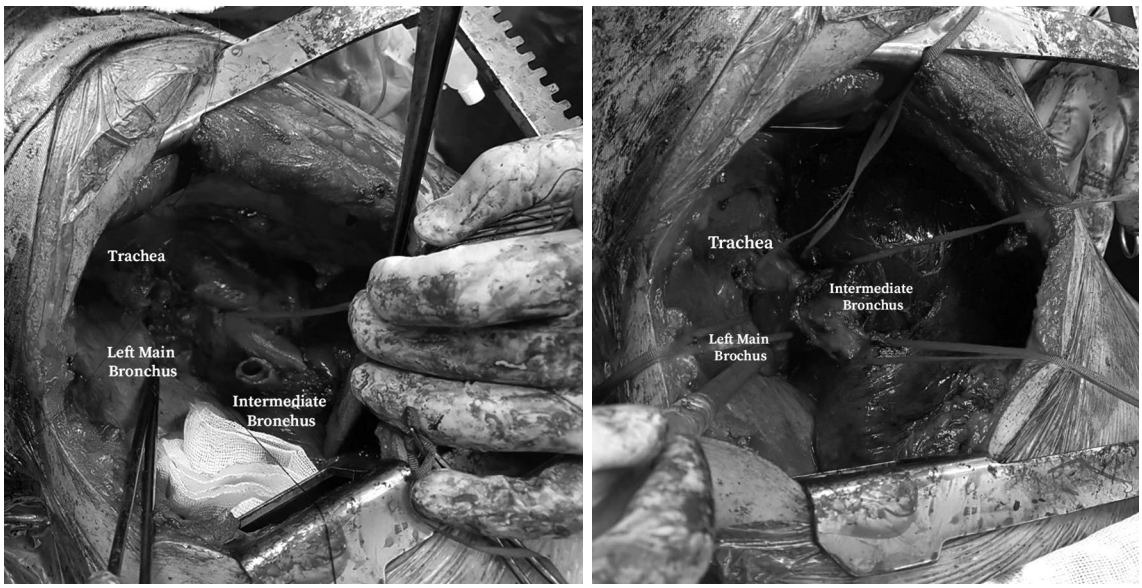

Figure 6. Anastomosis of the right intermediate bronchus to the left main bronchus and anastomosis of the left main bronchus to the trachea in Barclay operation.

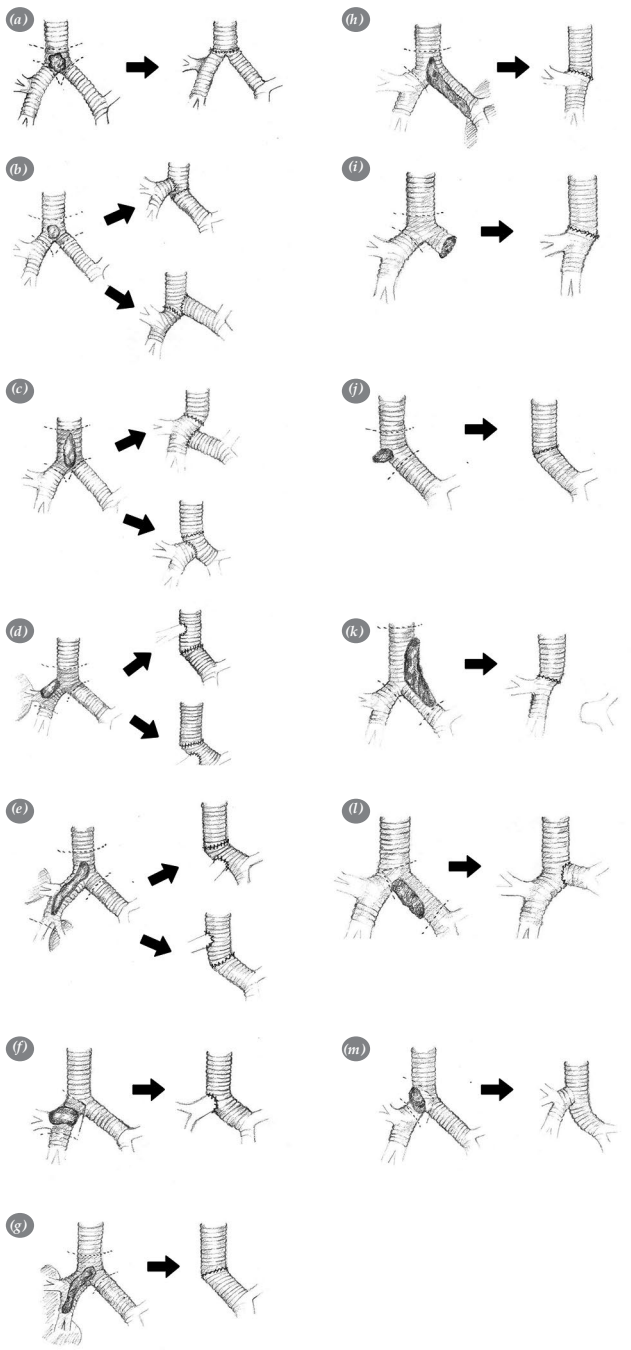

Figure 7. Variations of carina reconstruction. **(a)** Double-Barrel Technique: In limited carina resections, the right and left main bronchi are anastomosed to the distal trachea, and a new carina (neocarina) is formed. **(b)** End-to-Side Anastomosis Technique: In this technique, which is used without lung resection, tracheal end-to-end anastomosis is performed with the left main bronchus after resection, and a tracheal end-to-side anastomosis is performed with the right main bronchus (upper figure). Another option is to anastomose the right main bronchus end-to-end with the trachea and to the left main bronchus end-to-side with the trachea (lower figure). **(c)** Barclay technique: In this technique, the right main bronchus is end-to-end anastomosed with the trachea, and the left main bronchus and the intermediary bronchus end-to-side are anastomosed (upper figure). The other option is trachea and left main bronchus end-to-end, right main bronchus and left main bronchus end-to-end side anastomosis (lower figure). **(d)** Carina and Right Upper Lobectomy 1: Upper trachea and left main bronchus end-to-end, trachea end-to-side anastomosis with a right intermediate bronchus. In the lower figure, end-to-end anastomosis is performed between the trachea and the left main bronchus, and end-to-side anastomosis is performed between the right intermediate bronchus and the left main bronchus. **(e)** Carina and Right Upper Bilobectomy: The same method as Figure D is applied, and the right lower lobe bronchus is used instead of the intermediate bronchus. **(f)** Carina and Right Upper Lobectomy 2: As described by Abbott, it is resected in a wedge shape from the lateral wall of the trachea and the left main bronchus, the resulting opening is properly narrowed to the orifice of the right intermediate bronchus, and anastomosis is achieved. **(g)** Right Carinal (Tracheal) Sleeve Pneumonectomy: End-to-end anastomosis is performed between the trachea and the left main bronchus. **(h)** Left Carinal (Tracheal) Sleeve Pneumonectomy: End-to-end anastomosis is performed between the trachea and the right main bronchus. **(i)** Left Recurrence Carinal (Tracheal) Sleeve Resection: End-to-end anastomosis is performed by cutting the right main bronchus with the trachea in left main bronchial recurrence tumors or in case of bronchopleural fistula after previous left pneumonectomy. **(j)** Right Recurrence Carinal (Tracheal) Sleeve Resection: End-to-end anastomosis is performed by transecting the left main bronchus with the trachea with the same indications as in Figure 1. **(k)** Left Main Bronchus Exclusion: In cases where a major resection is required and reconstruction with the left main bronchus is not possible, the left main bronchus can be excised. **(l)** Left Carinal Wedge Resection: The carina is anastomosed with the left main bronchus. **(m)** Right Carinal Wedge Resection: It is anastomosed to the carina with the right main bronchus.

left main bronchus end-to-end anastomosis is started, wedge resection is applied to the right edge of the anastomosis to open enough for the right intermediary/lower lobe bronchus to sit, and the right intermediary/lower lobe bronchus is anastomosed to this area. There are several anastomosis techniques that are not described herein (Figure 5).[15]

After completion of the anastomosis, the anastomosis is checked from the inside with the FOB. Then, starting with low pressures, the anastomosis is checked for air leakage (20-25-30-35 mmHg). If there is no leakage, support of the anastomotic line with vital tissue is started.

Table 2. Mortality and mortality rates after carina resection and reconstruction

Author	Year	Number of patients	Morbidity (%)	Mortality (%)	The most common complication (%)		5-year survival (%)
Dartavelle et al.[22]	1995	55	-	10.9	Empyema	12.7	23
Mitchell et al.[8]	1999	134	38.8	12.7	Anastomotics	17.2	-
Porhanov et al.[21]	2002	231	36	16	Anastomotics	25.1	24.7
Regnard et al.[14]	2005	65	50.7	7.7	Arrhythmia	21.5	26.5
De perrot et al.[34]	2006	119	47	7.6	Anastomotics	10	44
Roviaro et al.[38]	2006	53	11.3	7.5	Recurrent nerve damage	3.8	33.4
Rea et al.[39]	2008	49	28.6	6.1	Arrhythmia	6.1	27.5
Eichhorn et al.[40]	2013	64	41	3	Empyema	11	31
Sezen et al.[6]	2020	64	48.8	10.9	Arrhythmia	29.7	42.2

Supporting the Anastomotic Line

The anastomotic line must be supported with vital tissue in all airway anastomoses. Although the parietal pleura is easy to access, it may be insufficient to protect the anastomosis after a difficult anastomosis, such as carina reconstruction. Therefore, tissues such as intercostal muscle tissue, pericardial fatty tissue, thymus, and omentum should be preferred to support the anastomotic line. One of the issues to be considered while using an intercostal muscle flap is that the periosteum should not be accompanied. In cases supported by 360-degree intercostal muscle flaps, secondary calcifications and anastomotic stenosis may develop due to ossification. In their study, Porhanov et al.[21] reported that patients with flaps could recover without surgery in patients with micro-fistula and reported that the best material was omentum.

Additional Resection

Carinal tumors, particularly ACCs, show extramural spread and may cause invasion of surrounding tissue. In this case, resection of the surrounding tissues may be required to achieve negative margins. The esophageal muscular wall is one of the most common areas of involvement. Areas with involvement, such as the SVC, aortic adventitia, and left atrium, should also be included in the resection. Published studies have reported that additional resection is performed in 10 to 48% of cases.[8,21,34]

Postoperative Care

Patients are extubated while still in the operating room and transferred to the postoperative intensive care unit. Some authors have argued that waking up with a laryngeal mask reduces the cough reflex and, thus, avoids the overpressure effect caused by coughing in the newly created anastomosis.[32] Patients who do not develop additional problems are taken to the service after one day of intensive care follow-up. The main goal of postoperative care is to provide intensive pulmonary physiotherapy and proper anastomosis recovery. Aggressive measures should be taken to remove secretions. Temporary tracheostomy should not be avoided in patients with limited respiratory physiotherapy, using broncodilators, having secretion clearance with recurrent FOB, if needed, and limited respiratory reserve. Pain control should be provided with patient-controlled analgesia or epidural analgesia, and the patient should not disrupt respiratory physiotherapies and proper breathing. Positive pressure ventilation is a relative contraindication, as it is an important factor that increases postoperative mortality.[8] Fluid restriction is recommended to avoid postoperative loading findings. Chin sutures are usually removed on Day 7, and it is recommended that the patient does not have neck extension for another week. Some authors have recommended chin suturing for 14 days.[15] Oral feeding should be started as early as possible. In patients with carinal sleeve pneumonectomy, nasogastric tube retention for 24 to 36 h and enteral nutrition are recommended.[7] Routine chest radiographs are also recommended during follow-up.

Complications

The morbidity and mortality rates after carina resection and reconstruction compiled from a large

series of studies are given in Table 2. Complications can be classified in various ways as major and minor, early and late complications. Major complications include ARDS, anastomotic complications, hemothorax, and pyothorax. Minor complications include arrhythmia, wound infection, pneumonia, atelectasis, chylothorax, and recurrent nerve damage. Complications such as ARDS, arrhythmia, pneumonia, and bronchopleural fistula are seen in the early period, while complications such as granuloma formation in the anastomotic line, restenosis secondary to the healing tissue, post-obstructive pneumonia and bronchiectasis due to the drainage problem of the lobe and empyema occur in the late period.

There are two main complications needed to be specifically addressed. One of them is ARDS, and the other is anastomotic complications. The former is observed at a rate of 4% after lung cancer surgery, with a mortality rate of 65% and a mortality rate of over 80% after pneumonectomy.[35,36] It accounts for 76% of deaths after carina resection.[8,21] Macchiarini et al.[7] reported that they avoided high oxygen concentration, multiple collapse, and re-expansion, hypoxic pulmonary vasoconstriction, hypoperfusion of the ipsilateral lung and fluid loading and that they did not consider ARDS as a complication. The cause of postoperative ARDS is not clearly known. It may be also accompanied by complications such as pneumonia, empyema, and bronchopleural fistula. In their studies, Mitchell et al.[8] and Porhanov et al.[21] reported an increased incidence of ARDS after carinal sleeve pneumonectomy.

Anastomotic complications are the most common complication in most articles. Complications related to anastomoses, such as fistula, dissociation, necrosis, stenosis, and granulation tissue formation, may occur. Healing of the anastomosis depends on several factors. These factors can be listed as anastomotic tension, aggressive carinal dissection, chemoradiotherapy, positive surgical margin, cachexia, diabetes, and immunosuppression. Mitchell et al.[8] reported that anastomotic morbidities had a mortality rate of 43%. They reported a mortality of 31% and a morbidity of 69% after left carinal pneumonectomy and that 38% of this morbidity was due to anastomotic complications. They attributed the reason to the difficulty in performing anastomosis due to the stenosis in the exposure and the fact that it was not preferred due to the high physiological burden of bilateral thoracotomy. In the same series, the authors reported 36% of anastomotic complications in those who underwent lobar resection with carina, and they considered the cause to be end-to-side anastomosis.[8] Porhanov et al.[21] reported that there was no significant difference between the suture types (continuous, interrupted, and combined) and anastomosis types (simple membrane-membrane and cartilage-cartilage type, telescopic type or rotating type) in terms of complication and mortality rates. To reduce the complications of anastomosis, an anastomosis should be applied surrounded by a well-nourished, unstretched, vital tissue.

Adjuvant Therapy

If no mediastinal lymph node invasion is detected during carinal resections, surgery provides the best survival. If downstaging is observed in the presence of mediastinal lymph node involvement after oncological treatment, patients can be re-evaluated for surgery. Macchiarini et al.[7] applied neoadjuvant therapy at a rate of 36% and found no significant increase in the rates of operative mortality and morbidity in their patients. Of 18 patients included in the study, downstaging was performed in seven, whereas no downstaging was performed in 11. Disease-free survival was higher in patients with downstaging. Therefore, patients scheduled for surgery after neoadjuvant treatment should be well selected. Regarding postoperative oncological treatment, Grillo and Mathisen[9] and Mitchell et al.[37] routinely recommended postoperative radiotherapy after resections of the carina. On the other hand, Regnard et al.[14] reported that postoperative radiotherapy provided no survival benefit in patients with negative surgical margins. We believe that chemotherapy should be given, if lymph node metastases are present and radiotherapy should be given, if the surgical margin is positive.

Prognosis

The five-year survival rate after carinal resection varies from 25 to 40%. In previous studies, postoperative mortality was found to be 5 to 10%, and morbidity was nearly 40%.[6,21,38-40] In resectable patients, survival is measured in months.[32] Gaissert et al.[17] reported that the five-year survival was 39.1% in patients with SCC who had involvement of the carina and trachea and 7.3% in patients who could not be resected. Erdogu et al.[41] observed that tumors with carina invasion and main bronchial invasion did not significantly differ in terms of survival. The five-year survival rate was 49.2% in the group with carina invasion and 46.4% in the group with main bronchial invasion. Although postoperative mortality and morbidity rates appear to be higher in carina resections compared to other resections, they offer a

significant survival advantage to patients. Therefore, appropriate patients should be surgically evaluated in experienced centers.

Long-term survival outcomes for ACC are not well defined due to late recurrence. Adenoid cystic carcinoma has a longer segment than SCC, microscopic surgical margin positivity is more common, and survival rates are higher.[17] Honings et al.[10] reported that the mean survival time for ACCs was 17.7 years, and the disease-free survival time was 10.2 years. They found that factors negatively affecting survival were positive surgical margin, extramural extension, surrounding tissue invasion, perineural invasion, and lymph node metastasis. In the study by Gaissert et al.,[17] the five-year survival rate was 2% for resected ACC and 33% for unresectable ACC.

Currently, many authors have agreed that the survival rate for mediastinal lymph node metastases is low and that surgery is contraindicated, particularly for SCC. Regnard et al.[14] reported that five-year survival was 5.3% in the presence of N2 and 38% in the presence of N0-N1 in patients with non-small cell lung cancer (NSCLC) carina involvement. Jiang et al.[15] found that the five-year survival rate was 37% in the presence of N0-N1 and 7.1% in the presence of N2. In the study by Sezen et al.,[6] the five-year survival rate was 45% in the presence of N0-N1, was 45%, whereas the survival rate in the N2 group was not demonstrated. Although lymph node invasion decreases survival in ACC, there are opinions that surgery is not contraindicated.[10,17]

According to the 8th TNM staging, carina invasion is considered a T4 tumor. Compared to other T4 tumors, survival rates are similar for invasion of the mediastinum, diaphragm, heart, great vessels, and trachea. In their study, Watanabe et al.[42] found that the five-year survival rate in T4N0 patients younger than 70 years was more than 50%, and no significant difference in survival was found between subgroups.

Future Directions

With the increase in anesthesia techniques and surgical experience, minimally invasive procedures can currently be performed in carina resections. In their multi-center study, Li et al.[43] performed carina and trachea resection with VATS in 12 patients. Jiang et al.[18] applied carina resection to four patients, while Peng et al.[44] applied carina resection to two patients under spontaneous ventilation. In addition to the cosmetic advantage of VATS, their advantage regarding pain is critical in terms of secretion management in the postoperative period, particularly in patients undergoing carina resection and reconstruction.

In a study, Martinod et al.[45] performed the first replacement of a long tracheal segment using an aortic allograft. Later on, Wurtz et al.[46] used aortic allografts in six patients and achieved satisfactory results. The authors reported that fresh allografts were used in two of these patients and cryopreserved allografts in four patients, and that all patients were followed with a lifelong stent. In tracheal replacement, trachea developed with solid prostheses, porous prostheses, tracheal allografts, free fasciocutaneous flaps, and bioengineering are also promising.[47] Although all of these methods are useful in crossing the 4-cm threshold for resection of the carina, large-scale studies and long-term follow-up are still needed. Currently, primary reconstruction is the most reliable method for resection and reconstruction of the carina. In resectable tumors, endoscopic methods with palliative treatment are the most reliable methods.

In conclusion, carinal resections are technically difficult and risky operations with high morbidity. In experienced centers, these operations can offer patients a survival advantage. Of note, the presence of mediastinal lymph node metastases should be investigated during preoperative evaluation. Mediastinoscopy should be performed concurrently with resection of the carina, as exposure of the pre-tracheal fascia provides an additional resection margin. During resection, aggressive dissection should be avoided and anastomotic feeding should be considered. After resection, the newly created anastomosis must be wrapped with vital tissue. To prevent neck extension and reduce anastomotic tension, chin sutures should be applied for seven to 14 days. If possible, the patient should be awakened in the operating room, and postoperative intensive respiratory physiotherapy and secretion cleaning should be performed. A well-nourished and tension-free anastomosis is the key to success in carina resections.

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