Chapter

Surgical Management of Bronchiectasis

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Abstract

Bronchiectasis is a chronic clinicopathological disease of the lung characterized by chronic cough, sputum production, recurrent pulmonary infection, and persistent bronchial dilatation on computed tomography. For many years, bronchiectasis associated with high mortality and morbidity particularly before the advent of antibiotics. The medical treatment of bronchiectasis includes antibiotic therapy, airway clearance, bronchodilators, and anti-inflammatory agents. Surgery is mainly performed for localized disease after failure of the medical treatment, including: segmentectomy, lobectomy, and pneumonectomy. This chapter highlights the current surgical considerations for treatment of bronchiectasis, regarding indications of surgery, preoperative evaluation and preparation, available operative procedures, postoperative outcomes, and other important surgical issues.

Keywords: lung, bronchiectasis, productive cough, thoracic surgery, lung resection

1. Introduction

Bronchiectasis was originally described by René Laënnec in 1819. This term comes from two Greek words; "Bronkhia" and "Ektasis" meaning "Airway widening". As a medical term, bronchiectasis refers to chronic lung disease associated with irreversible dilatation of the bronchial tree. For many years, it was considered as an orphan disease; however, the detection of bronchiectasis has been increased in the recent years as a result of increased health awareness and modern advances in the imaging techniques [1, 2].

The prevalence of bronchiectasis varies in relation to geographic location. The estimated prevalence of bronchiectasis in developed countries (USA, UK, Germany, Spain) is up to 566 cases per 100,000, with 40% increase in the past decade [3, 4]. The recent findings from the British lung foundation's project showed that around 212,000 people are currently living with bronchiectasis in the UK, with predominence of female gender and over-70 age [5]. In USA, 252,362 patients were indentified with an average annual prevalence of 701 per 100,000 persons between 2006 and 2014, with mean age of 76 years, predominace of female gender (65%), and dual diagnosis of chronic obstructive pulmonary disease (COPD) in most of the patients (51%) [6]. In China, the overall prevalence of physician-diagnosed bronchiectasis in people aged 40 years or older is estimated at 1.2% and is trending upward with aging of the population [7]. In comparison to European estimates, the recently reported patients with bronchiectasis in India were younger (median age

of 56 years), more likely to be men, and showed a high frequency of severe, cystic bronchiectasis. Tuberculosis and other severe infections were the most frequently reported underlying cause [8].

Most of the cases of bronchiectasis are idiopathic in etiology, however, it may be found in a variety of pulmonary diseases, genetic or acquired, such as cystic fibrosis (CF), Kartagener syndrome (triad of situs inversus, chronic sinusitis, and bronchiectasis), COPD, alpha 1-antitrypsin deficiency, bronchial asthma, or primary immunodeficiencies [9, 10]. In the absence of CF, particularly with post-infectious and allergic hypersensitivity causes, the disease is known as non-cystic fibrosis bronchiectasis (NCFB) [10].

The pathogenesis of bronchiectasis is based on the "vicious cycle hypothesis" which begins by infectious or noninfectious insult to the lung, resulting in neutrophil inflammation (proteases) and impairment of the mucociliary clearance followed by microbial colonization or infection, bronchial obstruction, and exaggerated inflammatory response. The "vicious cycle" (**Figure 1**) refers to the occurrence of repeated infections with repeated impairment of the mucociliary apparatus subsequent to infection and inflammation [10–12].

The clinical diagnosis of bronchiectasis is challenging as it manifests early non-specific symptoms and signs. However, the presence of chronic cough with overproduction of sputum which may worse at the morning increases the index of suspicion for bronchiectasis especially in non-smokers [13, 14]. Other significant signs of bronchiectasis include: hemoptysis, chronic respiratory failure, pulmonary hypertension, and right-sided heart failure [13].

Bronchiectasis can be classified anatomically (cylindrical, varicoid, or cystic), and radiologically (localized or diffuse) [14]. Chest radiographs show non-specific findings of bronchiectasis such as: atelectatic changes, and hyperinflation [13, 14]. High-resolution computed tomography (HRCT) of the chest is a useful imaging tool for diagnosis of bronchiectasis and detection of the underlying causes. On HRCT, bronchiectatic changes include dilated airways, thick-walled bronchi with failed tapering at the periphery of the lung,, ring opacity, tram-track sign, and finger-in-glove sign, and signet-ring sign when the dilated bronchi is larger than the companion pulmonary artery branch (Bronchial-to-arterial ratio > 1) [14].

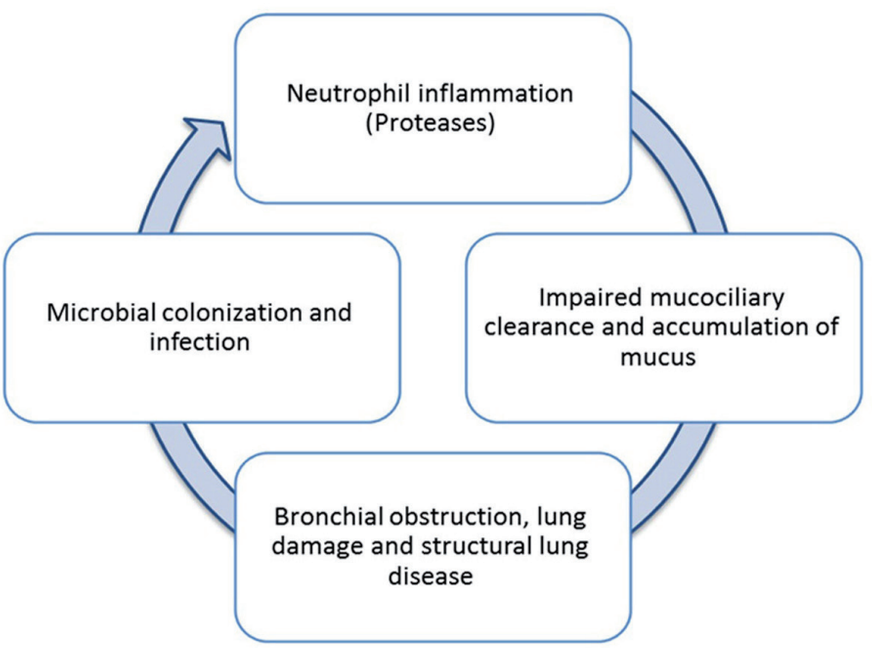

Figure 1.
Vicious cycle of bronchiectasis.

A bundle of minimum etiological tests has been recommended by European Respiratory Society (ERS) for newly diagnosed patients with bronchiectasis including: differential blood count, immunoglobulins (IgA, IgM and IgG), and allergic bronchopulmonary aspergillosis (ABPA)-specific tests (total IgE, specific IgE to Aspergillus, IgG to Aspergillus and eosinophil count), in addition to sputum culture for monitoring of bacterial and non-tuberculous infections [15].

Etiology-specific investigations include: Sweat chloride assessment and cystic fibrosis transmembrane conductance regulator (CFTR) genetic analysis for cystic fibrosis, serum alpha1-antitrypsin level and phenotyping for Alpha-1-antitrypsin deficiency, measurement of nasal nitric oxide levels and ciliated epithelial biopsy for primary ciliary dyskinesia, Rheumatoid factor and anti-cyclic citrullinated peptide (CCP) for autoimmune/connective tissue diseases, and specific CT findings of congenital malformations including Williams-Campbell syndrome (bronchomalacia); Mounier-Kuhn syndrome (tracheobronchomegaly) and lung sequestration [16].

Bronchoscopy is not a routine diagnostic tool for bronchiectasis in the era of HRCT, but there are several indications for diagnostic bronchoscopy in such cases including: exclusion of foreign body obstruction especially in children, exclusion of proximal obstruction in adults with localized disease, obtaining microbiological results in acute ill patients, sampling of lower respiratory tract secretions when serial sputum testing did not yield results, obtaining endobronchial biopsy of airway cilia, and localizing the site of bleeding in patients with bronchiectasis and hemoptysis [17].

The age-adjusted mortality rate for both male and female patients with diagnosed bronchiectasis is more than twice the mortality in the general population [4]. The independent risk factors influencing long-term mortality (over 13 years) in patients with bronchiectasis include: age, St George's Respiratory Questionnaire activity score, *Pseudomonas aeruginosa* infection, total lung capacity (TLC), residual volume/TLC, and the transfer factor coefficient [18]. Therefore, in order to reduce the suspected poor prognosis with bronchiectasis, the treatment should be directed to improve symptoms, enhance quality of life, reduce exacerbations, and limit progression of the bronchiectatic lesions [15, 19].

Treatment of bronchiectasis has been considered by ERS guidelines according to the vicious cycle hypothesis [15]. Thus, the options of treatment include: long-term inhaled or oral antibiotic therapy, eradication of new pathogenic microorganisms and antibiotic treatment of exacerbations for chronic bronchial infection, long-term anti-inflammatory therapies for inflammation, long-term mucoactive treatments and airway clearance techniques for impaired mucociliary clearance, and long-term bronchodilator therapy, surgery and pulmonary rehabilitation for structural lung disease.

2. Indications of surgery

Optimization of the medical management and proper selection of patients are crucial in the decesion making for surgery. Therefore, the current guidelines by ERS and British Thoracic Society (BTS) did not consider surgery until the symptoms are controlled by optimized medical treatment [15, 20]. The indications of surgery as recently mentioned by BTS guideline (**Figure 2**) include: persistent symptoms despite up to a year of comprehensive medical treatment, exacerbations that are either severe or frequent and interfere with social/professional life, recurrent refractory or massive hemoptysis, post obstruction bronchiectasis distal to tumors, localized severely damaged lobe/segment that may be a source of sepsis that left in situ may lead to extension of lung damage, and treatment of complications such as empyema or lung abscess [20].

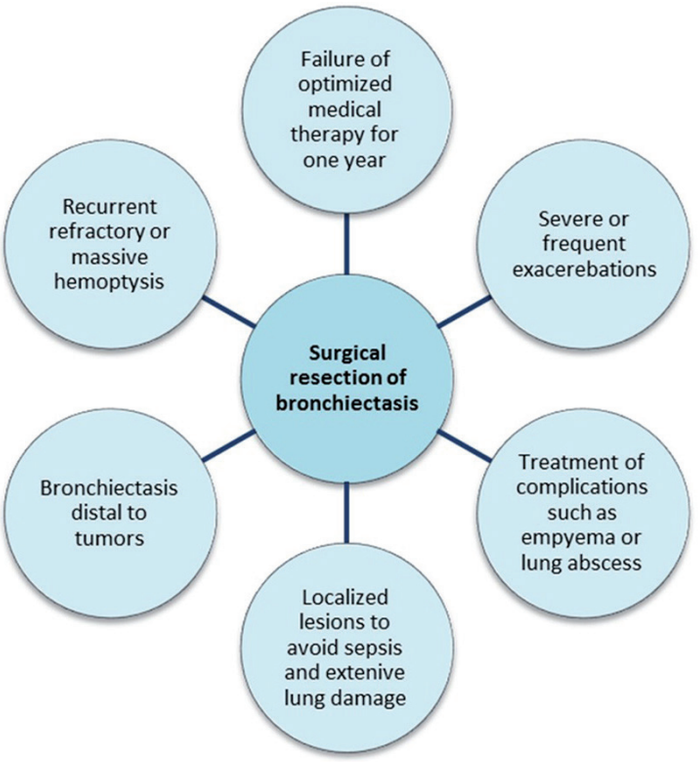

Figure 2.
Current indications for surgical treatment of bronchiectasis [15, 20].

Up to date, there are only 46 published studies in literature between 1960 and 2019, evaluating the surgical management of bronchiectasis [21–66]. The most common clinical manifestations in these studies were: productive cough in 17.4–100% [54, 57], fetid sputum in 15.1–80% [35, 57], and hemoptysis in 10–76.5% [44, 59], while the main and indications of surgery include: failure of medical therapy in 39.6–100% [43, 50], recurrent chest infection in 19.8–100% [23, 54], massive or recurrent hemoptysis in 3–44.3% [32, 43], lung abscess in 1.8–36.5% [32, 58], lung masses or tumors in 1.4–17.6% [42, 46], and empyema in 1.1–8.1% [30, 57]. The mean duration of symptoms before surgery ranged from 1.78–10.6 years [30, 66].

Failure of prudent medical treatment is the main indication of surgery in these studies, especially with frequent exacerbations and repeated hospitalizations [41]. Some authors considered failure of treatment if sputum production persists after 2 or 3 cycles of treatment [35]. The permanently damaged areas of bronchiectasis have poor antibiotic penetration leading to failure of antibiotic therapy, and acts as a microbiological reservoir with subsequent recurrence of infection [61]. Moreover, medical treatment for long periods with persistent symptoms has additional psychological and social effects [32].

Therefore, surgery after failed medical treatment should aim to improve clinical condition and health-related quality of life, in addition to resolution of terrible bronchiectasis-related complications. This aim can be achieved when the focal lesions are completely removed, however, patients with multisegmental lesions should have palliative limited resection after failure of medical treatment or in the presence of life-threatening hemoptysis [47].

Recurrence of pulmonary infection is an important indication of surgery, as it can result in increased cost and side effects of antibiotic therapy for acute infection, in addition to affection of the normal lung tissue with extension of lung destruction during each episode [32]. When bronchiectasis is associated with lung abscess, surgery should be delayed until adequate control with antibiotic therapy and avoiding

of preoperative drainage is recommended, however, the immediate indications of surgery in the presence of lung abscess include increased abscess size, unceasing sepsis, and contralateral contamination [30].

Recurrent or massive hemoptysis of more than 600 mL of blood within 24 hours indicates surgery which is considered as emergency after failure of the conservative therapy for hemoptysis. Even after initial cessation of bleeding by balloon blockade of the bleeding bronchus or bronchial artery embolization, early surgical treatment is indicated to avoid life-threatening recurrence of hemoptysis [30].

In children, the indications for surgery are the same as in adult patients. Growth retardation can be considered as an additional indication for surgery in children with satisfactory postoperative results [43]. It is crucial to exclude the underlying diseases such as Kartagener syndrome and cystic fibrosis which limit the surgical resection [36].

3. Preoperative evaluation

Preoperative evaluation should include physical examination, imaging studies, arterial blood gases, pulmonary function tests, bronchoscopy, and perfusion scans if indicated. Additional diagnostic work-up may be required for patients with cardiovascular diseases including echocardiography, stress testing, myocardial perfusion studies, and coronary angiography [48].

3.1 Chest radiography

Chest radiography represents non-specific features of bronchiectasis with low sensitivity and difficult appreciation. The suggestive findings in moderate to severe patients include: stranding, cystic lesions, volume loss with crowding of vessels, atelectasis, tram-track appearance, ring-like opacities, and tubular densities [28, 67]. Despite inadequate role of chest radiography in evaluation of bronchiectasis, abnormalities on chest radiography is significantly correlated with severity of the disease on HRCT [68].

3.2 High resolution computed tomography (HRCT)

The images of HRCT have higher sensitivity for diagnosis and localization of bronchiectasis than radiography with very low false negative and false positive results [41, 69]. The indications of HRCT include: clinical suspicion despite normal chest radiography, clarification of abnormalities on chest radiography, and decision making for surgery [70]. The use of HRCT is not restricted by age of the patient, thus HRCT is not uncommon diagnostic tool in children with bronchiectasis [56].

In addition to the great help of HRCT in diagnosis of different types of bronchiectasis (**Figure 3**), preoperative localization of the lesions by HRCT has specific importance in making the decision for complete anatomic resection or limited resection with preservation of the lung tissue [30].

3.3 Bronchoscopy

Bronchoscopy should be performed in all patients to determine the underlying causes of bronchial obstruction including: foreign body aspiration, endobronchial epithelial tumors, and enlarged hilar lymph nodes with lobar collapse [30, 36].

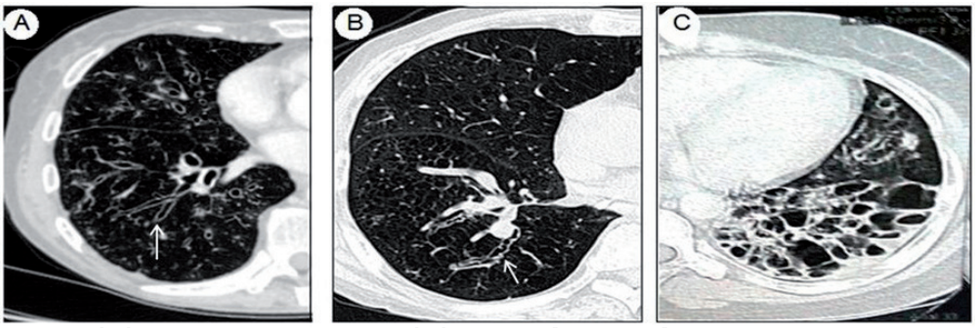

Figure 3.
Images of high resolution computed tomography show types of bronchiectasis: (A) cylindrical, (B) varicose, and (C) cystic.

Preoperative removal of the secretions and clearing of the airways is an important indication of bronchoscopy in adult and children patients [63], as it is associated with lower rate of postoperative complications [41].

3.4 Pulmonary function tests

Pulmonary function tests (PFTs) are not routinely performed in cases of bronchiectasis when the lesions are localized, but PFTs should be performed in diffuse bronchiectasis and in cases of repeated operations [36]. Pulmonary function tests can be performed in adult patients or in children older than 6 years of age [59]; however, cooperation of the child may affect completeness of the pulmonary function tests [35].

The patients with bronchiectasis may have obstructive ventilatory pattern related to mucus retention or immunological abnormalities. The surgical resection of pulmonary segments with little contribution to ventilatory process is expected to have no or minimal effect on postoperative pulmonary function [31]. The expected loss of pulmonary function after surgical resection of bronchiectasis can be calculated from the equation: expected loss of function = preoperative function * (number of functional segments in the lobe to be resected/total number of segments of both lungs) [53].

3.5 Perfusion scans (ventilation/perfusion scintigraphy)

Ventilation/perfusion (V/Q) scintigraphy provides information about hemodynamic features (vascular perfusion), gas exchange, and quantitative lung function, which has a particular help in cases with diffuse bronchiectasis as it can determine the most affected non-perfused areas to be surgically resected [36, 37]. The affected area is considered non-perfused when the perfusion is <10% of the expected [37]. Moreover, V/Q scintigraphy is indicated in patients with poor pulmonary function to provide more quantitative information about ventilation function [38].

Some authors tried to find the correlation between morphologic type of bronchiectasis and the hemodynamic perfusion features. The study by Ashour in 1996, determined a correlation of cylindric morphology with pulmonary perfusion, contrary to non-perfusion predominance in cystic type, thus the surgery for diffuse bronchiectasis can be reserved for non-perfused cystic lesions which are more damaged than cylindrical lesions [71]. Thereafter, Al-Kattan and colleagues reported a new hemodynamic classification of bronchiectasis in patients with diffuse or bilateral disease, combining the perfusion and morphologic features to provide a reasonable extent of surgery and to obtain maximum postoperative clinical improvement [37].

4. Preoperative preparation

The preoperative preparation of patients with bronchiectasis should aim to provide the best possible status. Therefore, the preoperative preparation should be performed by a multidisciplinary team consists of infectious disease specialists, pulmonologists, and thoracic surgeons [72].

4.1 Sputum culture analysis

The patients should have appropriate preoperative preparation until the sputum volume reduced to 20-50 mL per day [54, 63], or the antibiotic therapy is modified according to new culture sensitivity results of the sputum [63]. As the gram-negative bacterial infection has a significant risk for perioperative complications, surgery should be performed after negative proof of Gram-negative bacillus on sputum culture analysis [58].

In patients with a history of tuberculosis, surgery should be reserved for patients with inactive disease. Some surgeons postponed elective surgery 6 months if the sputum culture was positive for acid-fast bacilli and after the completion of antituberculosis treatment [41].

4.2 Infection control

Preoperatively, patients should be hospitalized and prepared for at least 2 weeks before surgery [48]. The patients who are scheduled for surgery should have no active pulmonary infection at the time of surgery. Therefore, broadspectrum antibiotics should be given for 48 hours prior to surgery, or prophylactic antibiotics are given according to results of sputum culture and sensitivity tests [36, 54]. For prophylaxis, cephalosporin and aminoglycoside are preferred if the culture is negative and the patient has no contraindications or allergies [48].

4.3 Chest physiotherapy and postural drainage

The patients should have intensive chest physiotherapy in the preoperative period, to obtain acceptable decrease of the daily volume of the sputum [54]. Patients should have chest physiotherapy including postural drainage for at least 2 weeks bfore surgery [57], or it should be continued until the daily sputum is ≤50 mL [50]. Preoperative postural drainage is essential to clean intra-tracheal secretions, decrease the sputum volume and sputum accumulation, and hence control of the infection and optimize the respiratory status [50, 58].

The recommended airway clearance techniques are active breathing techniques or oscillating positive expiratory pressure (PEP). Review of HRCT findings is helpful to determine the appropriate postural drainage in relevance to the affected pulmonary segments. The gravity assisted positioning, where not contraindicated, is recommended to enhance the effectiveness of an airway clearance technique. Modified postural drainage without head down tilt should be considered when the postural drainage is not tolerated and when the symptoms of gastroesophageal reflux increased with the technique [17, 20].

4.4 Other considerations

Nutritional support and pulmonary rehabilitation should be considered before surgical referral [20]. In patients on long-term steroid therapy, the doses may be increased by 5–10 mg/day, but surgery should be postponed in patients with uncontrolled respiratory symptoms [72].

5. Surgical procedures

5.1 Thoracotomy

The anesthetic management during surgery for bronchiectasis should consider: (1) cleaning of the bronchus opposite to the side of surgery by aspiration before placement of endotracheal tube, and (2) avoiding contralateral contamination by: insertion of double-lumen endotracheal tube, use of Fogarty embolectomy catheter as a bronchus blocker, or advancing of the endotracheal tube to the main bronchus of the opposite side of resection [35, 37, 41, 54, 57].

Posterolateral thoracotomy is the standard approach for pulmonary resection in patients with bronchiectasis. Preservation of the integrity of chest wall muscles using muscle-sparing technique is essential to reduce postoperative pain and generate an effective cough [29]. When the decision is for bilateral lung resection, the second operation can be performed with an interval of 1–4 months [49, 53].

The extent of lung resection is determined by extent of the disease and cardiopulmonary reserve, thus lobectomy is performed for lesions limited to one lobe, segmentectomy is performed for fairly limited disease or when the pulmonary function is impaired, while pneumonectomy is reserved for extensive disease affecting the whole lung [33, 50, 54]. In some instances, bilobectomy and lobectomy plus segmentectomy can be performed [40, 44, 48, 50, 52, 61]. Extrapleural dissection is preferred to avoid spillage of lung content into pleural space. After identification of the hilar structures and opening of the major fissure, arterial, venous, and bronchial branches are isolated and divided, respectively [39, 63].

Certain recommendations can be followed to prevent or reduce the incidences of postoperative air leak and bronchopleural fistula (BPF) after lung resection including: preservation of peribronchial tissues and avoidance of extensive lymph node dissection near to bronchi to minimize bronchial devascularization, division of the bronchus before mobilization of the resected part to avoid contamination of the healthy segments, division of the bronchial stump as short as possible which sutured by non-absorbable materials or closed with a mechanical stapler then buttressed by tissue glue or a flap from pleura, pericardium, pericardial fat pad, muscle, or omentum [41, 73].

To reduce the extension of contamination during surgery, extrapleural intrapericardial pneumonectomy is recommended when there is pleural sepsis or complete fusion of the pleura. Also, the evidence of pleural infection indicates pleural space irrigation with antibiotic [73]. Following placement of the chest drains, bronchoscopic evaluation of the bronchial sutures with removal of any secretions in the airway should be performed [63]. The resected specimens should be sent for histopathological examination [41].

5.2 Video-assisted thoracoscopic surgery (VATS)

There is a little research work regarding use of VATS in the management of bronchiectasis. The reported VATS approaches for lobectomy in patients with bronchiectasis include three ports, two ports, or one port VATS [55, 62, 66]. Additionally, a two-port thoracoscopy with a utility mini-thoracotomy has been reported [45].

For three ports completely VATS procedure, the ports are placed through the 7th or 8th intercostal space in the midaxillary line for a 10-mm 30° thoracoscope, the 4th or 5th intercostal space along the anterior axillary line (4–5 cm incision), and the 7th or 8th intercostal space in the auscultatory triangle (1.5 cm incision) [55]. For two ports VATS lobectomy, a 2 cm camera port through the 7th or 8th intercostal space in the anterior axillary line and a 3–5 cm utility incision through the 4th

or 5th intercostal space in the anterior or mid axillary line [62]. Ocakcioglu et al. described uniportal VATS lobectomy through a utility incision of 3–5 cm from the 5th intercostal space in the anterior position without use of rib retractor. A 10 mm 30° thoracoscope is placed in the anterior part of the incision, while dissecting and holding clamps are placed through the dorsal part [66].

During 3 ports VATS, the incisions change depending on the type of lung resection, whether it is an upper or lower lobectomy [62]. The presence of intrathoracic adhesions is a challenging problem during VATS which can be released by blunt or sharp dissection, or it may result in conversion of the VATS procedure to open procedure [55, 64]. As in open thoracotomy, the pulmonary artery is firstly identified and divided before the division of the veins to avoid congestion of the lobe, with separate dissection of the major pulmonary veins and the bronchus [64]. The dissection of vascular and airway structures is performed by an endoscopic linear cutter [55]. At the end of VATS procedure, the thorax is closed after retrieval of the resected specimens and meticulous control of air leak and hemorrhage [66].

5.3 Postoperative care

Bronchoscopy can be performed in the operating room for bronchial hygiene, immediately after surgery [56]. The early postoperative care should include: pain control including epidural analgesia, chest physiotherapy, antibiotic therapy according to results of culture and sensitivity [37, 56].

Generally, the duration of postoperative systematic antibiotic therapy is 5 days, but it can be longer according to the inflammatory condition. Early ambulation and active cough, and 3–4 times percussive chest physiotherapy are essential for proper expectoration and lung re-expansion. The standard criteria for removal of chest tube are: stable vital signs, small amount of drainage (<100 mL/day) with clear color, lung re-expansion on chest X-ray, and absence of air leak [63].

After discharge, patients should have specific or wide-spectrum antibiotic therapy for 1 week. Chest physiotherapy can be reinitiated at home and continued for 2 weeks after discharge [33].

6. Postoperative outcomes of lung resection

6.1 Mortality

To date, few studies have evaluated postoperative outcomes after lung resection for bronchiectasis (**Table 1**). There is no perioperative mortality (early, operative, in-hospital, postoperative, or 30-days) after surgical resection of bronchiectasis in most of the published studies. The reported rates of perioperative mortality ranged from 0.41% [23] to 8.3% [25]. The causes of early mortality in literature include: respiratory failure [2, 27, 28, 41, 49, 57], intraoperative bleeding [24, 28, 46], postoperative pneumonia [25, 37], empyema [25, 32], pulmonary edema [27, 46], cardiac-related causes including myocardial infarction or arrhythmia [27, 35, 47, 49, 58], speptic shock [27, 56], gastrointestinal bleeding due to sepsis and stress ulcer [39], uncontrolled hemoptysis [27], pulmonary embolism [22, 32, 48, 58], cardiac arrest in patients with Kartagener syndrome [36], disseminated intravascular coagulation [44], nephropathy [22], downstream consequences of bronchial stump fistula [48, 60], multiple organ failure [48, 60], and causes unrelated to disease or technique such as cerebral edema in a child due to previously undiagnosed aquaeductus stenosis and hydrocephalus [24]. The disease-related consequences which indirectly attribute to early death include: severe disease requiring

Author	Year	Number	Morbidity (%)	Early mortality (%)	Late mortality (%)	Asymptomatic (%)
Hewlett and Ziperman	1960	107	20.6	0	1.9	36.4
Streete and Salyer	1960	240	22.1	0.8	2.1	22.3
Sanderson et al.	1974	242	33.5	0.4	2.9	62.5
George et al.	1979	99	88.9	3	4	39.6
Annest et al.	1982	24	12.5	8.3	8.3	45.8
Wilson and Decker	1982	84	10.7	0	1.2	73.8
Dogan et al.	1989	487	10.7	3.1	0.4	73.3
Agasthian et al.	1996	134	24.6	2.2	0	59.2
Ashour et al.	1999	85	12.9	0	0	74.1
Fujimoto et al.	2001	90	22.2	0	0	45.6
Prieto et al.	2001	119	12.6	0	0	67.6
Kutlay et al.	2002	166	10.8	1.8	0	75
Balkanli et al.	2003	238	8.8	0	0	82.5
Mazieres et al.	2003	16	18.8	0	0	31.3
Haciibrahimoglu et a	2004	35	17.1	2.9	0	64.7
Otgun et al.	2004	54	7.4	5.6	0	45.1
Al-Kattan et al.	2005	66	18.2	1.5	0	73.8
Schneiter et al.	2005	48	18.8	0	0	62.5
Aghajanzadeh et al.	2006	29	37.9	3.4	0	67.9
Yuncu et al.	2006	81	18.5	0	0	81.7
Eren et al.	2007	143	23.1	1.4	0	75.9
Guerra et al.	2007	51	15.7	0	0	77.8
Sirmali et al	2007	176	13.1	0	0	73.3
Stephen et al.	2007	149	14.8	0.7	0.7	54.3
Giovannetti et al.	2008	45	11.1	0	0	71.1
Bagheri et al.	2010	277	15.9	0.7	0	68.6
Gursoy et al.	2010	92	16.3	1.1	0	84
Zhang et al.	2010	790	16.2	1.1	0	67.7
Caylak et al.	2011	339	12.7	0.6	0	71
Cobanoglu et al.	2011	62	19.4	0	0	45
Gorur et al.	2011	122	13.1	0	0	77.3
Sehitogullari et al.	2011	129	22.5	0	0.8	60.2
Hiramatsu et al.	2012	31	19.4	0	0	74.2
Al-Refaie et al.	2013	138	13	0	0	84.2
Zhou et al.	2013	56	23.2	0	0	58.9

Author	Year	Number	Morbidity (%)	Early mortality (%)	Late mortality (%)	Asymptomatic (%)
Andrade et al.	2014	109	36.7	0.9	0.9	NR
Balci et al.	2014	86	16.3	1.2	0	82.6
Jin et al.	2014	260	11.5	0.8	1.9	78
Sahin et al.	2014	60	20	0	3.3	74.1
Vallilo et al.	2014	53	24.5	3.8	0	34.1
Coutinho et al.	2016	69	14.5	0	0	73.3
Baysungur et al.	2017	41	9.8	0	0	NR
Dai et al.	2017	37	21.6	0	0	62.2
Hao et al.	2019	99	17.2	0	0	26
Nega et al.	2019	22	22.7	4.5	0	89.5
Ocakcioglu et al.	2019	14	14.3	0	0	85.7

NR: Not reported.

Table 1.
Reported outcomes (%) after surgical treatment of bronchiectasis [21–66].

pneumonectomy or completion [28, 58], massive bleeding during the operation because of dense adhesions due to chronic and recurrent infections [44, 46], and Kartagener syndrome [36].

The rates of late or long-term mortality ranged from 0.41% [27] to 8.3% [25]. The reported causes of late mortality after surgical management of bronchiectasis included: respiratory failure [24, 52], progressive respiratory disease [25], sepsis [59], coronary artery thrombosis [22], cor pulmonale or pulmonary heart disease [22, 58], myocardial failure [22], glomerulonephritis [22], kidney failure [58], post-pneumonectomy pneumonia in the remaining lung [56], massive bleeding from the Malecot catheter used for drainage ofresidual space infection [44], suicide [22], and other causes of late deaths not attributable to bronchiectasis [21, 23, 26].

6.2 Morbidity

The reported rates of morbidity ranged from 7% [7] to 38% [39]. The most common complication is atelectasis or sputum retention requiring bronchoscopic intervention, followed by persistent air leak (**Table 2**). Most of the reported complications were minor, transient, and treatable.

In comparison to the published studies in the 3rd and 4th decades of 20th century, the relatively low incidences of complication in the after while studies can reflect effective antibiotic therapy, improved anesthetic techniques, adequate blood transfusion, and detailed postoperative care [21, 22]. Other factors include: surgeon's experience, preoperative awareness of the undesirable consequences of retained secretions, preoperative teaching of breathing exercises, scheduling tracheal suction or bronchoscopy in the early postoperative period [21], good intraoperative hemostasis and careful dissection [37], low number of pneumonectomies, accurate patient selection, and careful perioperative management [45].

Treatment of postoperative complications after surgery for bronchiectasis depends on its type and severity. The treatment options for complications include: physiotherapy, tube thoracotomy, bronchoscopic treatment for atelectasis, negative suction applied to the chest tubes for prolonged air leak, surgical reintervention for closure

Complications	Minimum rate [Reference]	Maximum rate [Reference]
Atelectasis or sputum retention	0.9% [21]	33.3% [24]
Prolonged air leak	0.7% [54]	26.4% [23]
Pneumonia	1.2% [57]	12.5% [34]
Bronchopleural fistula	0.4% [48]	9.1% [65]
Residual air space or expansion defect	2.2% [45]	9% [51]
Empyema	0.6% [32]	8.1% [44]
Wound infection	1.3% [44]	7.4% [27]
Bleeding	1.1% [30]	8.3% [25]
Cardiac arrhythmias	0.4% [58]	5.4% [63]
Pulmonary embolism	0.4% [58]	3.8% [60]
Respiratory insufficiency	0.8% [52]	3.5% [57]
Pulmonary edema	0.8% [52]	2.2% [28]
Pleural effusion	0.6% [32]	0.7% [54]

Table 2.
Reported rates of complications after surgical treatment of bronchiectasis.

of bronchopleural fistula, medical treatment or decortication for pleural empyema, pharmacological control of supraventricular arrhythmias, reexploration for postoperative bleeding, and mechanical ventilation for respiratory insufficiency [39, 41, 60].

Cobanoglu et al. did not report any significant statistical difference between tubular and saccular morphologic types of bronchiectasis regarding postoperative complication rates; however, the most severe postoperative complication, bronchopleural fistula, developed in 2 (3.22%) cases with saccular bronchiectasis [50]. Zhou et al. did not find statistically significant difference in the rates of postoperative complications between thoracotomy and VATS procedure. Minor postoperative complications were reported after thoracotomy or completely VATS lobectomy, which included pneumonia, prolonged air leak (>7 days), and atelectasis [55]. Moreover, Hao et al. did not observe major postoperative complications such as bronchopleural fistula or respiratory insufficiency was observed in VATS and thoracotomy groups. The most common complication was persistent air leak for >7 days in 8.1% of VATS group and 6% of thoracotomy group [64].

6.3 Symptomatic improvement

The clinical results after surgical resection of bronchiectasis are frequently classified into three categories. The first category (asymptomatic; excellent response) includes patients who are completely free of any symptoms suggestive of bronchiectasis, and considered themselves cured. The second category (clinical improvement; good response) includes those considered improved who have had some relief of the symptoms but still had some chronic pulmonary complaints. The third category (no improvement; poor response) includes patients with no-change, no-reduction in preoperative symptoms, or who are worse off since surgical resection. [22, 31, 32, 35, 44, 46, 47, 50]. Some authors referred to the excellent response as well outcome [36] or perfect response [41].

Sanderson et al. expanded the classification of the clinical symptomatic outcome to five categories as: excellent (no symptoms at all), good (full physical capacity, occasional cough and sputum), fair-improved (tendency to cough and sputum

with susceptibility to respiratory infection, hemoptysis or dyspnea), poor (residual symptoms), and worse (steady deterioration) [23]. Other authors reduced the classification of the clinical condition in two categories only by dividing the patients into an improved group ("excellent" or "good" outcomes) and an unimproved group ("no change" or "worse" outcomes) [52].

In literature, through a range of follow-up between 9 months and 14 years, the proportion of asymptomatic patients or excellent improvement after surgery ranged from 22.3% [22] to 89.5% [65], while the proportion of clinical improvement with reduction of preoperative symptoms ranged from 9.6% [64] to 80.7% [56], and no improvement, worseness or relapse was reported in 1.6% [58] to 42.3% [22].

6.4 Quality of life (QOL)

Patients with bronchiectasis report worse quality of life (QOL) than do persons in the general population [74, 75]. Recurrent bronchiectasis exacerbations are related to deterioration of lung function, progression of the disease, impairment of quality of life, and increased rate of mortality [76]. Postoperative QOL and the functional consequences of lung resection (pulmonary function and exercise capacity) are poorly addressed.

Vallilo et al. reported a significant improvement of the QOL in patients with symptomatic bronchiectasis which was particularly relevant in the functional and physical QOL domains. Resection of the lung area which had not contributed to ventilatory response during exercise before surgery might enable the patients to maintain the exercise performance after lung resection without impairment to the response of the ventilatory system during maximal testing [60].

6.5 Complete versus incomplete resection

The proper surgical treatment should aim to complete resection of the bronchiectatic lesions. Thus, intraoperatively detected lesions should be resected as appropriate whether determined on preoperative imaging studies or not [32]. Complete resection is defined as an anatomic resection of all affected segments preoperatively identified by high-resolution computed tomography or bronchography [48, 54, 57]. However, some authors considered pulmonary resection complete if the patient was believed to be free of bronchiectasis after thoracotomy [31, 35].

Completeness of surgical resection is affected by localization of the disease and pulmonary function (**Figure 4**). In patients with unilateral localized bronchiectasis, the most important prognostic factor for good surgical outcomes is complete resection of all diseased segments. In bilateral localized bronchiectasis, complete surgical resection should be attempted if lung function permits, including combinations of lobectomy with segmentectomy or wedge resections on the same siting or staged [24, 39, 73]; however, limited resection of the most predominant lesion is preferred for selected patients with bilateral diffuse bronchiectasis [34, 63]. The reported completeness of resection in patients with localized bronchiectasis ranged from 55.4% [23] to 94.2% [54].

Sanderson et al. found a preponderance of excellent results after complete resection in comparison with incomplete resection (36% versus 10%, $P < 0.005$) [23]. Agasthian et al. found that complete resection resulted in a significant increase in proportion of asymptomatic patients than incomplete resection (65.2% versus 21.4%, $p < 0.05$) [28]. In the study by Kutlay et al., the excellent to good results of complete resection were significantly better than those of incomplete resection (98.5 versus 76.5%, $P < 0.05$) [32]. Similarly, other authors reported significantly better clinical results with complete resection than incomplete resection [35, 36, 44, 46, 50, 52].

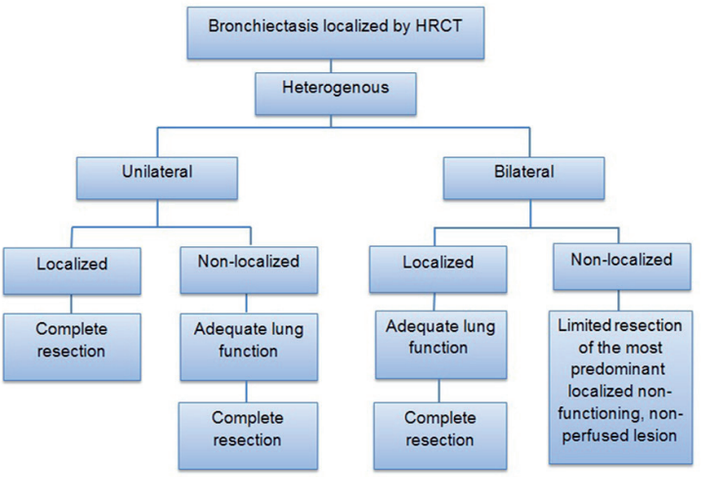

Figure 4.
Simplified algorithm for complete surgical resection according to extent of bronchiectasis.

6.6 Predictors of postoperative outcomes

There is no single independent perioperative variable that can predict occurrence of adverse events after lung resection with scant available data. In the study by Fujimoto et al., the logistic analyses extracted the type of bronchiectasis (cylindrical or others), the history of sinusitis, and the type of resection (complete or incomplete) for discrimination between patients with excellent or improved clinical outcome and patients with no clinical change [30]. Hiramatsu et al. reported immuno compromised status, *Pseudomonas aeruginosa* infection, and extent of residual bronchiectasis, as independent and significant factors of postoperative shorter relapse-free interval [53].

Eren et al. fond that the lack of preoperative bronchoscopic examination, a FEV1 of <60% of the predicted value, a history of tuberculosis, and incomplete resection were independent predictors of postoperative complications [41]. Bagheri et al. statistically evaluated several variables including: sex, age, localization of disease, and complete or incomplete resection using multivariate logistic regression. Complete resection was found to have a significantly better surgical outcome compared to incomplete resection [46]. In the study by Zhang et al., the logistic regression analysis showed that tuberculous bronchiectasis, type of bronchiectasis (saccular versus others), and type of resection (incomplete or complete) were three independent factors associated with poor surgical outcome [48]. The multivariable analyses by Jin et al., showed that age, sputum volume, gram-negative bacillus infection, and bronchial stump coverage were the four independent factors related with poor surgical outcome [58].

According to the reported results by Sahin et al., the prognostic variables in pediatric patients were: FEV1 less than 60% of the predicted value, hemoptysis, and duration of symptoms [59]. Interestingly, Gorur et al. stated that multi-segmental resectable bronchiectasis should not be considered an occult risk factor for morbidity after lung resection. Moreover, the number of resected segments, hemoptysis, and absence of preoperative fiberoptic bronchoscopy were not associated with postoperative complications. Impaired pulmonary function was significantly associated with residual air space; however it did not predict the risk of persistent air leak, atelectasis or empyema [51].

Completion pneumonectomy is historically recognized as a high-risk procedure especially when done for a benign disease [77]. To reduce the high-risk of completion pneumonectomy when indicated, precautions such as optimal exposure,

intrapericardial isolation of blood vessels, and bronchial reinforcement are recommended [78]. In the study by Agasthian et al., all died patients after lung resection had completion pneumonectomy. The causes of death were respiratory failure and intraoperative bleeding [28]. However, Fujimoto et al. reported acceptable mortality and morbidity after completion pneumonectomy without mortality and only one patient had postoperative bronchopleural fistula that could be managed conservatively [30].

7. Specific surgical considerations

7.1 Non-localized bronchiectasis

Patients with non-localized (multi-segmental or bilateral) bronchiectasis are generally regarded as an exclusion of surgery [39]. However, considering the limited and palliative effect of medical treatment and the risk of transplantation or radical operation, recent studies offered a limited operation to some of these patients [34, 63]. Moreover, some surgeons favored surgery in non-localized bronchiectasis to prevent extension of the disease to the unaffected lung [38].

George et al. suggested that bilateral bronchiectasis need not be a contraindication to operation. In properly selected patients, lasting symptomatic improvement can be provided by resection [24]. Mazieres et al. reported favorable outcome after a limited lung resection in properly selected symptomatic patients with severe multisegmental bilateral bronchiectasis, particularly those with cystic lesions and functionless territories [34].

Schneiter et al. found the same patients' satisfaction at 6 months after surgery for patients who had resectable non-localized or localized bronchiectasis, with non-significant differences in the rates of recurrent infection and hemoptysis [38]. Aghajanzadeh et al. reported the benefits of surgery in 87 bilateral non-localized bronchiectases, and concluded that staged bilateral resection for bronchiectases can be performed at any age with acceptable morbidity and mortality [39]. Additionally, Dai et al. reported the safety of lobectomy for the predominant lesions in non-localized bronchiectasis, with significant relief of symptoms, good rates of satisfaction, no operative mortality, and minimal postoperative complications [63].

7.2 Surgery for bronchiectasis in children

The prevalence of bronchiectasis in children ranges from 0.2 to 735 cases per 100,000 [79]. Cystic fibrosis is the most common cause of bronchiectasis in developed countries while in developing countries non-CF etiologies particularly post-infectious causes are more common [80]. Surgical treatment of bronchiectasis in children is considered for cases with resectable disease after failure of the proper medical treatment. Moreover, surgery can be considered in children with diffuse disease who have expected benefit after excision of the most predominant lesions [36, 79].

In literature, the studies that evaluate surgical treatment of bronchiectasis in children are scanty. However, these studies confirmed the safety of surgery for childhood bronchiectasis with low rates of mortality and morbidity. Complete resection can be considered when possible, as most of the children can benefit from surgery especially if the total excision is accomplished [26, 35, 36, 43, 56, 59].

The reported surgical outcomes in children with bronchiectasis highlight: acceptable mortality and morbidity [35, 36, 43, 56, 59], significant impact of surgery on improvement of symptoms and quality of life [43, 56], good results

after segmentectomy when the pulmonary segment is entirely free of disease [26], increase the chance of cure after complete resection which results in significantly better outcome than incomplete resection [35, 43], preference of pneumonectomy instead of leaving residual disease when bronchiectasis is unilateral [36], and significant impact of duration of symptoms and timely intervention on the management and prognosis [59].

8. Conclusions

Bronchiectasis is a significant chronic lung disease associated with vicious cycle of inflammation, infection, mucus accumulation, and structural tissue damage. Current guidelines recommend surgical treatment of bronchiectasis in patients with localized disease when symptoms are not controlled by optimized medical treatment. Other indications in literature include recurrent refractory or massive hemoptysis, bronchiectasis distal to tumors, and treatment of subsequent complications.

HRCT is the gold standard imaging tool of bronchiectasis, as has a great help in preoperative localization of the lesions which affects the decision making for surgery. Preoperative bronchoscopy is important to diagnose the underlying causes of bronchial obstruction and to clear the airways by removal of secretions. Preoperative PFTs can be performed to determine the segments with little ventilatory contribution and minimal effects on postoperative pulmonary function after surgical resection. Perfusion scans can be used to determine the most affected non-perfused areas to be resected, particularly when the pulmonary function is affected. According to hemodynamic analysis of perfusion scans in diffuse bronchiectasis, surgery can be reserved for non-perfused cystic lesions which are more damaged than cylindrical lesions.

Preoperative preparation for lung resection should include sputum culture analysis to modify antibiotic therapy with culture sensitivity results. It is crucial to eradicate active pulmonary infection and provide prophylactic antibiotic therapy with cephalosporin and aminoglycoside before surgery. Preoperative airway clearance techniques including active breathing, oscillating PEP, and postural drainage, are recommended to control infection and optimize the respiratory status. Other important preoperative considerations include nutritional support and pulmonary rehabilitation.

Posterolateral thoracotomy is the standard approach for the surgical resection of bronchiectasis. The extent of resection depends on extent of the disease and cardiopulmonary reserve. Preservation of peribronchial tissues, short bronchial stump, and buttressing techniques are recommended to reduce postoperative air leak and BPF. The safety and feasibility of VATS in the treatment of bronchiectasis was shown in scant studies with low morbidity and mortality. The proper care after surgery should include bronchoscopic removal of secretions, pain control, chest physiotherapy, and appropriate antibiotic therapy.

In literature, the mortality rates after lung resection range from 0.41% to 8.3%. The most common causes of early mortality are respiratory failure, intraoperative bleeding, postoperative pneumonia, empyema, pulmonary edema, and cardiac-related causes; while the most common causes of late mortality are respiratory failure, progressive respiratory disease, sepsis, coronary artery thrombosis, and cor pulmonale. The morbidity rates range from 7–38%. Atelctasis or sputum retention is the most common postoperative complication, followed by persistent air leak, pneumonia, and BPF. Most of the reported complications are minor, transient, and treatable. During follow-up periods between 9 months and 14 years, the proportion of asymptomatic patients (excellent improvement) after surgery ranges from 22.3% to 89.5%. Postoperative QOL is poorly addressed, but it can be improved after resection of functionless pulmonary segments.

Complete resection of the affected parenchyma results in better clinical outcome than incomplete resection; however, completeness of resection is affected by localization of the disease and pulmonary function. A large number of predictors of surgical outcomes were investigated in literature, including: type of resection, type of bronchiectasis, immuno compromised status, *Pseudomonas aeruginosa* infection, extent of residual bronchiectasis, lack of preoperative bronchoscopic examination, FEV1 < 60% of the predicted value, tuberculosis, hemoptysis, duration of symptoms, age, sputum volume, gram-negative bacillus infection, bronchial stump coverage, and impaired pulmonary function.

Recent studies reported acceptable outcomes after a limited lung resection for the most predominant lesion in properly selected patients with non-localized bronchiectasis. Surgery can be safely performed in children with bronchiectasis, particularly when the disease is resectable disease after failure of the proper medical treatment. Acceptable postoperative rates of mortality and morbidity and a significant symptomatic improvement were reported in children.

Abbreviations

ABPA	allergic bronchopulmonary aspergillosis
BPF	bronchopleural fistula
BTS	British Thoracic Society
CCP	cyclic citrullinated peptide
CF	cystic fibrosis
CFTR	cystic fibrosis transmembrane conductance regulator
COPD	chronic obstructive pulmonary disease
ERS	European Respiratory Society
FEV1	forced expiratory volume in 1 second
HRCT	high resolution computed tomography
NCFB	non-cystic fibrosis bronchiectasis
PEP	positive expiratory pressure
PFTs	pulmonary function tests
QOL	quality of life
TLC	total lung capacity
VATS	video-assisted thoracoscopic surgery

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