Airway Stenting in Interventional Radiology

Xinwei Han
Chen Wang
Editors

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Foreword

The first edition of Dr. Han and Dr. Wang book is interesting and well written, providing a comprehensive and updated volume and addressing the goal expressed in the title *Airway Stenting in Interventional Radiology*. Airway disease has been described in a clear and meticulous way, starting from histology, passing to anatomy, and ending up with the procedure. In a discipline such as interventional oncology, which has changed considerably in the last 15 years, this book is innovative because it includes not only a precise description of the procedure but also possible complications related to the procedure and their management, making the book technical as well as clinical at the same time.

The editors and their contributors have done an outstanding job in presenting a challenging topic in an easy way, accessible to the reader.

This book does provide systematic instruction in the techniques of airway stenting at either a basic or advanced level. I'm sure that it will become an important reference for all interventional radiologists; in fact, it will be essential for resident at the beginning of their training, but also useful for more experienced fellows and consultants who will find crucial information and important tips. Moreover, anatomy description and radiological measurement are detailed, even for nonradiologists.

Dr. Han and Dr. Wang and their colleagues have done a meticulous job in illustrating and cross-referencing the book. Moreover, the use of tables and boxes that summarize key points in the text are a really useful tool for the readers.

I strongly recommend this book for beginners and more advanced practitioners and congratulate Dr. Han and Dr. Wang for producing a high-quality text. I am sure that *Airway Stenting in Interventional Radiology* will become a useful tool for interventional radiologist as well as for other physicians performing these kinds of procedures.

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Contents

1 Tracheobronchial Histology, Anatomy, and Physiology

Hongqi Zhang, Xinwei Han, and Lihong Zhang

The respiratory tract, an important part of the respiratory system, is also called an airway because it is the passage that air travels in through the lungs. It is composed of the nose, pharynx, larynx, infraglottic cavity, trachea, and bronchi. Separated from cricoid cartilage, the upper part of the respiratory tract consisting of the nose, pharynx, larynx, and infraglottic cavity, it is called the upper respiratory tract, while the lower part of the respiratory tract includes trachea and all levels of bronchi below cricoid cartilage.

1.1 Tracheobronchial Anatomy

The lower respiratory tract, including trachea and all levels of bronchi, functions not only as the passage for oxygen intake and carbon dioxide emission but also as the organ used to remove foreign bodies inside the trachea and bronchi and adjust the humidity and temperature of entering air.

Lobar bronchi and other branches, such as the main bronchi, branch repeatedly in the lungs, which causes a dendritic shape to form. Because of its inverted tree shape, it is called the bronchial tree, and its branches have around 24 different levels (Fig. 1.1). The trachea (the trunk) is considered to be the zero level, and the left and right main bronchi the first level. The main bronchi stretch to the lung and branch out into the lobar bronchi, which are the second level of the bronchial tree. The right main bronchus branches out into three lobar bronchi, while the left main bronchus branches out into two lobar bronchi.

In the lung lobes, each lobar bronchus branches out into two to five pulmonary segmental bronchi, which are the third level of the bronchial tree. All segmental bronchi stretch out of the lobar bronchi at some angle.

The segmental bronchi bifurcate in the pulmonary segment repeatedly, their diameter continues to branch from 5–6 mm, and when the diameter of branches is less than 1 mm, bronchioles develop. In each pulmonary lobule, only one bronchiole exists and branches out into terminal bronchioles, which then branch out into respiratory bronchioles. Each respiratory bronchiole branches out into 2–11 alveolar ducts, which link alveolar sacks and alveoli [1, 2] (Table 1.1).

Technological improvement has make it possible and practicable to place inner stent in lobar bronchi and in the distal end of segmental bronchi, rather than only trachea, main bronchi, and intermediate bronchi.

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1.1.1 Trachea

The trachea, from the first cricoid cartilage (the six cervical vertebral level) to the lower edge of the last C-shaped cartilaginous ring (sternal angle plane, located at the junction of the fourth and fifth thoracic vertebral bodies), connects infraglottic cavity and carina. In the lower cervical area and upper chest, the trachea is called the cervical trachea and thoracic trachea, respectively.

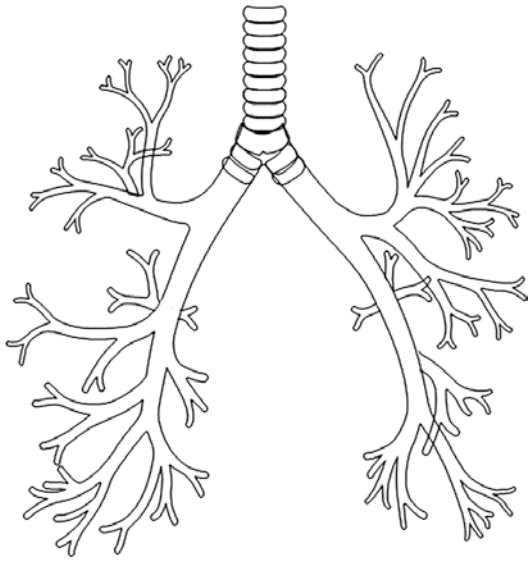

Fig. 1.1 Diagram of bronchial tree

With deep inhalation, the carina region will descend about 20 mm, while at the same time the trachea will extend about 20 mm. The larynx and infraglottic cavity will rise 15–20 mm, and the trachea will extend about 20 mm accordingly when head hypsokinesis. The cervical trachea is one-third and thoracic trachea two-thirds the total length of the trachea in adults.

1.1.1.1 Shape of Trachea

The shape of the trachea varies according to breathing patterns, age, and other factors. The shape of a cross section of the trachea is almost round in young adults. The diameter of the anteroposterior cross section of the trachea is nearly the same as that of the left-right cross section under calm breathing. In exhalations, the anteroposterior diameter contracts into the shape of a kidney, or a "C" or "U" shape (Fig. 1.2. Informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study.). Many significant changes in shape happen with deep inhalations, coughing, and sneezing. For the elderly or pulmonary emphysema sufferers, the anteroposterior diameter lengthens, the left-right diameter decreases, and the cross section looks like the scabbard of a sword (Fig. 1.3).

Table 1.1 Branches of tracheobronchial tree in the human body

Branch level	Name	Lumen diameter (mm)	Lumen length (mm)	Comments
0	Trachea	18	120	
1	Main bronchus	12	48	
2	Lobar bronchus	8	19	
3	Segmental bronchus	6	18	
4	Subsegmental bronchus	5	13	
5–10	Small bronchus	4	5–11	
11–13	Bronchiole	1	3–4	Disappearance of glands and cartilage
14–16	Terminal bronchiole	1–0.5	2	Integrity of annular smooth muscles
17–19	Respiratory bronchiole	0.5	1–2	
20–22	Alveolar duct	0.4–0.5	0.5–1	
23	Alveolar sac			
24	Alveolus	244 μm	238 μm	

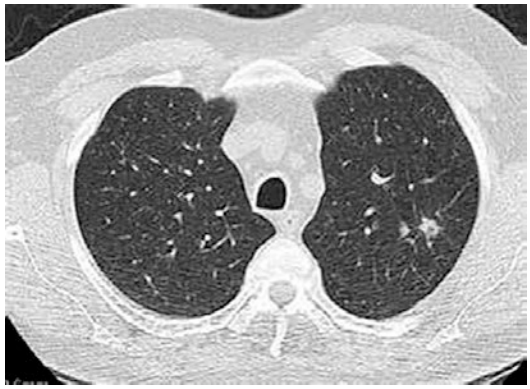

Fig. 1.2 Trachea in "C" or "U" shape

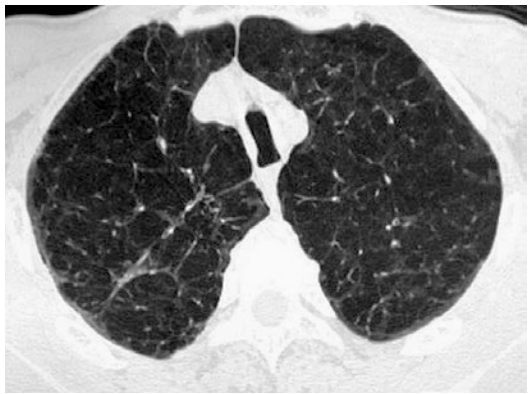

Fig. 1.3 Scabbard-shaped trachea

The inner diameter of the trachea may be the most variable line in human organs. The individual difference varies considerably (according to anatomical literature, for adult men and women, the variation range of the transverse diameter is 9.5–22.0 mm, and that of the sagittal diameter is 8.0–22.5 mm). If a stent is placed in the inner trachea, a multislice spiral computed tomography (MSCT) scan is performed using a special mediastinal window 400–500 HU wide with a level of −50 to −100 HU to measure the inner diameter of the sufferers' trachea [3]. The diameter and specification of the tracheal inner stent should be measured individually. The back wall of the commonly seen C-shaped or U-shaped trachea is tabular. The average inner transverse diameter is approximately 16.5 mm, while the sagittal one is about 15.0 mm.

The length of the trachea shows notable variation between a living body and a corpse. The measurement results from living adults are different to that of corpse. Because the action of respiration affacts the length of trachea. The length of the trachea also changes notably at different breathing amplitudes. It lengthens downward during deep inhalations and contracts upward during deep exhalations. When the head rises and falls backward, the trachea can extend approximately 15 mm upward.

1.1.1.2 Structure of Trachea

The wall of the trachea is composed of tracheal cartilages, smooth muscle fibers, and connective tissues.

1. *Tracheal cartilages*. Tracheal cartilages are hyaline cartilages of horizontal C or U shape with a half-ring structure containing backward openings. The perimeter of tracheal cartilages is about two-thirds that of the trachea. There are 14–17 C-shaped cartilaginous rings in the human body, and men on average have one more than women. The first C-shaped cartilaginous ring at the side of the head is high and wide, while others are similar in shape and size with a height of 4 mm and a wall thickness of 2.2–2.5 mm. C-shaped tracheal cartilages develop to the point of calcification at the ages of 40–50 years. Tracheal cricoid cartilages have a supporting function as stents, so they can keep the inner cavity of the trachea open forever to ensure the normal functioning of respiration ventilation function. C-shaped tracheal cartilages with gaps show significant variation in lumen diameter when external pressure or expansion is exerted, which should be given full consideration when tracheal inner stent placement is to be carried out.
2. *Membranous wall of trachea*. Membranous wall of the trachea refers to the elastic fibers and smooth muscles in the back wall of a closed trachea. The membranous wall possesses a certain amount of elasticity. The rear part of the membranous wall is closely connected to the esophagus. The elasticity of the membranous wall makes it possible for giant

food pellets to descend into the stomach smoothly. Giant food pellets, giant esophageal neoplasms, as well as inner stents with relatively large diameter in the esophagus can all push trachea posteriorly, leading to tracheal stenosis and dyspnea.

3. *Annular ligaments*. Annular ligaments are also called tracheal ligaments, whose adjacent cricoid cartilages are connected together by annular ligaments formed by elastic fibers. Annular ligaments possess elasticity and a certain flexibility. The change of length of the trachea in connection with breathing and raising of the head mainly depends on flexible changes in the annular ligaments.

1.1.1.3 Adjacency of Trachea

The cervical trachea is located at the anterior middle of the neck and adjacent to the thyroid and carotid sheath on the side. The isthmus of the thyroid covers the front part of the first, second, and third tracheal C-shaped cartilaginous rings (occupied 58.7% of total number). For people who are old or who have short necks, the isthmus is relatively low with enormous width variation ranging from covering one C-shaped tracheal cartilaginous ring to seven. While the beginning part of the trachea is shallow and almost close to the skin at a depth of 5–20 mm, it gradually gets deeper in the lower part of the neck and can attain a depth of 40 mm below the skin at the suprasternal fossa. Its anatomical features should be given due attention when performing a tracheotomy.

The thoracic trachea, among left and right pleural sacs and lungs in the superior mediastinum, connects to the manubrium sterni, thymus or thymus remnants, and great vessels (ascending aorta, aortic arch and superior cena cava) in the front, and is connected to the esophagus and parallel to it vertically in the back. There are repeating laryngeal nerves in grooves between the trachea and the esophagus. The trachea is surrounded by areolar tissues, which contain lymph nodes (there are abundant lymph nodes around the lower part of the trachea). Enlargement of the lymph nodes can exert pressure on the trachea and lead to an irritating cough when mild and result in fatal tracheal stenosis when severe. When a thymic tumor or ascending aortic aneurysm exerts pressure on the trachea from front to back, or when an esophageal lesion or descending aortic aneurysm exerts pressure on the trachea from back to front, this leads to tracheal stenosis.

The trachea is surrounded by loose connective tissues, which gives the trachea a significant range of motion so that it is able to move toward the same side as the head does. Because the trachea and surrounding structures are loosely fixed, lesions in the lung, pleura, and other adjacent areas can pull or thrust the trachea, causing displacement. On the one hand, the loosely fixed displaceability is regarded as a self-protection mechanism that keeps the inner cavity of the trachea open. On the other hand, it also protects the trachea from external compression and compression-induced tracheal stenosis that are the results of pulmonary and pleural space-occupying lesions.

Surgical treatment of esophageal cancer has been advocated recently. It features extensive and radical resection of the esophagus, as well as esophagus-stomach anastomosis in the neck. The stomach is lifted to pleural cavity and post mediastinum where the esophagus primarily existed. With operation wounds, bleeding, and exudation, the subsequent organization and fibrosis cause the intrathoracic stomach to become closely linked to the back wall of the trachea and integrated with the trachea, forming a new tracheal–intrathoracic stomach with an anatomically adjoining relationship. If a relapse of esophageal cancer, gastric wall ulcer, gastric wall ischemia, necrosis, or perforation occurs, the intrathoracic stomach—airway fistula can be developed; or if tumor is not resected completely, stereotactic radiotherapy (such as X-knife radiosurgery, γ-knife radiosurgery, or intensity-modulated radiation therapy) should be performed for residual tumor after the operation. The total doses of radiotherapy are calculated on the basis of the radiation tolerance doses of the trachea (6000~8000 cGy). For stomachs with low radiation tolerance doses (only 4000 cGy), overdoses of radiation will bring injuries, ulcers and perforation. In this

condition, gastric juice flow to trachea through intrathoracic stomach—airway fistula, causing a series of pathological changes of lung injuries and displaying a whole string of complicated clinical manifestations.

1.1.2 Carina

The carina is generally known as a special anatomical marker at the bottom of the trachea. It is described as "carina cristae," which is treated as the intersection of the trachea and bilateral main bronchial branches. Morphologically, no complete, systematic, and detailed investigation has been carried out on the carina. A search of the domestic and foreign literature revealed that it remains an anatomical blind spot. The issue whether the carina is an anatomical marker or an anatomical region has been neglected, from the point of view of either human anatomy or clinical medicine and surgery. With the popularization of interventional radiology, especially the wide application of inner stents at the lower part of the trachea and inner stents at the opening of the left and right main bronchi at the junction of the trachea and main bronchi, researchers have started to focus on producing a detailed understanding of the anatomical structure of the carina.

1.1.2.1 Shape of Carina

In the traditional view of anatomy, the trachea bifurcates at the bottom, from which the left and right main bronchi branch. Here a special change can be observed in terms of the shape of the tracheal rings. The middle part of the bottom of cartilaginous rings shows a downward tendency to form a sharp protrusion. The crescent-shaped carina cristae is an upward facing bulge in the trachea that forms upon bifurcation of the trachea. The cricoid cartilage looks like an inverted saddle (Fig. 1.4).

The carina is formed at the intersection of the bottom of left and right main bronchi and is known as the carina of the trachea. Generally, the bottom of the bilateral main bronchi is smooth, while the angle of the carina is sharp. The

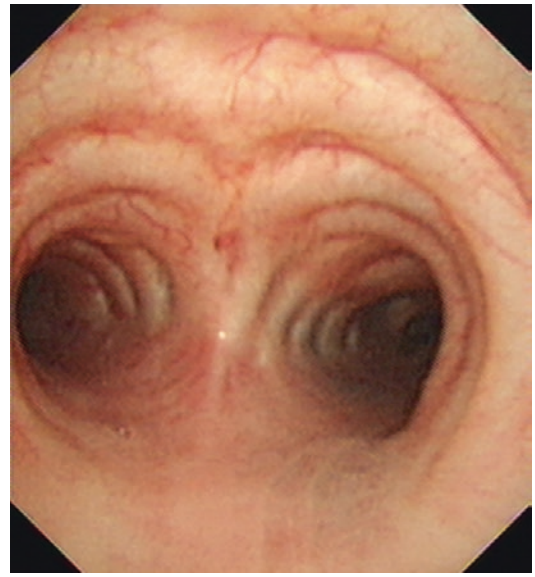

Fig. 1.4 The saddle and the inverted saddle

intersection angle of bilateral bronchi equals the angle of bifurcation of the trachea, which, 60° to 85°, is the angle of the carina in clinics . The size of the angle is related to the shape of the thoracic cage. The wider and shorter the thoracic cage, the larger the angle, and vice versa.

Dr. Xinwei Han treats the carina as a special anatomical zone between the trachea and the bilateral main bronchi. When the upper bound is the bottom of a C-shaped cartilaginous ring at the lowest part of the trachea, the lower bound is the top of the first C-shaped cartilaginous ring at the bilateral main bronchi. The structure of the carina includes an annular ligament of the trachea, a cartilaginous ring in the shape of an inverted saddle, an annular ligament of the left main bronchus, an annular ligament of the right main bronchus, and a section of membranous wall in the rear of the annular ligament of the right main bronchus. An inverted triangular or trapezoidal section is arranged with the inverted saddle-shaped special cartilaginous ring at the center (Fig. 1.5). From the point of view of either anatomy or histology as well as function, this section is different from both the trachea and the main bronchi. The carina is regarded as a special anatomical zone, referred to as the carina region.

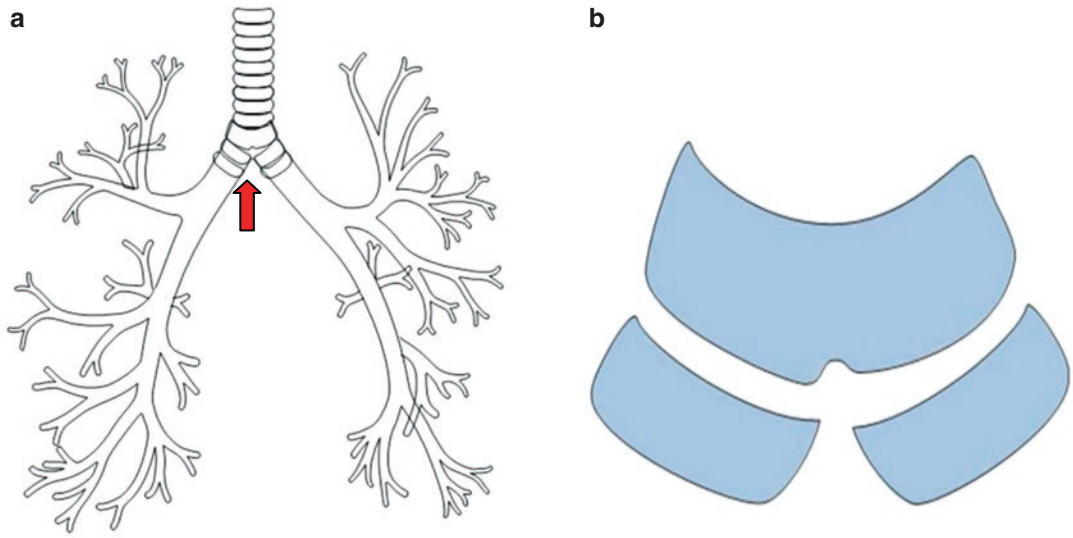

Fig. 1.5 Diagram of carina of trachea: (**a**) bilateral main bronchi in trachea-carina region; (**b**) local amplification of carina region

1.1.2.2 Adjacency of Carina

The left atrium is located at the anterior inferior part of the carina. Enlargement of the left atrium due to heart disease can push the bilateral main bronchi and carina to increase the angle of the carina.

The right front part of the carina is in the top of the vena cava. An enlarged transitive tumor of the lymph node often appears between the carina and superior vena cava. Enlarged lymph nodes are able to compress the right main bronchus and carina, leading to carina stenosis, and they can compress the superior vena cava, resulting in superior vena cava compression syndrome.

The area around the carina, especially the anterior and inferior part of carina, has the widest distribution of mediastinal lymph nodes. Various types of tumors, such as those of lung cancer, esophageal cancer, and stomach cancer, may lead to mediastinal lymph node metastasis concentrating around the area of the carina, which results in polystenosis in the central airway. Polystenosis in the central airway includes the lower part of the trachea, the carina region, and the left and right main bronchi; as a result, these polystenoses will lead to dyspnea and even asphyxia and death in patients when serious. A Y-shaped integrated self-expandable inner stent and delivery system for the airway created by Dr. Xinwei Han are irreplaceable therapy for this kind of compound main airway stenosis.

The rear of the carina is close to the esophagus. If an esophageal neoplasm grows forward, it directly pushes the carina and causes fatal stenosis in the carina region, which is a main airway with three divergences. Accordingly, if an esophageal tumor in the progressive stage grows outward, it can damage airway walls in the carina region directly, resulting in a connection between esophagus and the carina region, which is one of the three divergences. As a result, esophagus-carina fistula can form.

After surgical resection of esophageal cancer, the stomach develops into the pleural cavity and localizes around the esophageal bed, which originally occupies the posterior of the mediastinum and forms an intrathoracic stomach. The intrathoracic stomach closely connects to the back wall of the tracheal carina and is integrated with the carina. In the case of relapse of the tumor, gastric ulcer, gastric ischemia, necrosis, and perforation may occur, resulting in intrathoracic stomach–airway fistula; or if the tumor is not resected completely, stereotactic radiotherapy should be performed for residual tumor after the operation. Overradiation will lead to damage to the gastral cavity in the area originally occupied by the esophageal bed. The intrathoracic stomach–

airway fistula occurs because of ulcer and perforation of the gastric wall, and etch of the wall of digestive tract by gastric juice.

1.1.3 Main Bronchi

There are two main bronchi, the left and right main bronchi, composing the first level of the bronchial tree. The main bronchi are able to move downward and outward in a diagonal direction. So far, the best technique to measure the inner diameter and length of the airway is a special mediastinal window (fat window) using MSCT transverse scan imaging. Certain image reformation and data reconciliation are carried out together with a CT image measurement of the cross section or diameter of the main bronchi that move in a diagonal direction.

1.1.3.1 Structure of Main Bronchi

The structure of the main bronchi wall, similar to that of the trachea, is also composed of main bronchial C-shaped cartilaginous rings, annular ligaments, and membranous wall. The difference between both of them is that the C-shaped cartilaginous rings are relatively small, while the membranous wall of smooth muscles and fibrillar connective tissues is relatively wide. At this point, the contractility of main bronchi becomes stronger, the lumen becomes thinner, and the air turbulence becomes more intense with coughing, expectoration, and sneezing, which makes it easier for sputum and foreign bodies to be eliminated. While the left main bronchus is longer with seven to eight cartilaginous rings, the right main bronchus is shorter with only three to four cartilaginous rings.

1. *Left main bronchus*. The left main bronchus, usually 40 mm long with an average of 48 mm for men and 45 mm for women and 10 mm inner diameter. The average transverse diameter is 11.2 mm for men and 9.3 mm for women; furthermore, the average sagittal diameter is 9.3 mm for men and 7.5 mm for women.
2. *Right main bronchus*. Compared to the left main bronchus, the right main bronchus is both short and thick. Usually the length is 15–20 mm with an average of 21 mm for men and 19 mm for women. Its inner diameter is above 10 mm, and the average transverse diameter for men is 15.1 mm and that for women is 13.1 mm. The average sagittal diameter for men is 14.1 mm and 9.3 mm for women.

1.1.3.2 Adjacency of Main Bronchi

There are abundant lymph node groups around the main bronchi. Mediastinal lymph node metastasis in thoracic malignant tumor may emerge mainly in the area around the main bronchi and compresses main bronchi to stenosis.

1. *Adjacency of left main bronchus*. The rear of the left main bronchus is near the esophagus, thoracic duct, and descending aorta. Esophageal cancer or descending aortic aneurysm pushes on the left main bronchus. The middle part of the left main bronchus is bypassed by the aortic arch from above and the left pulmonary artery, which is in front of the aortic arch. It is difficult to expose the left bronchus in an operation because of the occlusion of the pulmonary artery and descending aortic aneurysm, which causes a relatively long segment bronchus stump in left lung resections. If a left main bronchopleural fistula occurs, and bullet covered inner stent closure treatment needs to be carried out; this kind of relatively long stump is good for the placement of an inner stent.

   With the surgical resection of esophageal cancer, the stomach is lifted to the pleural cavity. The intrathoracic stomach is around the area where the esophageal bed is originally located in the posterior mediastinum, so that it closely connects to the back wall of the left main bronchus. If a tumor relapse, gastric wall ulcer, and additional stereotactic radiotherapy on the residual tumor after surgery occur, overradiation will lead to injuries to the gastral cavity originally occupied by the esophageal bed. Ulcer and perforation of the gastric wall and etch of the wall of the digestive tract by gastric juice

will result in intrathoracic stomach–left main bronchus fistula.

2. *Adjacency of right main bronchus*. The superior vena cava is located in the front of the right main bronchus. From backward to forward, the azygos vein bypasses the right main bronchus from above. The right pulmonary artery is at the bottom of the azygos vein. The right main bronchus is relatively short, which makes it easier to expose it during an operation. If a bullet-covered inner stent closure needs to be done to treat a right main bronchopleural fistula, attention should be paid to the fact that there is a very short or even no stump in order to choose the most suitable covered inner stent.

1.1.4 Intermediate Bronchus

The intermediate bronchus, a unique structure in the right part of the bronchial tree, extends from the right main bronchus. The section of the bronchus from the opening of the superior lobe to that of the middle lobe belongs to neither the superior lobe or the middle lobe without branches. Like the structure of the main bronchus, the wall of this section is also composed of relatively small C-shaped cartilaginous rings, relatively wide annular ligaments, and membranous wall. With the ability to contract, the intermediate bronchus becomes stronger, and its lumen becomes thinner; at the same time, the air turbulence becomes more intense, especially with coughing, expectoration, and sneezing, which are easier methods for the elimination of sputum and foreign bodies. The total length of the intermediate bronchus is 20–30 mm and its inner diameter is 10–11 mm. When inner stent interventional therapy is applied for intermediate or lower lobe bronchial lesions, it is an extremely useful structure to fix the inner stent.

There are abundant lymph nodes around intermediate bronchus. Metastatic lymph node enlargement can very easily compress intermediate bronchus, resulting in stenosis. If stereotactic radiotherapy is used for residual tumor after the surgery due to relapse or incomplete tumor resection, overradiation can lead to injuries to the gastral cavity where the esophageal bed is located. Ulcer and perforation of gastric wall, and etch of digestive intermediate bronchus wall by gastric juice will result in intrathoracic stomach–intermediate bronchus fistula.

1.1.5 Upper Lobe Bronchus

The lobe bronchus is the second level of the bronchial tree. Both lungs contain an upper lobe bronchus, but with different structures.

1.1.5.1 Upper Lobe Bronchus of Right Lung

The majority of upper lobe bronchi of the right lung are about 10–20 mm away from the carina. Almost at a right angle from the right edge of the right main bronchus after branching, the upper lobe bronchus of the right lung rises to the upper lobe of the right lung. Then it branches out into three segmental bronchi, anterior branch, apical branch, and posterior branch. The apical branch, ascending vertically, is treated as the direct extension of the upper lobe bronchus. When an inner stent is placed in the right upper lobe bronchus, a guide wire will enter the deep part of the upper lobe bronchus through the apical branch. It is beneficial to fix a guide wire in an inner stent. The length of the right upper bronchus is 10–20 mm and its width is 8–10 mm. While a few right upper lobe bronchi can branch directly from the lower part of the bronchus, the right main bronchus and intermediate bronchus will integrate together without any branches.

1.1.5.2 Upper Lobe Bronchus of Left Lung

The upper lobe bronchus of the left lung is 40–50 mm away from the carina. It branches almost in a horizontal baseline of the left edge of the left main bronchus. The left upper lobe bronchus is very short with 10–20 mm length and branches out into two branches, the top and the bottom branches. The top branch is equivalent to the right upper lobe bronchus, while that of the bottom, namely, the tongue, is equivalent to the right intermediate lobe bronchus.

1.1.6 Middle Lobe Bronchus

While the right lung occupies the independent middle lobe bronchus, the middle lobe (blade) is integrated with the upper lobe in the left lung and its bronchus branches from the front wall of the lower part of the intermediate bronchus. It is about 15 mm long and 7 mm wide. The middle lobe bronchus drops and stretches forward and then branches out into two segmental bronchi, external and internal branches.

1.1.7 Lower Lobe Bronchus

While the right lower lobe bronchus is the continuation of the intermediate bronchus, the left one is the extension of the left main bronchus. The opening of the bilateral lower lobe bronchus is in a similar location as the carina.

1. *Right lower lobe bronchus*. The right lower lobe bronchus, 10 mm in diameter, has a short trunk that branches out into the dorsal bronchus almost at the opening of the intermediate bronchus. Then it stretches the trunk of the base bronchus, which develops four pulmonary segmental branches one by one, the internal base bronchus, external base bronchus, front base bronchus, and back base bronchus.
2. *Left lower lobe bronchus*. The trunk of the right lower lobe bronchus is also very short with 5–10 mm length. The first branch of it is also the dorsal branch, which develops into three pulmonary segmental branches, the front internal base bronchus, external base bronchus, and back base bronchus.

1.2 Tracheobronchial Histology and Physiology

The structure of the trachea wall is similar to all levels of bronchi. The structure includes a mucosa, submucosa, and adventitia (Fig. 1.6).

1.2.1 Mucosa

The mucosa consists of the epithelium and lamina propria. The mucosal epithelium, a typical pseudostratified ciliated columnar epithelium, functions diversely as endocrine, exocrine, homeostasis regulation, swing movement, etc. The thickness of epithelium is 22–62.6 μm with an average of 41.5 μm. It is composed of ciliated columnar cell, goblet cells, basal cells,

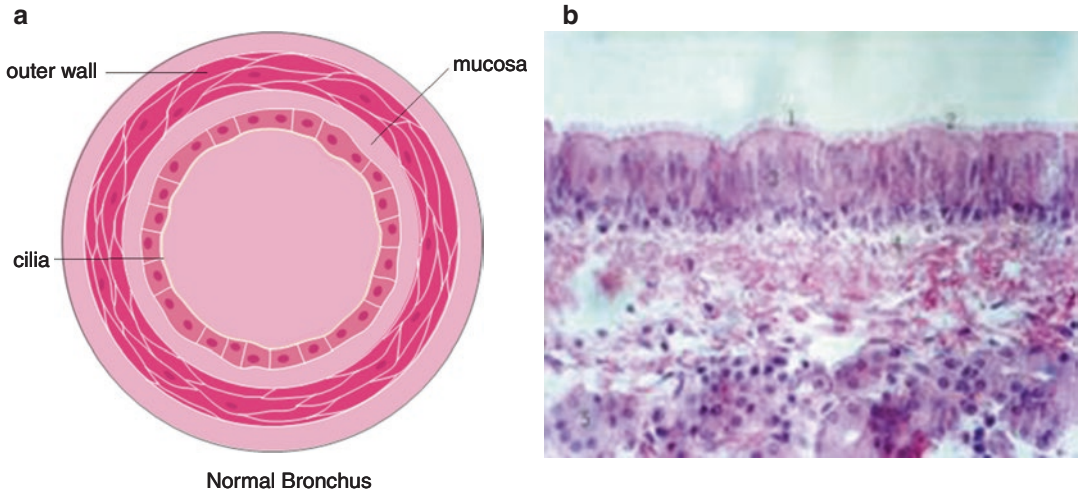

Fig. 1.6 Tracha. (**a**) Wall of trachea (x 10, H&E) *1* epithelium; *2* lamina propria; *3* glands; *4* hyaline cartilage (**b**) Trachea (x 40, H&E) *1* cilium; *2* goblet cell; *3* pseudostratified ciliated columnar epithelium; *4* lamina propria; *5* basement membrane

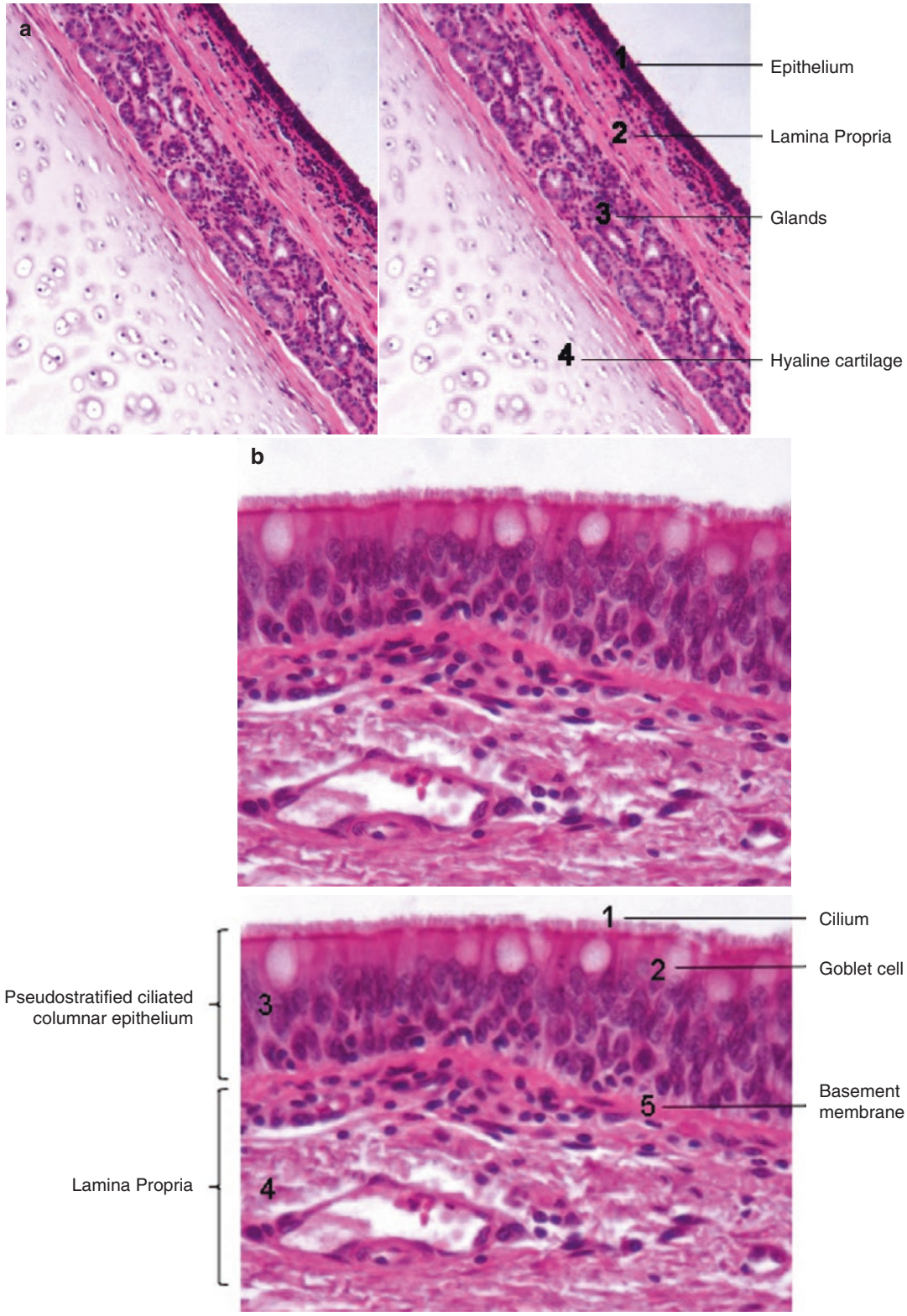

Fig. 1.6 (continued)

brush cells and dispersed neuroendocrine cells. Of all these, columnar epithelial cells account for 61%, basal cells account for 32%, goblet cells account for 6%, and there are a few granulocytes (0.6%) and lymphocytes (0.2%).

1.2.1.1 Mucous Blanket

There is an intact layer of mucus on the surface of the tracheal and bronchial mucosal epithelium. The mucous layer forms an intact mucous blanket, which is a double-layer liquid structure and the complex of mixtures secreted by various cells in the mucosal epithelium and glands.

1. The shallow layer functions as a gel layer. Particles and foreign bodies in the airway can cling to the gel layer by its strong adhesive force. At the top of the cilia with a thickness of 0.5–2.0 μm, the gel layer is mainly mucoprotein secreted by mucous glands. Gel macromolecules in mucoprotein form an interconnecting network and various glycoconjugates in mucoprotein cling to bacteria and viruses through chemical action, which are then eliminated through ciliary movement. This kind of network configuration and arrangement of molecular bonds varies quickly due to the influence of various physicochemical factors.
2. The deep layer belongs to the sol layer and functions as lubrication for cilia and provides water for mucus. The sol layer contains IgG, ions, lipids, and other substances, in which cilia are able to move freely. The movement of ions and proteins in sol can regulate the extent of hydration of mucus; at the same time, the sol layer around cilia can maintain the constancy of water molecules and supply water lost in mucus activity in time. These various cellular activities are almost all performed under the regulation of the change of concentration of calcium ions in cells. Internal and external environmental changes in the respiratory system and cardiovascular system influence the normal physiological activity of tracheal endothelial cells. Mucous blanket abnormality or cilia activity abnormality will result in abnormal elimination of bacteria, viruses, and other hazardous substances in the trachea and then lead to respiratory tract infection.

1.2.1.2 Ciliated Columnar Cells

Each ciliated columnar cell contains about 300 cilia. The diameter of a cilium is 0.25 μm and its length decreases as the diameter of the bronchus decreases (Fig. 1.6b). Cilium shows consistent wavy swing motions toward the laryngopharynx. The swing frequency of a cilium is 5–20 Hz. Through the swing of cilia, the mucous blanket is pushed to the laryngopharynx. Bacteria, viruses, and foreign bodies brought to the laryngopharynx by the mucous blanket are eliminated with coughing. Then sputum, a respiratory secretion that containing bacteria, viruses, and foreign bodies, develops. The viscosity of mucus secreted by normal mucosa is different, which determines the differences in the quality of the mucous blanket. To be more exact, the quality and number of mucous blankets is closely related to the frequency of the heartbeat and respiration. Abnormalities in the respiratory and circulatory systems affect the mucous blanket and swing frequency of cilia.

Adjacent cilia swing toward the laryngopharynx regularly in a certain order. Mucus, as well as dust, bacteria, and other foreign bodies that cling to mucus are pushed towards laryngopharynx and then eliminated from body through coughing. The mucous blanket on cilia, pushing in the same direction (namely, toward the pharynx) at the rate of 5 mm/min, eliminate mucus, viruses, bacteria, and other foreign bodies out of the airway concurrently. ATP and epinephrine beta receptor agonists enhance ciliary movement.

The regular swinging of ciliated cells and constant movement of the mucous blanket play an important role in purifying the respiratory tract. The physical and chemical conditions required for ciliary movements are strict, including proper temperature, humidity and acidity. Swelling and denaturation of mitochondria in ciliated cells and the consequent decrease in the ability of ciliary movement are observed in chronic bronchitis sufferers. Decrease or disappearance of cilia in ciliated cells happens in

long-term smokers. The long-term and chronic effect of air pollution, toxic gas, and harmful type of work also inevitably affect the function and structure of ciliated cells. Severe or repeated damage of the epithelial cell structure will result in squamous metaplasia, and following squamous epithelium overproliferation and canceration. Gastroesophageal reflux and intrathoracic stomach–airway fistula cause lots of acidic gastric juices to spill into the trachea and bronchi, which affect ciliary movement if it is not serious and damage ciliated cells as well as the whole mucosa epithelium structure if it is severe. It is important to maintain respiratory health by a favorable internal and external environment and a regular lifestyle. Glucocorticoids can promote the growth of cilia in bronchial epithelial cells.

1.2.1.3 Goblet Cells

Goblet cells are scattered among ciliated cells. Mucus, secreted by goblet cells, covers the surface of the mucosa and develops into a mucus barrier with other secretions of tracheal glands. The mucus barrier adheres to and dissolves dust particles, bacteria, and other harmful substances in air. The number of goblet cells is far less than that of ciliated columnar cells. Cytoplasm at the top of cells contains a large number of metamucous grains, which secrete mucoprotein through exocytosis. Mucoprotein, at the top of cilia, forms a mucous layer, which is a mucous blanket with secretions released by endobronchial glands. Through the oriented swing of cilia, the mucous layer and foreign bodies move toward the laryngopharynx, and then mucus and foreign bodies are eliminated by coughing. Coughing and expectoration are indispensable normal physiological activities.

In chronic bronchitis patients, the number of goblet cells and mucus inside the bronchial cavity increases, and the secretion of mucus is highly enhanced. Hypertrophy and proliferation of mixed glands in bronchial walls is observed. Excessive amounts of mucus accumulate to form sputum; therefore, there is sputum retention in the bronchial cavity, which leads to the expansion of the bronchial cavity and thickening of bronchial walls, aggravating bronchitis or lung inflammation.

1.2.1.4 Basal Cells

The top of basal cells cannot reach the free surface of the epithelium since basal cells are deep in the epithelium. Basal cells are undifferentiated stem cells with the ability of proliferation and differentiation. When the epithelium is damaged, basal cells become ciliated columnar cells and goblet cells by proliferation and differentiation, as well as scalelike epithelial cells through metaplasia. In this way, basal cells function as a backup cell repository for mucosa epithelium of bronchi.

1.2.1.5 Brush Cells

Brush cells are columnar cells without cilia. The free surface of brush cells has brushlike microvilli, which are both orderly and dense. The function of brush cells is controversial; it is regarded that brush cells either function as cells in transition and ciliated cells through metaplasia or as mucous pinocytosis and updated mucous transference. It maintains the relative homeostasis of the amount of mucus secreted. Also, brush cells are considered receptor cells that can feel stimulation in bronchi and then motivate the secretion of goblet cells or movement of columnar cells because there are synapses at the basal plane of brush cells.

1.2.1.6 Neuroendocrine Cells

Neuroendocrine cells are scattered in the mucosal epithelium along the whole respiratory tract. As manifested through silver impregnation method, there are tiny argyrophilic grains in both cell bodies and protuberances. Immunocytochemistry shows that there are 5-hydroxytryptamine, bombesin, calcitonin, enkephalin, gastrin, and other chemically reactive substances like histamine, bradykinin, etc. in cells. Through paracrine or blood circulation, secretions regulate the contraction of the respiratory tract and vascular smooth muscles as well as the secretion of glands. Furthermore, they also regulate and protect the normal physiological functioning of the body, and cause adverse reactions like bronchospasms, vasoconstriction, and monocyte aggregation, for example.

1.2.2 Submucosa

Submucosa is loose connective tissue with lots of blood vessels, lymphatic vessels, nerves, mixed tracheal glands, lymphoid tissues, plasma cells, and so on. Mucus, secreted by mucous acinus in tracheal glands and goblet cells, covers the surface of the mucous membrane to form a mucous blanket and clings to dust and foreign bodies. The lubrication functions cannot only benefit the normal swinging of cilia but push the movement of the mucous blanket in the ciliary swing also.

Plasma cells in submucosa synthesize IgA and J chains (glycoprotein). When passing through the mucosal epithelium, IgA combines with secretory pieces released by the epithelium to form secretory immunoglobulin A (SIgA), which damages antigens inhaled into the cavity and play a role in local immunity. SIgA prevents not only bacteria, especially streptococcus, from agglomerating or adhering to the surface of the mucous membrane but also viruses from infecting epithelial cells to weaken the infection combined with lysozymes, and SIgA can enhance the bacteria-engulfing ability of pulmonary macrophages. People who lack SIgA can easily infected with respiratory tract infections. The lungs of newborn infants are prone to pneumonia due to the lack of plasma cells secreting IgA, but as the age increases, the plasma cells capable of secreting IgA appear and gradually increase, the incidence of pneumonia gradually decreases.

1.2.3 Adventitia

Hyaline cartilage rings and connective tissues compose trachea and adventitia. Cartilage rings are C-shaped or U-shaped with gaps toward the back side. The gaps are a membranous wall of the trachea, which consists of smooth muscle bundles and connective tissues. The smooth muscle tissues are arranged in an annular array. Contraction of smooth muscle tissues narrows the trachea. During the process of cough reflex, smooth muscle tissue contracts, the tracheobronchial cavity narrows, and airflow accelerates in the airway. The impact of high-speed airflow makes it easier for sputum to be taken away and expectorated.

The number of tracheal and bronchial cartilaginous rings is different among people. Adjacent cartilaginous rings are connected to each other through annular ligaments that are composed of fibrous connective tissues. In smaller bronchi, C-shaped cartilage rings degenerate into irregular cartilage slices. C-shaped cartilage rings prop up bronchial cavities, keep the tracheal and bronchial cavities unobstructed, and possesses elasticity. For chronic bronchitis sufferers, cartilaginous rings or slices in small and medium-sized bronchi show different degrees of atrophy and denaturation, which are caused by a decrease in the size of the cartilaginous rings, a shrinkage or disappearance of chondrocytes, uneven dyeing in a hyaline cartilaginous matrix, and change of hyaline cartilages into fibrous cartilages. As a result, the wall of the bronchi becomes thinner, its supporting ability becomes weaker, and the wall of small bronchi collapses and even folds up. In this way, if the airflow is obstructed, it will result in chronic pulmonary emphysema or fibrosis.

For radiotherapy, amyloidosis, relapsing chondritis, and tracheal intubation sufferers, long-term and sustained hypertrophy, compression, and other ailments on air sacs together will lead to the denaturation of hyaline cartilaginous rings [4–6]. Thus, hyaline cartilaginous rings will be unable to prop up the main airways, such as the trachea and main bronchi, which will lead to main airway stenosis, dyspnea, compulsive orthopnea, and even suffocation and death.

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2 The Symptoms and Causes of Tracheobronchial Diseases

Guojun Zhang, Xinwei Han, Songyun Ouyang, and Tengfei Li

In medicine, it is essential to first establish the diagnosis, and then the choice of treatment follows. If the diagnosis is specific, the treatment is clear. The disease diagnosis relies on information from a complete medical history, detailed physical examination (observing, touching, knocking, listening), indispensable laboratory tests, special equipment, and specialized procedures, such as endoscopy and imaging.

2.1 The Symptoms of Tracheobronchial Diseases

2.1.1 Dyspnea

Dyspnea (shortness of breath) refers to a condition in which patients have insufficient air or need to exert excessive respiratory effort to breathe. Often there is a lack of balance in respiratory frequency and depth (breathing fast and shallow or slow and deep) and abnormal rhythm. In severe cases and if the patient breathes hard, mouth breathing, nasal flap, orthopnea, and cyanosis are present.

2.1.1.1 Classification of Dyspnea

Dyspnea is classified into five types based on the pathogenesis [1, 2].

1. Lung-induced dyspnea
   Lung-induced dyspnea is caused by disease of the respiratory organs (including respiratory, pulmonary, and pleural), mediastinal diseases, and thoracic and respiratory muscle dysfunction. There are three subtypes of lung-induced dyspnea.
   (a) Inspiratory dyspnea
   This subtype is characterized by difficulty in inhalation and exhalation. Difficulty in breathing is caused by severe stenosis of the airway. The excessive inspiratory effort results in sweating and deep, slow breathing. There is a characteristic chest retraction (that is, sunken), including the three concave signs – the upper fossa, supraclavicular fossa, and intercostal space.
   (b) Expiratory dyspnea
   If the cricoid cartilage merges into the bronchioles (1.0 mm in diameter), the complete circular smooth muscle is replaced. This absence of cricoid muscle leads to expiratory breathing difficulties, bronchial inflammation, spasm, and

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obstruction. Although the pressure of the chest is elevated, the air in the bronchioles and the alveoli is not expelled, which results in emphysema.

(c) Mixed dyspnea
Mixed dyspnea, also called bipolar dyspnea, is a reduction in the effective respiratory area (oxygenation area) of the lung caused by extensive pulmonary parenchymal lesions, such as inflammation and pulmonary edema, or large pleural effusions. Spontaneous pneumothorax causes large tracts of lung tissue to collapse, which can lead to mixed dyspnea.

2. Cardiogenic dyspnea
Heart failure, especially left ventricular dysfunction, left atrial and pulmonary venous hypertension, pulmonary edema, blood stasis, and alveolar ventilation dysfunction reduce cardiac output and blood flow velocity and cause ventilation dysfunction, hypoxia, and carbon dioxide retention. As a result, ischemia and hypoxia, the double barrier of pulmonary blood circulation and pulmonary oxygen gas exchange, develops. Cardiogenic dyspnea is characterized by difficulty breathing in both sitting and sleeping postures.
3. Toxic dyspnea
In this condition, a toxin stimulates the respiratory center to increase or decrease the excitability level, resulting in an abnormal respiratory frequency. Toxic dyspnea can lead to pulmonary edema, bronchospasm, cardiac dysfunction, reduced blood cell oxygen carrying capacity, and respiratory muscle weakness.
4. Hematogenous dyspnea
Severe anemia and massive blood loss or shock decreases the blood exchange and oxygen carrying capacity. This causes respiratory distress, which can also result from circulatory ischemia, hypoxia, and respiratory center stimulation.
5. Neuropsychiatric dyspnea
Severe encephalopathy in the respiratory center causes breathing difficulties, accompanied by an abnormal respiratory rhythm.

2.1.1.2 Etiology of Dyspnea

1. Lung-induced dyspnea
(a) Large airway stenosis
Treated as a typical inspiratory dyspnea.
- Trachea foreign body
This is more common in children and comatose patients. Large foreign bodies stuck in the laryngeal cavity result in severe dyspnea and even suffocation. A foreign body stuck in the trachea will result in an irritating cough, and the foreign body will finally become lodged in the main bronchus or below the main bronchi, which causes obstructive emphysema, atelectasis, or intractable obstructive pneumonia.
- Tumor of the trachea, carina, or main bronchial cavity
Polyps, adenomas, or cancer in the trachea, carina, or main bronchial walls can block the airway lumen and cause obstructive atelectasis with a gradual increase in tumor volume. Obstructive atelectasis and inspiratory-oriented dyspnea can force the patient to sit for ease of breathing. Airway neoplasms are observed using fiberoptic bronchoscopy; however, it is difficult to pass through the narrow areas and obtain pathological biopsy samples. Sometimes patients are not able to endure fiberoptic bronchoscopy because of severe airway strictures. The volume scanning of the chest spiral CT scan is able to explore the tumor size, shape, and extent, and provide detailed reference for interventional therapy.
- External compression induces stenosis in the trachea, carina, and main bronchus
Thyroid cancer, thymic carcinoma, esophageal cancer, and metastatic lymph nodes directly compress the trachea, carina, and the main bronchus, leading to severe stenosis, irritable cough, and dyspnea. Using fiberoptic bronchoscopy, airway stenosis and

compression displacement is easily detected. By continuous scanning of the thoracic spiral CT scan, the degree of airway stenosis, scope, size, and morphology of the tumor can be clearly observed for specific diagnosis.

- Scars can induce stenosis in the trachea, carina, and main bronchus
  Scars can cause airway intimal hyperplasia or fibrous connective tissue hyperplasia, airway stenosis, or obstructive atelectasis. Scars can form from a tracheotomy, trachea cannula, surgery, injury, endomembrane tuberculosis, chemical erosion, radiotherapy, and endobronchial stent implantation. Patients may suffer from progressive dyspnea and even severe orthopnea in some cases.

  Fiberoptic bronchoscopy is able to detect the narrowness of the airway, but it is hard to pass through this narrow space. Furthermore, patients with severe stenosis cannot endure this procedure. A thoracic spiral CT scan with the coronal plane, sagittal plane, and 3D imaging can illustrate the degree and scope of airway stricture.
- Cartilaginous stenosis of the trachea, carina, and main bronchus
  This type of stenosis causes degeneration and necrosis of airway elastic cricoid cartilage, and can be caused by a tracheotomy, endotracheal intubation, trauma, endometrial tuberculosis, or radiotherapy. The stenosis may damage the supported capacity of the large airway lumen and cause the cartilage to lose elasticity. When patients are in a recumbent position, the airway is almost closed (atresia) and even blocked; consequently, this leads to severe dyspnea. However, when patient is in a sitting posture, the lumen is open and this relieves the feeling of dyspnea.

  Under high-voltage thorax fluoroscopy, it is possible to detect the negative shadow of the airway changes in thickening and thinning with inhalation and exhalation. Fiberoptic bronchoscopy is used to check the airway's loss of elasticity. The fiberoptic bronchoscopy is able to pass through and expand the narrow airway easily, but when it is pulled out, the airway narrows again. The degree and scope of airway stenosis can be seen using the thorax spiral CT scan combined with coronal plane, sagittal plane, and 3D imaging.

(b) Bronchial and pulmonary lesions

- Bronchiolitis
  Acute bronchiolitis usually occurs in children. The symptoms disappear when the infection is under control. When an adult has an acute infection, this can aggravate the ventilation barrier of bronchioles and also affect the gas exchange function of alveoli.
- Acute fibrinous bronchitis
  This is a rare disease. The characteristics of this type of bronchitis are fever, intense paroxysmal cough, and dyspnea, with dendritic gelatinous sputum.
- Lobar and diffuse pneumonia
  Multiple and diffuse lobar or lobular pneumonia influences the ventilation capacity of lung tissue and causes dyspnea.
- Pulmonary tuberculosis (TB)
  This disease can damage normal lung tissue, affect the exchange of gases, and lead to dyspnea. Examples of this disease include acute miliary TB, caseous pulmonary TB, and chronic fibrocavitary pulmonary TB.
- Bronchial asthma
  Bronchial asthma, an allergic and seasonal-onset disease, is triggered by certain allergens. Recurrent dyspnea, the main complaint of this disease, is treated by the patient with antispasmodic drugs. Examples of special types of asthma include occupational asthma (cotton dust) and hay fever.

- Pulmonary eosinophilia
  This disease is a result of a large number of eosinophils infiltrating the lung tissue, which results in abnormalities in bronchial ventilation and alveolar gas exchang, and even dyspnea. Pulmonary eosinophilia consists mostly of fulminant respiratory allergic syndrome, allergic pneumonia (Loffler Syndrome), and tropical eosinophilia.
- Chronic obstructive emphysema
  Middle-aged and senior citizens with chronic bronchitis, bronchial asthma, pulmonary TB, pulmonary fibrosis, bronchiectasis, or pneumoconiosis are more likely to suffer from diffuse obstruction in the bronchiole and a decreased number of capillary beds, which may further cause ventilation dysfunction and dyspnea. Expiratory dyspnea is a common manifestation, while mixed dyspnea occurs in some severe cases.
- Pulmonary fibrosis
  Diffuse lung tissue fibrosis that results from pulmonary TB, pneumoconiosis, radiation pneumonia, scleroderma, and sarcoidosis causes bronchial obstruction, which further affects pulmonary ventilation and leads to dyspnea. Patients may develop cyanosis, clubbed fingers, and chronic pulmonary heart disease as the disease worsens.

  Idiopathic diffuse pulmonary interstitial fibrosis (also called Hammen–Rich syndrome) is characterized by progressive dyspnea. The etiology for cyanosis, clubbing, and chronic pulmonary heart disease is unknown.

  Chemotherapy-related pulmonary fibrosis is a type of fibrosis caused by certain chemotherapy drugs (bleomycin, methotrexate) and characterized by progressive dyspnea.
- Acute pulmonary edema
  Acute chest tightness, coughing, dyspnea, cyanosis, and pink bubble phlegm, accompanied by excessive sweating and anxiety are common symptoms of acute pulmonary edema. Common etiologies include left ventricle heart failure, inhalation of harmful gas, altitude sickness, craniocerebral trauma, stroke, excessive fluid input, near-drowning, empyrosis, excessive liquid release during thoracentesis, and allergic reactions. In these cases, hydrostatic pressure and permeability increase in pulmonary capillaries, while plasma colloid osmotic pressure decreases. This can lead to excessive liquid extravasation into interstitial tissues and alveoli, which may affect lung ventilation and gas exchange. The pterygium effusion of the center of the bilateral pulmonary portal is detected by chest X-ray.
- Pulmonary embolism (PE)
  PE is given more attention as it is a clinical emergency and is characterized by the sudden onset of chest pain, dyspnea, cyanosis, and the feeling of impending death. It is fatal for some patients experiencing severe symptoms, including sudden cardiac and respiratory arrest. PE is the primary reason for sudden death among inpatients world-wide.

  The patients are usually in the hypercoagulable state for blood and are at risk of deep vein thromboses in their legs, such as the elderly, those who are bedridden, or patients who are pregnant or have recently undergone childbirth, pelvis and lower extremity surgery, or have cancer. Physical activity causes the deep vein thrombosis to migrate to the lung circulation system via the inferior vena cava, right atrium, right ventricle, and pulmonary artery. Eventually the pulmonary embolism is formed and this affects pulmonary oxygenation, leading to severe pulmonary arterial hypertension. This may cause low heart ejection, which presents as a life-threatening syndrome.

- Acute respiratory distress syndrome (ARDS)
  ARDS is an acute progressive respiratory failure triggered by various non-cardiogenic pathologies. It is characterized by severe dyspnea, respiratory distress, and difficult-to-treat hypoxemia. Generalized pulmonary edema is formed between the transparent membrane of the lung and the pulmonary interstitial fibrosis, which occurs in the later stage of the increase of the permeability of the pulmonary microvessels, thickening of the pulmonary interstitial edema, and exudation of protein-rich fluid in the alveoli.
- Pulmonary amniotic fluid embolism
  During the last stage of childbirth, women may suffer from dyspnea, cyanosis, convulsions, shock, and coma when amniotic fluid accidentally enters the bloodstream. Amniotic fluid moves into the veins and returns to the pulmonary artery causing embolism of pulmonary arterioles and capillaries, which causes severe hypoxia. Heterogeneous proteins can cause allergic reactions and even shock because of the systematic spasm of small blood vessels.
- Pulmonary alveolar proteinosis (PAP)
  Alveoli and bronchioles are filled with positive staining PAS and granular protein substances. These particles influence the ability of bronchial ventilation and alveolar air exchange, leading to progressive dyspnea.
- Pneumoconiosis
  A diffuse lesion of the lungs can be caused by the inhalation of harmful dust. Dust inhalation is responsible for pulmonary fibrosis and pneumoconiosis, which affect the respiratory function of the lungs and cause dyspnea.

(c) Pleural diseases
Various diseases may oppress lung tissues, inhibit respiratory function, and result in dyspnea, such as spontaneous pneumothorax, massive pleural effusion, and severe pleural thickness.

(d) Mediastinal lesions
Mediastinal lesions may also cause dyspnea when the lesions compress the trachea.

- Acute mediastinitis
  Acute mediastinitis usually occurs from a pyogenic infection. It is characterized by hyperpyrexia, chills, and retrosternal pain aggravated by swallowing and deep breathing. The lesions are mostly in the upper mediastinum. Anterior neck swelling, pain, and tenderness often occur. If inflammation occurs on the esophageal or tracheal perforation at the same time, it can result in mediastinal and subcutaneous emphysema and even dyspnea.
- Chronic fibrosing mediastinitis
  Chronic fibrosing mediastinitis, mostly secondary to suppurative or tuberculous mediastinitis, is also found in fungal or syphilitic infections. Long-term chronic inflammation of the mediastinum often leads to scar contraction and abnormal growth of fibrous tissues. It can lead to symptoms such as trachea and bronchus compression symptoms, shortness of breath, and breathing difficulties. Furthermore, it can also lead to the oppression of the superior vena cava, compression of the recurrent laryngeal nerve, and compression of the esophagus.
- Pneumomediastinum
  Severe pneumomediastinum may cause dyspnea, cyanosis, and tachycardia. Subcutaneous emphysema can be found in the neck, back, and anterior part of the chest. During palpation of the patient, the skin can feel like “rice krispies”. Pneumomediastinum is most commonly caused by the spread of air from the mediastinum to the surrounding organs under the tracheobronchial rupture, to adjacent organs through an open wound in the neck, from the inter-

stitial lung to the pulmonary vein and the mediastinum in alveolar rupture, and air in the abdominal cavity entering the mediastinum via the abdominal aorta and para-esophageal tissues.

- Mediastinal tumor and cyst
  When the volume of a mediastinal tumor and cyst, such as thymoma, retrosternal goiter, teratoma, bronchial cyst, pericardial cyst, and neurogenic tumor, has reached a certain amount, the tumor/cyst will push the trachea and bronchus, and result in various degrees of dyspnea.

(e) Thoracic and respiratory muscle lesions
Thoracic motion abnormalities, respiratory muscle paralysis, and diaphragmatic paralysis decrease the effective respiratory area, leading to dyspnea. Severe thoracic deformity, nerve root inflammation, and myasthenia gravis may limit thoracic movement and cause dyspnea.

2. Cardiogenic dyspnea
Dyspnea is one of the most important symptoms of heart failure. Dyspnea and orthopnea are caused by left ventricular dysfunction, pulmonary congestion, alveolar gas exchange dysfunction, hypoxia, or the retention of carbon dioxide.

(a) Congestive heart failure
Dyspnea is the main clinical manifestation of congestive heart failure and is the earliest subjective symptom of heart failure.

- Acute left ventricle heart failure
  The main symptom of acute left ventricle heart failure is paroxysmal dyspnea (cardiac asthma), resulting from pulmonary congestion or edema, especially during sleep. It is as fatal as hypoxia and dyspnea and it should be dealt with as early as possible.
- Chronic left ventricle heart failure
  The main symptoms include dyspnea, orthopnea, and pink bubble phlegm. It is common in hypertensive heart disease, valvular heart disease, and coronary heart disease.
- Acute right ventricle heart failure
  The main symptoms are sudden dyspnea, cyanosis, tachycardia, venous hypertension, and hepatomegaly. The most frequent symptoms are acute pulmonary embolism, acute pulmonary heart disease, acute rheumatic heart disease, toxic myocarditis, and aortic sinus aneurysm rupture into the right ventricle. In severe cases, such as massive pulmonary embolism and sudden dyspnea, shock may occur rapidly. Emergency managements like mechanical ventilation are indispensable for cardiopulmonary function and life support following apnea and cardiac arrest.
- Chronic right ventricle heart failure
  The clinical manifestation of this type of heart failure (chronic congestion syndrome of systematic circulation) includes jugular venous distention, palpitation, accelerated breathing, edema, hydrothorax, and ascites. Dyspnea is less severe in this case.

(b) Pericardial effusion
Acute and chronic pericarditis results in extensive pericardial effusion, which may oppress the bronchus and lung tissues and bring about dyspnea. The limitation of respiratory movement and dyspnea may be caused by massive pleural effusion, hepatomegaly, and massive ascites.

3. Toxic dyspnea
Toxic dyspnea can be classified into endogenous and exogenous toxicity.

(a) Acidosis
Metabolic acidosis in multiple diseases such as uremia and diabetic ketoacidosis increases the concentration of carbon dioxide in blood and decreases the pH value. In the respiratory center, the chemoreceptors located around the carotid sinus and aorta are stimulated and ventilation is increased. Extensive pulmonary lesions cause shallow dyspnea with cyanosis.

(b) Chemical toxicity
Chemicals interacting with hemoglobin may inhibit erythrocytes from carrying

oxygen. This systemic hypoxia causes dyspnea to develop further.

- Carbon monoxide poisoning
  Carbon monoxide (CO) toxicity is caused by inhalation of excessive CO. Medium CO toxicity occurs when the concentration of blood carboxyhemoglobin (COHb) reaches 30–40%, and the clinical symptoms include chest tightness, shortness of breath, dyspnea, and unconsciousness. The symptoms of severe CO poisoning (COHb concentration of 40–60%) consist of sudden coma, respiratory depression, pulmonary edema, arrhythmia, and heart failure. Aspiration of vomit in unconscious patients will result in aspiration pneumonia and this can exacerbate dyspnea and pulmonary edema.
- Cyanide toxicity
  The normal cellular respiratory process is affected when cyanide ions combine with iron ions in cytochrome oxidase (Cox), and this causes hypoxia and even severe dyspnea. Cyanide toxicity may be caused by improper treatment or excessive consumption of cassava and bitter almonds, which contain cyanide. In addition, inhalation of steam or dust from electroplating, smelting, or cyanide production can also lead to cyanide poisoning.
- Nitrite and aniline toxicity
  These substances are able to convert hemoglobin into methemoglobin by transforming ferrous iron molecules in hemoglobin into ferric iron molecules. Consequently, hemoglobin loses the ability to combine with oxygen, resulting in hypoxia. Methemoglobin may result in cyanosis, hypoxia, and even dyspnea. Nitrite and aniline toxicity may also result from consumption of excessive nitrite in vegetables or inhalation of aniline during chemical production.

(c) Drug intoxication
Many drugs, such as morphine and barbiturate, inhibit the central nervous system. Abuse or aspiration of these drugs can inhibit the respiratory center and lead to dyspnea with slow and shallow breathing.

(d) Toxemia
The high fever seen in toxemia is caused by acute infection of the blood with toxic metabolites. This fever stimulates the respiratory center so that the patient breathes rapidly.

4. Hematogenic dyspnea
   (a) Severe anemia
   As measured by the hemoglobin (Hb) concentration, anemia is classified as mild (above 90 g/L of Hb), moderate (60–89 g/L of Hb), severe (30–59 g/L of Hb), or extreme severe (below 30 g/L of Hb). Erythrocytes synthesize more compensatory 2,3-diphosphoglycerate to promote oxygen decomposition of Hb [3]. The curve of hemoglobin oxygen dissociation shifts to the right, which means it provides more oxygen for tissues and alleviates hypoxia in mild anemia. In mild and moderate anemia, accelerated breathing and palpitation may occur during ordinary activities. Exacerbated anemia and increased activities may result in more obvious dyspnea and palpitation. Tachypnea and orthopnea may occur at rest in severe anemia. Patients with severe anemia may be breathless even in a calm state.

   (b) Massive blood loss
   Hemorrhaging may be caused by the rupture of large vessels or internal organs. When rapid blood loss of more than 20% of the total blood volume occurs, hemorrhagic shock may occur. The developing symptoms include dyspnea, tachycardia, and clammy skin.

5. Neuropsychiatric dyspnea
   (a) Severe brain disorders
   The respiratory center may be directly involved in severe brain diseases (encephalitis, stoke, tumor, etc.), which causes dyspnea and abnormal respiratory rhythm. Severe brain disorders are usually accompanied by disturbance of consciousness or

coma and respiratory arrest may occur during the process.

(b) Central neurogenic hyperventilation
The injury of the lower midbrain or upper pontine may lead to tachypnea (respiratory rate over 100 breaths per minute). The situation is too severe to be alleviated with pure oxygen inhalation and, as a result, respiratory acidosis occurs. The patients are usually in a stuporous or comatose state.

(c) Hysterical dyspnea
Patients with hysteria may exhibit paroxysmal dyspnea as shown by rapid (80–100 breaths per minute) and shallow breathing. Hyperventilation may cause chest pains and respiratory alkalosis, with tetany. The disorder can be diagnosed based on patient history and is treated with psychotherapy.

(d) Myasthenic crisis
Myasthenic crisis is more common in female patients around 30 years old or male patients aged 50–60 years. It is caused by upper respiratory infection, pneumonia, stress from miscarriage or delivery, thymus surgery, thymus radiation therapy, extensive intake of steroids or barbiturates, or withdrawal of anticholinesterase drugs. It is an extreme form of dyspnea in myasthenia gravis patients incapable of independent autonomous respiration, and emergency mechanically-assisted ventilation is necessary.

2.1.1.3 Further Classification of Dyspnea

Dyspnea is a type of clinical symptom that includes both mild symptoms affecting daily life and severe cases threatening life. There are many ways to classify it, for example, inspiratory, expiratory, and mixed dyspnea according to the stage of occurrence, and slow or rapid dyspnea according to the respiratory rate. Based on the mechanism involved, it can be classified into pulmonary, cardiogenic, hematogenic, neurogenic, and toxic dyspnea [4, 5]. Until now, there has been no dyspnea classification standard based on categories, diagnosis, and prognosis because the majority of clinicians do not understand the high incidence and mortality of this disease.

1. Severity classification of dyspnea
Dr. Xinwei Han recommends categorizing dyspnea into mild, moderate, and severe dyspnea based on clinical manifestation and life-threatening degree.
   (a) Mild dyspnea
   Mild dyspnea affects ordinary work and the daily activities of patients, with the patient incapable of running, walking fast, or performing physical labor.
   Mild dyspnea is relieved through terminating physical activities and resting peacefully in a sitting or recumbent position. Special medical intervention is usually not necessary.
   (b) Moderate dyspnea
   The patient is not able to rest normally, including during both ordinary activities and resting peacefully. Dyspnea occurs at rest in sitting or recumbent positions for patients who have previously had to give up physical labor and most daily activities. Medical care is required for these patients. They cannot maintain a normal living and resting status.
   (c) Severe dyspnea
   The patient has a feeling of impending death and is unable to undertake ordinary working and living activities or to rest in sitting or recumbent positions. The patient is in a state of near-death. Medical treatments, such as hyperbaric oxygen therapy, administration of expectorants, edema relief, antisepsis, and anti-inflammation are applied to prevent respiratory arrest.
2. Scoring system of breathlessness from American Thoracic society (ATS) (five degrees and four grades)
   0: no breathlessness (dyspnea) in any activities.
   I: breathlessness (dyspnea) on fast walking.
   II: breathlessness (dyspnea) when walking at a normal pace.

III: severe breathlessness (dyspnea) when walking at a normal pace and forced to stop for breath.
IV: breathlessness (dyspnea) on any slight physical activity.
Breathlessness, also termed accelerated breathing or polypnea, is similar to shortness of breath. It refers to all kinds of breathing difficulties, such as rapid breathing frequency, shortness of breath, and shallow breathing. Although the concept of breathlessness is not exactly the same as dyspnea, it is seen as equivalent to dyspnea.
Grade 0 (normal people without any symptoms of dyspnea) is defined according to the scoring system of breathlessness from the ATS. Dyspnea related to normal activities is determined as mild dyspnea and classified into four grades. This is the five degrees and four grades classification system. Dyspnea of the above four grades may affect the normal daily life and working status of patients, and represents mild dyspnea and is not fatal. However, ATS scoring includes mild dyspnea, without including moderate and severe dyspnea at rest, and the latter is more life-threatening. It is necessary for patients to receive emergency medical care to recover normal respiratory status when severe dyspnea occurs.

3. Han's scoring system of dyspnea (eight degrees and seven grades)
Dr. Xinwei Han supplements the ATS classification system of breathlessness (five degrees and four grades: 0, I, II, III, IV) in a detailed assessment of moderate and severe dyspnea. Han's scoring system classifies large airway stenosis dyspnea into eight degrees and seven grades (an additional V, VI, and VII). Han's classifications of eight degrees are as follows:
0: no breathlessness (dyspnea) in any activities.
I: dyspnea on fast walking.
II: dyspnea when walking at a normal pace.
III: severe dyspnea when walking at a normal pace and forced to stop for breath.
IV: dyspnea with any slight physical activity.
V: dyspnea at rest in a recumbent position.
VI: dyspnea at rest in a sitting position (orthopnea).
VII: dyspnea at rest in a sitting position, and, even with oxygen administration, the patient experiences a feeling of impending death.
This novel dyspnea scoring system of eight degrees and seven grades developed by Dr. Xinwei Han is applicable for assessing pulmonary dyspnea, especially large airway stenosis dyspnea. Grades 0–IV are consistent with the ATS scoring system classifying mild dyspnea that affects everyday life. Grades V–VI are a supplement of moderate dyspnea that impacts the normal resting status. Grade VII further completes the scale with an additional severe dyspnea classification that threatens life in all cases.
Grade 0: natural status of daily life, free to perform any activity and exercise. Even though dyspnea may occur with strenuous exercise, the patient will recover after a short rest and no medical care is required.
Grade I: dyspnea occurs when walking fast. The patient is unable to take part in strenuous exercise due to limited respiratory dysfunction. However, they can complete mild daily activities.
Grade II: dyspnea occurs when walking at a normal pace. Patients with Grade II experience dyspnea during basic daily activities like walking. The patients are still able to tolerate this condition although they may feel tired.
Grade III: severe dyspnea occurs when walking at a normal pace and the patient is forced to stop for breath. The patient recovers to a normal state after rest. Patients are unable to care for themselves as they cannot perform normal daily activities.
Grade IV: any slight physical activity results in dyspnea. Patients cannot survive without assistance, because they are unable to complete basic daily activities. Medical care is required in the presence of weather change, air pollution, and inflammation.
Grade V: dyspnea occurs at rest in recumbent positions, while the patient recovers to breathe normally at rest in a sitting position. Patients

lose the ability to undertake daily activities, and rest in a recumbent position. Recumbent resting may be sustained with oxygen inhalation, otherwise, orthopnea will occur. Patients are only able to maintain basic daily life and rest in a recumbent position with medical intervention such as oxygen inhalation and administration of expectorants and anti-inflammatory drugs.

Grade VI: dyspnea occurs at rest in a sitting position (orthopnea). Even though patients are constrained to breathe in the sitting position, they still need to receive a continuous high level of oxygen to maintain natural breathing status. They cannot retain the natural status in a recumbent position. This results in respiratory failure and a variety of conditions, such as dys-expectoration, sputum obstruction, pulmonary inflammation, and physical fatigue. Emergency medical treatment is necessary.

Grade VII: dyspnea occurs in the sitting position at rest, even with oxygen administration, and the patient has a feeling of impending death. Patients lose the ability for a normal daily life, activities, and natural rest. They are often unconscious and forced into sitting positions. Dyspnea and the feeling of impending death still exist, even with continuous high-flux inhalation of oxygen. Patients can barely survive and respiratory failure is likely to occur at any time. Emergency medical care is required.

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3 Common Imaging Signs of Tracheal and Bronchial Diseases

Peijie Lv and Xinwei Han

3.1 Tracheobronchial Disease

3.1.1 Emphysema

Emphysema, a condition in which the lung tissue is inflated with excessive gas, can be classified as obstructive emphysema (including localized obstructive and diffuse obstructive emphysema), compensatory emphysema and interstitial emphysema [1].

Because of the valve effect with stenosis of the trachea and bronchus in incomplete tracheal or bronchial obstruction, the airway lumen expands slightly, and air enters smoothly through the incompletely obstructed airways into the alveoli during inspiration. In contrast, the airway lumen narrows slightly during expiration, and it is more difficult for air to be exhaled through the narrow airway, so more air accumulates in the lungs. The accumulation of air causes emphysema through the repeated valve effect in the trachea and bronchi of the pulmonary segment, pulmonary lobe, one lateral lung, or bilateral lung.

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If the alveoli are excessively inflated and the alveolar wall of the capillary bed is compressed, then blood supply disorders, infections, and complications can occur. Following this, the alveolar wall can rupture and fuse. Consequently, oxygenation is inadequate in the bullae of the lung (Fig. 3.1).

3.1.1.1 Obstructive Emphysema

Obstructive emphysema, caused by the obstruction of the trachea or bronchi with a foreign body, is a local emphysema of the bilateral lung, one lateral lung and one lobe, or one segment of the lung. Chest radiographs or computed tomography (CT) images show an increased radiolucency of the lungs, flattened hemidiaphragm, and local reduced lung markings. A multi-slice CT (MSCT) scan shows the area of tracheobronchial stenosis and the primary lesion and allows for diameter measurement and three-dimensional reconstruction of the trachea and bronchus. This provides adequate data for interventional radiology of stents for tracheobronchial stenosis (Fig. 3.2; informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study).

Causes of obstructive emphysema are as follows:

1. Large airway stenosis: This includes obstruction of the larynx, trachea, carina,

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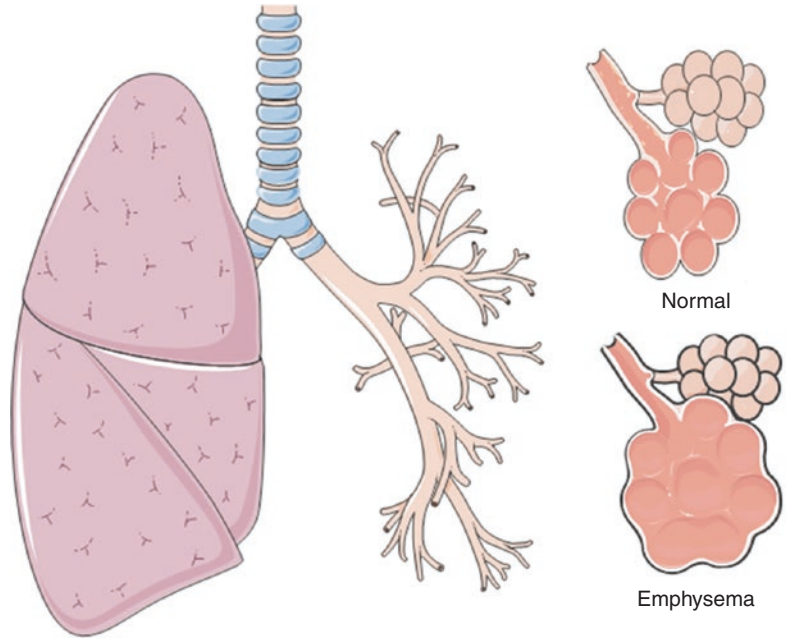

Fig. 3.1 Schematic representation of emphysema and bullae

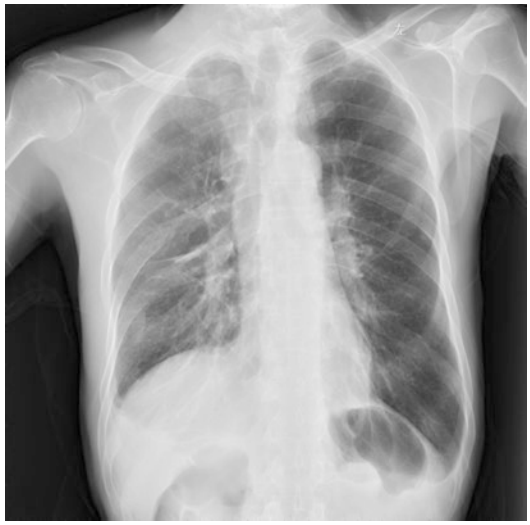

Fig. 3.2 X-ray image of unilateral emphysema

main bronchus, lobar bronchus, or segmental bronchus. Large airway stenosis can occur with factors including tumor, foreign matter, tracheobronchial malacia, tracheobronchial cicatrices, vascular ring, tracheobronchomegaly, and scabbard trachea. As a result, these factors result in intracavity stenosis intracavity, compression of the extra cavity, intracavity foreign body stenosis, hyperplasia of cicatrices stenosis, or malacia and collapsing stenosis of annular cartilage.

2. Pulmonary disease: This condition results from bullous emphysema, kyphosis or scoliosis deformity, cystic fibrosis, repetitive excessive inhalation (for example, in a trumpeter), unilateral pulmonary artery occlusion, and unilateral hyperlucent lung syndrome.

3.1.1.2 Chronic Diffuse Obstructive Emphysema

The diffused obstruction of the bronchioles results in chronic diffuse obstructive emphysema. Due to inflammation and convulsion of the terminal bronchioles of bilateral lungs, diffuse emphysema causes a valve effect. Chest radiographs or CT images show an increased radiolucency of the lung tissues, reduced and thinner lung markings, disappearance of lung markings in the middle and outer part, thickening of lung markings near the hilum, increased anteroposterior diameter of the chest, long and narrow heart shadow, decreased left and right diameter of the trachea, and increased anteroposterior diameter, leading to scabbard trachea.

3.1.1.3 Compensatory Emphysema

Compensatory emphysema is local non-obstructive emphysema, which is caused by fibrosis or atelectasis in part of the lung tissue or increased chest cavity volume after surgical resection. The remaining lung tissue expands excessively to compensate for the lost volume of lung tissue. This increases chest pressure, which results in excessive expansion of lung tissue, mainly by alveolar enlargement, if the alveolar wall structure is intact.

The range and extent of compensatory emphysema relies on the extent of resection or atrophy of the lung. Lateral complete pulmonary inflation may bring about a mediastinal hernia. CT scans will show increased radiolucency of the lung tissue in emphysema and reduced lung markings, which makes it easy to differentiate from normal lung tissue (Fig. 3.3).

3.1.1.4 Interstitial Emphysema

Severe coughing or irritable coughing can rupture the bronchi or alveoli. This causes air to enter the pulmonary interstitium from the main bronchi and alveoli, which causes interstitial emphysema. The air in the pulmonary interstitium can enter the mediastinum through the hilum along the peribronchial perivascular spaces, and leads to mediastinal air accumulation. Finally, the air moves along the vessels and reaches the pericardium, inducing pneumopericardium. Mediastinal accumulation can extend to the subcutaneous margin above the sternal notch, followed by subcutaneous accumulation and accumulation in the neck, chest, back, arms, and torso. This condition is life-threatening when severe mediastinal and pericardial accumulation causes compression of airways or large vessels. Severe coughing or severe obstruction of the airways can rupture the trachea or main bronchus, which causes air to enter the mediastinum and spread into the chest and dorsal soft tissue, resulting in extensive mediastinal or subcutaneous accumulation or subcutaneous emphysema. This condition can also be caused by chest puncture, tracheotomy, thyroid surgery, thoracic trauma, and airway stent implantation and removal.

It is easy to diagnose the local swelling that occurs rapidly following subcutaneous accumulation as palpated skin feels like “holding snow”. The chest X-rays and CT images show a unique phenomenon of multiple, banded, air-like, low-density subcutaneous and muscular tissue (Fig. 3.4).

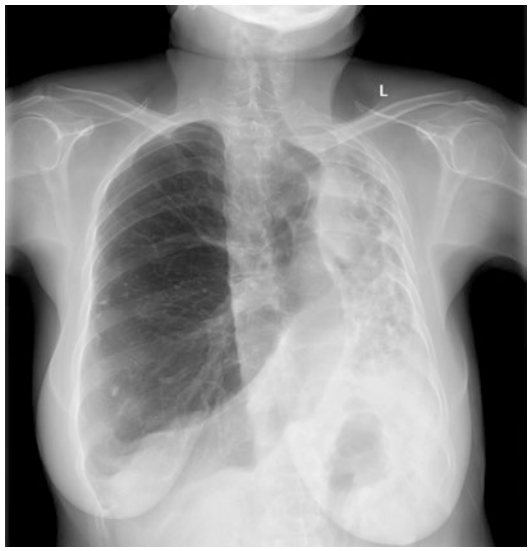

Fig. 3.3 X-ray image of compensatory emphysema

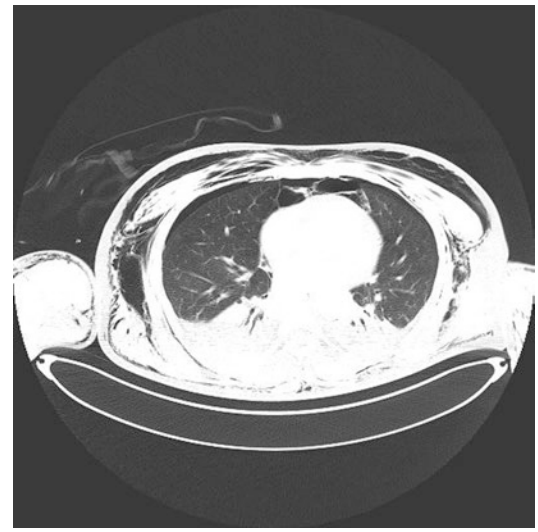

Fig. 3.4 CT image of interstitial emphysema

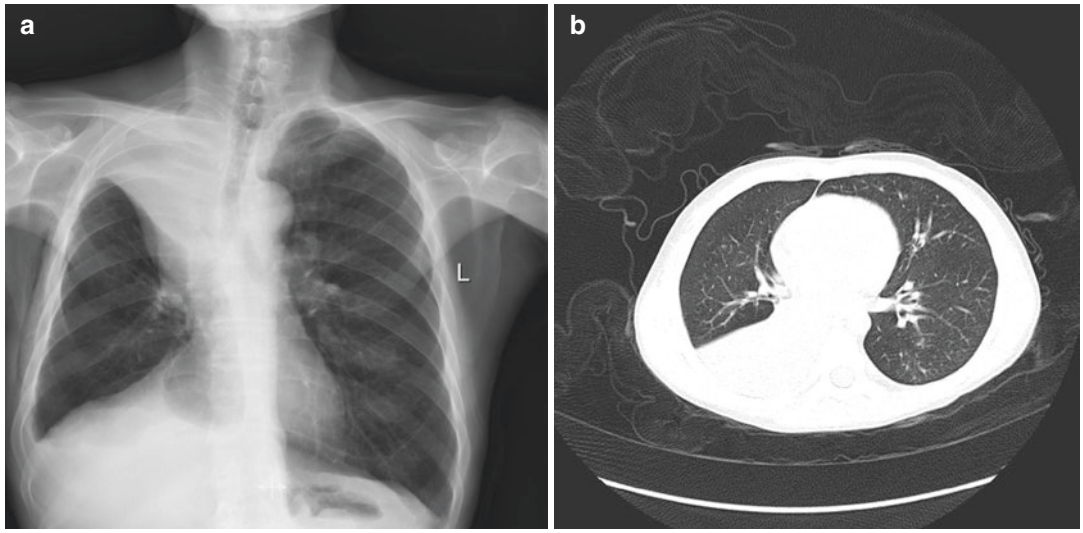

Fig. 3.5 Images of atelectasis; chest X-ray (**a**) and chest CT image (**b**)

3.1.2 Atelectasis

Atelectasis is the loss of lung volume that is induced by the partial or complete absence of air in the lung tissue. Atelectasis has many causes, which include bronchial obstruction, extrapulmonary compression, respiratory weakness, or partial restriction of respiration.

Chest X-rays and MSCT images show the higher density and lower volume of the pulmonary segment, pulmonary lobe, or one lateral lung in the pulmonary zone. The CT axial images show the presence of an air bronchogram, endobronchial air, and that the mediastinum or diaphragm is displaced by atelectasis (Fig. 3.5).

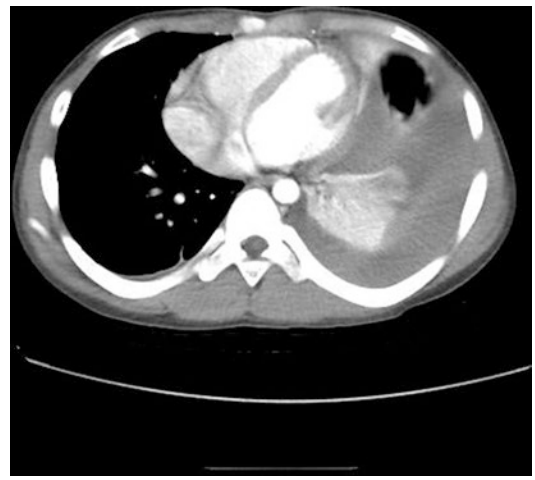

Fig. 3.6 Obstructive atelectasis with complete structure on CT image

3.1.2.1 Obstructive Atelectasis

Obstructive atelectasis is a form of lung collapse due to obstruction of the airways. After 18–24 h of obstruction, the alveolar gas is absorbed by blood circulation, a certain amount of exudate is formed in the alveoli, and the density of the lung tissue increases. This leads to consolidation due to atrophy of lung tissue and collapse of alveolar structure. At this moment, interventional radiology, such as tracheobronchial or endobronchial stents, may be applied for treatment.

In acute obstructive atelectasis, absorption of alveolar gas may induce the compensatory dilation of capillary beds and arterioles in the interstitium of the lung. Obvious and homogeneous enhancement can be seen in the arterial phase of chest-enhanced MSCT scans [2], which indicates the integrity of the lung tissue. Atelectasis of the lung tissue can be reversed when the obstruction in the bronchus is removed (Fig. 3.6).

In chronic obstructive atelectasis, the causes of pulmonary fibrosis and permanent atrophy include destruction of alveolar tissue,

interstitial structure, and pulmonary capillary bed. Heterogeneous enhancement is shown on enhanced CT images. The lung tissue may not recover from this condition even with removal of the obstruction (Fig. 3.7).

The clinical manifestations of pulmonary atelectasis depend on the type of atelectasis, such as lobar atelectasis, multilobed atelectasis, and pulmonary atelectasis. It is often accidentally observed in a chest X-ray or CT examination. In acute atelectasis, if a large airway (for example, one lateral main bronchus) is blocked, it results in a large area of atelectasis and hypoxia, which causes chest tightness, shortness of breath, dyspnea, cyanosis, tachycardia, and other symptoms. As a result, severe respiratory disease or pulmonary circulatory system failure may eventuate. The symptoms are significantly decreased with prompt treatment by opening the narrow/blocked bronchi.

It is helpful to study the structural integrity of atelectasis by chest CT scan and evaluate the possibility of lung tissue expansion after removing the bronchial obstruction. The bronchial obstruction should be removed as early as possible to save lung tissue. After removal, the structure of lung tissue is normal with significant improvement in the arterial phase. If there is no enhancement or heterogeneous enhancement, this indicates destruction of lung tissue and there is no need to open the obstructed bronchi.

CT scans show the location and extent of a tracheobronchial obstruction, and are useful for the measurement of the diameter and length of the trachea and bronchus. It is useful to make a customized internal endotracheal stent and to implant the stent to relieve stenosis and obstruction. The obstruction is usually in the main bronchi, bronchi, or segmental bronchi, and examples of obstructions include tumors, foreign bodies, scars, cartilage degeneration or trauma, and bronchial rupture.

A disease leading to pulmonary consolidation is different from obstructive atelectasis. Obstructive atelectasis mainly includes aspiration pneumonia, lung contusion, lobar pneumonia, pulmonary embolism, pulmonary abscess, stomach acid-corrosive pneumonia, eosinophilic pneumonia, radioactive pneumonia, torsion of the lung in children, and pulmonary fibrosis.

3.1.2.2 Compressive Atelectasis

In this condition, there is a large amount of effusion, pneumatosis, or larger masses on the same side as the chest lesion. This compresses adjacent pulmonary segments, lobes, or one lateral lung. Partial atelectasis, also termed both incomplete atelectasis and part atelectasis, is the most common type of compressive atelectasis [3]. A chest X-ray or CT scan clearly shows atelectasis caused by spontaneous pneumothorax or artificial pneumothorax. It is difficult to diagnose atelectasis because of compression of pleural effusion or mass on conventional X-rays; however, it is easy to diagnose on CT images (Fig. 3.8).

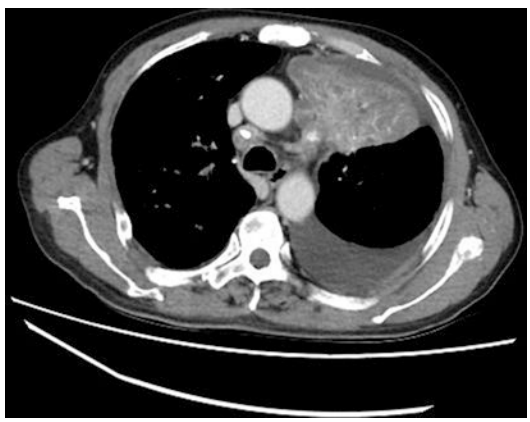

Fig. 3.7 Obstructive atelectasis with incomplete structure on CT image

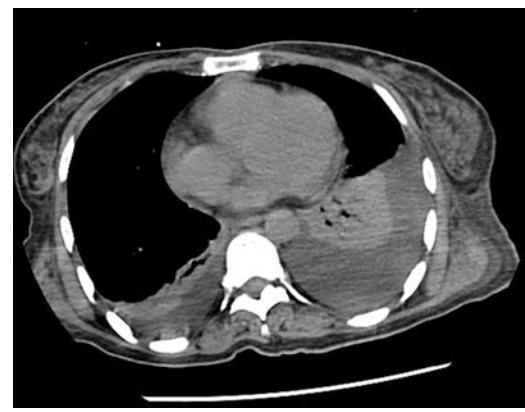

Fig. 3.8 Compressive atelectasis on a CT scan

Higher abdominal pressure affects diaphragmatic movement, which results in obvious upward displacement of the hemidiaphragm and compression of the lung bases. This abdominal pressure can have various causes, such as massive ascites or diaphragmatic lesions, hepatic interventional embolization, and partial splenic embolization treatment. The tissue of the lung bases is poorly aerated so a partial atelectasis is formed, mostly manifesting as plate-like atelectasis. The CT scan shows local and partial atelectasis in adjacent diaphragmatic areas, for which patients usually show no characteristic symptoms, and it sometimes can be combined with infection.

3.1.2.3 Passive Atelectasis

Passive atelectasis is often caused by severe pleural thickening, chest wall fixation, or a loss of elasticity of lung tissue with respiratory restriction. Partial atelectasis results in a decreased volume of air entering the lung and subsequent incomplete expansion. Common causes of incomplete expansion are pleurisy with massive pleural effusion, thoracic trauma, and hemothorax. Incomplete pulmonary expansion may cause massive pleural effusion and fibrous tissue hyperplasia, pleural thickening, and collapse of the chest wall, and can induce chronic atrophy or swelling of the lung tissue. Chest X-ray and CT scans show pleural thickening, chest collapse, and incomplete pulmonary expansion, which manifest in a higher lung density and an increased number of lung markings.

3.1.2.4 Atelectasis Neonatorum

This condition is mainly seen in newborns. Some alveoli are not inflated in normal fetuses, and breath amplitude increases gradually to a normal state a few days after birth. If the respiratory system of a newborn is weak (for example, preterm infants), the alveoli are not able to inflate properly, resulting in atelectasis neonatorum. This condition represents as lobular atelectasis involving the pulmonary lobes of the bilateral lung, rendering as a diffusely distributed, miliary and granulated shadow in the bilateral lung field. The dense lesions have a ground-glass density with air bronchograms inside.

Atelectasis neonatorum is different to miliary pneumonia and miliary pulmonary hemorrhage, which rarely exhibit air bronchograms.

3.1.3 Tracheobronchial Stenosis

When the lumen narrows continuously beyond normal limits, this is termed luminal stenosis; conversely, when the lumen exceeds the normal limit, this is defined as luminal dilatation. There is great variability and compensation in the diameter of human physiological cavities. The diameter of different parts of the bronchus differs greatly depending on location along the bronchus.

3.1.3.1 The Diameters of Normal Tracheobronchial Branches

The diameters of normal tracheobronchial branches are mostly derived from autopsy data. Compared with in vivo data, data from cadavers are insufficient. Human physiological organs are vastly different to standardized machine equipment. All parts of modern mechanical equipment are constant standard parts; however, human organs are very different. The lumen diameter of the trachea and bronchi in vivo is different in different people and different breathing states; therefore, measurement of the diameter of the trachea and bronchus should be on an individual basis.

1. Tracheal Diameter
   The length of the trachea in males is 103 ± 8.9 mm and in females 97.1 ± 6.6 mm. Most tracheas are “C” shaped, horseshoe shaped, or “U” shaped. The transverse diameter of the lumen is 16.5 mm in males and 13.6 mm in females. The sagittal diameter of the cavity is 15 mm in males and 12.6 mm in females. Anatomical diameter measurements are lower than in vivo CT measurements.
2. Left Main Bronchial Line
   The length of the left main bronchial line in males is 48 ± 4.8 mm and in females 45 ± 5.5

mm; The transverse diameter is 11.2 mm in males and 9.3 mm in females. The sagittal diameter is 9.3 mm in males and 7.5 mm in females.

3. Right Main Bronchial Line
   The length of the right main bronchial line in males is 21 ± 4.8 mm and in females is 19 ± 3.2 mm. The transverse diameter is 15.1 mm in males and 13.1 mm in females. The sagittal diameter is 14.1 mm in males and 9.3 mm in females.
4. Inclination of the Main Bronchus
   The inclination of the left main bronchus (with an angle between the midline) is 44.7° ± 8.7°for males and 43.0° ± 7.8°for females; and for the right main bronchus, 34.8° ± 8.1°for males and 36.2° ± 4.6°for females.
5. Main Bronchus Angle
   The left and right main bronchus angle in males is 79.5° ± 13.6° and 79.2° ± 9.7° in females.

3.1.3.2 Stricture of the Trachea and Bronchus

If a patient has tracheal bronchial stenosis, the ventilatory function of breath is affected and the following symptoms can occur: dyspnea, cyanosis, or arrhythmia, with severely affected patients in danger of suffocating. Obstructive emphysema, obstructive pneumonia, or obstructive pulmonary disease can occur with bronchial occlusion. Tracheal bronchial stenosis can lead to shortness of breath or breathing difficulties.

1. Tracheobronchial Stenosis
   Various types of tumors such as adenoma, adenocarcinoma, and squamous cell carcinoma in the respiratory tract grow in the lumen of the airway spaces and fill the airway directly, resulting in airway stenosis. On the X-ray, it is difficult to detect, but the soft tissue mass of the trachea and bronchial lumen are easily detectable on CT examination, with the lumen being very narrow (Fig. 3.9). Various interstitial tumors of the respiratory tract, such as smooth muscle tumors, can grow inside the lumen and fill the lumen, resulting in tracheobronchial stenosis. The CT scan shows that the tracheobronchial wall is thickened, the lumen oddly-shaped and narrow, and the lumen of the trachea is in a crevice (Fig. 3.10).

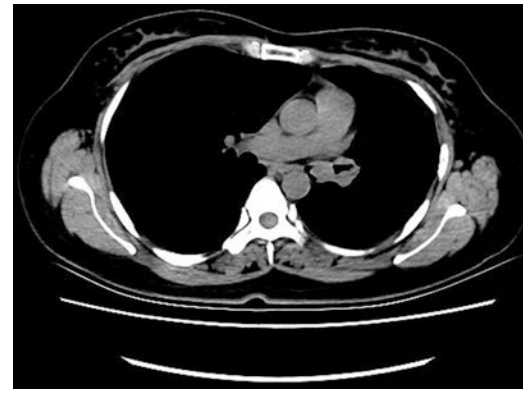

Fig. 3.9 Thoracic CT image shows an intraluminal tumor occupying the airways and narrowing the lumen

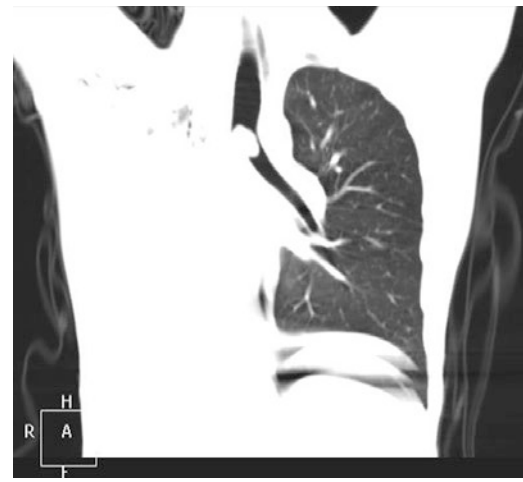

Fig. 3.10 Thoracic CT image shows thickening of the trachea wall and eccentric stenosis of the trachea lumen

The most common cause of tracheobronchial stenosis is the external pressure caused by compression by adjacent tumors (thyroid, thymic, and esophageal tumors) or metastases (lung and esophageal cancer). The mediastinal lymph node distribution is the area with the most lymph nodes, and it is at the lower end of the tracheal carina and main bronchus, spreading left and right around the opening. Lung cancer, esophageal carcinoma, thymic

carcinoma, and cardiac and gastric cancer occur after mediastinal lymph node metastasis, and are often concentrated in the area of the three forks of the trachea, carina, and main bronchus, bilateral around the intersection. Mediastinal lymph node enlargement causes a direct compression of the trachea, carina, and main bronchus under section three, resulting in stenosis of the composite fork (Fig. 3.11), and the traditional treatment method is insufficient. The "Y"-shaped self-expandable metal stent implantation and interventional technology provide possible treatments for complex airway stenosis.

A large number of clinical observations found that patients with a certain degree of airway stenosis (e.g., 50%) can show no symptoms, especially with the slow appearance of airway stenosis. Therefore these patients are more tolerant of stenosis. For example, the two nostrils can be completely blocked, and there are no symptoms of acute respiratory distress or respiratory distress. Therefore, when there is a clinical observation of acute respiratory distress syndrome, the degree of severity of airway stenosis is already quite serious.

2. Cicatricial Stricture of the Trachea and Bronchus
   Respiratory tract injury, inflammation, and other secondary causes result in large amounts of fibrous connective tissue hyperplasia and scar tissue contraction, leading to tracheal or main bronchial lumen stenosis. This can be seen in the tracheotomy of patients with secondary fibrous connective tissue hyperplasia, long after tracheal intubation and/or intimal injury secondary to fibrous connective tissue hyperplasia, tracheal injury (such as hanging, burn), endometrial tuberculosis, or postoperative secondary fibrous connective tissue hyperplasia. There is a typical history of tracheobronchial inflammation or trauma, and the chest CT scan shows the narrow, irregular stenosis of the trachea or main bronchial tube, with or without the limitations of the tube wall (Fig. 3.12).
3. Chondrogenic Stenosis of Trachea and Bronchus
   Various causes lead to destruction of cricoid cartilage, which results in the collapse of the lumen and loss of the supporting cartilage ring. In some cases, there is also an excessive hyperplasia of fibrous connective tissue. Cartilaginous tracheobronchial stenosis is divided into localized stenosis and extensive stenosis. Localized stenosis can be caused by any of the following scenarios: tracheotomy method where multiple cartilaginous rings were cut; long-term endotracheal intubation with the air pressure too high for too long, causing local cartilage ring degeneration; trauma (such as hanging, burn injury) to cartilage rings; and radiotherapy cartilage

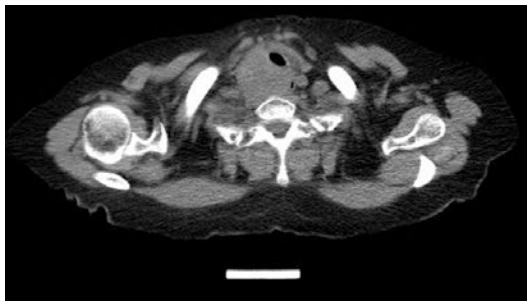

Fig. 3.11 Thoracic CT image shows the extensive mediastinal lymphadenopathy and invasion of the trachea

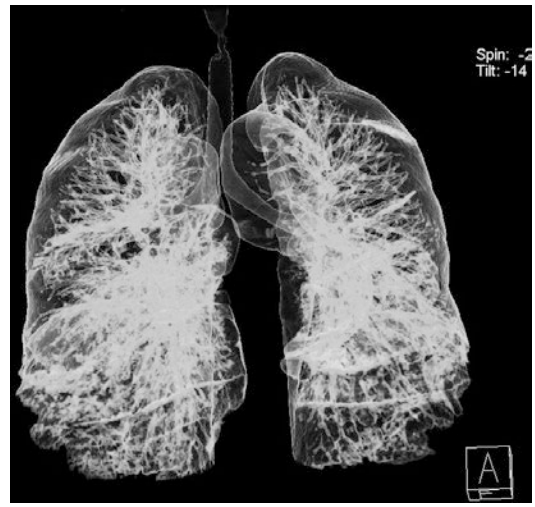

Fig. 3.12 Thoracic CT image shows tracheal scar stenosis

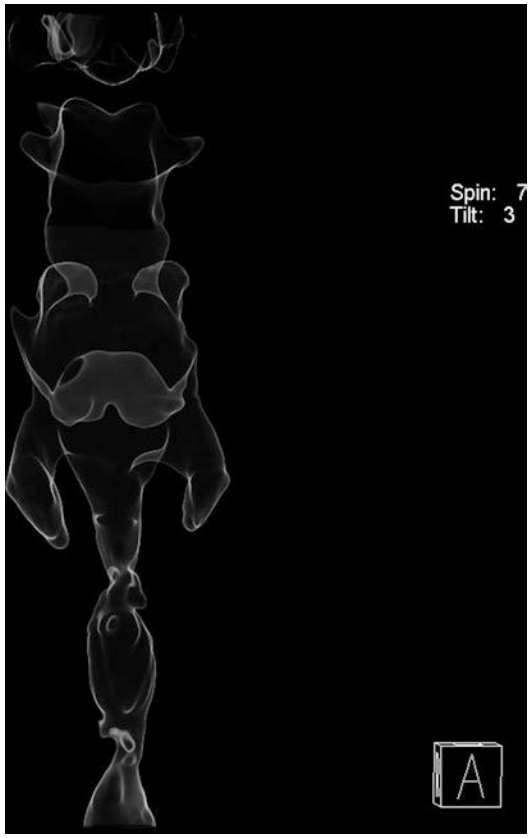

Fig. 3.13 Thoracic CT showing tracheobronchial cartilage stenosis

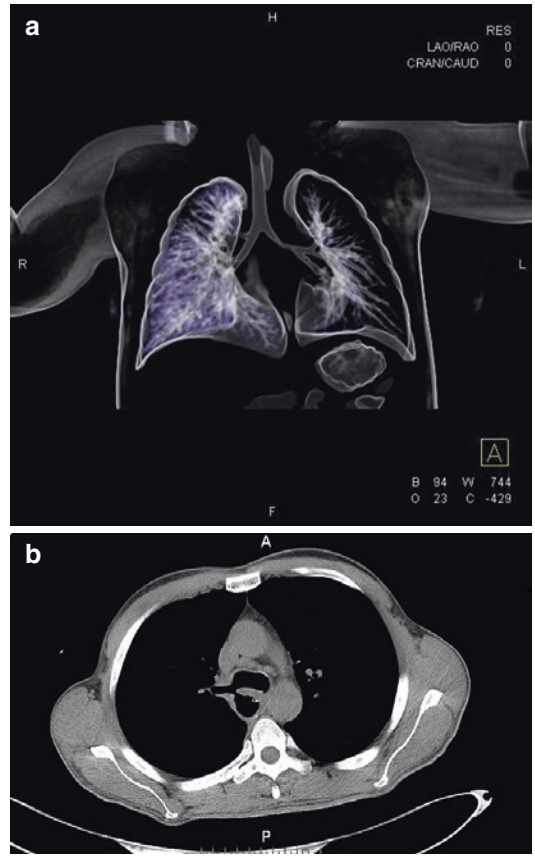

Fig. 3.14 (**a**) Thoracic CT image shows abnormal vascular compression of the trachea. (**b**) Thoracic CT image shows the esophageal-right main bronchial fistula

ring degeneration. Endobronchial tuberculosis, amyloidosis, recurrent polychondritis, and tracheopathia osteoplastica are examples of multiple tracheobronchial stenosis. The chest X-ray shows that the airway is as small as the bowel, and the CT scan shows airway deformation and stenosis (Fig. 3.13).

4. Bronchiolitis Stenosis
   Inflammation, such as purulent mediastinum inflammation and endometrial tuberculosis, leads to complete inflammatory edema of the trachea, bronchus, and intima or tube wall. The lumen is narrow and ventilation is difficult. After stent implantation, the local inflammatory response around the stent and the excessive proliferation of reactive endothelial cells lead to stenosis or restenosis of the lumen at both ends of the stent.
5. Congenital Stenosis of the Trachea
   Dysplasia is the localized stenosis of the trachea or bronchus. Severe airway stenosis is often fatal to newborns, therefore it is rare to see this condition in clinical practice. Airway stenosis may be associated with esophageal stenosis or esophageal airway fistula (Fig. 3.14).

3.1.4 Tracheobronchial Fistula

The wall of the trachea and bronchus ruptures and breaks through one or more channels to communicate with adjacent organs or surfaces to form a fistula. The fistula formation can cause bronchial secretions to overflow (pleural fistula, mediastinal fistula), pollution of adjacent organs

or skin damage, and the normal physiological function to be affected. This condition can also be caused by adjacent organs or secretions (esophageal, stomach) entering the endotracheobronchial system, which results in respiratory failure of the structure, the normal physiological function being affected, and the formation of a series of diseases.

The trachea and bronchus are special physiological channels with a specific negative pressure. This allows the throat, pharynx, and oral and nasal cavity to communicate with the outside environment. A tracheobronchial lumen communicates with the outside environment, but the mouth, epiglottis, vocal fold physiology, and ventricular fold can be closed, which forms a closed tracheal bronchus to maintain the necessary physiological pressure or positive pressure change. If a tracheobronchial fistula appears, it will communicate with the outside environment, then cause the necessary physiological negative and positive pressure to be lost, consequently affecting the normal breathing function, leading to breathing difficulties and possibly endangering the patient's life.

Types of Tracheobronchial Fistulae

1. Esophageal-Tracheal (bronchial) Fistula
   The esophagus is adjacent to the trachea, carina, and the left main bronchus. Esophageal lesions, especially esophageal cancer, can lead to the formation of a fistula between the esophagus, trachea, and bronchi. The mouth swallows saliva or food through the esophagus into the stomach, and if there is a tracheal-bronchial fistula , the esophageal contents pass through the fistula and can flow to the airway, causing an irritation cough, a series of other symptoms, and refractory lung infection.

   Advanced esophageal cancer can directly destroy the esophagus wall and form the fistula with the trachea and bronchial wall. The radiation treatment of esophageal cancer can cause damage to the wall of the esophagus, trachea, and bronchus. Arterial infusion chemotherapy of esophageal carcinoma can cause rapid tumor necrosis, and the normal tissue cannot repair as well as the fistula. The fistula can form when the tracheal and bronchial walls are damaged by surgery and other causes. The recurrence of cancer after esophageal cancer can destroy the tracheobronchial wall and result in a fistula. Improper stent insertion into the esophagus or trachea can form a secondary fistula. Endoscopic surgery can also form fistulas. The digital gastrointestinal dynamic contrast shows typical signs of contrast media passing through an esophageal fistula into the airways. Fiberoptic endoscopy (endoscopy or bronchoscope) and chest MSCT can directly reveal the fistula (Fig. 3.14a).
2. Trachea (Bronchus)-Mediastinum Fistula
   A severe cough, chest surgery, bronchoscopy, treatment of tracheobronchial stent implantation and removal, radiotherapy, and accident trauma can cause airway rupture, formation of trachea (carina, bronchus)-mediastinal fistula, serious mediastinal emphysema, mediastinitis, and mediastinal abscess. The different types of this condition are named according to the fistula site: tracheal carina mediastinal fistula, mediastinal fistula, left main bronchus mediastinal fistula, right main bronchus mediastinal fistula, and bronchial fistula. Fiberoptic bronchoscopy can directly display the fistula; chest MSCT scans can also directly display the fistula and can assist with diagnosis. If the tracheobronchial fistula is not associated with mediastinal emphysema, there is no mediastinal inflammation, infection, and clinical manifestations (Fig. 3.15).

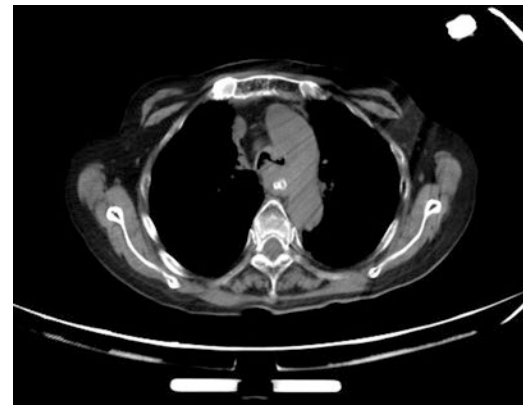

Fig. 3.15 Thoracic CT image shows tracheal-mediastinal fistula

3. Tracheal Neck Fistula
   Tracheotomy can result in a tracheal neck fistula in adults. If a tracheotomy is performed using an endotracheal tube, the tracheal incision and the subcutaneous channel can heal independently. Trauma, effects of radiation therapy, and other tracheal neck fistulas are difficult to treat. The typical appearance and clinical presentation of the condition are easy to diagnose, and a neck MSCT scan can assist with the diagnosis of cutaneous fistulas and fistulas communicating with the trachea.
4. Thoracic Stomach-Tracheal (Bronchial) Fistula
   The normal stomach is located in the abdomen, which is far from the airway. These systems do not communicate with each other. The modern surgical treatment of esophageal carcinoma advocates wide excision, gastric pull-up, chest and cervical esophageal reconstruction of the upper digestive tract, placement of the stomach on the pleural cavity and moving it to the posterior mediastinum (the original esophagus bed area), and ultimately the formation of the intrathoracic stomach. The stomach and thoracic trachea, carina, and main bronchus are adjacent to each other. postoperative hemorrhage, exudation and inflammation, fibrous tissue hyperplasia and machine, anterior wall and posterior wall of the trachea and bronchus pleural stomach together as one. If there is a stomach-penetrating ulcer, gastric necrosis, local infection, suspected esophageal cancer surgery and residual tumor after radiotherapy, or gastric and tracheal bronchial wall perforation simultaneously or successively, a thoracostomach tracheal (bronchial) fistula forms. Depending on the site of the fistula, thoracic stomach - trachea (bronchial) fistula can be called thoracic stomach - trachea fistula, thoracic stomach - carina fistula, thoracic stomach - left main bronchial fistula, thoracic stomach - right main bronchial fistula, thoracic stomach - middle bronchial fistula and thoracic stomach - lobar bronchial fistula.

   The thoracic stomach-tracheal (bronchial) fistula presents a typical “decubitus burning-like cough”, which can be referred to as “lying burning-irritating cough syndrome.” The cough has a strong fiery burning sensation causing severe irritation, is almost unbearable, is increased when in the supine or sitting position, can disappear or be reduced, and if influenced by eating. This is because when in the sitting position, the stomach contents of the intrathoracic stomach sink into the lower part of the gastric antrum and body. In the supine position, the gastric contents diffuse into the gastric body and to the gastric bottom and it is very easy for the stomach fistula to overflow into the trachea and bronchus.

   To diagnose this condition, a chest MSCT scan is needed; this can directly display the intrathoracic stomach-tracheal fistula and carina or main bronchus communication features, and it is easily identifiable (Fig. 3.16). The lung can be complicated with lung segment or lobar pneumonia-like lung injury changes. If necessary, the penetrating ulcer of the stomach wall can be seen in the chest and stomach through the fiberoptic gastroscope, and a large amount of thick moss is covered around the ulcer. Moreover, the diagnosis can be made by seeing the special annular cartilage image of the trachea and bronchus through the ulcer.
5. Broncho - pleural fistula (also called bronchial stump fistula) is the most common, serious, difficult and worst-prognosis complication after surgical resection of lung lobes. After lobectomy, the bronchial stump

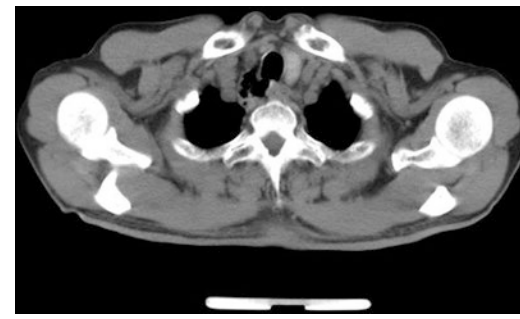

Fig. 3.16 Thoracic CT image showing the thoracic stomach-left main bronchus fistula

and pleural cavity communicate with each other to form a bronchopleural fistula due to various reasons. The reasons include ischemia caused by over-close suture of the bronchial end or stump, local air leakage caused by over-close suture, local inflammatory reaction, local bacterial infection, and local tumor recurrence. According to the site of the fistula, they are called carina - pleural fistula, main bronchus - pleural fistula, intermediate bronchus - pleural fistula and lobar bronchus - pleural fistula.

After the formation of a bronchial-pleural fistula, a large amount of bacterial secretions from the airway (phlegm fluid) enter the clean pleural cavity, forming an intractable pleural cavity and suppurative infection, accelerating the development of a fistula. Communication between the fistula and pleural cavity makes it difficult to maintain the negative pressure in the respiratory tract, which can affect breathing, resulting in hypoxia and dyspnea. The presence of a fistula and a large amount of concentrated pleural effusion that passes through the fistula in the mouth into the bronchus and into normal lung tissue, causes lung infection, damage to the residual normal lung tissue, and destruction of lung structure, resulting in impairment of lung function.

As seen with closed drainage of the pleural cavity after surgery, the drainage bottle has a large amount of purulent sputum secretion. With coughing or forced evacuation of the pleural cavity, there is negative pressure in the drainage bottle and bubbles form. This strongly suggests the occurrence of a bronchial stump pleural fistula. The fiberoptic bronchoscope can directly observe the fistula of the bronchial stump. A chest MSCT scan shows the signs of communication between the bronchial stump and the pleural cavity [4, 5] (Fig. 3.17).

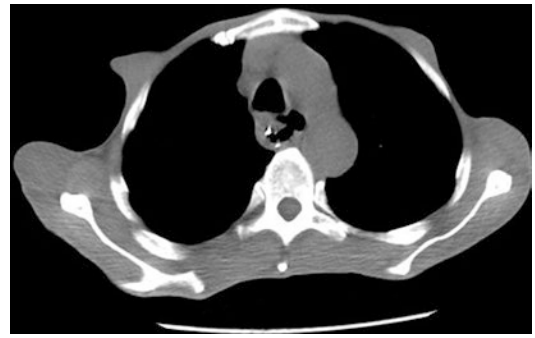

Fig. 3.17 Thoracic CT image showing a left bronchial pleural fistula

3.2 Pulmonary Lesions

3.2.1 Pulmonary Exudative Lesions

Lung inflammation, edema, and blood stasis cause pulmonary exudative lesions. In the pulmonary circulation, the fluid in the blood vessels or the components of the fluid and blood cells seep out of the blood vessels into the pulmonary interstitium and alveoli. Interstitial lung exudation leads to increased lung texture, and fluid replacement gas exuded from alveoli leads to consolidation of the lung. This condition appears as a cloud-like dense shadow or ground-glass shadow, with an unclear lesion edge and uneven density. Exudative lesions can appear as lung lobules or they can have a big leaf-like or irregular shape. They can be single or multiple. Exudative lesions are able to be quickly absorbed after appropriate treatment (1–2 weeks). The difference between exudative lesions in the lung tissue (dense shadow volume) and atelectasis (shadow that significantly reduces the lung tissue volume) can be clearly seen.

Lung exudate is common in all kinds of pneumonia, such as bacterial, viral, or fungal infectious pneumonia, obstructive pneumonia, aspiration pneumonia, allergic pneumonia, tuberculosis, pulmonary edema, etc.

3.2.2 Pulmonary Edema

When liquid from the pulmonary interstitial capillary seeps into the pulmonary interstitium and alveoli, this causes thickening of the interstitium and disappearance of alveolar gas. This affects the lung's gas exchange and results in a lack of oxygen. Depending on the main location of the capillary internal liquid overflow, it is divided into interstitial pulmonary edema and alveolar pulmonary edema.

Interstitial pulmonary edema exudate is mostly contained within the pulmonary interstitium, interlobular septa, and interstitium of lung parenchyma tissue. The interstitial thickening affects the gas exchange and oxygen supply. Interstitial pulmonary edema is mostly chronic pulmonary edema, which can develop into pulmonary fibrosis. The chest X-ray manifestations of interstitial pulmonary edema are increased and blurred lung texture, enlarged and blurred lung hilum, effusion and hypertrophy of interlobular septum, and the appearance of septum line, namely Kerley B line and Kerley A line.

The alveolar pulmonary edema consists of alveolar fluid and is almost simultaneous with interstitial pulmonary edema; the gas in the alveoli is replaced by liquid, which negatively affects the function of gas exchange, and the large area of alveolar pulmonary edema causes severe hypoxia and respiratory failure, which endangers life. The typical chest X-ray of alveolar pulmonary edema shows a butterfly shape around the symmetrical distribution of the top of the lung, and the lung field appears as frosted glass. Alveolar pulmonary edema is a more acute type of pulmonary edema; appropriate effective treatment can cure the edema in a short time.

3.2.3 Lung Mass

Normal tissue cells can lose the ability to regulate growth, causing abnormal proliferation, which often form local clumps or lumps. The mass can be a benign or malignant tumor. The tumor can compress the airway leading to obstructive emphysema, obstructive pneumonia, or obstructive pulmonary disease; tumor invasion of blood vessels can cause phlegm in the blood or large hemoptysis. Radiographs will show the size and shape of each of the nodules or masses that occur in any part of the lungs.

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The Radiological Diameter of Tracheobronchial Tree

4

Xinwei Han and Peijie Lv

4.1 Summary

Tracheal shape varieties form horseshoe, oval, and round-like to scabbard-shaped. The shapes of trachea and bronchus are not only different, but also the inner diameter of different individuals varies greatly. Up to now, there is no normal measurement standard for diameter at home and abroad, and there is no relevant equation or regression equation to calculate the normal diameter of airway. The inner diameter of trachea and bronchus of different individuals should be measured individually, and the diameter and specification of balloon or inner stent must be selected according to the specific measurement index of trachea and bronchus of the target individual.

If gas in the airways on a chest PA or LAT image is taken to measure the tracheobronchial diameter, then image should be corrected for magnification. Additionally, image blurring would make it difficult to accurately determine the edge of the airways. These issues brings about large inaccuracies so that chest X-rays are no longer applied for it.

Chest multi-slice spiral CT (MSCT), a high-speed volume scan on the entire chest in a single breath, contains multiple post-processing techniques, which includes three-dimensional reconstruction and various cross-sectional reconstructions. So MSCT is an ideal technology to diagnose tracheobronchial diseases and measure diameter.

Devices integrating the function of digital subtraction angiography (DSA) and C arm, or flat panel CT, were formed by combining multifunctional DSA with CT cross-sectional imaging, such as Dyna CT (Siemens, Germany), Innova CT (GE, USA), and X-per CT (Philips, Netherlands). Quite a few devices are applied to the diagnosis of tracheobronchial diseases, the measurement of inner diameter, and the follow-up observation of inner stent implantation. These devices can complete interventional treatment such as measurement, lesion diagnosis and stent placement at one time.

4.2 The Post-processing Techniques of Chest MSCT

The advent of CT was revolutionary in the history of imaging. The medical CT developed from head CT, body CT, single-slice spiral CT to MSCT, and now multispiral CT is able to produce hundreds of slices. CT has achieved volume scanning over 100 cm, which not only reaches subtle density resolution and spatial resolution but achieves dynamic functional display also.

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4.2.1 The Scanning Techniques of Chest MSCT

Patients with severe airway stenosis are not able to tolerate scanning in the supine position. However, 5–10 mg dexamethasone injection will make edema disappear, relieve dyspnea, and enhance ability to tolerate stress, allowing most patients to finish CT scans in the supine position if accompanied with supplemental oxygen.

In supine position, an issue in tracheobronchial fistula patients, especially thoracoabdominal-tracheobronchial fistula, results in the gastric contents to flow into the tracheobronchial tree and produces burning pain and irritating cough. However, it allows some patients to finish chest CT scans in the supine position with gastric acid inhibitors under the condition of fasting and inserting an internal drainage tube into the stomach to aspirate as much of the gastric contents as possible.

4.2.2 Post-processing Techniques of MSCT

The rapid development of computer technology quickly improves medical imaging. The combination of computer technology with X-ray tomography develops the epoch-making cross-sectional CT. MSCT acquires a mass of raw data by means of continuous axial scanning or volume scanning. Both cross-sectional images and 3D images, which are preferred as they are more like human anatomy and physiology, can be obtained by manipulating the data with various methods. These procedures to obtain different images are all post-processing techniques; common methods include the following aspects:

4.2.2.1 Multiplanar Reconstruction (MPR)

MPR, including curve planar reconstruction (CMPR), is a two-dimensional (2D) reconstruction technique. A new 2D image in one line or plane is obtained by reforming the raw transverse section data. Lining can be in the sagittal plane, coronal plane, or oblique plane at any angle depending on the purpose of the images. MPR images are better than transverse section images in the degree and range of airway stenosis, especially on anatomical and pathological features from any angle [1]. It is named as multiplanar reconstruction along the lesion direction.

A large amount of data is obtained from an MSCT volume scan so that the reconstructed images own uniform definition and resolution in all planes. MPR images display complex anatomical structures, like the diaphragm, hilum of the lung, mediastinum, etc. When displaying tracheobronchial diseases such as stenosis, fistula, or stent follow-up, the MPR image produces a holistic view and is better than transverse section images (Fig. 4.1, Informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study.).

CPR is termed as an extension of MPR. If the course of some structures is not in one line or plane, MPR images cannot display a comprehensive figure. Drawing a line in the center of target organs and reforming these 2D images along this line are necessary to reconstruct a new 2D CMPR image. CMPR images can straighten curved, twisted, and folded structures, like vessels, bone, bronchi, and other complex structures in one plane. It can prevent shortening and folding of structures from paralleling to the scanning plane and make it convenient to observe the lesion range (Fig. 4.2).

The process of measuring diameter and distance on a CPR image may cause large distortion that would arouse attention in clinic. Therefore, it is better to measure diameter on a raw scanning image.

4.2.2.2 Multiplanar Volume Reconstruction (MPVR)

There are main parameters of CT imaging, tissue density, and density difference. MPVR can be divided into three types of reconstruction based on density threshold: maximum intensity projection (MIP), minimum intensity projection (MinP), and average intensity projection (AIP). MPVR can provide simulated 3D anatomical

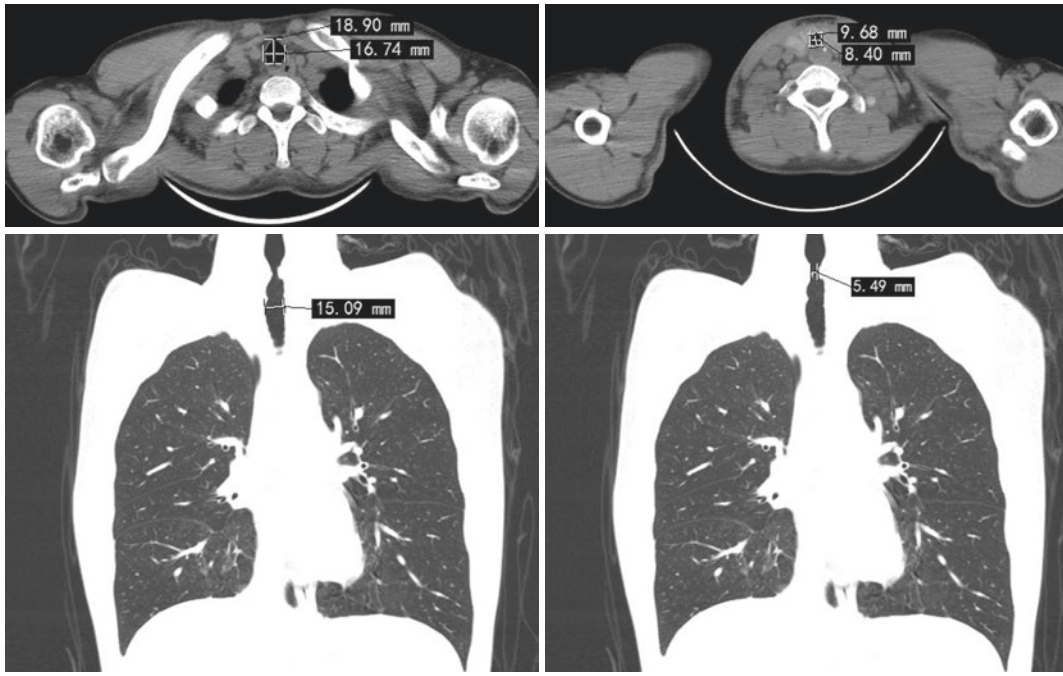

Fig. 4.1 Chest CT: transverse section and MPR images of tracheal stenosis

images and is a 3D technique which operates the volume data generated from raw data by projection based on the maximum, minimum, and average intensity of human tissue at a different angle or specific plane. This 3D image is observed from any perspective or angle without cover, overlap, or distortion of anatomical structures.

1. MIP, a 3D technique which projects the tissues with maximum intensity through a certain line, gets multi-directional images. Common imaging planes include the axial, sagittal, and coronal planes, similar to conventional X-ray images, which are easy to understand and observe. MIP images typically display high-density tissue and lesions, such as bone, lung mass, vessels, and obviously enhanced soft tissue mass (Fig. 4.3).

   MIP cannot show low-density or low-contrast structures.

   Manual or automatic editing during image reconstruction removes similar density tissue nearby target organs, such as bone surrounding vessels or calcified plaques of vessel walls, and optimizes the lesion displayed.
2. MinP is a 3D technique which projects the tissues with minimum intensity through a certain line for multi-directional images. Common imaging planes include the axial, sagittal, and coronal planes, similar to conventional X-ray images, which are easy to understand and observe. MinP images typically display low-density tissue and lesions, such as airways and dilated bile ducts in the enhanced liver (Fig. 4.4).
3. AIP is a technique which projects tissues of average intensity through a certain line for multi-directional images. This image has low-density resolution and is used less in clinical.

4.2.2.3 Surface Shaded Display (SSD)

SSD is a 3D technique which operates the raw volume data and reformats surrounding pixels over a set density threshold, with mathematical models. SSD images are beneficial for lesion localization with chiaroscuro, since they provide good 3D perception and clear anatomical relationship. The technique was initially used for the skeletal system, such as the craniofacial region, semicircular canal, pelvis, and other complex

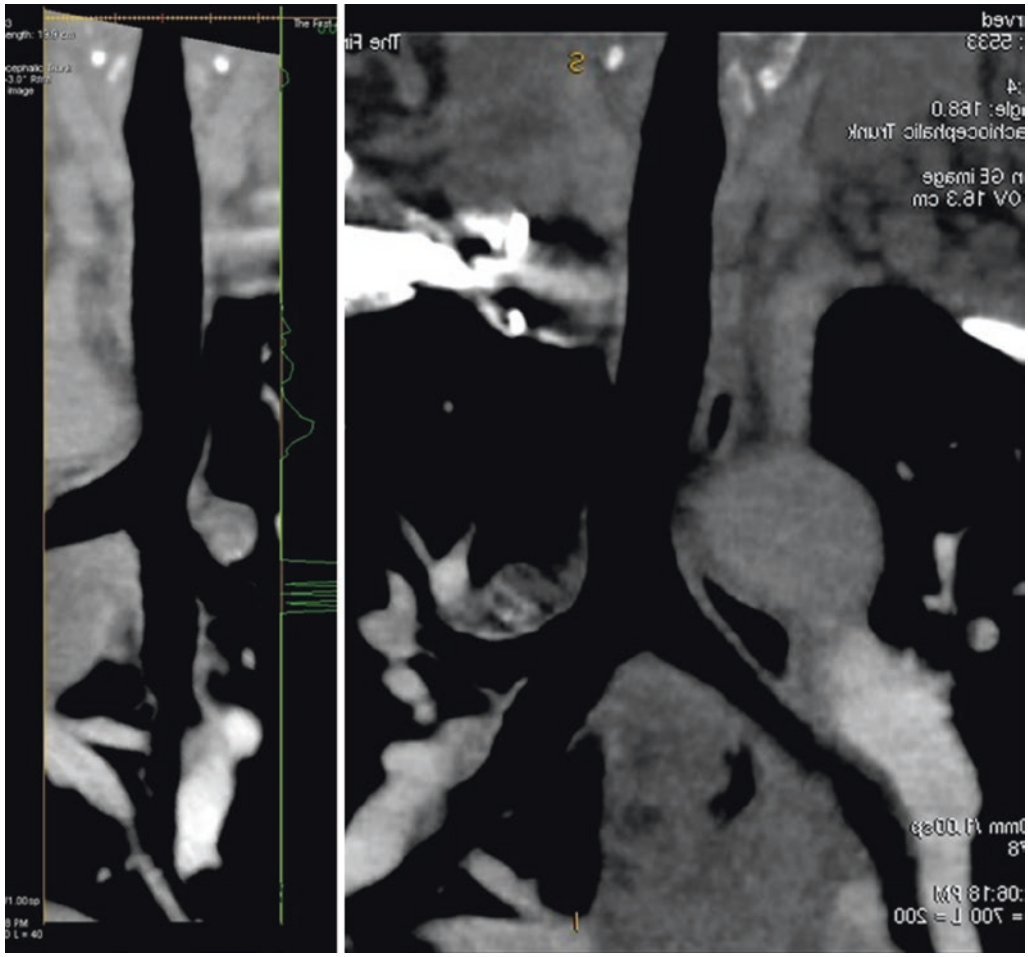

Fig. 4.2 CPR image of tracheal bronchus

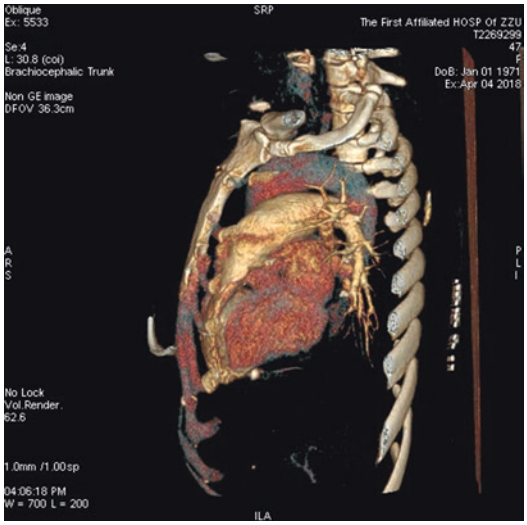

Fig. 4.3 MIP (pulmonary artery)

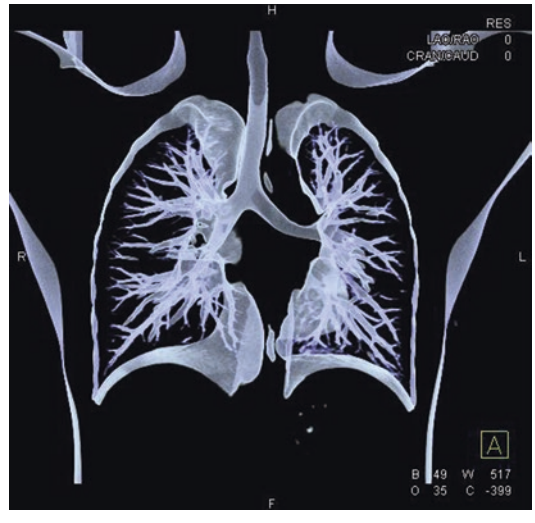

Fig. 4.4 Airway MinP, airways stand out clearly against surrounding tissue

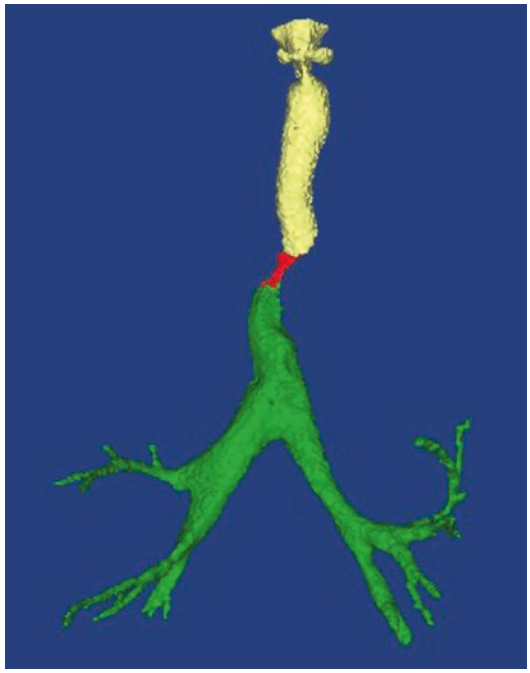

Fig. 4.5 SSD image on tracheobronchial tree

regions; however, it is now widely applied to cavity structure, like the tracheobronchial tree, vessels, and so on (Fig. 4.5).

Using incomplete volume data to make an SSD image negatively affects the set density threshold of the image, which results in blurred detail. High-density thresholds may affect the display of branch structures and cause poor image quality with high noise and many artifacts and create noncontinuous surfaces and irregular borders. Low thresholds cause fuzzy image borders and completely obscure local high-density structures, like airway stents, cricoid cartilage calcifications, bronchial stones, and so on. Without grayscale, SSD images would present all structures exceeding the density threshold as bright images, such as vessel wall calcifications with enhanced vessel lumens.

4.2.2.4 Virtual Endoscopy (VE)

VE, also known as internal 3D shaded surface reconstruction, reconstructs internal surface 3D images of hollow organs from CT volume data. The technology's similarity to the fibroendoscope is responsible for its name, virtual endoscopy. Excluding needless tissue or including necessary tissue can be achieved by setting transparency at 0% or 100%, respectively, through adjusting the density threshold in post-processing. It is also possible to adjust the artificial color scheme so that it matches the more familiar color scheme of the fibroendoscope. It achieves the results that multiple images continuously enlarge and close to observer by using perspective projection software with adjusting image distance, object distance, viewing angle, perspective direction, light, and continuously shortening object distance centering to the lumen. It is possible to get dynamic images similar to the fibroendoscope when it is entered and turned around with cineloop speed.

However, VE can extend further and can observe more angles than that of the fibroendoscope, which is beneficial because it can display lesion location and shape from multiple angles (Fig. 4.6).

VE can display the inner wall details of the pharynx, throat, trachea, and carina, and from the main bronchi to segmental bronchi, it can also display all kinds of airway stenosis, distortion, and fistula. Furthermore, it is able to measure the range and degree of airway stenosis and evaluate the distal lumen for airway stenosis and fistula, in the process of interventional therapy. Structures found outside the airway, such as enlarged lymph nodes, can be detected through the airway wall by adjusting its transparency (Fig. 4.7).

4.2.3 Measurement Methods of MSCT

The original cross-sectional images are primary for diameter measurement.

The starting point and end point are manually set up which the accuracy of these points is affected by the window quality of the CT image. Generally, the density of the structure or lesion is set as the window level, and it presents as medium gray which is easy to recognize. It allows the boundaries of the structure to be easily determined and makes lining and measuring more

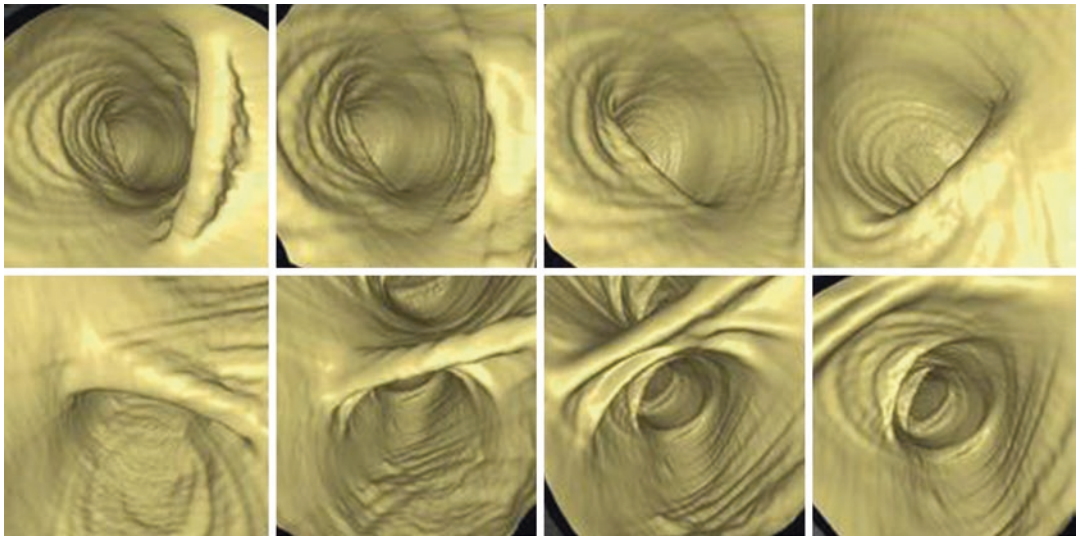

Fig. 4.6 VE image of tracheobronchial tree

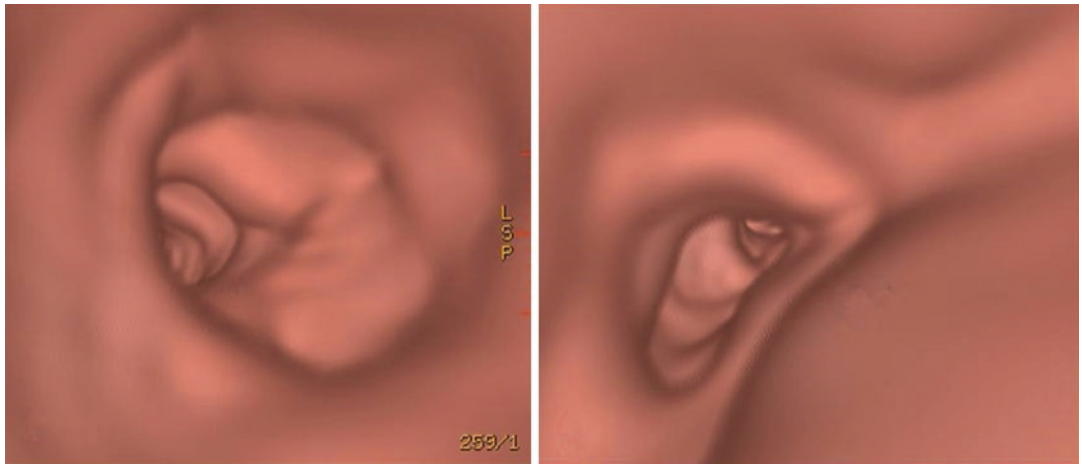

Fig. 4.7 Trachea stenosis, enlarged lymph node in the carina

accurate. If the window level is set too high, the lesion edge will be reduced or removed. Conversely, if the window level is set too low, the lesion edge will be enlarged or extended, resulting in diameter magnification [2] (Fig. 4.8).

4.2.3.1 CT Window Technique

CT window technique, including setting window width and window level, is an important skill in analyzing and processing the quantized image [3]. Anatomic lesions are best displayed with suitably adjusted window width and level. The range of matrix unit numbers in a CT image, in terms of shades of gray corresponding to density, changes from −1000 Hu (black) to +1000 Hu (white). It is well known that the human eye can only detect 16 grayscale shades apart. The contrast resolution of images, about 200 Hu, such as X-ray images, is very low. If the window width is set at 200 Hu, the minimum grayscale detectable by the eye is 200/16 = 12.5 Hu. Once the difference between the two tissues exceeds 12.5 Hu, the human eye can read the image.

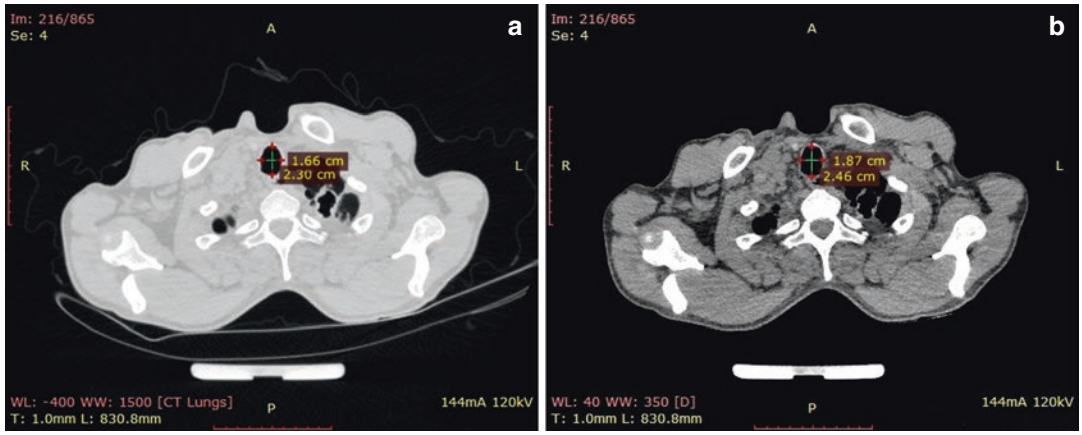

Fig. 4.8 Measurement comparison of different windows for trachea diameter. (**a**) Lung window, (**b**) mediastinal window

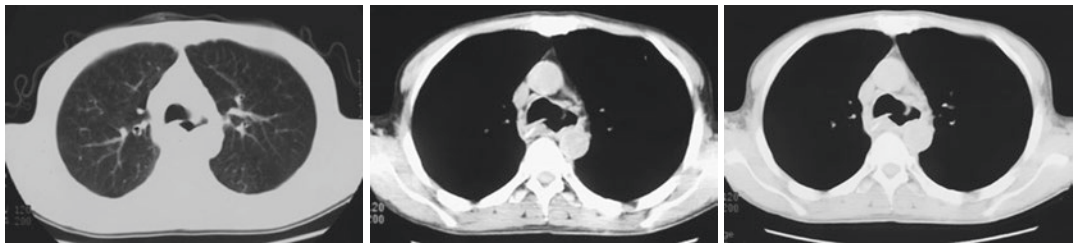

Fig. 4.9 Chest CT images display artificial change of tracheal diameter with fixed window width and different window level

4.2.3.2 Window Width and Window Level

Window width is the range of CT numbers that one CT image contains. Window width of the CT image defines the focused tissue range and density resolution that need to be focused on: the smaller window width, the higher density resolution. Choosing the window width is a technique that allows only specific target organs with suitable window width and window level values to be viewed, after converting to 16 grayscale. The maximum and minimum CT numbers of window width are both the brightest and the darkest point in the image according to the window level.

Window level, the center of the window, is the midpoint of the CT number. The normal CT number of the target organ is commonly set as the window level. If the density of regions in the organ varies, pronounced contrast will display these regions clearly. The window level of the lung is −500 to −700 Hu, similar to the density of air, while the window level of mediastinum is −50 to −100 Hu, similar to fat density.

The conventional window width for observing mediastinal lesions is 400 Hu, and mediastinum is various soft tissues surrounded by adipose tissue. If the window level is set as −50 Hu, close to fat density, the displayed CT number range in the image changes from −250 Hu to +150 Hu. In the image tissue displays, white at the density is above 150 Hu and dark at the density under −250 Hu (Fig. 4.9).

4.3 The Diameter Measurement of Trachea, Main Bronchus and Lobar Bronchus

The inner diameter variation of nonvascular physiological orifices such as the digestive tract and the respiratory tract is quite variable. As such, it is difficult to have a normal measurement as a reference standard or a related standard. If stent interventional radiology therapy is performed, the diameter of the trachea, main bronchus, and each lobar bronchus would be measured, respectively.

Tracheal form can vary in the process of breath, which shows the circle shape in cross section in young adults during quiet inspiration; the diameter is nearly the same in anteroposterior and transverse, while it displays as a "C" or "U" shape during expiration with a shorter anteroposterior diameter. However, it can appear scabbard-shaped in cross section in the elderly or in emphysema, as the tracheal anteroposterior diameter becomes longer while the transverse diameter becomes shorter. Tracheal diameter varies greatly among individuals (in the anatomy literature, endotracheal transverse diameter in adults ranges from 9.5 to 9.5 mm, and the sagittal diameter ranges from 8.0 to 22.5 mm).

4.3.1 The CT Window Technology in the Measurement of Tracheal and Bronchial Diameter

Pulmonary window width is 1000 Hu with window level set at −700 Hu. However, the mediastinal window normally has a window width and level of 400 Hu and 50 Hu, respectively. In chest CT images, it is not good for observing soft tissue, especially in the trachea and bronchus. In thinner patients, lower fat content in the mediastinum would result in the primary bronchi, and even the distal trachea and the tracheal carina, close to the lung tissue. In the case of the mediastinal window level being set at 50 Hu, the distal trachea, tracheal carina, and the primary bronchi would display black as the lung, which makes it impossible to determine the borders, structure, or diameter of the airway.

The condition of the CT window technology, in general, is about the diameter measurement of the trachea or bronchus. However, we recommend a modified mediastinum window condition, which window width is set as 400 Hu and window level is −50 to −100 Hu. Using these parameters, all structures of the mediastinum can be clearly shown, and the edges of the airway can be accurately defined. It could be termed as the mediastinal-fat or modified special mediastinal window because the CT value of the window level is similar to adipose tissue (Fig. 4.10).

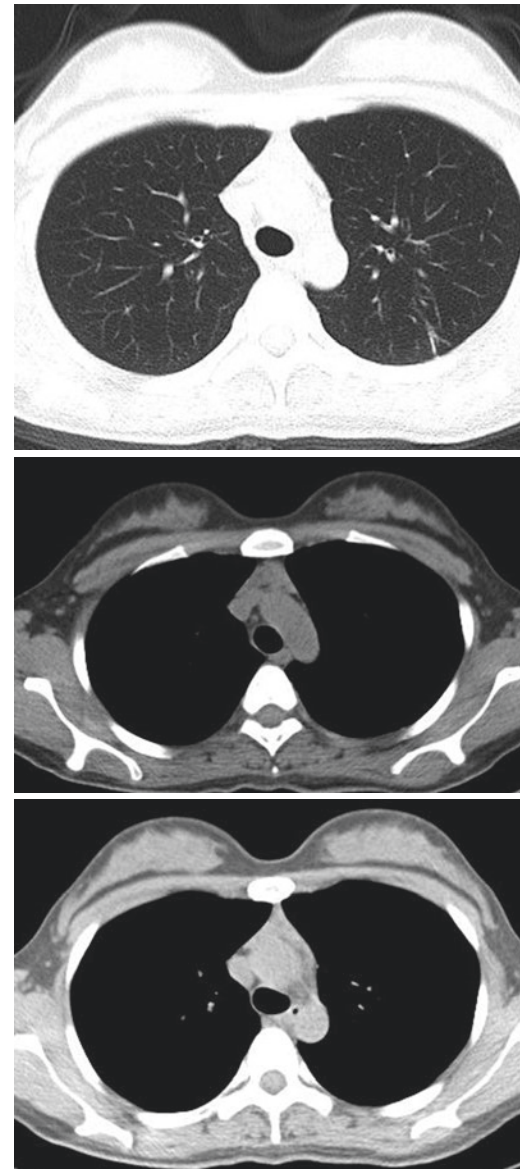

Fig. 4.10 Chest CT: airway clearly shown in routine lung window, mediastinal window, and mediastinal-fat window

4.3.2 The Diameter Measurement of the Trachea

The area from the fissure of glottis to the cricoid cartilage is the glottis. The lower part of the glottis is narrow and gradually expands into a conical shape and extends to the "C" or "U" shape of the trachea. Normal tracheal lumen owns a similar shape and size: the trachea runs superoinferiorly

along the long axis of the human body in the mediastinum, perpendicular to the CT cross-sectional scanning images [4, 5]. The distortion of the cross-sectional image of trachea on CT cross-sectional image is the smallest, which can truly reflect the shape and size of trachea. Therefore, we can directly measure the anteroposterior diameter (sagittal diameter) and transverse diameter (diameter) in the tracheal lumen, by the improved mediastinal window or special mediator fat window.

4.3.2.1 The Measurement of "C"-Shaped Tracheal Diameter

The normal tracheal shape in adolescents and adults shows the "C" or "U," if there is no chronic lung disease, such as long-term cough or history of asthma. Tracheal ring cartilage displays C shape and supports both sides and the anterior part of the trachea. The posterior part of the trachea, a fibrous membrane, connects the ends of the cartilage in a straight (or slightly concave) shape, forming the "C" shape in a trachea cross section. However, with chronic smoking, the original straight posterior fibrous membrane will gradually bulge backward, causing the trachea cross section to appear circular or almost oval. The measured "C"-shaped trachea is substantially equal in diameter to the transverse diameter, or the anteroposterior diameter is slightly longer than the transverse diameter (Fig. 4.11).

In the C-shaped trachea, the maximum sagittal or transverse diameter of the trachea is treated as the diameter of the trachea, which is referred to in tracheal balloon bronchoplasty or stent placement.

When performing a balloon dilation procedure on strictures in tracheal annular scarring stenosis, then selected balloon diameter must be equal to or 10% larger than the normal diameter of the internal trachea.

Tracheal segmental scarring stenosis can be treated or therapied by inserting a tracheal stent, which is fully or partially coated with film and has a diameter 10–15% greater than the measured inner diameter of the trachea.

In the case of malignant tracheal segmental stenosis: tracheal stenosis caused by compression of the trachea by external lesions can be treated by placing a bare intratracheal stent with a standard diameter of 10–15% larger than the inner tracheal diameter. If the tracheal stenosis is caused by endotracheal malignancies, endotracheal stent replacement can be performed by a fully or partially coated stent with a standard diameter of 10–15% greater than the inner diameter.

Tracheal rupture, perforation, and various tracheal fistulas (tracheal-mediastinal fistula, esophageal-tracheal fistula, thoracic stomach-tracheal fistula, etc.) can all be surgically treated with a tracheal tube stent, fully or partially coated, with

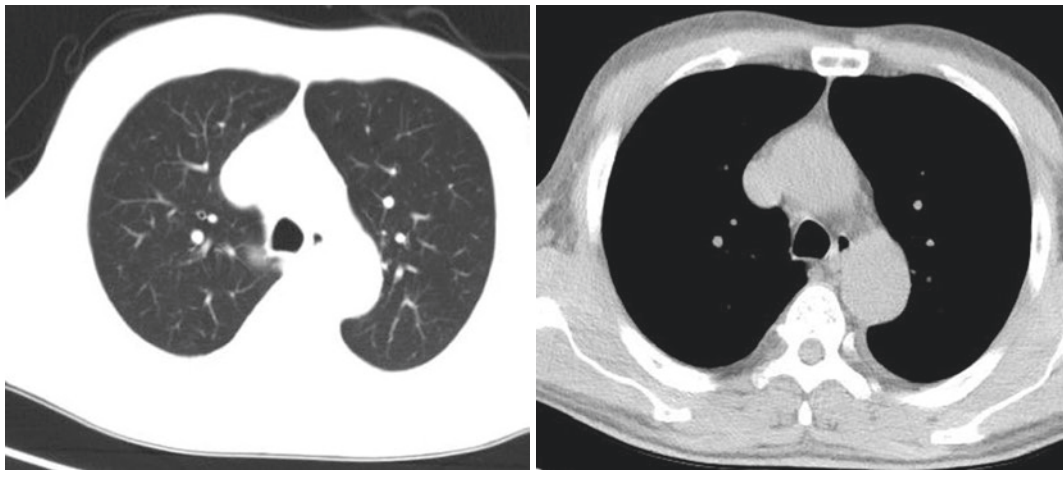

Fig. 4.11 "C"-shaped trachea on CT images

a standard diameter of 15–20% greater than the internal diameter of the trachea.

4.3.2.2 Measurement of Oval Tracheal Diameter

The normal C-shaped trachea can gradually develop into an oval trachea in response to certain pathologies, such as increased long-term tracheal pressure, chronic cough, increased pleural cavity pressure, asthma, or mild emphysema. The original straight fibrous membrane of the posterior wall of the trachea begins to protrude posteriorly, which also naturally occurs in the elderly or in long-term smokers. The sagittal diameter of the oval trachea is significantly greater (at least 20%) than the transverse diameter due to the protruding posterior wall (Fig. 4.12).

When using balloon dilation to treat strictures due to tracheal annular scar stenosis in an oval trachea, the standard balloon diameter should be slightly less than 10% larger than the tracheal diameter.

If an oval trachea develops segmental scar stenosis, the tracheal stent inserted should be partially or fully coated with film and should be at least 5–10% larger than the tracheal diameter.

In the case of malignant tracheal segmental stenosis in an oval trachea: tracheal stenosis, caused by external lesion compression of the trachea, can be treated by placing a bare intratracheal stent with a standard diameter of 10–15% larger than the inner tracheal diameter. If the tracheal stenosis is caused by endotracheal malignancies, endotracheal stent replacement is performed by a fully or partially coated stent with a standard diameter of 10–15% greater than the inner diameter.

Tracheal rupture, perforation, and various tracheal fistulas (tracheal-mediastinal fistula, esophageal-tracheal fistula, thoracic stomach-tracheal fistula, etc.) can all be surgically treated with a tracheal tube stent, fully or partially coated, with a standard diameter of 15–20% greater than the internal diameter of the trachea.

4.3.2.3 Measurement of Scabbard-Shaped Tracheal Diameter

As previously discussed, the normal "C" shaped trachea will gradually evolve into an oval shape under the condition of pathological changes. If these pathologies deteriorate and develop to long-term chronic cough, severe lung emphysema, or increased pleural cavity pressure, the tracheal morphology may change again and gradually become scabbard-shaped (sword-like). By this stage, the tracheal diameter is significantly narrow, and the sagittal diameter increases significantly. Therefore, the tracheal shape looks like brackets "()" or "swords-like." In even more serious cases, the tracheal cavity appears as a long and narrow fissure (Fig. 4.13).

In scabbard-shaped tracheal morphology, it is relatively easy to measure the maximum sagittal and transverse diameters but difficult to revise the morphology back to the true size of the tracheal lumen. When performing the interventional treatment of a tracheal stent for a sheath-shaped trachea, there are several variations in measure-

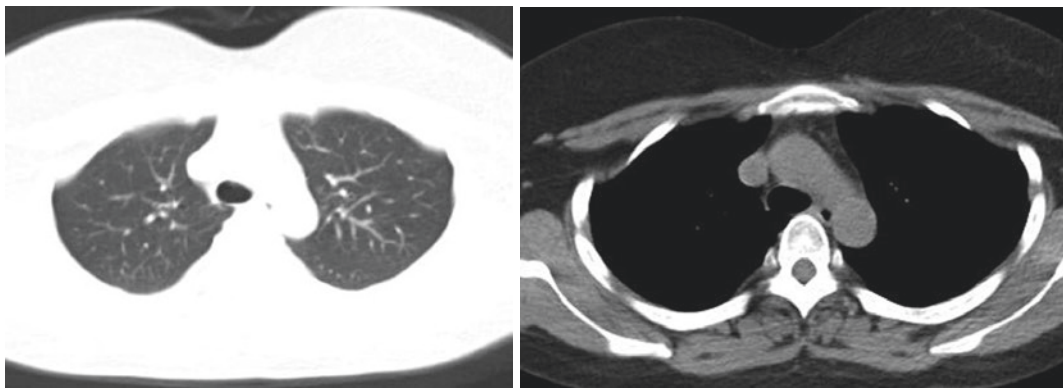

Fig. 4.12 The lung window and mediastinal window of the oval trachea in CT images

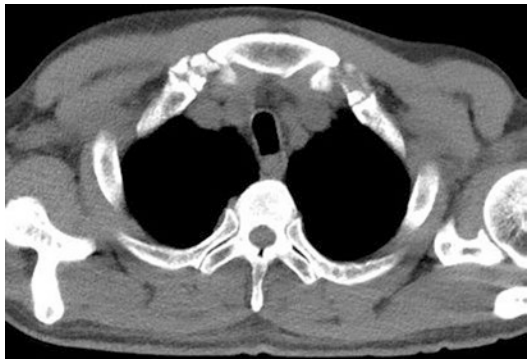

Fig. 4.13 CT image of scabbard-shaped trachea

ment technique regarded for reference, as neither the sagittal nor the transverse diameter can be considered a reasonable reference.

1. Select a relatively normal oval- or "C"-shaped tracheal plane in the neck.
   Although long-term chronic cough, emphysema, and increased pleural pressure will cause the thoracic cavity develop scabbard-shaped, many patients will maintain a similar tracheal morphology to the "C-" or "U"-shaped trachea in the cervical trachea region, particularly in the subglottic tracheal region. Therefore, it is possible to measure the diameter of the cervical trachea as a guide when selecting the tracheal stent specifications.
2. Measure the area of the sheath-like tracheal lumen.
   This procedure is performed as a CT post-processing function. Labeling the inner edge of the trachea using an electronic pen (cursor) makes it a complete sword-like shape as a CT value of the sampling volume by applying the function keys to measure the CT value. The surface area value (area *J*) of the scabbard-like sample volume is also shown as the CT value.

   The scabbard-shaped trachea's surface area values can then be used to determine the equivalent circular surface area. The equivalent circular surface area can be calculated from these surface area values (area *J*) to the diameter (*D*) of the same circular surface area (*Y* area). *D* can be used as a guide for selecting the diameter of the tracheal stent.

   Take the circular surface area to be:
   the surface area of the trachea: *J* area = *Y* area
   Formula of circular area: *Y* area = $\gamma^2\pi$
   Therefore, the diameter is:

$$D = 2\sqrt{_{Y\,\text{area}}/\pi}$$

   The *D* value can be treated as a reference for the diameter of the trachea when treating the sheath-shaped trachea.
3. Measure the circumference of the sheath-like tracheal lumen.
   Labeling the inner edge of the trachea with the pen (cursor) produces a smooth and complete sword-like shape. The CT imaging program can automatically display the length of this arc, which makes the diameter of the circle calculated. This circular diameter, calculated from the circumference of the scabbard shape, can be regarded as a guide for the diameter of the trachea in the scabbard-like trachea.
4. The diameter of the trachea is developed from the diameter of the main bronchus.
   The diameter of the main bronchus and the trachea had a certain correlation: the diameter of the trachea is generally greater than that of the main bronchus about 10 mm, according to clinical experience from long-term tracheal stent interventional radiology. The main bronchus is generally not involved in the sheath-like changes of the trachea. Therefore, the diameter of the trachea can be roughly performed by measuring the diameter of the main bronchus and adding 10 mm. This tracheal diameter can be used as a standard for the diameter of the scabbard-shaped trachea.
5. The anteroposterior diameter of the sheath-shaped trachea is used as the maximum diameter of the trachea.
   The more severe the scabbard-shaped tracheal morphology is, the more likely the tracheal diameter is exaggerated. Do not use this simplified method unless doctors are experienced with airway intervention.

   When balloon dilation is applied to treat strictures due to tracheal annular scar stenosis

in a scabbard-shaped trachea, the standard balloon diameter should be at least 10% larger than the tracheal diameter.

If a scabbard-shaped trachea develops segmental scar stenosis, the tracheal stent inserted as treatment should be partially or fully coated with film, at least 10–15% larger than the tracheal diameter.

In the case of malignant tracheal segmental stenosis in an oval trachea, tracheal stenosis, caused by external lesions compression on the trachea, can be treated by placing a bare intratracheal stent with a standard diameter of 10–15% larger than the inner tracheal diameter. If the tracheal stenosis is caused by endotracheal malignancies, endotracheal stent replacement can be performed by a fully or partially coated stent with a standard diameter of 10–15% greater than the tracheal diameter.

Tracheal rupture, perforation, and various tracheal fistulas (tracheal-mediastinal fistula, esophageal-tracheal fistula, thoracic stomach-tracheal fistula, etc.) can all be surgically treated with a tracheal tube stent, fully or partially coated, with a standard diameter of 15–20% greater than the internal diameter of the trachea.

4.3.2.4 Diameter Measurement of Twisted Trachea

Tracheal distortions are mostly caused by external compression of the trachea, which can be a result of mediastinal masses, severe pleural effusion (effecting the position of both the trachea and the mediastinum), or external traction such as atelectasis or resection on the side of the lung. Tracheal distortions are limited to a certain segment and will not affect any of the other tracheal segments; therefore, the normal diameter of the trachea can be measured and used as a reference for tracheal stents.

4.3.3 Measurement of Bronchial Diameter of Main Bronchus and Middle Segment

The main bronchi and segmental bronchi are titled along the long axis of the human body at an angle of 30° to 50°, which is not vertical with the CT cross-sectional image. Therefore, CT cross-sectional images of the main bronchi and the segmental bronchi are not cross sections, but inclined sections, which lead to the main bronchial transverse diameter larger on the CT image. This means that CT cross-sectional images will inaccurately reflect the form and size of the main bronchi and the segmental bronchi.

The diameter of the main bronchi and segmental bronchi on the coronal plane is not affected by the sagittal tilt and can be measured on CT to provide the true diameter of the main bronchus.

The structure of the main bronchi and segmental bronchi is similar to that of the trachea, by composing of the cartilage ring, smooth muscle fibers, and connective tissue. However, in the early bronchi, the size of cartilage rings is small, and the fiber of the membrane wall is relatively long. These structures result in the almost-round main bronchial morphology. This round shape allows the coronal diameter of the main bronchus previously mentioned to be measured on cross-sectional images of the MSCT, which is referred as diameter when placing inner stents.

The diameter of the right main bronchus is 1–2 mm larger than that of the left side. If the full length of the main bronchus is narrow, the diameter of the main bronchus could be easily estimated by measuring the diameter of the contralateral main bronchus.

Generally, the diameter of trachea is about 10 mm larger than that of main bronchi. If the bilateral main bronchi are completely narrow, main bronchial diameter may be evaluated through the tracheal diameter.

Measurements can be made using a graduated gold-labeled catheter for tracheal or bronchial through the DSA, if it is hard to get on CT images.

4.3.4 Measurement of Lobar Bronchial Diameter

The orientation of the lobar bronchi is variable, either along the human body axis or along the coronal or sagittal axes. When multiple lobar bronchi on the section exist, a relatively circular lobar bronchus is chosen to measure its inner

diameter. If it is difficult to find a circular or approximately circular lobar bronchus, the minimum diameter on the inclined section is referred as diameter for bronchial stents.

4.4 Length Measurement of the Trachea and Main Bronchus

The thickness of the modern MSCT volume scan is generally less than 1 mm (e.g., 0.625 mm). If the original scan thickness is used to reconstruct the image, there are hundreds, potentially nearing a thousand, of chest scan images to process. In general, 3 or 5 mm is used to interpolate the reconstructed cross-sectional image in the volume of the volume scan. The thickness of the reconstructed image has a parameter display on each CT image. The original total thickness and the total length of the axial scan, for example, the total length of the trachea, can be calculated from the thickness of the layer displayed on the reconstructed image.

In the MSCT scan, the position parameters (mm) of the patient and the examination bed are also displayed continuously on each level of the image. Likewise, in the reconstructed image, the volume parameters (mm) of the bed are continuously displayed. The total length and thickness of the volume scan can be calculated based on the difference in CT measurement of the position of the bed in the first and last CT slice.

4.4.1 Tracheal Length

The length of the trachea varies with the position of the head, depending on whether the head is upward or downward. It is mainly the extension and shortening of the cervical and upper thoracic segments of the trachea to the head side. The cervical trachea and upper thoracic trachea extend upward as the head rises and shorten toward the chest as the head downward. Meanwhile, the position of carina remains basically unchanged. Additionally, the length of the trachea varies between expiration and inspiration, mainly through the extension and shortening of the trachea toward the distal trachea [6]. The thoracic trachea extends downward during deep inspiration and, depending on expiration time, the position of carina may move down 2–3 cm during deep inspiration.

Chest MSCT scans are performed on patient who take a deep breath and hold it while lying in an upward supine position. In this position, and in the inspiratory phase, the trachea is fully extended and stretched; therefore, the length of trachea measured by CT image is close to the physiological length, as there is no illusion of contraction [7].

The length of trachea, tracheal stenosis, and tracheal fistula can be detected by two kinds of MSCT scanning data.

1. Product of the slices' thickness + total slices number of the reconstructed images:
   (a) Total length of trachea: from the lower part of the glottis to the top of the carina
      - Slice thickness (mm) of axial images × no. of slice
   (b) Length of stenosis: from the beginning slice to the end slice of tracheal stenosis
      - Slice thickness (mm) of axial images × no. of slice
   (c) Length of tracheal fistula: from the beginning slice to the end slice of tracheal fistula
      - Slice thickness (mm) of axial images × no. of slice.
2. Position of bed (mm) in starting slice and position of bed (mm) in terminal slice:
   (a) Total length of trachea = location of scanning bed on the slice under the level of cavum infraglotticum (mm) and location of scanning bed on the slice above the level of the carina (mm)
   (b) Length of stenosis = location of scanning bed on the slice at the beginning of the stenosis (mm) and location of scanning bed on the slice at the end of the stenosis (mm)
   (c) Length of tracheal fistula = location of scanning bed on the slice at the beginning of tracheal fistula (mm) and location of scanning bed on the slice at the end of the tracheal fistula (mm)

4.4.2 The Length of Main Bronchus

The main bronchi are relatively localized, so their length doesn't vary with the position of the head; however, the length does vary slightly during breathing. The diameter change is smaller than that of trachea, but as there is an angle between the main bronchus and the center line of the human body, it is difficult to measure directly.

The length of the trachea, tracheal stenosis, and tracheal fistula can be calculated by two kinds of MSCT scanning data:

1. Application of mathematical formulas—the Pythagorean theorem:
   The Pythagorean theorem: $C = \sqrt{A^2 + B^2}$
   Total length of main bronchus:
   (a) Measure the slice number between the inferior edge of carina and the superior margin of upper lobe bronchus (A)
   (b) Measure the horizontal distance between the superior edge of the upper bronchial and the carina (B)
   (c) Use the Pythagorean theorem to calculate the length of the main bronchus (C):
   Length of main bronchus = $\sqrt{\{}$(slice number of carina to upper lobe bronchus × slice thickness (mm))^2 + distance from upper lobe bronchus to midline$\}$
2. Coronal position of three-dimensional reconstruction of main bronchus:
   Multiplanar reconstruction of the main bronchus can be accomplished with MSCT with which length of the main bronchus is measured directly on the coronal position of the main bronchus. However, the measurement of length will be slightly shorter than the true length according to the main bronchi which are at a dorsally inclined angle.

4.4.3 Length of Lobar Bronchus

Every level of lobar bronchus is basically composed of cartilage rings; the length of these bronchi varies slightly with the amplitude of respiration and can be measured directly. Measurements can be performed on different reconstructed images from the opening of lobar bronchus to the beginning of segmental bronchus.

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5 The Interventional Radiology Techniques for the Trachea and Bronchi

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Surgery has changed dramatically because of the development made in modern science and clinical medicine, especially the establishment of minimal invasive therapy.

Minimally invasive therapies consist of three techniques, which are stereotactic radiotherapy; endoscopic therapy such as fiber-optic bronchoscopy, thoracoscopy, gastroscopy, and laparoscopy; and interventional radiology under the guidance of modern imaging systems.

Interventional radiology has been promoted as the interventional medicine by certain famous scholars and referred as an imaging system guided with various diagnostic and therapeutic procedures under different apparatus (e.g., puncture needle, catheter, or guide wire). There are much advantages of interventional radiology such as microtrauma, good curative effect, low cost, fast recovery, and maintenance of the anatomical structure and physiological function of the human body.

Interventional radiology is classified as therapeutic interventional radiology (interventional therapy) and diagnostic interventional radiology according to its function. It is further classified as cardiac interventional radiology, interventional radiology on oncology, peripheral vascular interventional radiology, and respiratory interventional radiology, based on the human anatomy. However, the above classifications are not comprehensive, by lack of scientific rigor and practicality, for scientific research, discipline construction, clinical division of labor, personnel training, operation room establishment, and surgical arrangements [1]. Up to date, scholars have advocated the classification of interventional radiology as vascular interventional radiology (intravascular) and nonvascular interventional radiology, depending on the surgical approaches. Nonvascular interventional radiology techniques have been applied in tracheobronchial diseases [2].

5.1 Nonvascular Interventional Radiology Techniques

There are two kinds of techniques for nonvascular interventional radiology. First, all interventional radiology equipment are put into the human body directly through the surface physiological openings of the body, such as the mouth, nose, urethra, anus, or vagina, or via an internal cavity, such as the esophagus and gastrointestinal tract, trachea, and bronchus, rectum, colon, uterus, and fallopian tube. The interventional

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diagnosis and treatment procedures are monitored under an imaging system, which is suitable for physiological cavities.

The second technique is percutaneous puncture. Suspicious lesions of target organs, such as the lung, mediastinum, neck, liver, kidney, bone, bile duct, and the renal pelvis, are punctured by different needles to accomplish diagnostic or treatment procedures, which are suitable for parenchymal organs and hollow organs.

5.1.1 Nonvascular Interventional Radiological Procedures

5.1.1.1 Transoral Intubation

The interventional procedures associated with the trachea, carina, the main bronchus, and lobar bronchus zones could be completed through transoral intubation. Tracheal intubation under the digital subtraction angiography (DSA) guidance is better than laryngoscopy-guided intubation under anesthesia, especially for patients with extensive tracheal stenosis, tracheotomy, or failed intubation by anesthesiologist. That's because intubation can still be completed easily using a guide wire-catheter technique.

1. Instrument preparation: Mouth gag, 0.035 in. hydrophilic membrane wire (150–180 cm), single bend multifunctional catheter or vertebral artery catheter, and 0.035 in. strengthened guide wire (180–260 cm) and other interventional devices, such as stents, balloon catheter, etc.
2. Preoperative preparation: Diazepam (10 mg) is injected intramuscularly 10–30 min to relieve the patient's tension before the interventional procedure. Anisodamine-2 (10 mg) is injected intramuscularly to reduce oral and respiratory secretions and relax smooth muscle. For patients with dyspnea with severe airway stenosis, dexamethasone (5–10 mg) is injected intravenously to eliminate the tracheal edema and increase the tolerance of patients.

   The iodine contrast medium is diluted to about 30%, and epinephrine (1 mg) is diluted to 10 mL for the interventional procedures.

   The heart rate and blood oxygen saturation will be monitored under a multifunctional physiological instrument. A vacuum aspirator was prepared for pump oral or airway secretions or large amounts of blood when it is necessary.

   Local anesthesia can be performed with throat spray or thyrocricoid puncture. The majority of the interventional procedures for airway obstruction is for patients with severe airway stenosis. Patients with severe dyspnea were not allowed or cannot tolerate endotracheal intubation. General anesthesia without endotracheal intubation is unsafe, which anesthesiologist will not perform such general anesthesia.
3. Patient position: In the supine position without pillow, the patient's head was put to the right side by 30–45° (operator standing side) back as far as possible. Sterilization is not indispensable because the mouth and esophagus are open organs. Dentures and active teeth should be removed in order to avoid loss during the operation, such as swallowing them or coughing them to the trachea. The C-arm should be rotated to the left anterior oblique by 20–30°, and the effect vision was adjusted to the neck and chest following the mandible. The head side includes the hypopharynx and the lower areas. The mouth gag was placed into the open mouth between the incisors.
4. Transcatheter tracheal angiography and anesthesia: With the coordination of guide wire, the catheter is gently rotated to mouth, then advance to pharyngeal cavity; the operator adjusts the orientation of catheter toward the front and lower hypopharyngeal airway negative shadow after the guide wire and catheter reaching the pharynx and larynx. The guide wire and catheter are put into the trachea smoothly when the patient coughs, the sign of reaching the airway. Then, 1% lidocaine (2–3 mL) is injected into the airway for bronchial local anesthesia, and 3 mL 30% iodine contrast agent is injected into the transcatheter quickly within 30–60 s to complete tracheal bron-

chial angiography for lesions and normal bronchial structure.

5. Establish the hardened guide wire tract:
   The catheter and guide wire are manipulated into the trachea, carina, and main bronchus and are exchanged with strengthened guide wire to establish a pathway for further interventional surgery.

5.1.1.2 Trans-nasotracheal Intubation

The interventional radiology procedure of trachea intubation can be completed through the mouth and throat and also through the nasal cavity, the pharyngeal cavity, and the larynx cavity. Endotracheal intubation through the nose by interventional radiology techniques of DSA is an endotracheal intubation approach that cannot be achieved under a laryngoscope by an anesthetist. Airway intubation through the nasal cavity prolongs the period of retaining of tracheal intubation and avoids leaving the catheter in the mouth, restoring oral autonomic function, and increasing the patient's comfort greatly.

The detailed procedural information for Sect. 5.1.1.1.

5.1.1.3 Transoral Esophagus and Gastrointestinal Intubation

The interventional procedures can be performed by intubation through the oral cavity into the esophagus, stomach, duodenum, and upper jejunum.

1. Equipment preparation: Mouth gag, 0.035 inch hydrophilic membrane wire (J shaped head, 150–180 cm), 5F Cobra catheter or 5F vertebral artery catheter (the arc shaped at the front, 5 cm), and 0.035 inch strengthened guide wire (180–260 cm), a stent, stent hook, and balloon catheter.
2. Preoperative preparation: Diazepam (10 mg) is injected intramuscularly 10–30 min before the interventional procedure to alleviate pressure, and 10 mg anisodamine was injected for reducing oral, esophageal, and gastrointestinal secretions. If the interventional procedure was associated with the stomach, duodenum, or jejunum intubation, especially procedures within the duodenum and jejunum, such as stenting, anisodamine would not be used to avoid smooth muscle relaxation causing cavity expansion abnormally.

   20–40 mL of water contrast medium was diluted to 30% for next step.
3. Patient position: Referred to Sect. 5.1.1.1(3).
4. Stomach intubation: The guide wire and catheter are inserted into the oral cavity, and the catheter was rotated gently to allow it to enter into the esophagus and stomach cavity. Then, the guide wire is withdrawn, and the contrast agent is injected into the transcatheter for angiography to show the structure of gastric mucosa and confirm the correct position of the catheter in the gastric cavity. Strengthened guide wire is inserted to retain and fix the guide wire for the interventional radiology procedures.
5. Duodenal intubation: A catheter with a total length of 100–120 cm and 260 cm of guide wire is prepared. According to the structure of the stomach for the duodenum or jejunum intubation, the catheter is inserted into the stomach cavity, with iodinated contrast medium via the transcatheter for angiography to confirm the structure of the body, gastric antrum, and duodenum. The catheter interfaces with the guide wire toward the antrum, then it is fixed, and the wire is pushed forward with rotation into the deep duodenum through the antrum. The wire is then fixed before the catheter is slowly pushed into the duodenum along the guide wire, trying to enter the deep part of the duodenum (descending part and horizontal part). The catheter is inserted into the stomach cavity, and iodinated contrast medium is injected via the transcatheter for angiography to confirm the structure, such as gastric antrum and duodenum. If interventional procedures, such as a stent, are performed, the guide wire should be pushed into the jejunum at a certain depth.
6. Jejunum intubation: The catheter and guide wire are advanced to antrum, then the operator fixes the cather and pushes the guide wire, and the guide wire will slowly reaches the jejunum. Then push the wire and the catheter

slowly in turn (with rotation) until they both get into the jejunum at 30–50 cm in depth, and then confirm the position by the transcatheter injection of iodine contrast agent. Then exchange the guide wire for strengthened guide wire. Keep and fix guide wire to establish an approach for interventional radiology of the duodenum or jejunum.

5.1.1.4 Transnasal Cavity, Esophagus, and Gastrointestinal Intubation

These procedures follow the details provided in Sect. 5.1.1.3.

5.1.1.5 Lung and Mediastinal Percutaneous Puncture

Lung and mediastinum solid lesions' pathological diagnosis, tumor radiofrequency ablation, microwave, cryoablation, ^{125}I seed implantation and lung and mediastinum cystic lesions (abscess, cyst, pulmonary bulla, etc.), are all procedures performed under an imaging guidance system.

1. Instrument preparation: 18 G coaxial cutting needle, 22 G Chiba needle, radiofrequency or microwave ablation needle, and multifunctional drainage tube.
2. Guidance system: Multi-slice computed tomography (MSCT), multifunction DSA with C-arm CT, open magnetic resonance (MRI), or large aperture MRI. Ultrasound (US) is not suitable for the lung because of the total reflection characteristics of the gas ultrasonic echo.
3. Patient position: Try to meet the vertical or horizontal puncture operation. CT can accurately measure the direction of the needle angle; however, it is easy to grasp the needle angle only horizontally or vertically according to the patient's chest CT. We can choose supine, prone, lateral, or oblique positions in order to get the horizontal or vertical position into the operating position for needle aspiration lesions.
4. Puncture pathway: In order to puncture the target accurately and avoid pneumothorax occurrence, normal lung tissue should be puncture as little as possilbe, espeiclally for tissue with emphysema or bullae on the puncture path. According to the location of the lesions, we choose different puncture pathes. According to the location of the lesion, the needle can be inserted into the chest wall, the side, or the back, wherever is the closest to the lesion of the chest wall.
5. Respiratory control: It needs respiratory for lesions located under the lower lung affected by certain amplitude on the shift. To maintain even breathing, breath training is applied for ensuring the same minimum respiratory rate during the patient's respiratory phase in order to reduce the displacement error between the puncture target and the body surface location caused by the inconsistent respiratory amplitude after the CT location scan.

   For the DSA with C-arm CT function, the procedures are monitored in real time to avoid the maximum respiratory amplitude mismatch with changes in position.
6. Lung puncture technique: The patient position should be adjusted to meet the requirement of vertical (horizontal) puncture operation as far as posibile. The needle orientation and depth was mesureed on CT scan pictures. The needle entry point should be sterilized, and the needle is punctured into the lung until reaching the predetermined orientation direction after local anesthesia. When the needle reaches the target site, another CT scan is performed to determine the needle location, after which biopsy or ablation and other interventional radiology operations are performed through the pucture path.

   Mediastinal puncture thechnique: There are so many large vascular branches and imprtant organs in the mediastinal zone, therefore, chest enhanced CT must be performed to obtain detail information about the spatial relationship between the lesions and the vessels. As for pucture technique, we should avoid puctur-ing lung or vessels as possible as we can.

5.1.2 The Eight Common Skills of Nonvascular Interventional Radiology

5.1.2.1 Percutaneous Radiography and Catheterization Radiography

1. Percutaneous radiography: It refers to making the physiological tract visible by a contrast agent injected or catheter introduced into the percutaneous physiological orifices of the target organs (e.g., the pleural cavity, bile duct, and renal pelvis) to display the structure and the lesion of the physiological tract. However, the application of new technology such as ultrasound, CT, and MRI makes pure diagnostic physiological cavity percutaneous radiography rarely applied. As a result, the use of therapeutic physical cavity percutaneous radiography has increased.
2. Catheterization radiography: It is applied to make the nonvascular tract (trachea and bronchus, esophagus, and gastrointestinal tract) visible with a contrast agent injected through a catheter introduced through the physiological openings of our body. It is special for the diagnosis and therapy of serious diseases that cannot be diagnosed with conventional angiography, imaging, or endoscopy, such as esophagotracheal fistula, bronchopleural fistula, serious stenosis or occlusion of the main bronchus and bronchial, thoracostomach trachea fistula, severe stenosis or occlusion of the gastrointestinal tract, and gastrointestinal fistula. Radiography via either a catheter introduced through the sinus tract or fistula is used for micro-traumatic intervention to treat complex abscesses, sinus tract, and fistula (e.g., bronchial-alveolar-pleural fistula, bronchial stump-mediastinal-pleural fistula, and bronchial stump-mediastinal-esophageal fistula).

5.1.2.2 Image Assistance for Puncture and Clamp Biopsy

With the more cases of cancer and the rising demand for pathological diagnosis and immunohistochemical and gene mutations from interventional therapy, chemotherapy, targeted therapy, radiotherapy, and cancer surgery, the use of image assistance for puncture and clamp biopsy has increased. Image for biopsy procedures is widely applied in every system regardless of whether a parenchymatous organ or hollow organ is applicable.

1. Puncture biopsy: This technique is applicable to both substantive lesions of the parenchymatous organs and large and substantive lesions of hollow organs. Pathological examination is performed by aspiration of broken pieces of the diseased tissue or by cutting the diseased tissue using a needle placed in the diseased tissue of the target organ under image assistance. Puncture biopsy is essential for high level of cytological and histological diagnosis and has greatly improved the reliability and accuracy of imaging diagnosis. Instead of surgical biopsy, percutaneous needle biopsy has been expanded in the field of pathological diagnosis before treatment and has been developed in the scientific rigor of disease diagnosis and treatment.
2. Biopsy: First, the guide wire and catheter are introduced into a physiological nonvascular physiological cavity (trachea and bronchus, esophagus, and gastrointestinal tract) through the physical openings of the human body. Second, radiography is completed by transcatheter injection of a contrast agent. Third, a sheath of at least 8F is exchanged through the guide wire, to enable biopsy of the stenosis of the cavity tract, the space-occupying lesion of the cavity, the ulcer, or the fistula of the cavity canal, which is accomplished with a clamp introduced through the sheath.

5.1.2.3 Puncture and Aspiration

The liquid obtained from the aspiration of the cystic lesions or other lesions containing liquid objects is used for cytological, biological, and

other diagnoses. With the assistance of image, a puncture needle is directly probed into the liquid lesions in the target organs, and the accumulated liquid substances are aspirated out, after which the liquid is prepared for cytological, bacteriological, or biochemical diagnostic tests. In other words, aspiration of abnormal fluids (e.g., pleural effusion, mediastinum accumulation, blood, bile, urine) can also alleviate the condition.

Image-guided aspiration is suitable for cystic lesions in various sites as well as puncture fistula, puncture colostomy surgery, sclerotherapy, and interventional operations.

5.1.2.4 Fistulation and Drainage

Image-guided fistulation and drainage include two techniques: percutaneous fistulation and drainage and indwelling catheter through a stoma with fistulation and drainage.

1. Percutaneous fistulation and drainage: First, the physiological cavity or fluid accumulation area of the target organ is punctured with a modified Seldinger puncture technique under local anesthesia. Then, a special multisided hole drainage catheter is inserted with the guide wire exchange technique to establish a flow passage to the body. The flow passage can be used for liquid suction or continuous drainage and for the entry and discharge of other objects. This technique is applicable for draining an abscess, empyema drainage, intractable hydrothorax, pleural cavity drainage, intractable pericardial effusion, pericardial drainage, gall or drainage of a bile lake, and drainage of pancreatic pseudocysts.

   For intractable pleural effusion and refractory ascites, it is difficult to diagnose and treat ascites-peritoneal cavity-upper vena cava internal drainage and pleural effusion-pleural cavity-superior vena cava internal drainage. The application of internal drainage reduces the amount of fluid loss comparing to conventional drainage and avoids the loss of circulating blood volume. Thus, it protects the patient's circulatory balance.

2. Stoma indwelling catheter fistulation and drainage: Using a body wall physiological opening, such as the nose or the mouth, the guide wire and catheter are introduced into the physiological cavity, such as the trachea, bronchus, esophagus, stomach, or duodenum, and a drainage tube or fistula are made with the guide wire-catheter exchange technique. The clinical applications include the following aspects.

   Drainage of the esophagus pleural cavity through the nose: This technique is suitable for esophagus and pleural cavity fistulas with esophageal carcinoma or spontaneous or traumatic rupture of the esophagus. Under these conditions, a large amount of saliva, food, and gastric juice overflow into the pleural cavity and result in mixed infection of the pleural cavity. The therapeutic effect of traditional internal medicine and surgery is not ideal; however, modern interventional radiology is effective. First, a drainage tube is introduced (usually a 5F pig tail catheter) at the lower part of the pleural cavity through the nose and esophageal anastomotic fistula, and then the entry of bacteria in sputum, food, and gastric juice into the pleural cavity is blocked by sealing the fistula or rupture with a covered stent. During negative pressure tube drainage period, the pleural cavity become smaller and smaller, and finally, the fistula will be cured. Pleural drainage through the nose and esphagus instead of conventional percutaneous chest wall method will greatly improve the patient's life quality and solve the drainage problem at the same time. Those patient are able to rest in any position, take a shower or bath, and quickly go back to normal life.

   Drainage of esophagus mediastinum fistula via the nose: In patients with perforated esophageal ulcers and esophageal mediastinal fistula, and additional infection of the fistula area and the digestive function of the saliva, the fistula becomes larger which is dangerous for life. Under the interventional radiology treatment, a drainage tube (usually a 5F pig tail catheter) at the lower part of the fistula area is

inserted through the nose and esophageal anastomotic fistula and then blocks the entry of bacteria in sputum, food, and gastric juice into the mediastinum by sealing the fistula or rupture with a covered stent. The drainage catheter can then be used to drain the contents of the fistula cavity out. If necessary, antibiotics can be injected for healing of the fistula or sterilizing of the fistula cavity. Drainage of an esophagus mediastinum fistula through the nose and esophagus instead of the percutaneous chest wall puncture drainage has been greatly improved for patients. The patients are able to rest in any position, take a shower or bath, and quickly go back to normal life.

Stomach tube implantation through the nose and esophagus: It is necessary for patients with chest-stomach trachea bronchus fistula, esophagus-stomach anastomosis fistula, stomach-intestine anastomosis fistula, or stricture to fasten solid and liquid and evacuate gastric fluid in order to prevent the gastric juice from spilling into the surrounding tissue through the fistula and causing fatal injury. The procedure includes that a negative pressure aspiration catheter is inserted into the stomach cavity through the nasal cavity and the esophagus, and the external end is connected with a negative pressure drum.

Implantation of a nutrient tube through the nose, esophagus, stomach, and jejunum: Solid and liquid fasting is necessary for patients with chest-stomach trachea bronchus fistula, esophagus-stomach anastomosis fistula, stomach-intestine anastomosis fistula, or stricture. In addition, adequate nutrition is required for jejunum to maintain a positive nitrogen balance. A nutrient tube is inserted into the jejunum through the nasal cavity, esophagus, stomach, and duodenum, and nutrients are infused regularly.

Intestinal obstruction catheter implantation through the nose, esophagus, stomach, and intestine: With multiple intestinal obstructions, the patient experiences nausea, vomiting, eating difficulties, and nutritional failure symptoms. In order to alleviate pain and maintain the normal function of the gastrointestinal tract, it is necessary to implant an intestinal obstruction catheter through the nose, esophagus, and stomach into the jejunum. The catheter is pushed slowly forward through multiple sections of intestinal obstruction, and then intestinal function recovery and multiple intestinal obstruction relief are consequently achieved.

5.1.2.5 Image-Guided Physiological Channel Dilatation

In this section, physiological cavity is referred as the lumen of all physiological organs except vascular organs; thus, they are nonvascular physiological cavity, such as the respiratory tract (laryngeal and tracheobronchial), digestive tract (esophageal, gastrointestinal, biliary), urinary tract (renal pelvis, ureter, urethra), genital tract (tubal), and all the soft tissue pipes or tubes. A balloon catheter is introduced through the stoma of the body, such as the trachea or bronchus, or a percutaneous cavity of the physiological tract, such as the bile duct or ureter. A contrast medium is then infiltrated into the balloon at a certain pressure, and the narrow cavity is expanded by the external swelling force of the balloon. At a certain pressure in the balloon filled with contrast agent, the balloon expansion force narrows the cavity itself. Physiological cavity angioplasty is applicable to, for example, airway stenosis, esophageal achalasia, esophagus and anastomotic stenosis, and anastomotic stenosis.

1. Simple balloon angioplasty: Balloon angioplasty is applied for local or annular cicatricial stenosis of the trachea or main bronchus by a balloon diameter of 15–20 mm. Large lumen stenosis, such as achalasia, congenital megacolon, and anastomotic stenosis, requires a larger balloon (25–45 diameter mm) for a better expansion effect.
2. Balloon dilatation and internal prosthesis implantation: After angioplasty of benign or cicatricial stenosis of a fine cavity, such as the bile duct or ureter, a pipe or tube is also needed to support connotation for a period of time

(usually about 3 months) and to maintain sufficient fibrous connective tissue remodeling. The lumen is not easily narrowed after scar tissue has completely formed.

3. Balloon angioplasty and stent implantation: As a principle, benign or cicatricial stenosis is unsuitable for stenting or at least for permanent stenting. For the cicatricial stenosis of the trachea, such as trauma, operation, endobronchial tuberculosis, and cricoid degeneration, stent implantation is indispensable when balloon dilatation is ineffective. A covered recyclable stent is applicable and then removed or replaced after 3 months.

5.1.2.6 Natural Orifice Transluminal Stent Placement

Natural orifice transluminal stent placement is applied for the stent conveyor through the physiological openings in the body wall, such as through the oral cavity to the tracheal bronchus, or percutaneous puncture to the physiological cavity such as percutaneous puncture of the biliary tract as a result, it releases the external expansion stent in the physiological cavity of the lesion. Relief of stenosis then relies on the external expansion of the stent or on the expansion of the stent and covered stent to a closed wall fistula.

Previously, a stent was used to treat stenosis of the cavity, and a covered stent was used to seal the fistula. Since then, the use of a covered stent has been greatly improved the efficacy of the malignant lumen stenosis. The covered stent effectively limits the growth of tumor cells along the inner mesh into the lumen. Recently, benign cicatricial strictures, such as trachea and main bronchial stenosis, have been recommended for biocompatible stents or retrievable covered stents. Either for benign or malignant lesions, and either relieving stenosis or occlusion of the fistula, covered stents in the nonvascular physiological cavities have been more widely developed.

1. Stent placement
   Direct stent placement, if the stenosis is not very serious, or around tissue margin (malignant tumor), does not require pre-expansion. The stent can be successfully implanted through the stenosis area to have a pre-expansion effect [3]. After release of the stent, the expansion force can effectively alleviate the narrows. A variety of malignant tumors can cause cavity stenosis. Tumor tissue is relatively fragile, and stent expansion can solve the stenosis problem. Cavity fistula can also be solved by convered stent to isolate fistula theoretically. Generally, cavity fistulas do not show serious stenosis and can also be put directly into the stent graft-sealing fistula.
2. Balloon dilatation and stent placement
   For benign scars of severe cavity stenosis, such as bronchial endometrial tuberculosis stenosis, the scar consists of a large amount of fibrous connective tissue. The tissue in the narrow area is extremely tough, which is hard to pass through for the stent carrier; therefore, the stent cannot be released and effectively expand. In these cases, a balloon or even high-pressure balloon should apply for pre-expansion. The balloon diameter is selected according to the normal cavity, and stent implantation performs after balloon expansion.
3. Retrieval stent placement
   Stent placement is usually permanent. With the increase in the application of stents in physiological cavities, permanent stents bring about various complications; therefore, temporary and recyclable stents have been developed. These stents are used in retrieval internal stent placement, which is also referred as temporary stent placement. Temporary stents are used to lift the stenosis or occlusion of the fistula and are able to convert into a full-scaffold stent when the narrowing is released and scar tissue remodeling is done. During fistula healing (bronchial pleural fistula), the stent is for the intended treatment, after which the internal stent is removed in order to avoid long-term internal stent complications.

   The literature also has reported biodegradable endotracheal stents; however, these have been still in the laboratory stage [4, 5].

5.1.2.7 Natural Orifice Transluminal Foreign Body and/or Stone Extraction

Natural orifice transluminal foreign body extraction is used to remove foreign bodies through a body wall opening or via direct percutaneous puncture by introducing foreign body capture equipment, such as a foreign body clamp or foreign body basket. The foreign body is viewed under image monitoring and then pulled out. Currently, the foreign bodies mostly comprise iatrogenic foreign bodies, such as fractured catheters, displaced drainage tubes, and foreign object/stones that block stents. Those foreign body can be removed using interventional radiolgoy method.

1. Displaced stent extraction: It is generally applied for slipped upper tracheal stents, displaced main bronchial stents, and esophageal or cardiac stent removal from the stomach cavity. With interventional radiology techniques, a guide wire and catheter, guide wire exchange can be used to retrieve the stent. The reinforced guide wire is inserted into the inner bracket to take out the hook suit; then, the fixed bracket is then hooked, and the internal support in the large sheath tube is pulled out.
2. Extraction of a retrieval stent: To resolve refractory scar stenosis or occlusion of the fistula, a stent can be placed temporarily, such as a temporary tracheal stent. After the posterior fistula is cured by the implanted stent, or after the completion of plastic surgery including stent placement in scar tissue, the stent can be removed to avoid or decrease the chance of long-term complications. The guide wire and the catheter reinforcing wire are then exchanged along the inner stent cavity to the inner stent. The reinforced guide wire is pushed along the inner bracket to take out the hook suit, and the fixed end is hooked to the end of the recovery line or directly hooked to the inner frame of the prepared wire, and then the internal support of the large sheath tube is pulled out of the body, or the stent is pulled out of the body directly through the physiological lumen. This technique is an important technical advance in interventional radiology recently. It makes an achievement in the pathogenesis of bronchial benign stenosis, bronchopleural fistula, esophageal stenosis, and esophageal fistula.

5.1.2.8 Ablation

The word “ablation” refers to the melting of ice or snow from a glacier or an iceberg or to the surgical removal of body tissue. Image-guided ablation is classified into two different techniques: puncture ablation of solid tumors and cavity organ tumor catheter ablation.

Most percutaneous malignant tumor abaltion can be performed under local anesthesia. The ablative material, such as ethanol, pinyangmycin, or liquid helium, is then injected into the lesion using a needle or through a special puncture needle (ablation needle) connected to an external device to produce microwave heating, radiofrequency (RF) heating, or freezing action. The tissue is thus degenerated and necrozed to eliminate the disease or treat the tumor. Puncture ablation is widely used for benign and malignant solid tumors, small cancer, residual cancer, small adenoma, simple cysts, intractable abscesses, arteriovenous malformations, hemangiomas, and ganglions. The treatment of solid tumors by puncture ablation can achieve the same effect as radical treatment or surgical resection. Minimally invasive ablation has become the main surgical treatment for solid tumors.

Catheter ablation: Catheter ablation of the lumen or wall of the tumor is performed by radiofrequency catheter ablation through the nasal cavity (oral cavity) into the trachea and bronchi (esophagus). It is for treatment on tracheal tumors, main bronchial tumors, lobar bronchial tumors, and esophageal cancer; moreover, it also plays an important role in the treatment of cavity canal tumors.

1. Chemical ablation: Tumors or lesions are subjected to local injection of chemical substances, such as tumor cells degenerate, coagulate, and undergo necrosis. It is recognized that anhydrous ethanol is the ideal

chemical ablation agent which is responsible for tumor cytoplasm dehydration, protein coagulation, and denatured cell destruction. It also results in tumor tissue vascular endothelial cell degeneration and necrosis, secondary thrombosis, and tumor tissue necrosis. Chemical ablation can be used to treat lung bullae, lung cysts, bronchial cysts, and mediastinal lymphatic cysts.

2. Microwave ablation: Microwave ablation is a sort of thermal ablation technique. Microwaves are electromagnetic waves with a frequency of 300 MHz to 30 GHz. Their short wavelength and concentrated energy allow microwave puncture needles to create a high-frequency magnetic field around the water molecules and other charged ions, resulting in frictional heat conducted to the surrounding tissue in a very short period of time, a local temperature of 65–107 °C, and tissue degeneration and necrosis. A new type of microwave puncture antenna with cycled water or a condensate circulation puncture needle does not generate heat in the tumor tissue coagulation process, resulting in no overheating of the surrounding tissue, allowing longer-term transmission of high-powered microwaves for treatment up to 60 mm. The ablation technique can also be applied to tumor more than 100 mm, when adopting multi-antenna needles trategies.
3. Radiofrequency (RF) ablation: RF ablation is a thermal ablation technique that was first used in 2000 to treat lung cancer. Since then, RF ablation has been applied to a variety of benign and malignant substantive tumors. A physical current in the range of 200–1200 kHz with high-frequency oscillation generates friction heat that results in tissue coagulation and necrosis. Heating tissue at 45 °C for several hours causes irreversible damage. Temperatures above 60 °C can cause quick coagulation and necrosis. RF can cause coagulation and necrosis of both tumor tissue and peripheral normal tissue; however, in tumors around vascular tissue, coagulation forms a reaction zone that prevents tumor metastasis from restoration of tumor blood supply.

   RF ablation is suitable for all kinds of benign and malignant solid tumors in various parts of the body.
4. Nano-cryoablation: Nano-cryoablation is now a new ablation technology in the market.
5. Cryoablation: Cryoablation/cryotherapy is an old technology. The US FDA-approved Cryocare™ surgical system, the use of argon in refrigeration, helium targeting rewarming, biosensing, real-time monitoring, and many other technologies exploit ultra-low temperatures. Cryoablation with multi-needle combinations can extend the tumor ablation range as more than 100 mm. The use of special puncture needles with argon can generate ultra-low temperatures at −140 °C. This results in the formation of therapeutic ice crystals in cells, with rapid necrosis, whereas ice formation in cells outside the target area is minimal. The treatment stimulates the body immune response, without pain to improve the immunity.
6. Radiation particle ablation: Radiation particle ablation involves in the imaging-guided insertion of multiple metal bodies comprising radioactive sources/particles via local puncture into the tumor. The subsequent sustained local radiotherapy can completely kill the tumor. Radiation particle ablation is used for treating lung cancer and mediastinal lymph node metastasis.
7. Bone cement: In recent years, percutaneous vertebroplasty has led to a higher level of local puncture and ablation. In this technique, bone cement, which solidifies at 80 °C to a substance as hard as stone, is percutaneously injected into a tumor. After heating at 80 °C, the solidified bone cement is able to kill the local tumor tissue, eliminate intractable pain, and stabilize the reconstruction of the spine for allowing patients to resume normal activity.
8. Laser ablation: Laser ablation, another local thermal ablation technology, includes interstitial laser therapy and photodynamic therapy.
   Interstitial laser photocoagulation: The laser probe is incorporated into the puncture needle or endoscope. At the tumor area, the longitudinal

conduction of the laser probe is converted into radial scattering to result in higher tissue temperature, denaturation, coagulation, and even necrosis. Tumors with a diameter of 20 mm can be destroyed immediately. Larger lesions are caused by repeated treatment or by the multi-pin coupler synchronous treatment. Interstitial laser photocoagulation can be applied for various benign and malignant tumors and discs.

Photodynamic therapy: A photosensitizer is intravenously injected and selectively retained in the tumor. An appropriate wavelength of laser irradiation is then applied to the local tumor and stimulates the instantaneous generation of single-phase oxygen, which has an affinity for the tumor cell matrix to destroy tumor cells. Photodynamic therapy can definitely affect the tumor; however, the effect on the surrounding normal tissue is very small. This technique is mainly for the treatment on body surface or cavity tumors, such as tracheobronchial cancer.

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6 Interventional Radiology Instruments and Stents in Tracheobronchitis

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6.1 Guidewire

The traditional guidewire used to treat tracheobronchitis is a complex structure composed of a thin steel wire core and spiral coat. It is classified according to the activity of the inner core wire: either a fixed core guidewire or a movable core guidewire. In the latter, the softness of the front end of the guidewire can be adjusted. The traditional guidewire that is mainly used is the strengthening or exchange guidewire because of its stiff texture and large friction force potential.

Types of modern guidewire include ordinary, exchange, and stiff guidewires. The ordinary guidewire has almost been replaced with the hydrophilic film-coated guidewire. The external diameter is measured in inches (in.), for example 0.032 in., 0.035 in., and 0.038 in. The 0.035-in. guidewire is the most common. The length of the guidewire is measured in centimeters (cm), for example 45 cm, 150 cm, 180 cm, 260 cm, etc. A 0.035 in. × 150 cm (180 cm) guidewire is commonly used for clinical intubation or selective intubation. There is a 3- to 10-cm soft segment at the front of the guidewire to avoid damage to blood vessels or the physiological lumen. The head end of the guidewire is straight or curved in a J shape, and is more commonly used in clinics.

6.1.1 Hydrophilic Film-Coated Guidewire

There are different brands of hydrophilic film-coated guidewires. The hydrophilic film-coated guidewire made by the Terumo Company of Japan is commonly called the black loach guidewire because of its color. It is divided into ordinary, soft, and super stiff according to its hardness/rigidity. Recently, the U.S. Merit Aureate, Inter V hydrophilic membrane-coated guidewire became available. This hydrophilic membrane-coated guidewire is mainly used a guiding catheter for selective or super-selective intubation.

6.1.2 Exchange Guidewire

The exchange guidewire is also called the elongated guidewire. It has the same diameter as the ordinary guidewire, the hardness is the same or harder than that of the ordinary guidewire, and its

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length is 180–260 cm or longer. The exchange guidewire is mainly used to exchange and introduce the guide tube, balloon catheter, stent push device, etc., which are long and/or relatively thick or hard instruments.

6.1.3 Super Stiff Guidewire

The super stiff guidewire is also known as the super stiff exchange guidewire. The super stiff guidewire includes hydrophilic film coating (RF PA35263M, Terumo, Japan; TSMG-35-260-LES, COOK, USA), an ordinary guidewire structure (RFPC-35-260, COOK, USA; M00146500, Boston, USA), and a steel structure (76xx3035-06, Germany). This guidewire is mainly used for operations with a longer path or a tortuous vascular path for switching and introducing coarse and/or hard interventional devices, such as stents to target sites. Furthermore, for airway stenosis, super stiff guidewire is indispensable in surgical procedures like balloon dilatation and stent placing.

6.2 Catheter

The catheter is a thin-walled, large cavity, smooth, slender tube made of plastic (e.g., polyethylene), which has a high atomic number material, such as barium, to increase its X-ray radiopacity. The outer diameter of the catheter is measured in F (French No.), i.e., the French unit. This is a measurement of the outer perimeter of the catheter (mm), for example, a 5 F catheter has an outer perimeter of 5 mm, while the outer diameter is equivalent to $5/\pi = 1.59$ mm (5/3.14). The inner diameter of the catheter is measured in inches, which is convenient for coordinating with the guidewire, 0.035 in. and 0.038 in. catheters are commonly used. The length of the catheter is measured in centimeters, for example 80 cm, 100 cm, and 120 cm. In thoracic and abdominal vascular surgery, an 80-cm catheter is often used. When operating through the oral or nasal passage, trachea, or tracheal bronchus, an 80–100 cm catheter will be used.

The front end of the catheter can be a straight head or a special shape. In order to adapt to the target blood vessel and the passage of the lumen path, the head of the catheter can have a customized shape to facilitate the selective catheterization of the target blood vessel, bronchus, etc. The head of the catheter often has an end hole. Besides the end hole at the head end, there are many different side holes, such as a pigtail catheter, straight head multi-side hole catheter, etc.

Catheters are classified into soft, common, and stiff types. Different brands are made with different textures. Soft catheters are produced by the Terumo Company (Japan) and by COOK (USA), and stiff catheters are produced by the Cordis Company (USA). Surgeons must choose the catheter according to the type of surgery, for example, a harder texture catheter for trachea and bronchus intubation.

6.2.1 Straight Head Multi-Side Hole Catheter (HNR5.0-35-100-P-10S-0, COOK, USA)

This catheter is a tip high-flow catheter, 5 F in diameter, 0.035-in. core, and 100 cm in length with a plastic tail and ten side holes. The injection rate can be increased to 27 ml/s under a pressure of 1,200 psi (pounds per square inch; 1 pound per square inch (PSI) = 6.894757 kPa). It is one of the most common catheters in interventional radiology therapy. It is also used in angiography for the injection of drugs, negative pressure suction, and drainage of local effusion and empyema.

6.2.2 Pigtail Catheter (HNR5.0-35-100-P-10S-PIG, COOK, USA)

This catheter has a pigtailed shape: its head end has multiple side holes (approximately ten holes) and is curved in a pigtail shape. It improves the contrast effect because of its pigtail shape and avoids damage caused by high pressure constantly applied in one direction, damaging vascular walls, when a straight catheter is used to perform high pressure angiography. The pigtail catheter can also be used for the drainage of local effusion and empyema.

6.2.3 Aurous Centimeter Sizing Catheter (N5.0-35-100-P-10S-0, COOK, USA)

This catheter is a specific type of pigtail catheter, with gold bands at 10-mm intervals immediately after the pigtail bend in the head. During angiography of a physiological cavity, the catheter's delineations can be used to measure lesion size because of the different magnification rate of X-rays.

6.2.4 Hunter Head Catheter (451-535HO, Johnson, USA)

This catheter was designed by Hinck and Judkins for cerebral vascular intubation and is commonly used in tracheal intubation through the oral or nasal cavity.

6.2.5 Cobra Catheter (451-543HO, Johnson, USA)

This catheter was also designed by Judkins, and is so named because of the shape of its snake-like curved head end. It is one of the most common multifunctional catheters. According to the angle of the head end bend, the catheter is divided into three types: C1, C2, and C3. In the interventional treatment of massive hemoptysis, this catheter is mainly used for bronchial artery catheterization and interventional embolization therapy.

6.3 Balloon Catheter and Dilator

6.3.1 Balloon Catheter

6.3.1.1 The Structure of a Balloon Catheter

The double lumen balloon catheter is the most commonly used balloon catheter. The front end of the catheter is wrapped with a balloon, and a small hole on the tube wall of the wrapped balloon connects with one lumen of the catheter. There are two cavities in the catheter: one cavity continuously connects with the balloon from the side wall of the tail end to the front end, to fill and dilate the balloon, the other cavity is continuous from the head end to the tail end for transport of the guidewire and injection of drugs or contrast agents.

The diameter of the balloon catheter core is 0.018 in., 0.035 in., or 0.038 in. The 0.038 in. catheter is the more common type as it allows the exchange guidewire and stiff guidewire to pass through. The exterior diameter of the rod part of a balloon catheter is 5 F, 6 F, 7 F, 8 F, or 8.5 F. The outer wall is smooth for passing the sheath over or easily guiding the catheter. The length of the rod part of the balloon catheter ranges from 70 to 135 mm. The diameter of the balloon catheter lumen ranges from 2 to 45 mm, and the length of the balloon ranges from 2 to 20 cm. Both sides of the effective expansion length of the balloon catheter have a radiopaque tip for accurate positioning through narrow areas, and the maximal tolerated filling pressure of the balloon ranges from 1 to 20 atmospheric pressure (1 standard atmospheric pressure (ATM) = 101.325 kPa).

6.3.1.2 Types of Balloon Catheter

1. Gruntzig balloon catheter: This is the typical double lumen balloon catheter, the most basic type of balloon catheter and the most common balloon catheter in interventional radiology.

   The Large Omega NVTM Valvuloplasty Balloon Catheter (LONV8.5-38-100-30-5.0 made by COOK, USA) is a typical double lumen balloon catheter with an 8.5 F exterior diameter, 0.038 in. inner core, total tube length of 100 cm, maximum balloon diameter of 30 mm (diameter can be 20, 22, 25, 27, or 30 mm), and effective balloon length of 5.0–8.0 cm; the balloon can withstand four atmospheres. The inner core rod of the balloon part of the balloon catheter and the remaining part of the catheter are integrated (if the balloon diameter is greater, it will need a 14 F sized sheath) and this provides sufficient hardness, support force, and thrust force. This type of catheter is easy to puncture through the skin and easy to pass through the lumenal obstruction.

2. Cutting balloon catheter: This type of catheter is also a double lumen balloon catheter and is a new interventional instrument invented and applied in clinics in recent years. The balloon part, or area above the balloon, has a micro blade. In balloon angioplasty, the blade is used to cut away areas of calcification or severe fibrosis tissue at the same time as balloon dilatation. The calcified stenotic vessels or bronchial lesions are easy to expand. If the calcification is removed, the rate of restenosis after the expansion is decreased. At present, there is only small or middle-sized cutting balloon catheter (approximately 10 mm in diameter) available.

6.3.1.3 Dilating Force

The dilating force refers to the pressure on the surrounding tissue after filling the balloon, which consists of hydrostatic pressure produced by injecting a contrast agent into the balloon and the hoop stress (HP) produced by balloon dilatation. According to Laplace's law, HP = $P \times D$, with P being the pressure inside the balloon and D the diameter of the balloon. The greater the pressure and diameter of the balloon, the greater the dilating force of the balloon. The higher the pressure of the inner balloon, the greater the dilating force of the balloon on the stenosis, so the pressure of the filled balloon must reach or be close to the allowed standard. If the pressure is too low for lesion expansion, the patient can relapse easily after treatment. If the pressure of the balloon is too high to expand. The heavier the degree of the stenosis, the stronger the dilating force it can bear. If there is uniform toughness around the stenosis and the acceptable tension is evenly spread, the area will be easy to expand. Otherwise, the accepted expansion force will not be uniform and the pressure is irregular. Therefore, the long-term effect of simple balloon dilation is not ideal for those with calcification, inhomogeneous stenosis, eccentric stenosis, and so on. This issue still needs further efforts to improve the treatment efficacy.

6.3.1.4 Balloon Compliance

Balloon compliance refers to the change in the diameter when the unit pressure in the balloon changes. The diameter of the balloon does not change when there is a change of pressure inside the balloon (from 1 to over 10 ATM, 101–1,010 kPa); even if the balloon ruptures, its diameter remains constant. It is not the pressure inside the balloon but the retraction force of the lesion that causes resistance when the balloon is inflated and the lesion expanded.

6.3.2 Dilator and Coaxial Dilating Catheter

The coaxial dilating catheter, made by sheathing a thin catheter in a coarse catheter (Figs. 6.1 and 6.2), gradually increases the vessel diameter to avoid or reduce the possible cavity damage caused by direct dilating using crude dilatation. The coaxial expansion tube can produce longitudinal thrust to the narrow pipe wall during the pushing process and reduce the risk of longitudinal tear of the tube wall. With the use of the balloon catheter, the coaxial dilating catheter is rarely used. Nowadays, the coaxial catheter technique is used in the 12–16 F large sheath tube for introducing a tracheal cannula.

In 1964, Dotter first reported the vascular coaxial catheter technique. In 1968, Staple

Fig. 6.1 Coaxial dilating catheter

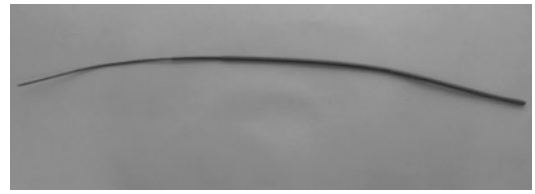

Fig. 6.2 Coaxial dilating catheter

Fig. 6.3 Dilating catheter

Fig. 6.4 Inner core and sheath

modified Dotter's coaxial catheter technique in which he replaced the coaxial catheter with a tip tapering off catheter. The catheter surface is smooth so that it easily passes through the narrowed area, and was known as a dilating catheter or dilator (Fig. 6.3), for dilating puncture pathways in the modified Seldinger puncture technique. Since this time, along with the extensive application of vascular sheath tube technology, the expander is used as the inner core of the sheath (Fig. 6.4). There is not a large market for the individual coaxial dilating catheter.

6.4 Stents

Depending on the physical support characteristics, a stent can be divided into three categories: self-expanding stent, thermal shape memory alloy stent, and balloon expandable stent.

6.4.1 Self-Expanding Stents

There are many kinds of self-expanding stents, most of which are made with stainless-steel wire. For use in clinics, there are Z-shaped stents, Wallstents, double spiral stents, etc.

1. Z-shaped stent: There are several subtypes of Z-shaped stents, such as Gianturco, Gianturco-Rosch, retrievable, spiral Gianturco, etc.
   (a) Gianturco stent: This is a basic Z-shaped stent. The stainless-steel wire is folded into a round tubular structure with a diameter of 0.25–0.5 mm. The outer transverse diameter is 5–35 mm and the length is approximately 10–40 mm. The greater the number of struts, the greater the angle between the struts. The greater the diameter of the steel wire, the greater the expansion force of the stent. The longer the length of the single stent, the smaller the expansion force. When the length of the lesion is long enough, multisegmental stents with the same diameter (total length is 50–75 mm) can be used.

   Z-shaped stents contain a small bracket wire frame so the connection area of the steel frame and the physiological lumen wall is very small. The stent wall is partially covered by the wire frame, which results in little effect on vascular branches, except for veins where blood flows relatively slowly. In the airway, this stent has little influence on expectoration function due to covering fewer ciliated columnar epithelial cells of the airway.

   (b) Gianturco-Rosch stent: Rosch modified the structure of the Gianturco stent. The Gianturco-Rosch stent has the reflexed point at the two ends of the stent welded into a mesh hole, or bent into a small hole, and then the holes are connected into a ring structure by a nylon operation thread (Fig. 6.7) to avoid both ends of the stent becoming over-expanded. To prevent stent displacement, it is necessary to install a small hook or thorn on the stent. This type of stent can be connected with several stent monomers into a complex or multi-structure by sewing holes at both ends of the stent with a nylon thread or welding several single stent segments using a single steel wire to lengthen the stent. The lengthened stents possess good flexibility and strong expansibility, suitable for long segment diseases. The different lengths are: 25 × 50 mm (25 mm in diameter, 50 mm in length), 30 × 50 mm (30 mm in diameter, 50 mm in length),

and 30 × 75 mm (30 mm in diameter, 75 mm in length).

(c) Retrievable stent: This stent is often encountered in clinical practice. The stents described above cannot be adjusted or removed if the position is not correct. In a retrievable stent, in order to improve the structure of the Z-shaped stent, the head end inflection point of the last segment stent connects with the tail end inflection point of the other segment of the stent into a unit with a long connecting rod, and the connection points are welded with each supporting rod into small holes with silver, and then a single strand of surgical nylon thread is threaded through all the holes to form a nylon thread ring with a diameter of 1 mm. This thread ring is connected to a single strand of fluorocarbon thread of diameter of 0.2 mm to retrieve the stent. During the operation, if the stent is in an appropriate location, the fluorocarbon thread is removed; if the stent is in the incorrect location, the fluorocarbon thread can be pulled to retrieve the stent and replant it with a stent transporter.

2. Wallstent: This is a woven stent. The stent is made using a universal weaving method where a tubular structure is woven using 20 surgical stainless-steel wires, creating a tube with a diameter of 0.1 mm. The cross point of the wire braid is easy to move or slide. This stent has good flexibility (30–40%) under compression.

Due to the staggered woven structure, this stent has longitudinal flexibility and does not become flat or collapse if the stent bends. Therefore, it is suitable for tortuous and narrow vessels. This stent can be endothelialized quickly and causes reduced damage to the branch vessels (arterial blood vessels) with the thin braided wire and a relatively large mesh (up to 77% of the area). In order to adapt to different vascular vessels, the stent can be woven with different diameters and lengths. Excessive proliferation of endothelial cells at both ends of the stent does not occur because of a good radial compliance and an even supporting force, thus creating a natural transition between the stent and the vessel. When the stent is not completely opened at the lesion, the operator can use a balloon to expand posteriorly.

6.4.2 Thermal Shape Memory Alloy Stent

Nickel titanium (nitinol, NT) is an alloy with the ability of shape memory. At low temperatures (4 °C), the alloy changes into an extremely soft, stretched structure, while at a higher temperature (medical memory alloy at 25–50 °C), the alloy will recover its original shape.

6.4.2.1 Carved Thin Wall Nickel Titanium Alloy Tube Stent

This is a stent in rhombus frame structure carved by a laser. This stent has good flexibility, large expansion force, abrasion resistance, corrosion resistance, easy delivery, good biocompatibility, and rapid endothelialization. It is similar to a Wallstent stent but has improved elasticity and a larger mesh.

6.4.2.2 Nickel Titanium Alloy Wire Braided Expander Stent

This stent is made by weaving a single nickel titanium alloy wire around a stent mold. It can be woven into various tube shapes: tube with L-shaped branch, L-shaped branch and tubular integrated, L-shaped branch and sub warhead integration, Y-shaped branch and tubular integrated, Y-shaped branch and single sub warhead integrated etc., in order to adapt to the physiological cavity, such as various complex inner structures of the trachea and bronchus. The most common stent used in the trachea and bronchus is a combination of a stent that has good dilatation and compliance. This stent contains an ordinary stent, bare stent (uncovered stent), partial covered stent, and covered stent according to its use. Domestic brands include the Nanjing Minimally Invasive Company, and imported brands include the United States Boston and Korea Cathay products.

1. Tubular tracheal stent: This is the most widely used endotracheal stent and the only tracheal stent in the world with only a single tubular structure. It includes an ordinary tubular bare stent, a tubular partially covered stent, and a tubular full covered stent (Fig. 6.5).
   (a) Ordinary tubular stent: This is a tubular stent with one or two markers often attached to both ends of the stent. These markers allow the ends to be located in an X-ray. The stent is loaded into a delivery conveyor, assembled into a delivery system, and reserved for sterilizing in the package. The most commonly used stent is 40–80 mm in length with a diameter of 12–26 mm.

   The tubular stent is mainly used for a tracheal tumor or tumor outside the tracheal wall, such as mediastinal lymph node metastasis tumors, which cause tracheal stenosis. The length of the stent should be 10–20 mm longer than the length of stenosis, and the diameter is 10% more than that of the normal trachea. Because the biocompatibility of NiTi alloy wire is poor, stenosis may be caused by lumen over-hyperplasia in the open environment of the lumen and trachea with bacteria. Therefore, the tubular bare stent is not suitable for long-term implantation for benign tracheobronchial stenosis.
   (b) Partially covered tubular stent: 50–80% of the outer wall of the stent is coated with a polymer medical polyester film or silicone membrane on one end of the stent (upper or lower) or in the middle. Severe coughing may easily result in stent displacement with small friction force because the covered segment is smooth, while the bare section exerts a fixing function due to a larger friction force. In general, the stent section plays a therapeutic role, which blocks the growth of tumor cells into the lumen, or seals a fistula, while the bare section plays a fixation role to prevent stent displacement.

   The partial covered stent is used for the treatment of airway stenosis of benign or malignant tumors, tracheal rupture, tracheal mediastinal fistula, upper esophageal tracheal fistula, gastroesophageal anastomotic fistula, thoracic cavity bronchogastric fistula, cicatricial stenosis after tracheotomy, tracheal intubation, etc. The upper airway lesions need a stent that has the upper section covered and the lower section bare. For middle trachea lesions, the covered upper or lower section stent is chosen. For lower tracheal segment lesions, the covered lower part stent is always applied; the bare stent tends to cause secondary over-hyperplasia of the endothelial tissue. The tubular partial covered stent can also be used as a retrievable stent in the trachea [1, 2].
   (c) Tubular complete covered stent: The tubular stent is completely covered with medical polyester film. Fixation of the tubular stent is poor, as repeated violent coughing tends to displace the stent [3, 4]. Due to the lower level of irritation with good biocompatibility, the advantage of the stent is less proliferation of endothelial cells and stent restenosis rate. The covered stent can be removed easily, and is the most common retrievable stent type in the trachea (Fig. 6.6).

   The covered tubular stent is used for upper tracheal rupture, upper tracheal mediastina fistula, upper esophageal tracheal fistula, gastroesophageal anastomotic fistula, thoracic cavity bronchogastric fistula, cicatricial stenosis after tracheotomy, tracheal intubation, etc.

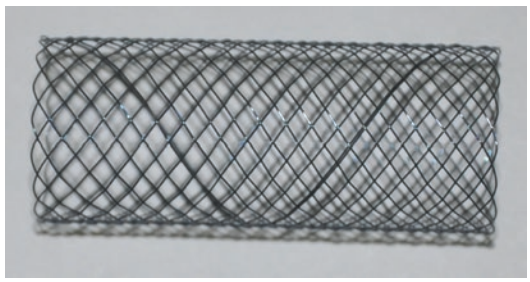

Fig. 6.5 Tubular airway stent

If the above lesions occur in the lower trachea, the Y-shaped integrated covered stent should be chosen, which has the advantage of being easy to fix, but not easy to move.

The tubular covered stent is not suitable for the bronchus, because it tends to move to the upper trachea and covers the contralateral main bronchus with less small frictional force and poor fixation, causing asphyxia and endangering life.

2. L-shaped tracheal branch stent (Patent NO. 3235769.9): The original name of the stent is the "main bronchus sliding free stent," or the "branch stent" for short. Domestic and foreign medical experts consider it a "Han Xinwei internal stent," one of a series of respiratory stents invented by Dr. Xinwei Han. The stent is L-shaped, with two parts, a main and a branch part. According to its function, it can be divided into an L-shaped trachea and main bronchus branch type (big branch type stent, main body in the trachea and branch part in the main bronchus), and main bronchial branch type (called a small branch stent, main body in the main bronchus, the branch part in the lobar bronchi). The stent is composed of two tubular stents with different diameters, the connection area of woven silk is located medially and laterally (small curved side), accounting for 90–180° of the circumference of the body. The inner side of the junction (greater curved side) is an opening area in the range of 30–50°. The angle between the main body and the branch is in the range of 120–150°. The diameter of the main part (such as the tracheal component) is larger, and the branch part (main bronchus component) is smaller. The commonly used type is the L-shaped partially covered trachea and main bronchus branch stent (Fig. 6.7).

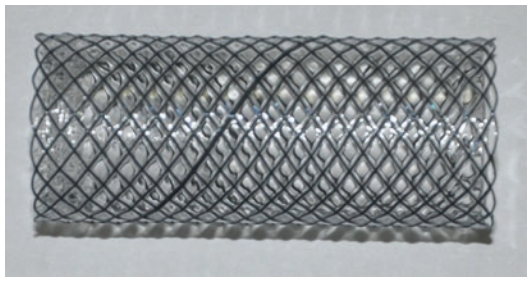

Fig. 6.6 Covered airway stent

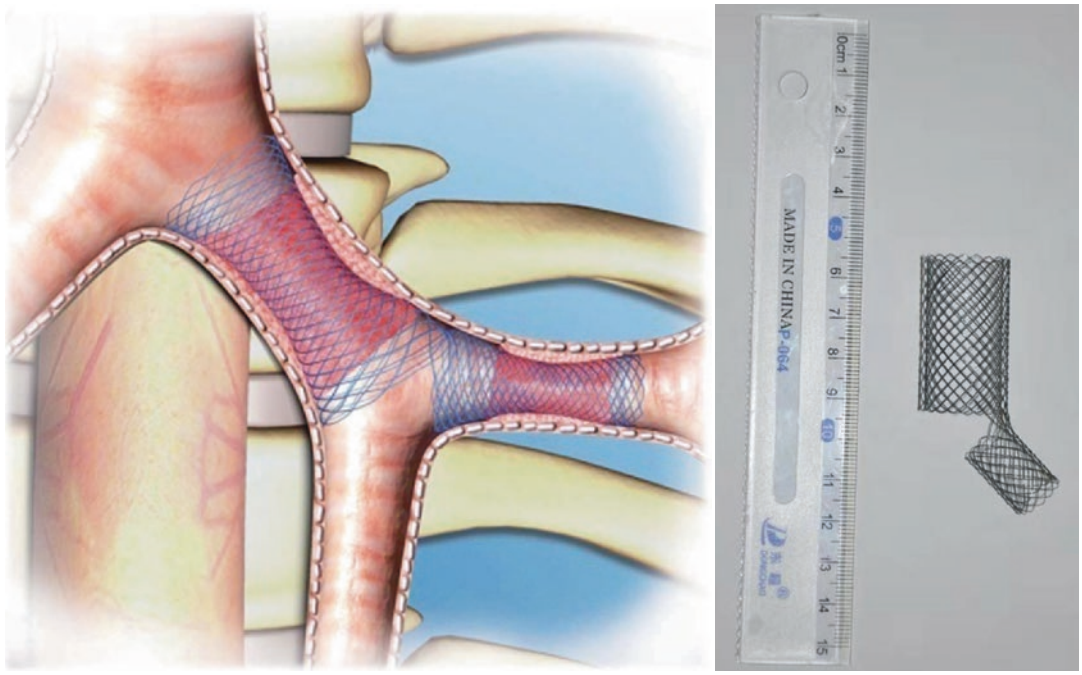

Fig. 6.7 L-shaped airway stent

(a) L-shaped trachea and bronchus branch bare stent: Both L-shaped trachea and bronchus branch bare stents are treated as bare stents. The stent is woven with a temperature-memory nickel titanium alloy wire for complex external pressure stenosis caused by mediastinal lymph node metastasis lesions involving two grades of bronchus, such as the lower trachea and unilateral primary bronchi; primary bronchial and upper lobe bronchus; intermediate bronchus and middle lobe bronchus. In this situation, both the main component and the branch component exert a treatment function. Furthermore, it is also applied to the simple primary bronchus or lobe bronchus stenosis caused by external pressure. In this way the branch component functions to fix the stent in place and prevent stent migration.

(b) L-shaped partial covered tracheobronchial branch stent: The branch component of the stent is covered by polymer medical polyester film, and so becomes a closed, airtight, watertight tube of nickel titanium alloy wire mesh wrapped in polyester film. The polyester membrane is highly biocompatible with human tissues without causing hyperplasia.

The partially covered tracheobronchial branch stent is suitable for benign or malignant bronchial stenosis, upper lobe bronchial pleura fistula, and other diseases. The covered part of the stent is used for therapy while the main component (bare stent) fixes the stent in place. The primary bronchial and lobe bronchial branch area covered stent is suitable for benign stenosis and inner cavity tumor stenosis of the upper lobe bronchus.

(c) L-shaped trachea and bronchus branch covered stent: Both the main component and the branch component are covered with polymer medical polyester film. The polyester film wraps the nickel titanium alloy wire and blocks the mesh completely, so that the body and branch components of the stent become two airtight, watertight, sealed tubular structures.

This type of stent is suitable for benign and malignant stenosis of the trachea and lateral primary bronchi, and fistula of the trachea and unilateral primary bronchus wall (tracheobronchial mediastinal fistula). The L-shape covered stent is suitable for benign stenosis or malignant inner cavity stenosis, etc. The primary bronchi and lobar bronchus branch complete covered stent is suitable for benign stenosis or inner cavity stenosis with tumor of the primary bronchi and upper lobar bronchus, benign stenosis, or inner cavity stenosis of the middle bronchus and middle lobe bronchus, etc.

3. L-shaped tracheobronchial branch integrated stent (Patent No. 20112005784.9): This is an improved type of L-shaped tracheobronchial stent branch, “branch integration stent” for short, and is another in a series of respiratory stents invented by Dr. Xinwei Han, which were called Hanxinwei’s stent. It contains both the L-shaped branch and straight tube cavity structures. According to the location site, it can be divided into the tracheobronchus branch integrated covered stent (large branch type) and the primary bronchus and bronchial branch integrated stent (small branch type). The stent is composed of a close connection between two tubular stents with different diameters, a connection area of woven wire around the entire circumference. The angle between the tracheal and bronchial component is in the range of 120–150°. The body component, such as the trachea component, has the larger diameter, while the branch component, such as the primary bronchus component, has the smaller diameter. The commonly used types are the L-shaped tracheobronchus branch covered stent, and the primary bronchus and lobar bronchus branch covered stent (Fig. 6.8).

(a) L-shaped tracheobronchus branch integrated covered stent: The body component, the connection component, and the branch component of the stent are completely covered with a polymer medical polyester film, which covers the nickel titanium alloy wire and completely blocks

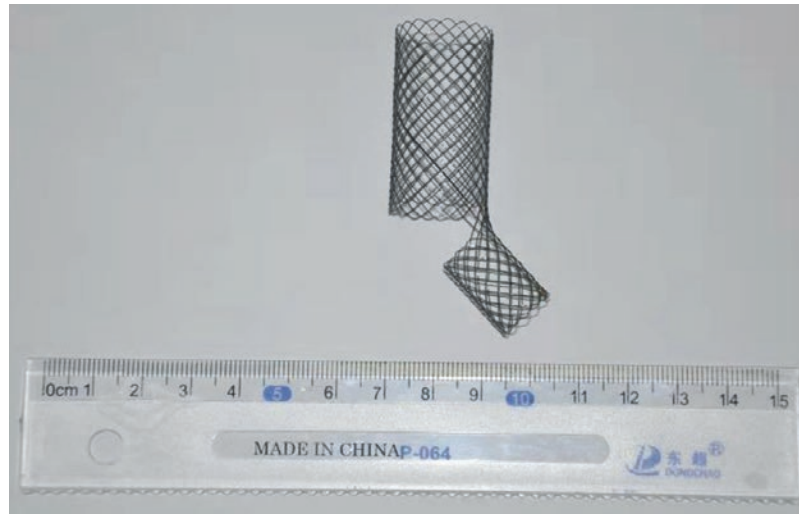

Fig. 6.8 L-shaped stent

the mesh; therefore, the main component, the connection area, and the branch component of the stent become an integral airtight and watertight sealed tubular structure.

The tracheobronchus branch integrated covered stent is mainly applied to the carina pleural fistula with absent right primary bronchi stump or right primary bronchopleural fistula with an extremely short (<5–10 mm) bronchi stump after total resection of the right lung. The primary bronchi and lobar bronchus branch integrated covered stent is used for plugging therapy of middle bronchopleural fistulas secondary to resection of the right middle and lower lobe pulmonary with right lower lobe bronchopleural fistulas secondary to resection of the right lower lobe pulmonary, as well as left lower lobe bronchopleural fistula secondary to resection of the left lower lobe pulmonary.

(b) L-shaped tracheobronchial branch integrated partial covered stent: The 10–20 mm upper segment of the body component of this type of stent is bare to increase the friction, stent fixation capacity, and stability; therefore, the partially covered stent was developed for its fixation capacity, compared with a covered stent. The lower part of the body stent, the connecting area, and the branch component are covered with a polymeric medical polyester film, which wraps all of the nickel titanium alloy wire except the bare section and blocks the mesh. Therefore, the middle and lower part of the body, the connection area, and the branch component become an integral airtight and watertight closed tubular structure. The indications are similar to the L-shaped tracheobronchus branch integrated covered stent, and the primary bronchi and lobar bronchus branch covered stent.

(c) Straight type tracheobronchial branch integral partial covered stent: Because of the limited stent knitting technology in the early years of stent invention, it was impossible to produce an L-shaped tracheobronchial branch integral partial covered stent. It is difficult to weave an even, uniform mesh structure but this is overcome by connecting straight stents with different diameters at the greater curved side of the curving connection area. Uniform woven wire is best covered by film (Fig. 6.9). At the same time, the structure of the trachea and left primary bronchi were found to mostly present as a straight line because of left lung, especially left lower lung, compensatory excessive expansion or even apparent left

lung mediastinal hernia with patients whose right lung has totally resected. If the patient has a carina pleural fistula secondary to right lung resection or right primary bronchiopleural fistulas with extremely short right primary bronchus stump occurs, then this stent should be chosen.

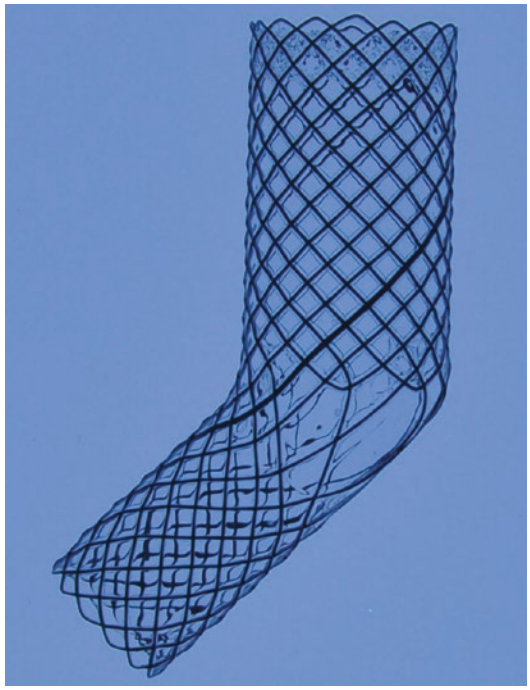

Fig. 6.9 Schematic diagram of a straight tracheobronchus branch integrated covered stent

4. Inverted Y-shaped tracheobronchus branch integrated stent: This stent's more appropriate name is "inverted Y-shaped tracheobronchus branch integrated self-expanding metallic stent," or "Han Xinwei's Stent," another in a series of respiratory stents invented by Dr. Xinwei Han. Dr. Xinwei Han developed the integrated knitting technique with a single wire for the inverted Y-shaped stent, and the techniques of loading, delivery, position, release, and placement for this type of stent. This stent can be divided into an inverted Y-shaped tracheobronchial branch integration stent (large Y-shaped) and a Y-shaped primary bronchial and lobe bronchial branch integrated stent (small Y-shaped) according to position. The stent is comprised of three tubular stents with different diameters and lengths, woven by a single nickel titanium alloy wire. The body part stent (such as the trachea component) has a lager diameter, while the branch stent (primary bronchi component) has a smaller diameter. There are many trifurcation areas in the trachea, primary bronchi, and lobe bronchus in the anatomical structure of the tracheobronchial tree. The lesions that are involved in the trifurcation areas are the best indications of the choice of inverted Y-shaped integration stent therapy (Fig. 6.10).

An early silicone Y-shaped or T-shaped stent is planted in the airway directly by surgical tracheotomy or a rigid bronchoscope under general anesthesia. Dr. Xinwei Han created

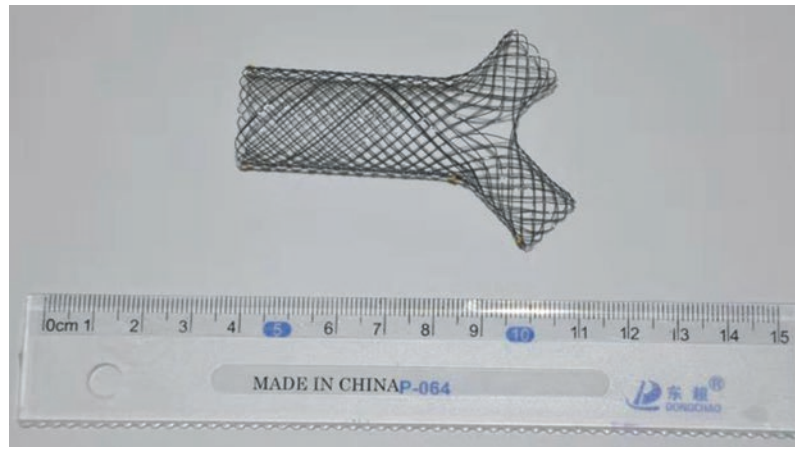

Fig. 6.10 Y-shaped integrated tracheal stent

the techniques of Y-shaped stent loading, delivery, position, and placement and the release and delivery system combined stent push technology with binding technology, allowing for almost all kinds of special stent deliveries and placements.

(a) Inverted Y-shaped tracheobronchial branch integrated bare stent: This stent is termed the "inverted Y-shaped tracheaobranchial branch stent", and is a type of bare stent. The stent is woven by a uniform nickel titanium alloy wire. It is fitted to the extraluminal compression complex stenosis in the lower trachea and bilateral primary bronchi, carina area stenosis, extraluminal compression complex stenosis in primary bronchi and upper and lower lobe bronchus or middle bronchi and middle and lower lobe bronchus caused by mediastinal lymph node metastasis lesions. In this condition, both the body and branch part of the stent function therapeutically on the extraluminal compression complex stenosis in bilateral primary bronchus, in right upper lobe bronchus and middle bronchus, or in middle and lower bronchus, etc. The branch section functions as treatment providing while the body section fixes the stent and prevents displacement.

(b) The inverted Y-shaped tracheobronchus branch integrated partial covered stent: this has a 10–20 mm long upper segment of the body stent that is not covered in film. The friction force, fixation ability, and stability are better than that of a coated membrane stent. The middle and lower segment of the body stent, connection area, and branch components are wrapped with polymer medical polyester film. Thus, the polyester film packs around the nickel titanium alloy wire and plugs the mesh, making the middle and lower segment of the stent body, the connection area, and branch component an integral airtight, watertight, and sealed tubular structure. Its indications are as follows:

Benign and malignant stenosis in the airway: complex stenosis in the lower trachea and bilateral primary bronchus, stenosis in the lower trachea and carina area, carina area bilateral primary bronchus stenosis, multi-stenosis in the primary bronchus and middle-lower lobe bronchus, multi-stenosis in the primary bronchus-middle bronchus and upper lobe bronchus.

Thoracic stomach airway fistula: fistulas in the thoracic stomach, lower trachea, carina, primary bronchus, middle bronchial area, etc.

Airway mediastinal fistula: communication between the respiratory tract and structural integrity destruction caused by various factors and airway-mediastinal fistula, which includes fistulas of the middle-lower trachea, carina, and primary bronchus with mediastina.

Bronchopleural fistula: upper lobe bronchiopleural fistulas, etc.

(c) The inverted Y-shaped tracheobronchus branch-integrated covered stent: The whole body section of the stent, connecting area, and bilateral branch stents are covered with polymer medical polyester film. Polyester film completely wraps around the nickel titanium alloy wire and blocks the mesh, making the body stent, connection area, and double branches into an airtight, watertight, sealed integral inverted Y-shaped tube. The inverted Y-shaped integrated covered stent is inserted into the airway and covers the trifurcation area with little movement. The indication for treatment is the same as for the Y-shaped trachobronchus branch partial covered stent.

5. The L-shaped tracheobronchial branch blind end covered stent: The original name of the stent is "blind end of the tracheobronchial branch covered stent" or the "branch bullet internal stent," which is also Han Xinwei's inner stent and belongs to one of a series of respiratory stents invented by Dr. Xinwei Han. This stent is divided into the L-shaped trachea main bronchus branch blind end part

that is covered with a covered stent (branch big bullet head stent) and main bronchus lobar bronchus branch blind end part covered with a plastic film bracket (small bullet stent). The inner stent is made by connecting a larger diameter tubular inner stent (main part or tracheal part) and a smaller diameter bullet head-like structure with a hemispherical closed end. The connecting part of the woven wire of the inner stent has a middle outer side (a small curved side), which occupies the circumference of the main part at an angle of 90–180°. The inner side of the connecting part (big bend side) is an open area with an angle of 30–50°, and the angle between the main part and the branch is 120–150°. Because the main part (such as the trachea) is thick, and the trachea part (main bronchus) is smaller in diameter, at least in the bullet head, it is covered with a solid medical polymeric polyester film, which forms a uniform sealed bullet-shaped inner cavity structure. The most common type is the L-shaped trachea main bronchus branch blind end partial covered stent, that is, the big bullet head stent (Fig. 6.11).

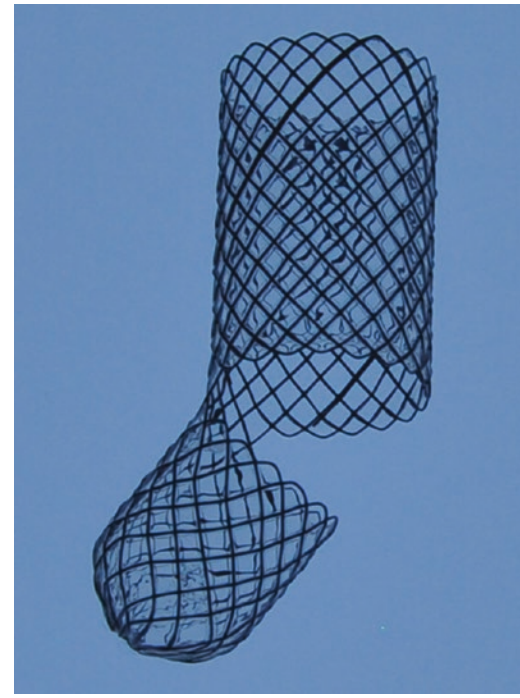

Fig. 6.11 L-shaped with branch-covered tracheal stent

(a) The L-shaped tracheobronchial branch blind end partial covered stent, one of the two subtypes of this stent type, is a stent with only the blind end partially covered while the stent body is bare to allow for the friction force between the stent and trachea, as well as the fixation ability and stability. However, the lower edge of the body portion of the stent is immediately adjacent to the carina region. The activities of the carina area of the airway are complex and frequent, and the completely exposed nickel titanium alloy wires are prone to stimulating hyperplasia of the endothelial cells and the emergence of fatal benign airway stenosis. The other stent type has only the main stent within the upper body 10–20 mm bare, while the lower part, the connecting part, and the branch part of the body stent are covered with a polymer medical polyester film. The lower edge of the main stent portion adjacent to the carina is covered with a film, which greatly limits the hyperplasia of endothelial cells in the carina region and allows for long-term retention of the stent in the airway. The stent branch (bullet head) is covered with polymer medical polyester film, which wraps around the inner stent branch (bullet head) nickel titanium alloy wire and seals the stent mesh. Therefore, the branch of the stent is a unitary airtight, watertight, closed, blind tubular structure (bullet structure). It is used for left main bronchus pleural fistula secondary to left main pneumonectomy, right primary bronchus pleural fistula with longer (> 15 mm) right primary bronchus stump after total resection of the right lung, and other diseases.

(b) The L-shaped tracheobronchial branch blind end with fully covered stent: The body portion, the connecting portion, and the branch portion (bullet head portion) of the stent are covered with a polymer medical polyester film, which completely wraps the nickel titanium alloy wire and seals the stent mesh. Therefore, the branch

of the stent becomes a unitary, airtight, watertight, closed tubular structure. This stent type is mainly used for left primary bronchus pleural fistula secondary to left main pneumonectomy, right primary bronchus pleural fistula with longer (>15 mm) right primary bronchus stump after total resection of the right lung, and other diseases.

6. The inverted Y-shaped tracheobronchial branches with unilateral blind end covered stent: This is treated as a Y-shaped single bullet stent. It has a relatively complex technique for delivery, which takes considerable training to master the positioning and placement of the L-shaped tracheobronchal branches bullet covered stent. This limits its application to a certain extent. Combined with Y-shaped stent implantation, which is easy to transport, convenient, allows for accurate positioning, and is easy to release, the improved L-shaped tracheobronchus branch blind end covered stent is an inverted Y-shaped tracheobronchus branches unilateral blind end covered stent. This stent is a hybrid product of the Y-shaped tracheobronchus branches integrated stent and an L-shaped tracheobronchus branch blind end stent, and takes advantage of the two types of stent. Combination of both the tubular body portion of the inverted Y-shaped stent and the contralateral tubular branch of the blind end branch allows the surgeon to exert a firm push on the fulcrum-branch blind end (bullet head) to accommodate a strong pushing and pinning effect. It not only increases the blocking effect of the blind end of the branch (bullet head), but improves the stability and fixation of the bullet head (Fig. 6.11).

   The stent is divided into two subtypes: the Y-shaped branch single bullet part covered stent and the Y-shaped branch single bullet full covered stent.

7. Straight tube blind end covered stent: This is called the "bullet head stent" for short and consists of two subtypes. One is a straight tube single blind end covered stent, which is the same as a bullet, and the other is a straight tube with double blind end covered stent, which is similar to having two bullets tail to tail (Fig. 6.12).

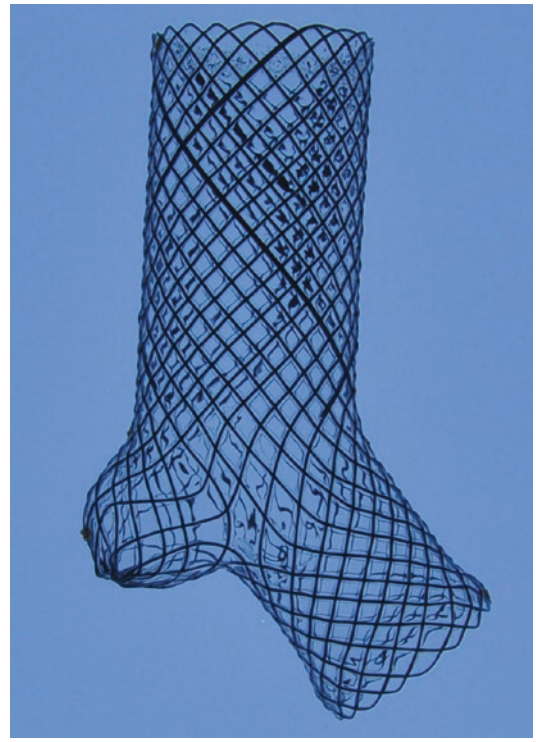

Fig. 6.12 Y-shaped with single branch-covered tracheal stent

The bullet head stent is designed to treat lobar, segmental bronchial, or bronchial fistula.

The transmission, positioning, and placement of the bullet head stent are accomplished with the Y-shaped stent delivery system. The bullet head stent is bound to the inner core of one side of the Y-shaped stent delivery system, and then transported to release the bullet head stent in the lobar bronchus or segmental bronchus through the delivery system. The procedure is similar to transportation of the inverted Y-shaped primary bronchus-lobe bronchial branches unilateral blind end covered stent.

6.4.3 Balloon Expandable Stent

There are three types of balloon expandable stents: Palmaz stent, tantalum wire stent, and stainless-steel wire stent. Balloon expandable stents are only used in small diameter vessels, such as the coronary artery, cerebral artery or renal artery.

1. Palmaz balloon expandable stent: Its thin (0.15 mm) stainless-steel wall is made with electrical etching or laser carving technology. After the carving, the stent wall is parallel with the rectangular narrow slot and after expansion of the balloon, the wall becomes a rhombus skeleton, to exert the maximum external supporting force. The advantages of this stent are: (1) this type of stent is able to be made with an exceedingly small diameter (3 mm); (2) its smooth profile is convenient to be installed with different balloons; (3) the stent is not easy to shift due to its good adhesion after dilatation; (4) it has great expansibility even if the stent is inelastic, with an expansion rate as high as 6 to 1; (5) its radial flexibility is good, due to expansibility, which sustains a continuous expansion pressure to the vascular wall after being expanded by the balloon, while it produces less reaction with the vascular wall (shear stress); (6) the open structure with little skeleton but a big mesh allows for rapid endothelialization for reducing thrombosis. However, because of the rigid or tetanic structure, its longitudinal flexibility is so limited that the stent cannot pass through tortuous vessels easily.
2. Tantalum wire balloon expandable stent: The Strecker stent is the most common tantalum wire stent, woven by a single tantalum wire with a diameter of 0.1 mm in a loose reticulate tubular shape. The diameter is about 6–12 mm and the length is 4 cm after expansion. The advantages of this stent are: (1) the stent has a good radial and longitudinal flexibility; (2) it has great expansibility (six times) and is the same as the Palmaz stent; (3) the stent can produce a metal oxide layer with negative charge in the blood thus preventing platelet aggregation; (4) the X-ray can be well developed for convenient plantation of the device; (5) non-magnets will not affect the MRI examination; (6) it possesses good tissue compatibility and strong corrosion resistance.

   There are other tantalum wire stents, such as the Wiktor stent, Forntaine stent, etc.
3. Stainless-steel wire balloon expandable stent: This stent is also known as the "Gianturco-Roubin flexed stent" with a tube made with a stainless-steel wire with a diameter of 0.15 mm. It has a number of V-shaped frame rings in a positive and negative direction and is used for coronary arteries and other small vessels.

6.4.4 Drug-Eluting Stents

Metal stents covered with biodegradable or non-biodegradable drug membranes are drug-eluting stents. The covered stent is mainly classified into two kinds of structures: those with the middle part of the stent completely covered or those that are partly covered while both ends are exposed. The metal stents are mostly Z-shaped, Wallstent, Strecker shape, so on. The materials vary, and include PTFE, polyester, polyurethane, silicone, nylon, polyester, silk, etc. Drug-eluting stents not only retain the physicochemical properties of metal stents supporting the stenosis, but also possess the special closed effect of a covered membrane for the treatment of aneurysm, aortic dissection, arteriovenous fistula, and anti-endometrial hyperplasia. Recently, Professor Maoheng Zu has succeeded in opening and rebuilding the inferior vena cava of Budd-Chiari syndrome using a covered stent.

6.5 Sheaths

The catheter sheath, also called the vascular sheath, creates a passage from the skin to the vascular system. It is a special instrument in interventional radiology for the convenience of repeatedly introducing or exchanging devices in the intravascular system and preventing vascular puncture. It is composed of a guidewire, sheath, and dilator, with the tail part of the outer sheath built with a hemostatic valve and side arm. The hemostatic valve not only prevents intravascular blood overflow but exoteric gas from the blood vessels. The side arm of the valve carries a switch, so the drug and flush heparin saline is injected to prevent coagulation in the gap between the outer sheath and rails through the side arm. The side arm can also be used as a channel for monitoring intravascular pressure, etc. To insert a catheter, exchange a catheter, introduce a balloon and biopsy forceps, or deliver a stent to a blood vessel

all require a catheter sheath. Generally, the diameter of the vascular sheath is 0.5–1 F larger than the above instruments. If necessary, the sheath can also be used as a dilator. The large lumen of the large duct sheath can also be used for the removal of a massive thrombus, especially for fresh thrombus aspiration. The diameter of the catheter sheath is 4–18 F generally, and 10–100 cm in length.

1. Common sheath: This is divided into two groups: either with a proximal arm or without. The sheath with side arm may prevent coagulation in the gap between the outer sheath and rails by heparin injection. Its outer wall is made of Teflon, and if it is without an internal wire, its breaking resistance is less than that of an anti-flex sheath.
2. Anti-flex sheath: The outer wall of the sheath contains fine steel wire and a spirally coiled pipe wall to strengthen the flexibility of the sheath. In order to improve its anti-bending ability and the thrust and twist force, the stent is allowed to pass through severe stenosis and provides good support in excessively tortuous vascular systems. The anti-flex sheath is often used to introduce the stent or balloon catheter and its head end has a radiopaque marker to identify the sheath's accurate position under fluoroscopy.
3. Stent delivery sheath: This is often treated as a stent implantation device or stent push device. It consists of three parts: an expander, an outer sheath, and a push rod. The push rod is similar to the expander, with its inner core allowing for the passage of a guidewire, but its front end is a flat head for pushing to release the stent.

   GZVI-12.0-60-RB (COOK, USA) and JR-12F (Beijing, Aetna Corp, China) are common intravascular stent delivery devices. The former is 12–16 F in diameter and 60–90 cm in length, with the latter similar to foreign products in specification. This kind of delivery device is separated from the stent. According to the normal anatomy and pathological nature of the diseased vessels, different sized stents are chosen. The vena cava stent is the most commonly used stainless-steel wire in the Z-shaped device. The Z-shaped stainless-steel wire stent is easy to load via the delivery device in vitro, and then pushed to the lesion area of the target vessel by the push rod and released.
4. Guide catheter: This is a long tube with a thin wall and large cavity. Its tail end is combined with the Y-shaped valve and switched to form a closed structure during the operation as a long sheath. Its head end is similar to an ordinary catheter and forms a certain bend according to the position. Its internal cavity is larger (2–3 mm in diameter). It allows for the passage of a therapeutic instrument such as a stent and balloon. The head is extremely soft, thus causing little irritation, while the body part has some hardness and maintains a certain thrust. The guidewire is able to overcome the weaknesses not only of the superfine interventional devices (such as a stent) that cannot reach far and deep parts or easily distort vascular tissue, but also reach the small cavity that the common catheter (0.035–0.038 in.) cannot pass the stent to.

   The guide catheter is multifunctional and can work with a vertebral artery, renal artery, left coronary artery, and right coronary artery guide tubes. There is no closed valve at the end of the guide catheter, thus it is used in conjunction with the Y-shaped valve and change-over switch in blood vessels. The biopsy forceps can be introduced into the inferior vena cava through the guide catheter, and introduced biopsy forceps, balloon, or stent, etc. interventional instruments into the hepatic vein.

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Benign Tracheal/Bronchial Stenosis

7

Zongming Li, Hongwu Wang, and Gauri Mukhiya

7.1 Introduction

Benign stenosis of the trachea and bronchi presents with symptoms such as productive (wet/chesty) cough and dyspnea, and limits the patient's working capacity and quality of life. Severe cases may even result in respiratory failure and death. In the Western world, benign tracheal stenosis is a complication of tracheal intubation, tracheal surgery, lung transplantation, and other related factors [1]. In China, benign stenosis is mainly due to endobronchial tuberculosis [2]; however, the incidence of iatrogenic benign tracheal stenosis is rising, with the development of modern medicine, and increasing use of tracheal intubation, tracheotomy, and other types of respiratory intensive rescue technology [3].

For severe benign stenosis, the traditional treatment focuses on tracheobronchial resection and reconstruction, but the surgery is associated with major trauma and serious postoperative complications such as anastomotic stenosis, rupture, and leakage. Moreover, surgery is often not an option due to the patient's poor general condition or because a long narrow stenosis makes resection and anastomosis impossible [4].

Recently, stent placement of interventional radiology has become a viable option for tracheobronchial stenosis. Interventional radiologists in China have accumulated considerable experience in tracheobronchial stent implantation and removal [5]. The broad principles of treatment of benign airway stenosis with stents are discussed here.

7.2 Etiology

Tracheal intubation, tracheotomy, trauma, and endobronchial tuberculosis are the most common causes for tracheobronchial stenosis. Less common causes include benign airway tumors, respiratory infections, and congenital stenosis (rare) [6].

1. Iatrogenic stenosis: Iatrogenic tracheal injury is the most common cause of adult benign tracheal stenosis. Tracheotomy causes disruption of multiple annular cartilage rings or a large amount of fibrous connective tissue hyperplasia. Prolonged tracheal intubation or excessive balloon pressure can damage tracheal intima and underlying structures and lead to scarring.
2. Traumatic stenosis: In rural China, the most common suicide method is by hanging. Survivors may develop tracheal stenosis due

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to annular cartilage damage. Trauma, especially to the chest, may also cause tracheobronchial rupture or ring cartilage fracture.
3. Benign tumors: Pleomorphic adenoma, leiomyoma, chondroma, fibroma, squamous cell papilloma, and hemangioma are some of the benign tumors that occur in the tracheal/bronchial cavity or walls. The trachea/bronchus could be compressed from the outside, for example by thyroid tumors and goiter, thymic hypertrophy or tumor, mediastinal cyst, aneurysm, or hematoma.
4. Airway infection: The most common airway infection is endobronchial tuberculosis. Fungal infections, such as histoplasmosis and yeast, may also cause stenosis. Rare infections include rhinoplasty, syphilis, and diphtheria. Serology and histopathology can help in the differential diagnosis.
5. Noninfectious inflammation: The most common causes of noninfectious inflammation are recurrent polychondritis and Wegener granulomatosis. Rare causes include primary amyloidosis and sclerosing mediastinitis.
6. Congenital airway stenosis: This is very rare due to the tracheal cartilage ring in the posterior tracheal fusion of the formation of annular stenosis. Vascular rings and other cardiovascular malformations (e.g., subclavian artery abnormalities) can also cause stenosis by compression of the trachea and bronchi.

7.3 Pathology

1. Inflammatory infiltration: The early pathological signs of endobronchial tuberculosis include mucosal congestion, edema, and gray miliary nodules in the bronchial mucosa. At this stage, airway narrowing is minimal, and the disease can be effectively treated with antituberculous drugs. Stent implantation is necessary in the late stages of the disease to treat severe stenosis.
2. Ulcerating necrosis: Besides congestion and edema, ulceration may occur in the mucosa. The surface is covered with a cheese-like necrosis and mucus plugs may block the airway. It is necessary to avoid airway obstruction and distal atelectasis and undertake timely removal of necrotic material and mucus by bronchoscopy. Thermal ablation is used for clearing necrotic material that cannot be removed by bronchoscopy. Balloon dilatation and recyclable stent implantation is required for long lesions or severe stenosis.
3. Granulation tissue proliferation: Granulation tissue proliferation during the healing process can block the airway lumen. Thermal ablation limits excessive granulation tissue proliferation and prevents stenosis. Recyclable airway stent placement is used to treat stenosis if initial balloon dilatation is not effective.
4. Scarring stenosis: Hyperplastic scar tissue and scar contracture may constrict the airway lumen during recovery from mucosal inflammation, as occurs in the healing stage of endobronchial tuberculosis. Under the microscope, this can be seen as smooth white scar tissue. In patients with mild stenosis, simple balloon dilatation may suffice. When the scar tissue is more flexible, balloon dilatation can cause an airway wall tear, and therefore airway stenting is preferable.
5. Softening of airway wall: Tracheal/bronchial ring cartilage structure is destroyed, leading to collapse of the wall. This is most common in the left main bronchus and the lower part of the trachea. Prompt implantation of an airway covered stent will restore ventilation and avoid obstructive atelectasis and emphysema. The stent can be removed after scar tissue remodeling is performed [7].

7.4 Diagnosis

7.4.1 Clinical Manifestations

Dyspnea is the main clinical symptom of tracheobronchial stenosis. Severe stenosis is characterized by the appearance of "three concavities" on the chest during inspiration. This refers to the depres-

sion of the sternal fossa, supraclavicular fossa, and intercostal space soft tissue during inspiration. Wheezing is common, and patients may be misdiagnosed as having asthma. Auscultation will reveal a biphasic wheeze in the middle of the chest (tracheal area) and dry rales in the middle of the chest (left and right main bronchial areas).

7.4.2 Grading of Severity of Airway Stenosis

No standard classification system exists for grading the severity of central airway stenosis. In 2008, Professor Han created a clinical grading system for dyspnea with airway stenosis that was largely based on the clinical evaluation criteria of the American Society of Thoracic Surgery. In this system, severity of dyspnea is indicative of the degree of stenosis and is used for selecting the appropriate treatment (Table 7.1). The grading system has been validated in close to 1,000 patients and continues to be of practical value even after a decade [8].

Table 7.1 Clinical classification of airway stenosis and selection of treatment

Classification	Clinical manifestations	Treatment
I	Difficulty breathing during fast walking	Treatment of primary disease
II	Difficulty breathing during normal walking	Treatment of primary disease
III	Forced to stop walking because of difficulty breathing during normal walking	Treatment of primary disease
IV	Difficulty breathing after slight activity	Treatment of primary disease
V	Difficulty breathing when calm and lying down	Early release of airway stenosis
VI	Difficulty breathing when calm and in sitting position	Emergency release of airway stenosis
VII	Difficulty breathing when calm and in sitting position and oxygen/asphyxia	Emergency release of airway stenosis

7.4.3 Imaging

7.4.3.1 Chest Radiography

Chest radiography has limited value for the diagnosis of airway stenosis. Anteroposterior and lateral chest radiographs may show distortion of the tracheal gas shadow. The site and extent of stenosis can sometimes be inferred from indirect signs, such as the location and severity of obstructive pneumonia or atelectasis (Fig. 7.1). Informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study.

7.4.3.2 Chest Multislice Computed Tomography (MSCT)

MSCT is the most useful and most common method for the diagnosis of airway stenosis. MSCT data can be used for three-dimensional reconstruction of a virtual image of the trachea and bronchi. It can be used to measure the length and shape of tracheal stenosis and the distal lung lesions with simulation endoscopy. Accurate measurement of the dimensions of the stenosis on chest MSCT images facilitates selection of the appropriate airway stent (Fig. 7.2).

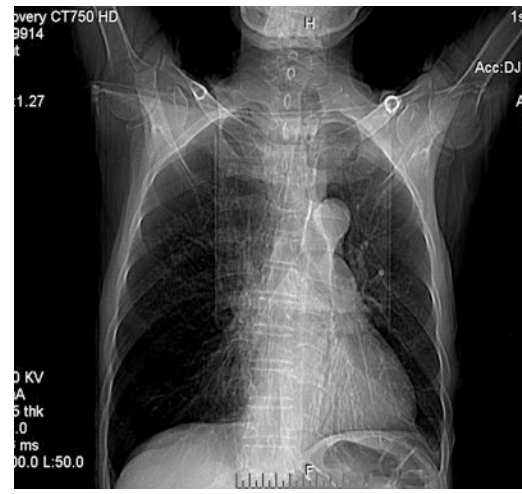

Fig. 7.1 Fluoroscopy shows an obstruction in the upper trachea (black arrow)

7.4.3.3 Fiberoptic Bronchoscopy

Fiberoptic bronchoscopy is used to visualize the length and severity of the stenosis, and also facilitates biopsy of lesions when necessary. The limitation of the bronchoscope is that it cannot pass through severe stenosis and therefore it is not able to examine the distal lumen. Furthermore, bronchoscopy cannot be performed in the severely dyspneic patient (Fig. 7.3).

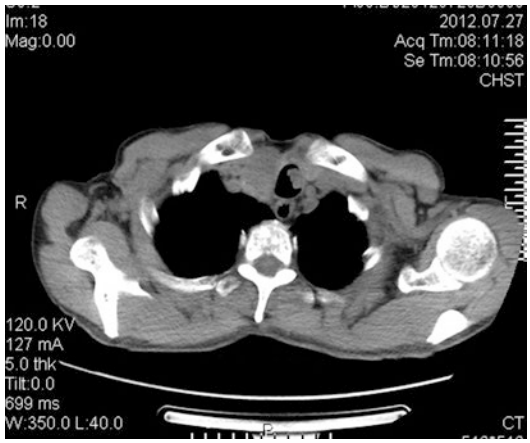

Fig. 7.2 Chest CT scan shows the tracheal lumen partly obstructed by a neoplasm

7.4.4 Different Sites of Benign Stenosis [9]

7.4.4.1 Tracheal Stenosis

This refers to stenosis in the region 1 cm below the annular cartilage to 2 cm above the carina crest. It is the most common location of benign airway stenosis due to prolonged tracheal intubation, tracheotomy, trauma, tuberculosis, multiple chondritis, and retrosternal goiter. It can be treated by balloon dilatation or airway tube stent implantation.

7.4.4.2 Carina Area (Complex) Stenosis

This refers to the region extending from the cartilage crest within 2 cm of the trachea, left or right main bronchial benign stenosis. It may be either a simple stenosis or a complex one, with stenoses in two or more airways. Common causes include respiratory tuberculosis and multiple chondritis. Treatment should take into account the special anatomical structure of the carina. The inverted Y-type integrated stent or an L-type tracheobronchial branched anti-skid stent can release the stenoses.

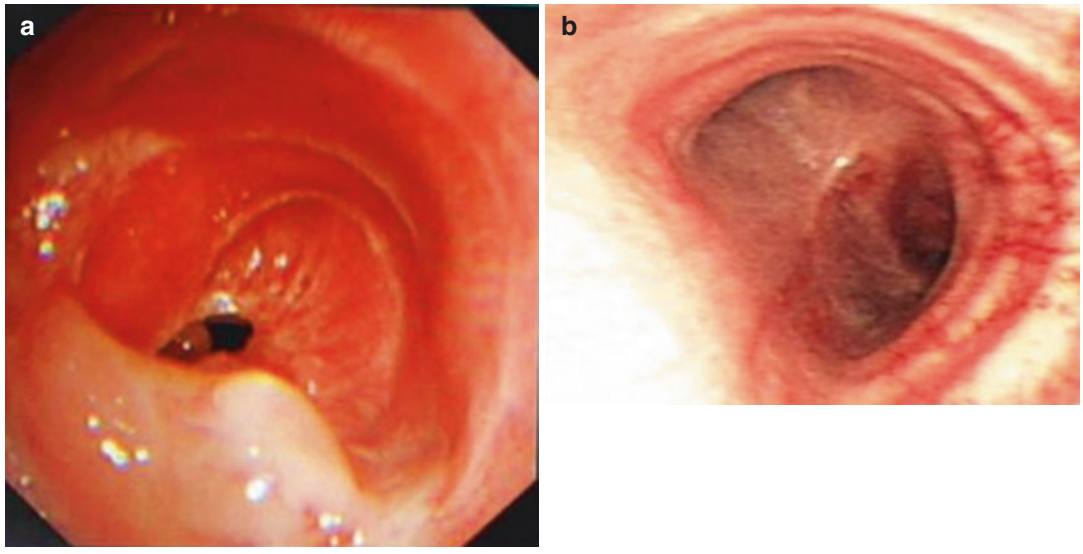

Fig. 7.3 (**a**) Severe throat stenosis; (**b**) airway patency distal to the stenosis

7.4.4.3 Right Main Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis, and it can be treated by an L-type branched anti-slip stent or a small Y-type integrated stent. The shape of the stent is similar to that of "L", including the main body and branch. The main body is placed in the trachea, the branch is placed in the right main bronchial, and the connection is open to ensure the ventilation of the left main bronchial. See Figure 7.12.

7.4.4.4 Right Upper Lobe Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated with balloon dilatation or a small Y-type integrated stent.

7.4.4.5 Right Middle Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated by balloon dilatation or a small Y-type integrated stent.

7.4.4.6 Right Middle Lobe Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated by balloon dilatation or a small Y-type integrated stent.

7.4.4.7 Right Lower Lobe Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated by balloon dilatation or a small Y-type integrated stent.

7.4.4.8 Left Main Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated by an L-type branched anti-slip stent or a small Y-type integrated stent.

7.4.4.9 Left Upper Lobe Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated by balloon dilatation or a small Y-type integrated stent.

7.4.4.10 Left Lower Lobe Bronchus Stenosis

The most common reasons for this type of stenosis include respiratory tuberculosis and multiple chondritis; it can be treated by balloon dilatation or a small Y-type integrated stent.

7.5 Treatment of Tracheobronchial Benign Stenosis

7.5.1 Medical Treatment

The main medical measures are supplemental oxygen to enhance the patient's oxygen reserves and proper positioning of the patient for optimal ventilation; at the same time, drugs are administered to promote expectoration of airway secretions and improvement of tolerance to hypoxia [10].

7.5.1.1 Oxygen

Oxygen is administered through a nasal catheter or mask. If necessary, noninvasive ventilation or tracheal intubation using positive pressure ventilation can be used. Humidification of the airway will prevent the airway from obstruction with thick sputum.

7.5.1.2 Position

The patient should be placed in a reclining or sitting position. Gravity will pull the abdominal organs down and relieve pressure on the diaphragm, and this allows for better ventilation.

7.5.1.3 Drugs to Promote Coughing and Expectoration

Administration of mucolytic and expectorant drugs is undertaken to facilitate the removal of viscous sputum and sputum scab.

7.5.1.4 Nebulization

Delivery of drugs via inhalation ensures a high concentration in the airway and a faster absorption rate and action. It also maintains humidification of the airway.

7.5.1.5 Elimination of Edema

Dehydrating agents, such as mannitol and furosemide, reduce tracheal/bronchial edema and partly relieve stenosis. Corticosteroid drugs also reduce tracheal/bronchial mucosal edema, especially the edema of regional lesions.

7.5.1.6 Antibiotics

Sputum retention in distal bronchi in patients with airway stenosis may lead to obstructive pneumonia and atelectasis. Appropriate antibiotics control lung inflammation and protect lung function.

7.5.1.7 Anti-proliferative Drugs

Different drugs affect the wound-healing process at different stages. Antibiotics and corticosteroids are administered during the inflammatory stage, while antibiotics, corticosteroids, mitomycin C, 5-fluorouracil, and triamcinolone are administered during the proliferation stage. Halofuranone influences the maturation stage; anti-reflux drugs, growth factors, immunosuppressive agents, and gene therapy influence all three stages.

7.5.2 Surgical Treatment

Two common surgical procedures are the segmental resection plus end anastomosis and sleeve resection plus airway plasty. The artificial trachea method is not a preferred option because it is not suitable for patients with long stenosis, and is associated with a high rate of secondary restenosis after surgery [11].

7.6 Interventional Treatment of Benign Stenosis

7.6.1 Tracheal Stenosis

7.6.1.1 Instrument Preparation and Selection of Stent

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter (100 cm), 0.035-in. hydrophilic guidewire (150 cm), 0.035-in. stiff guidewire (180–260 cm), partly or fully coated tubal stent (Micro-Tech, Nanjing, China or Micro-Tech, Taewoong, Korea), stent retrieval hook, sputum suction tube, 14F long sheath (Fig. 7.4), and tracheal intubation instruments.
2. Choice of stent: First, doctors need to measure the length and diameter of the tracheal stenosis on the chest MSCT cross-sectional (mediastinal-fat window) image, and customize the partly coated or fully coated tubal stent accordingly. Stent diameter should be 10%

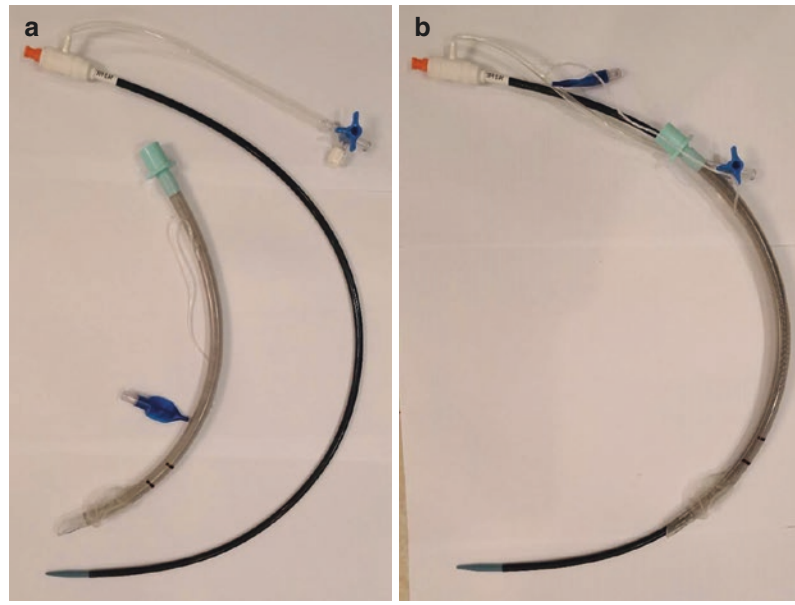

Fig. 7.4 (**a**) The14F sheath and tracheal tube; (**b**) the tracheal tube passed through the 14F sheath

more than that of the tracheal diameter. Stent length should be such that it will extend at least 10 mm beyond both ends of the stenosis after placement [12].

7.6.1.2 Preoperative Preparation

1. Laboratory investigations: This includes routine blood examination, liver and kidney function, serum electrolytes, blood coagulation tests, infectious disease tests, sputum bacterial culture and drug sensitivity test, electrocardiogram (ECG), and other relevant tests.
2. Imaging: Before the operation, a chest MSCT scan is needed, as well as a multiplanar reconstruction (MPR), curved planar reconstruction (CPR), and other post-processing functions to accurately identify the site and length of the stenosis, and to determine the distribution and severity of lung injury [13]. This imaging is needed to customize the stent according to these measurements (Fig. 7.5).

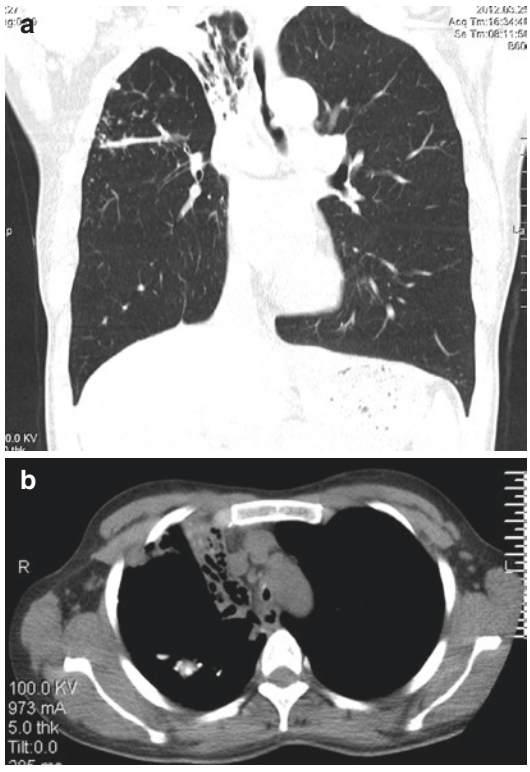

Fig. 7.5 (**a**) Tracheal stenosis (see fine line on chest CT scan, lung window); (**b**) the longitudinal diaphragm window shows severe tracheal stenosis

3. Gastrointestinal preparation: Fast the patient for 4–8 h before the operation to prevent vomiting and aspiration during stent placement.
4. Preoperative medication: About 10–30 min before stent placement, administer an intramuscular mood stabilizer 10 mg to reduce patient anxiety, and intramuscular anisodamine (654-2) 10 mg to reduce digestive tract and respiratory secretions and prevent smooth muscle spasm.

7.6.1.3 Procedure for Tubular Stent Placement

1. Patient position: The patient removes her or her clothes including radiopaque material (e.g., metal buttons) and lies relaxed in a supine position on the fluoroscopy examination table. Then, slightly raise the neck and shoulders; keep the head tilted backwards and turned 20°–30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, anesthetize the throat with 2% lidocaine spray, and insert the mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as necessary.

   Perform fluoroscopy with the C-arm angled 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body by approximately 50°). Adjust the collimator to include the oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopy, insert a catheter over a hydrophilic guidewire through the mouth, and advance it slowly up to the carina region. Pull out the guidewire, and inject 2–3 ml of 2% lidocaine solution through the catheter. Adjust the position of the catheter so that the tip is at the tracheal stenosis, and rapidly push 3 ml of 30–40% iodinated contrast agent through it to display the tracheobronchial anatomy. Determine the location and length of the tracheal stenosis and its distance from the glottis and the carina.
3. Insertion of stiff guidewire: After bronchography, insert a hydrophilic guidewire and catheter past the stenosis, at least 20 mm into the left or right main bronchus. Pull out the guidewire

and inject 1 ml of 30% iodinated contrast to confirm that the catheter is in the main bronchus. Pass a stiff guidewire deep into the main bronchus, taking care to keep the distal end within the fluoroscopy field of view. During the procedure, ask the assistant to maintain the position of guidewire and mouth gag.

4. Balloon pre-dilatation: In severe tracheal scar stenosis, the diameter of the stenosed area may be less than 5–8 mm, and it will be difficult to advance the tracheal stent delivery system past the stenosis or for it to exit after stent placement. In these situations, perform balloon pre-dilatation. Pass a balloon catheter with a 10- to 14-mm diameter balloon along the guidewire until the balloon lies across the tracheal stenosis. Rapidly inflate the balloon with 30% iodinated contrast agent and then quickly deflate it and withdraw the catheter.
5. Insertion of the stent delivery system: Insert the stent delivery system over the stiff guidewire and slowly advance it up to the tracheal carina. Ask the assistant or nurse to ensure that the patient lies still and inhales deeply with the glottis open during the procedure.
6. Placement of the stent: Under fluoroscopy monitoring, position the stent at the middle of the stenosis. Firmly holding the stiff guidewire and the posterior handle of the stent delivery system in front of the chest, pull back the front handle to release one-third of the stent. Confirm on the fluoroscope that the distal end of the stent extends at least 10 mm beyond the lower end of the stenosis. Release the middle third of the stent and confirm that the stent covers the entire stenosis. Then, quickly release the stent completely. Finally, keeping the stiff guidewire in position, pull out the stent delivery system smoothly.
7. Re-radiography: Introduce the catheter over the guidewire and inject 3 ml of 30% iodinated contrast agent. Check that the stenosis is completely released, the stent is accurately positioned and fully expanded, and the carina and main bronchi are unobstructed. If necessary, adjust stent position or perform post-dilatation.
8. Sputum suction: Pass a suction tube over a stiff guidewire deep into the left and right main bronchi. Apply suction to remove all residual contrast agent and sputum; gentle slapping on the patient's back will help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100% (Fig. 7.6). Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation. Apply oral suction to prevent aspiration of accumulated saliva.

7.6.1.4 Postoperative Management

1. Nebulization: After stenting, nebulize with saline 10 ml + 2% lignocaine 5 ml + ambroxol 30 mg + amikacin 0.2 g twice a day for 4–6 weeks to promote sputum expectoration and reduce stent foreign body reaction and inflammation.
2. Promotion of expectoration: Roll the patient over to the prone position, and slap gently on the back to help dislodge sputum. Encourage the patient to cough strongly and expectorate; this will not increase the risk of stent migration. Use expectorants, mucolytics, and other measures to facilitate sputum discharge.
3. Antibiotics: Choose the antibiotic according to bacterial culture and sensitivity test results. Perform regular bronchoscopic lavage to remove endobronchial mucus and pus; during bronchoscopy, high concentrations of the selected antibiotic can also be administered locally.
4. Chest CT: Review the chest MSCT and three-dimensional reconstructed airway 2–3 days after stent placement. Low lung ventilation due to tracheal stenosis may be associated with varying degrees of atelectasis. Rapid re-inflation of the lung after balloon dilatation or stent implantation can lead to pulmonary edema. If the patient complains of chest tightness, hypoxia, and cyanosis after stent placement, and chest CT confirms pulmonary edema, treat immediately with intravenous corticosteroids to eliminate edema and improve oxygenation (Fig. 7.7).

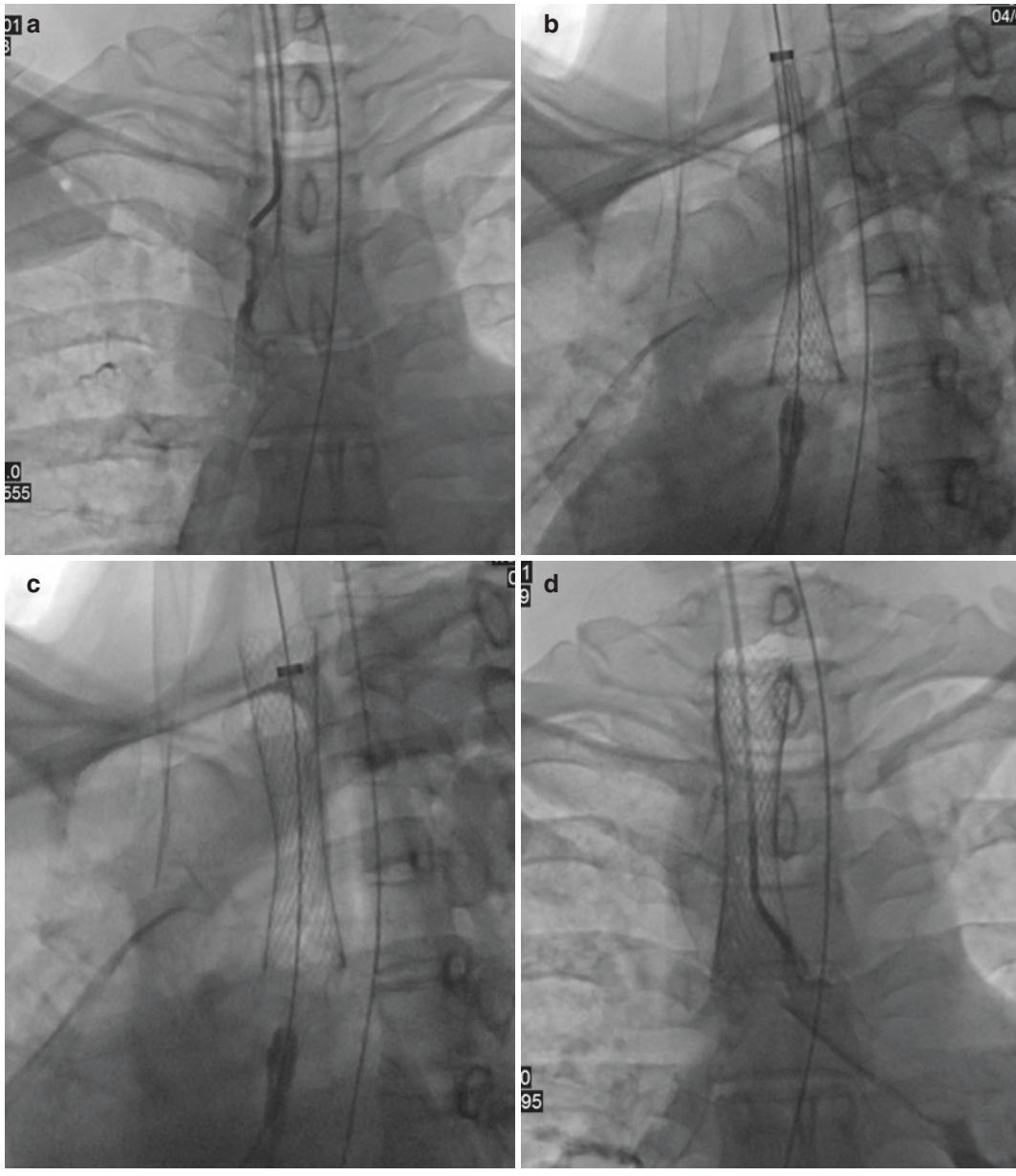

Fig. 7.6 (**a**–**d**) The process of tracheal tube stent implantation. (**a**) Transcatheter airway angiography shows upper and middle tracheal stenosis; (**b**) introduction of the stent delivery system and positioning of the stent across the stenosed section; (**c**) after release of the stent, stent lies across the stenosis; (**d**) correct stent positioning and good expansion of the stent

7.6.1.5 Prevention and Treatment of Complications [14]

1. Asphyxia: Patients with tracheal stenosis have severe hypoxia before surgery and lack of oxygen reserves in the body. X-ray guided tracheal stent implantation is completed when the patient is awake and there is no mechanical assisted ventilation. Therefore, the patient's breathing difficulties will be further aggravated during surgery. This requires the

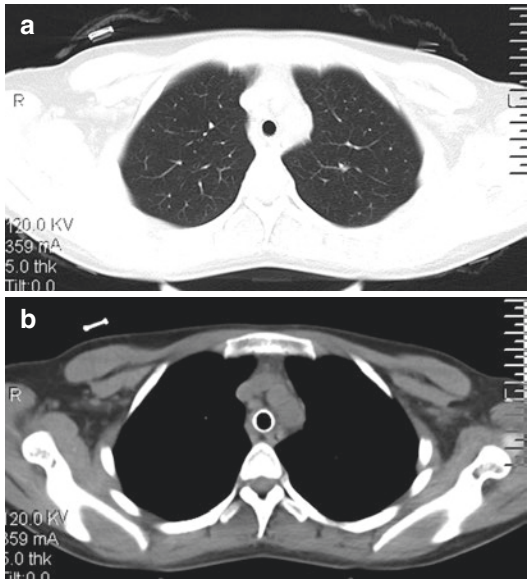

Fig. 7.7 Chest CT scan showing tracheal stenosis completely relieved 3 days after tracheal stent placement, (**a**) for lung window, (**b**) for mediastinal window

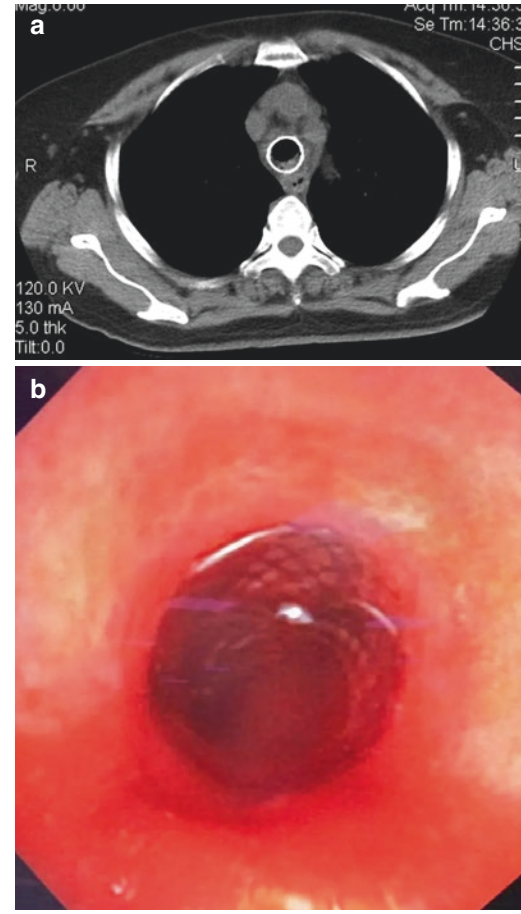

Fig. 7.8 Formation of granulation tissue 2 months after stent placement. (**a**) Chest CT scan shows new growth within the stent; (**b**) bronchoscopy shows marked granulation tissue proliferation, with the stent embedded in the endothelium

involved doctor to have accurate and skilled technology and cooperate with a close team. Minimize the operation time and reduce the incidence of intraoperative asphyxia.

An intravenous injection of dexamethasone (10–20 mg) given pre-surgery can improve hypoxia tolerance. In addition, inhalation of 100% oxygen before stent placement will improve oxygen reserves. The surgical operation platform should also have spare equipment for the appropriate type of tracheal intubation, sputum, and auxiliary ventilation oxygen if necessary.

2. Granulation tissue hyperplasia: Any physiological tube cavity in the body will react to a foreign body by endothelial cell proliferation. Stent stimulation and inflammatory reaction result in particularly obvious airway endothelial cell hyperplasia (Fig. 7.8). A metal stent is liable to provoke hyperplasia wherever it touches the endothelium, but this is especially marked at the ends of the stent. A coated stent causes minimal hyperplasia. Hyperplasia and scar stenosis may form at the ends of the stent.

   Mild endothelial cell proliferation that does not affect breathing needs no treatment, but endoscopic ablation becomes necessary when breathing and effective expectoration are affected. Microwave, radio frequency, laser, or thermal ablation are effective treatments; cryoablation appears to provide the best long-term results.

3. Hemorrhage: Blood in the phlegm is common after airway stenting. Small amounts of blood need no treatment and will usually stop in 10 min. If the hemoptysis continues, and especially if it is severe, it is necessary to inject 2–3 ml of 1:1000 adrenaline in saline through the catheter. This treatment would stop hemoptysis quickly by constricting the mucosal vessels; therefore, it is effective even if there is rupture of a small peripheral artery.

4. Stent obstruction by sputum: This is the most common complication of a coated airway stent. A coated stent completely covers the tracheal epithelium. If the airway's mucociliary blanket function is lost, expectoration is then solely dependent on the force of coughing. If the cough is weak, sputum will adhere to the stent, so that a sputum bolt may form and block the airway lumen. When this happens, with fiberoptic bronchoscopy the sputum bolt is removed to re-establish endotracheal air flow. In order to avoid phlegm retention, all measures (e.g., nebulization, expectorant drugs, and expectoration training) should be applied.
5. Incomplete stent expansion: Incomplete stent expansion is mainly because of lack of ability of the metal stent to resist the shrinkage of scar tissue. Incomplete stent expansion is common in tracheal stenosis caused by scar contracture. High-pressure balloon predilatation before stent placement will help prevent this problem. If full expansion is not seen 1–3 days after stent placement, perform high-pressure balloon post-dilatation.
6. Stent migration: If stent migration is suspected, chest CT or bronchoscopy should be used to confirm this. Stent migration may be due to improvement of the tracheal stenosis, with a decrease in the forces keeping the stent in place, or due to insertion of an inappropriately sized stent. It is treated by adjusting the stent position or by replacement of the stent.
7. Stent rupture: This complication is rare and is caused by the smooth muscle contractions during severe coughing spells. It generally occurs in tracheal stents. Entire stent disintegration is rare. Other examples of this complication include an isolated fracture of a wire with the patient spitting out a piece of the metal wire. Once stent rupture is confirmed, it is important to remove the stent in order to avoid damage to surrounding tissue and to reduce patient anxiety.
8. Chest pain: Chest pain may be related to balloon dilatation, stent placement, or other intraoperative and postoperative procedures. The pain is usually mild and does not require any special treatment. Oral analgesics should be prescribed if necessary.
9. Sore throat and hoarseness: This is related to local stimulation of the pharynx, throat, and glottis during stent implantation. It generally subsides in 1–2 days and no special treatment is needed. Aerosol inhalation may provide relief.

7.6.2 Carina Compound Benign Stenosis

The carina area starts at the lower edge of the last annular cartilage of the trachea and ends at the opening of the main bronchus. The area is shaped like an upside-down Y or trousers. Its center is a saddle-shaped special cartilage ring that contains a ring ligament, also known as the tracheal ligament, and is connected to the tracheal ring cartilage. Its left and right sides each contain a ring ligament connected to the left and right main bronchi.

Carina area stenosis is usually complex, with stenosis of the lower trachea combined with stenosis of the proximal left and right main bronchi. Previously, such complex stenosis was treated with placement of three tubular stents: one in the lower part of the trachea, one in the proximal left main bronchus, and one in the proximal right main bronchus. This operation was complicated and problems like stent docking dislocation or docking overlapping were common; on the whole, it is ineffective. Professor Han and his team created the Y-type stent conveyor (patent name: airway integrated dual-branch bracket dedicated conveyor; patent number: ZL2006200306639), which has made stent treatment of this complex stenosis much easier [15]. The inverted Y-shaped integrated metal self-expanding stent achieves a one-time, single-in-one stent implantation in the treatment of carina area complex stenosis, thus shortening operation time and decreasing costs. The Y-shaped stent provides much better results by matching the anatomical structure of the carina (Fig. 7.9).

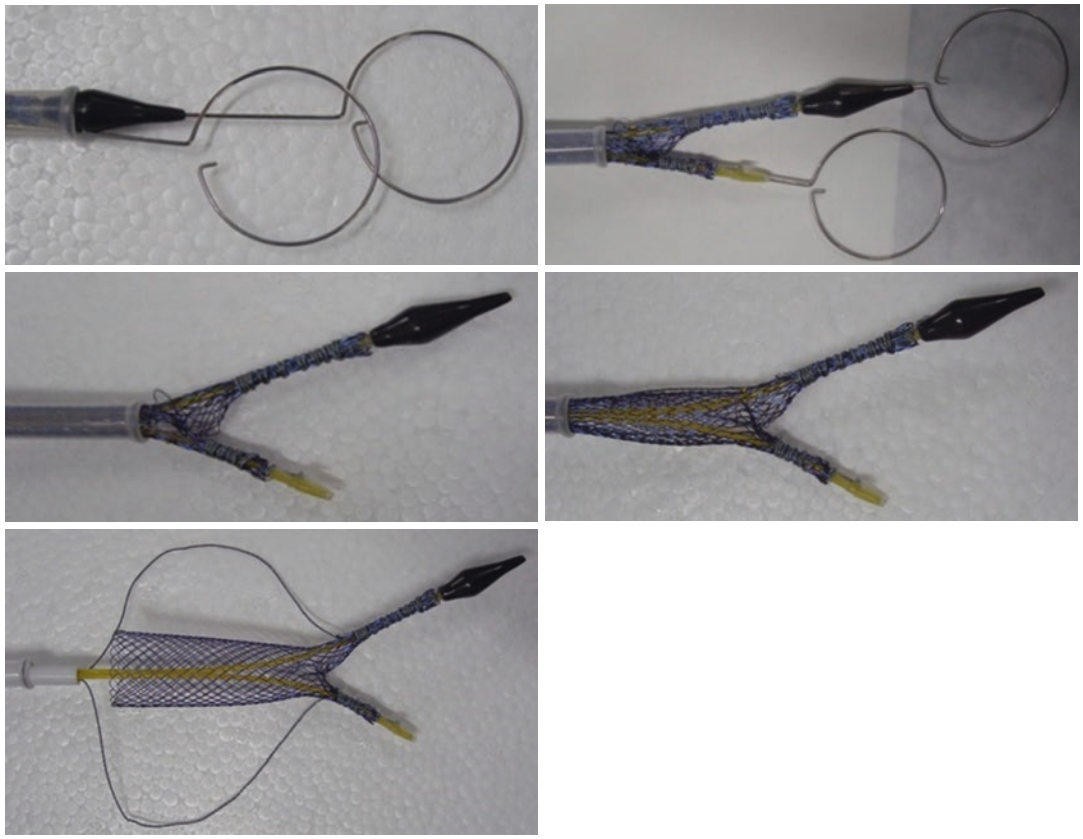

Fig. 7.9 The inverted Y-type stent delivery system with combination of the airway stent bundled and push release

7.6.2.1 Instrument Preparation

Interventional instruments and stent customization

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter (100 cm), 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing) (Fig. 7.10), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: The strategy of choosing an appropriate stent includes measuring the lengths and diameters of the stenoses in the trachea and the main bronchi on the chest MSCT cross-sectional image, and customizing the partly or fully coated inverted Y-shaped integrated self-expanding metal stent according to these measurements. The diameter of each limb of the stent should be 10% more than that of the corresponding stenosed airway. The lengths of the three limbs of the stent should be

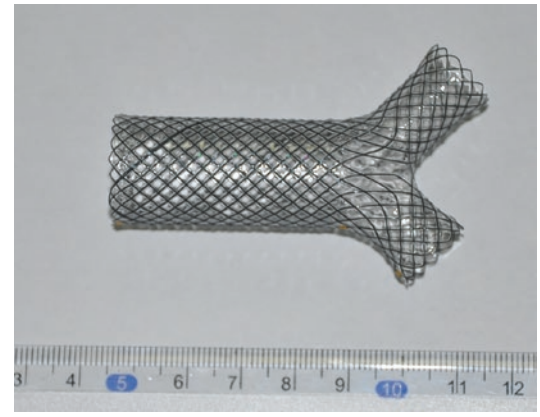

Fig. 7.10 The map of the inverted Y-type airway stent

10 mm more than that of corresponding stenosed sections. If the stenosis is adjacent to the opening of the upper lobe bronchus, two inverted Y-type stents are chosen to ensure that all stenoses are released [16].

7.6.2.2 Preoperative Preparation

1. Laboratory investigations: This includes routine blood examination, liver and kidney function, serum electrolytes, blood coagulation tests, infectious disease tests, sputum bacterial culture and drug sensitivity test, electrocardiogram (ECG), and other relevant tests.
2. Imaging: Perform chest MSCT scan and make full use of MPR, CPR, and other post-processing functions to analyze the image. Identify the site and dimensions of the stenoses and determine the distribution and severity of lung injury. Choose the appropriate stent on the basis of these features.
3. Gastrointestinal preparation: Fast the patient for 4–8 h before the operation to prevent vomiting and aspiration during stent placement.
4. Preoperative medication: About 10–30 min before stent placement, administer intramuscular mood stabilizer 10 mg to reduce patient anxiety, and intramuscular anisodamine (654-2) 10 mg to reduce digestive tract and respiratory secretions and prevent smooth muscle spasm.

7.6.2.3 Procedure of Tubular Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. The neck and shoulders should be slightly raised, and the head tilted backward and turned 20°–30° to the right side. Drape the patient, fix the nasal oxygen catheter, connect ECG leads, anesthetize the throat with 2% lidocaine spray, and insert the mouth gag; keep the suction apparatus ready to clear airway and oral secretions as necessary.

   Perform fluoroscopy with the C-arm tilted 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°); adjust the fluoroscopy collimator to include the oropharynx, trachea, and bilateral main bronchus in the field.
2. Transcatheter radiography: Under fluoroscopy, insert a hydrophilic guidewire and catheter through the mouth up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 ml of 2% lidocaine solution through the catheter. Next, adjust the position of the catheter so that the tip is at the stenosis, and through the catheter quickly push 3 ml of 30–40% iodinated contrast to display the tracheal and bronchial anatomy. Determine the location and length of the carina area stenosis, the distance from the glottis, and the position of the openings of the main bronchi and the upper lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and catheter past the stenosis into the right lower bronchus. Confirm the catheter's location, and then change to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the left lower bronchus. Mark the two guidewires so that it is clear which bronchus they are inserted in.

   An alternative method is as follows. Insert a 9F long sheath over the stiff guidewire to the lower part of the trachea just above the carina. Pull out the inner core of the sheath, and introduce a guidewire and catheter through the sheath into the left lower lobe bronchus. Change to stiff guidewire and fix in position.
4. Balloon pre-dilatation: In severe tracheal scar stenosis, the diameter at the stenosed area may be less than 5–8 mm, and it will be difficult to advance the tracheal stent delivery system past the stenosis or to exit it after stent placement. In such situations, it is feasible to perform balloon pre-dilatation. Pass a balloon catheter with a 10–14 mm diameter balloon along the guidewire until the balloon lies across the tracheal stenosis. Rapidly inflate the balloon with 30% iodinated contrast agent and then quickly deflate it and withdraw the catheter.

5. Insertion of stent delivery system: Under fluoroscopy monitoring, firmly fix the two stiff guidewires and hold them in position. Load the left and right bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Insert the stent delivery system over the stiff guidewire under fluoroscopy guidance. Tilt the patient's head backwards as much as possible, and slowly advance the delivery system. If resistance is encountered when the delivery system reaches the glottic area, and the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply with the glottis open and push the delivery system into the trachea. Put the delivery system above the carina and rotate it so that the left and right bronchus limbs of the stent are aligned with the corresponding main bronchus. Make sure that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side. Good cooperation between the operator, assistant, nurse, and technician is necessary to keep the stiff guidewires fixed, patient position unchanged, and oxygen saturation normal during the procedure.
6. Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the left and right main bronchus limbs of the stent in the lower trachea. Then, keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the limbs of the stent into the respective main bronchi. Resistance is encountered when the stent limbs are completely within the bronchi. Confirm with fluoroscopy that the stent bifurcation is in contact with the carina.

   With the delivery system and guidewire fixed in place, rapidly pull the two bundled silk threads to completely release the bronchus part of the stent; then, holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the trachea. The inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation has risen to 90–100%, and then pull out the stent delivery system slowly. Keep at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.

   If the patient suffers breathing difficulty and worsening of anoxia after stent deployment, perform fluoroscopy to exclude distortion, folding, or non-expansion of the stent. If that is ruled out, consider the possibility of blockage of the airway by sputum. Quickly pull out the stent delivery system, exchange it with a sputum suction tube, and clear out the right and left main bronchi. Apply suction until blood oxygen saturation returns to normal.
7. Re-radiography: Introduce the catheter over the guidewire to the carina region. Inject 3 ml of 30% iodinated contrast agent to check that all stenoses are completely released, the stent is correctly positioned and fully expanded, and both upper lobar bronchi are unobstructed (Fig. 7.11).
8. Sputum suction: Pass a suction tube over the stiff guidewires into the left and right main bronchi. Apply suction to remove all residual contrast agent and sputum; gently slap the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation; apply oral suction to prevent aspiration of accumulated saliva.

7.6.2.4 Postoperative Management (See Sect. 7.6.1.4)

7.6.2.5 Prevention and Treatment of Complications (See Sect. 7.6.1.5)

7.6.3 Left Main Bronchus Benign Stenosis

The length of left main bronchus (40 ± 3 mm) is much longer than that of the right main bronchus, so the left main bronchus occupies a large operat-

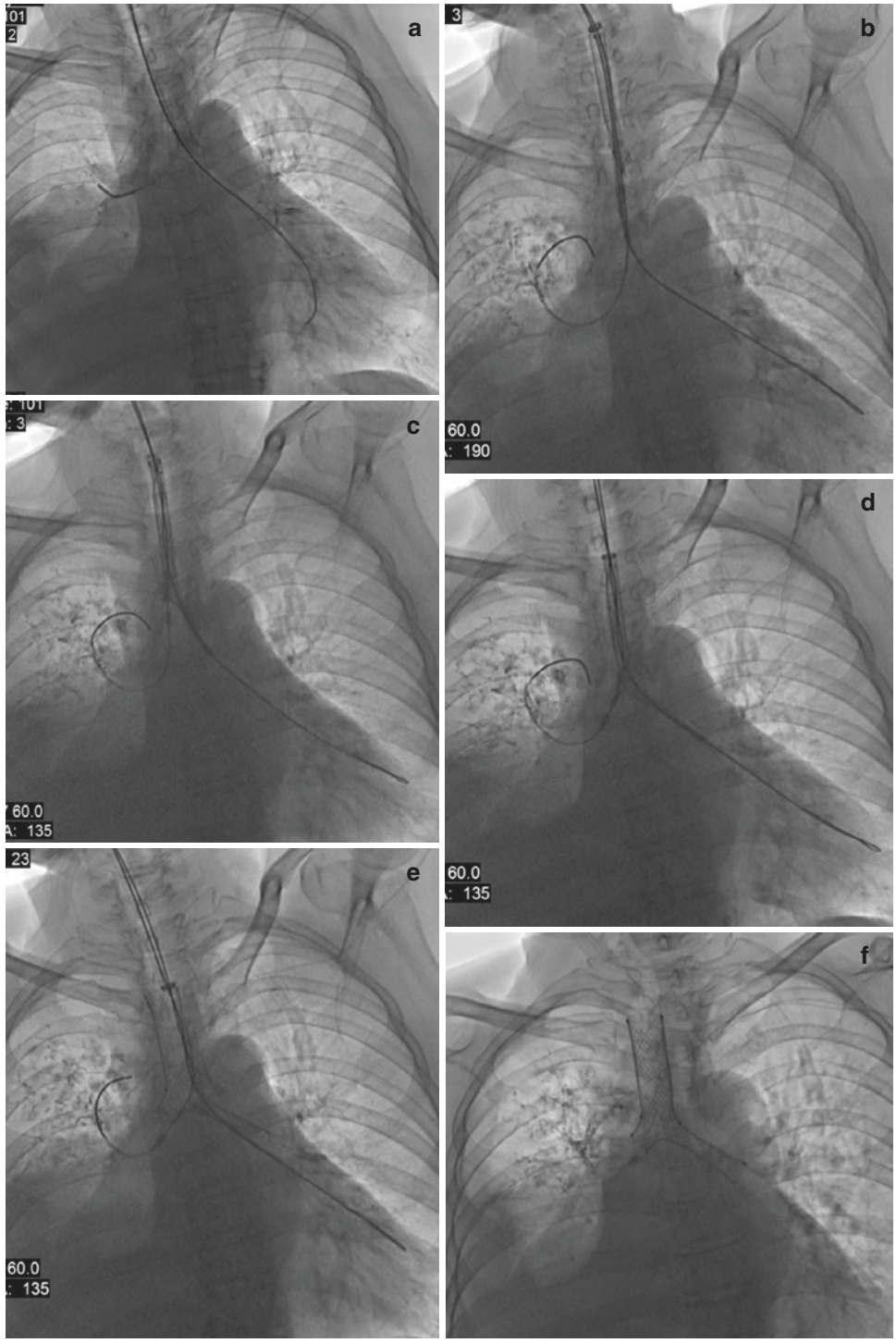

Fig. 7.11 (**a**–**f**) Process of the airway inverted Y stent placement. (**a**) Guidewires inserted into the left and right main bronchi; (**b**) the inverted Y-type bracket and its delivery system inserted along the two guidewires; (**c**) the delivery system rotated to align the left and right bronchus limbs of the stent with the corresponding main bronchi (the two guidewires are not twisted together); (**d**) the two stent limbs pushed into the left and right main bronchi; (**e**) release of the stent branch and the main body; (**f**) insertion of the delivery sheath along the guidewire

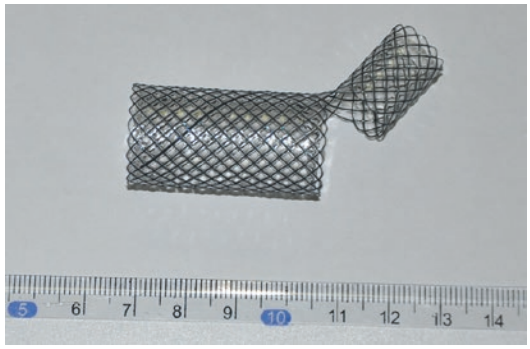

Fig. 7.12 The L-type anti-skid stent

ing space when stenosis is treated by the stent. Tubular stents have been used to treat left main bronchus stenosis close to the carina, but the stent tends to migrate upward to block the right main bronchus or downward to block the opening of the left upper lobe bronchus. Professor Han and his team created the L-type anti-skid stent [17] (patent name: main bronchial anti-skid detachable covered stent; patent number: ZL03235769.9) (Fig. 7.12) for treating these stenoses. The shorter arm of the stent is placed in the left main bronchus to alleviate the stenosis, while the main body of the stent stays in the trachea and anchors the stent in place. If the stenosis is at the distal end of the left main bronchus, a small inverted Y-shaped covered stent is chosen for treatment, with the main body in the left main bronchus, and the shorter branches in the left upper lobe and left lower lobe bronchi.

7.6.3.1 Instrument Preparation

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter (100 cm), 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, L-type anti-skid stent or small inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent:
   (a) L-type anti-skid partly covered stent: Measure the diameters and lengths of the stenosed trachea and left main bronchus on the MSCT image, and customize the L-type anti-skid partly covered stent according to the measurements. The diameter of the main part of the stent should be 10% more than that of the trachea; the length should be 40–50 mm above the carina, the upper 20 mm of the stent is bare, and the lower section of the stent is covered. The diameter of the shorter arm of the stent should be 10% more than that of the left main bronchus; the length should be such that the stent projects at least 10 mm beyond the distal end of the stenosis [11].
   (b) Small inverted Y-shaped stent: Measure the diameters and lengths of the stenosed left main bronchus and left upper and lower lobe bronchi, as well as the angle between the left upper and lower lobar bronchi, and customize the coated small inverted Y-shaped self-expanding metal stent according to these measurements. The length of the left main bronchus part of the stent should be the same as the length of the inferior wall of the left main bronchus; the diameter should be 10% more than that of the left main bronchus. The length of the left upper lobe bronchus part and of the lower lobe bronchus part of the stent should be ±10 mm; the diameters should be 10% more than that of the corresponding airway. The angle of the stent bifurcation should match the angle between the left upper and lower bronchi.

7.6.3.2 Preoperative Preparation

1. Laboratory investigations (see Sect. 7.6.1.2)
2. Imaging (see Sect. 7.6.1.2)
3. Gastrointestinal preparation (see Sect. 7.6.1.2)
4. Preoperative medication (see Sect. 7.6.1.2)

7.6.3.3 Placement of L-Type Anti-skid Partly Covered Stent

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination

table. Raise the neck and shoulders slightly, and tilt the head backward at 20°–30° to the right side. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine, and insert a mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as necessary.

Perform fluoroscopy with the C-arm tilted 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°); adjust the fluoroscopy collimator to include the oropharynx, trachea, and bilateral main bronchus in the field.

2. Transcatheter radiography: Under fluoroscopy, insert a hydrophilic guidewire and catheter through the mouth and advance it slowly up to the carina region. Pull out the guidewire and rapidly push 2–3 ml of 2% lidocaine solution through the catheter. Adjust the position of the catheter so that the tip is at the stenosis in the left main bronchus; quickly push 3 ml of 30–40% iodinated contrast agent through the catheter to display the tracheobronchial anatomy. Determine the location and length of the stenosis in the left main bronchus and its distance from the left upper lobe bronchus opening.
3. Insertion of stiff guidewire: Introduce a hydrophilic guidewire and catheter through the left main bronchus stenosis and into the left lower lobe bronchus. Pull out the guidewire, and inject 1 ml of 30% iodinated contrast agent to confirm that the catheter tip is in the left lower lobe bronchus. During the procedure, ask the assistant to keep the position of the guidewire and mouth gag unchanged.
4. Balloon pre-dilatation: In severe airway stenosis, the diameter of the stenosed segment may be less than 5–8 mm and it will be difficult for the airway stent delivery system to pass through the stenosis or exit after stent placement. In such cases, perform balloon pre-dilatation. Pass the balloon catheter, with an 8–10 mm diameter balloon, along the guidewire into the left main bronchus stenosis so that the balloon lies across the stenosis. Quickly inject 30% iodinated contrast agent to fully inflate the balloon, then quickly deflate the balloon and withdraw the catheter.
5. Insertion of L-shaped stent delivery system: Insert the stent delivery system over the stiff guidewire. While keeping the stiff guidewire in the left lower lobe bronchus, slowly push forward the L-shaped stent delivery system to the opening of the left main bronchus. Rotate the stent conveyor so that the window between the main body of the stent and the branch of the stent stays at the opening of the right main bronchus, as well as the gold X-ray mark on the small curvature of the inner bracket is located on the left side edge.
6. Placement of the stent: After fixing the stiff guidewire and the rear handle of the stent conveyor, slowly pull back the front handle and the outer sheath to release the branch part of the L-shaped stent in the left main bronchus, with the perspective detection when half of the branch is released. Maintain continuous monitoring to ensure that the lower end of the stent branch does not cover the opening of the upper lobe bronchus and the proximal end of the stent branch does not cover the opening of the right main bronchus. Then slowly release the branch of the stent, and check that the stent branch is correctly placed across the stenosis. During the release process, constantly adjust the stent conveyor to ensure that the window between the main body and the branch is aligned with the opening of the right main bronchus. Finally, quickly release the main body of the stent in the lower part of the trachea.

   The conveyor should be withdrawn slowly after the L-shaped stent is released, more attention should be paid to the back of the conveyor in order to avoid the barb inside the stent and migration of the stent. Leave the guidewire in place for subsequent interventions.
7. Re-radiography: Introduce a catheter over the guidewire and inject 3 ml of 30% iodinated contrast agent. Check that the stenosis is completely released, the stent is correctly localized and fully expanded, and the right

main bronchus and left upper lobe bronchus are unobstructed. If necessary, adjust the position of stent or perform post-dilatation (Fig. 7.13).

8. Sputum suction: Pass a suction tube over a stiff guidewire into the left and right main bronchi. Apply suction to remove all residual contrast agent and sputum; gently slap the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%. Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation; apply oral suction to prevent aspiration of saliva.

7.6.3.4 Postoperative Management (See Sect. 7.6.1.4)

7.6.3.5 Prevention and Treatment of Complications (See Sect. 7.6.1.5)

7.6.4 Left Upper Lobe Bronchus Benign Stenosis

Simple left upper lobe bronchial stenosis is relatively rare. When it does occur, it is usually accompanied by stenoses of the left main bronchus and left lower lobe bronchus. The small inverted Y-shaped airway stent can be used to expand the stenosis [18].

Most patients with dysfunction of only one lobe or one lung do not present the typical complaints of chest tightness, wheezing, and progressive increase in breathing difficulty. Typical signs (cyanosis, three concavities) are also absent. Unless the symptoms of obstructive pneumonia appear, the diagnosis may be missed and treatment delayed. If left upper lobe atelectasis or lung consolidation is present, determine the integrity of the collapsed/consolidated lung and whether normal structure and function can be recovered by removing the bronchial obstruction.

7.6.4.1 Instrument Preparation

Interventional instruments and stent customization

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter (100 cm), 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, small inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: Measure the lengths and diameters of the stenosed segments of the left main bronchus and the left upper and lower lobe bronchi on the chest MSCT cross-sectional image, and customize the fully coated small inverted Y-shaped integrated self-expanding metal stent according to the measurements. The length of the left main bronchus part of the stent should be the same as the length of the inferior wall of the left main bronchus and the diameter is 10% more than that of the left main bronchus. The length of the left upper lobe bronchus part of the stent should be 5 mm more than that of the stenosed segment of the left upper lobe bronchus, and the diameter should be 10% more than that of the left upper lobe bronchus. The length of the left lower lobe bronchus part of the stent should be 5 mm more than that of the stenosed segment of the left lower lobe bronchus, and the diameter should be 10% more than that of the left lower lobe bronchus. The angle of the stent bifurcation matches the angle between the left upper and lower lobe bronchi.

7.6.4.2 Preoperative Preparation

1. Laboratory investigations (see Sect. 7.6.1.2)
2. Imaging: Perform plain chest CT and enhanced scans to accurately determine the degree and extent of the stenosis and the resultant atelectasis. Examine whether the atelectatic lung is uniformly strengthened in the pulmonary arterial phase of the enhanced scan. Uniform

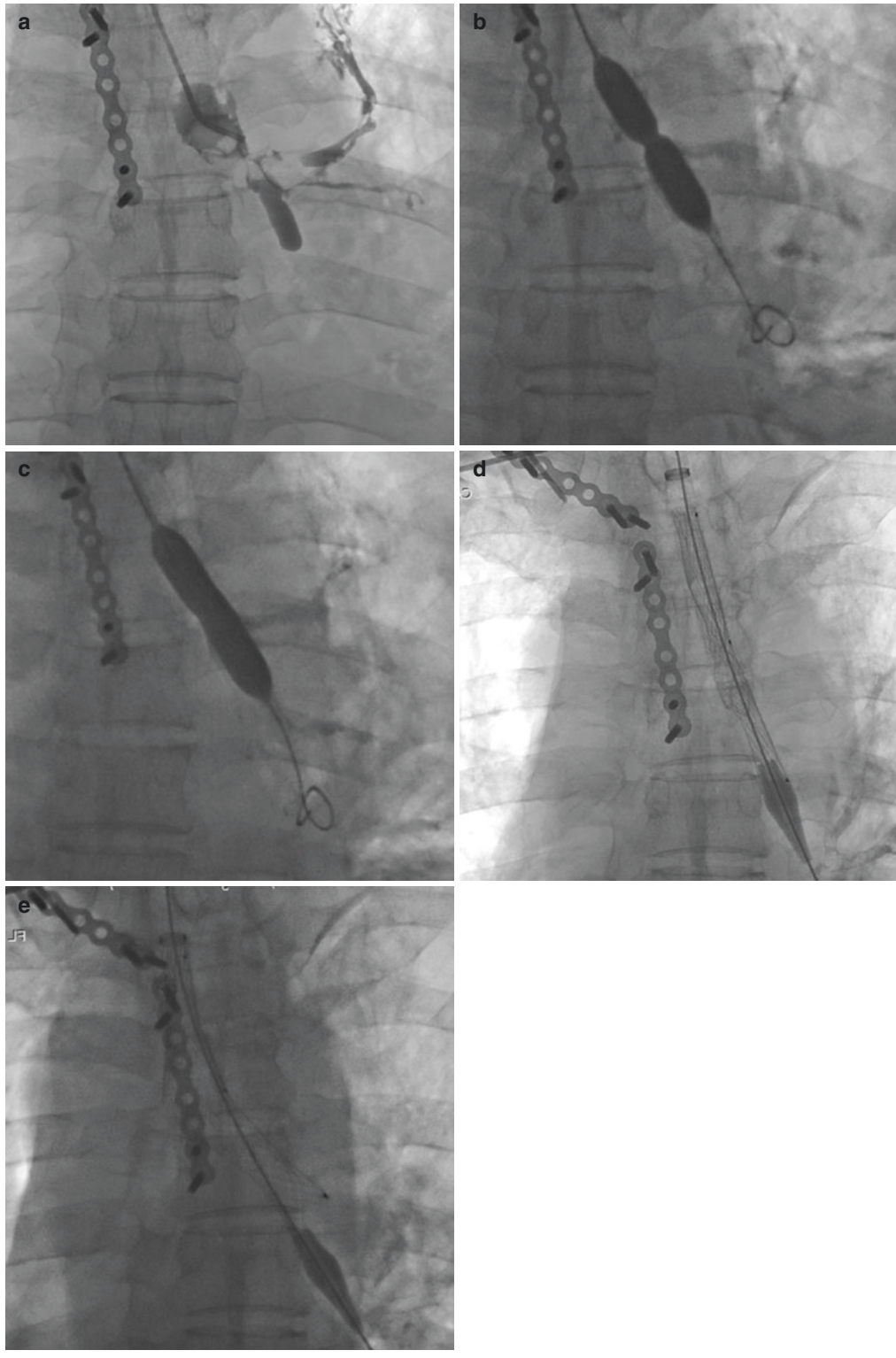

Fig. 7.13 The process of L-type anti-skid stent placement. (**a**) Transcatheter airway bronchography shows severe left main bronchus stenosis; (**b** and **c**) balloon dilatation of left main bronchus stenosis; (**d**) delivery system of L-type anti-skid stent being inserted; (**e**) fluoroscopy shows the stent is correctly localized and fully expanded

enhancement indicates that the lung tissue structure is intact and complete inflation can be achieved if the obstruction is relieved; therefore, these patients should receive stent implantation. Uneven enhancement or no enhancement indicates that the lung structure (alveoli, alveolar stroma, capillary bed) in the atelectatic part is either destroyed or severely damaged, and normal structure and function cannot be recovered by bronchial stenosis treatment.

3. Gastrointestinal tract preparation (see Sect. 7.6.1.2)
4. Preoperative medication (see Sect. 7.6.1.2)

7.6.4.3 Placement of the Tubular Stent

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. The neck and shoulders should be slightly raised, and the head tilted backward and turned 20°–30° to the right side. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine, and insert the mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as necessary.

   Perform fluoroscopy with the C-arm tilted 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°); adjust the fluoroscopy collimator to include the oropharynx, trachea, and bilateral main bronchus in the field.
2. Transcatheter radiography: Under fluoroscopy, insert a hydrophilic guidewire and catheter through the mouth and advance it up to the carina. Fix catheter and pull out the guidewire. Through the catheter, rapidly push 2–3 ml of 1% lidocaine solution. Adjust the position of the catheter so that the tip is at the left upper lobe bronchus stenosis, and quickly push 3 ml of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the precise locations and lengths of the stenoses in the left upper lobe and left lower lobe bronchi.
3. Insertion of stiff guidewire: After completion of radiography, a hydrophilic guidewire and catheter are passed through the stenosis into the left upper lobe bronchus. Confirm the catheter's location, and exchange to a stiff guidewire. Similarly, insert another stiff guidewire into the left lower lobe bronchus. Fix the two stiff guidewires in position.

   An alternative method is that a 9F long sheath over the stiff guidewire is inserted into the lower end of the trachea. Then, pull out the inner core of the sheath, and introduce the guidewire and catheter through the sheath into the left lower lobe bronchus. Change to a stiff guidewire and fix in position.
4. Insertion of stent delivery system: Firmly fix the two stiff guidewires and hold in position. Load the left upper and lower lobe bronchus parts of the Y-shaped stent onto the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding them at the mouth gag end. Keep the patient's head tilted backward as much as possible. Introduce the delivery system through the mouth and advance it slowly. If there is resistance when the delivery system reaches the glottic area, and if the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply while keeping the glottis open, and during the inhalation, push the delivery system into the trachea and advance it to the left main bronchus. Rotate the delivery system so that the left upper and lower lobe bronchus parts of the stent are aligned with the openings of the corresponding bronchi. Make sure that the two guidewires are not twisted together, and that the golden mark on the delivery system is on the correct side. Good cooperation between the operator, assistant, nurse, and technician is necessary during the procedure to keep the stiff guidewires fixed, patient position unchanged, and oxygen saturation normal.
5. Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the left upper and lower lobe bronchus

branches of the stent in the left main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the stent limbs into the respective bronchi. Resistance is felt when the stent limbs are completely within the respective bronchi.

Fixing the delivery system and guidewire, rapidly pull on the two bundled silk threads to completely release the main bronchus part of the stent. Hold the posterior handle and quickly pull back the anterior handle to release the main body of the stent in the left main bronchus. With this, the small inverted Y-shaped stent is entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation reaches 90–100%, and then pull out the stent delivery system slowly. Keep at least one stiff guidewire in place as an intervention pathway for subsequent procedures.

If the patient has breathing difficulties and declining blood oxygen saturation after release of the stent, perform fluoroscopy to exclude stent distortion and folding, or stent non-expansion. If these complications are ruled out, consider the possibility of blockage of the bronchus by sputum. Quickly pull out the stent delivery system, insert a sputum suction tube into the left main bronchus, and suck repeatedly until blood oxygen saturation rises to normal.

6. Re-radiography: Introduce a catheter over the guidewire into the left main bronchus and inject 3 ml of 30% iodinated contrast agent to confirm that all stenoses are completely released and that the stent is in the expected place and fully expanded (Fig. 7.14).
7. Sputum suction: Pass a suction tube over a stiff guidewire into the left main bronchus. Apply suction to remove all residual contrast agent and sputum; gently slap the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%. Watch for blood in the phlegm, difficulty in breathing, and a decrease in blood oxygen saturation; apply oral suction to prevent aspiration of saliva.

7.6.4.4 Postoperative Management

(See Sect. 7.6.1.4)

7.6.4.5 Prevention and Treatment of Complications

(See Sect. 7.6.1.5)

7.6.5 Left Lower Lobe Bronchial Benign Stenosis

Simple left lower lobe bronchial stenosis is relatively rare and, when it does occur, it is usually accompanied by stenosis of the left main bronchus or left upper lobe bronchus. A small inverted Y-shaped airway stent can be inserted to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not present the typical complaints of chest tightness, wheezing, and progressive increase in breathing difficulty. Typical signs (cyanosis, three concavities) are also absent. Unless the symptoms of obstructive pneumonia appear, the diagnosis may be missed with delayed treatment. If left lower lobe atelectasis or lung consolidation is present, determine the integrity of the collapsed/consolidated lung and whether normal structure and function can be restored by removing the bronchial obstruction.

7.6.5.1 Instrument Preparation

Interventional instruments and stent customization

1. Interventional instruments (see Sect. 7.6.4.1)
2. Choice of stent: Measure the lengths and diameters of the left main bronchus and left upper and lower lobe bronchi on the chest MSCT cross-sectional image, and customize the fully coated small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the left main bronchus part of the stent should be the same as the length of the inferior wall of the left main bronchus; the diameter should be 10% more than that of the left main bronchus. The length of left upper lobe bronchus and left lower lobe bronchus parts of the

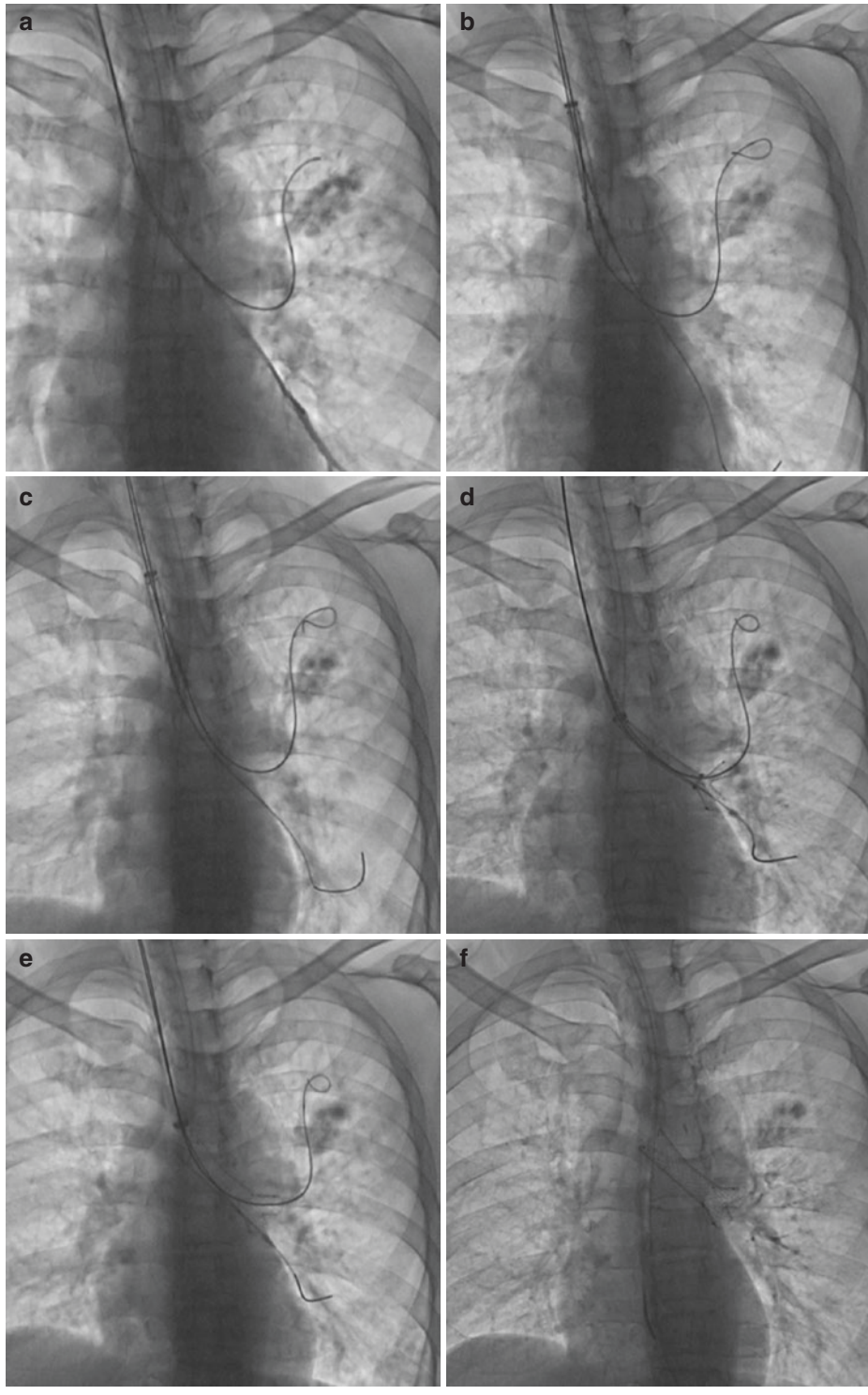

Fig. 7.14 (**a**–**f**) Process of the small Y-type airway stent placement. (**a**) Stiff guidewires were inserted into the left upper and lower lobe bronchi; (**b**) insertion of the small Y-type stent and its delivery system along the guidewire; (**c**) delivery system rotated to align the left upper and lower lobe limbs of the stent with the corresponding bronchi; (**d**) the two limbs of the stent inserted into the respective bronchi; (**e**) release of the branch and the main body of stent; (**f**) fluoroscopy confirms good stent position and expansion

stent should be 5 mm more than the lengths of the stenosed segments of the respective bronchi; the diameters should be 10% more than that of the corresponding airways. The angle of stent bifurcation should match the angle between the left upper and lower lobe bronchi [10].

7.6.5.2 Preoperative Preparation

1. Laboratory examinations (see Sect. 7.6.1.2)
2. Imaging (see Sect. 7.6.4.2)
3. Gastrointestinal preparation (see Sect. 7.6.1.2)
4. Preoperative medication (see Sect. 7.6.1.2)

7.6.5.3 Procedure of Tubular Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. The neck and shoulders should be slightly raised, and the head tilted backward and turned 20°–30° to the right side. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine, and insert the mouth gag; keep suction apparatus ready to clear airway and oral secretions as necessary.

   Perform fluoroscopy with the C-arm tilted 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°); adjust the fluoroscopy collimator to include the oropharynx, trachea, and bilateral main bronchus in the field.
2. Transcatheter radiography: Under fluoroscopy, insert a hydrophilic guidewire and catheter through the mouth and advance it up to the carina. Fix the catheter and pull out the guidewire. Rapidly push 2–3 ml of 1% lidocaine solution through the catheter. Adjust the position of the catheter so that the tip is at the left lower lobe bronchus stenosis, and quickly push 3 ml of 30–40% iodinated contrast agent through the catheter to display the tracheobronchial anatomy. Determine the location and length of the left lower lobe bronchus stenosis and the position of the opening of the left upper lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and catheter through the stenosis into the left lower lobe bronchus. After confirming the catheter's location, exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the left upper lobe bronchus. Fix the two stiff guidewires in position.

   An alternative method is as follows. Insert a 9F long sheath through the stiff guidewire to lower part of trachea or above the carina, pull out the inner core of the sheath, guidewire and catheter introduced through the sheath into the left upper lobe bronchus, exchange to stiff guidewire and fix in position.
4. Insertion of stent delivery system: Under fluoroscopy monitoring, firmly fix the two stiff guidewires and hold them in position. Load the left upper and lower lobe bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding them at the mouth gag end, and push the delivery system through the mouth. Keep the patient's head tilted backward as much as possible. Introduce the delivery system through the mouth and advance it slowly. If resistance is encountered and the patient coughs or appears to choke when the delivery system reaches the glottic area, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply while keeping the glottis open, and during the inhalation, push the delivery system into the trachea and then into the left main bronchus. Rotate the delivery system so that the left upper and lower bronchus parts of the stent are aligned with the corresponding bronchi. Make sure that the two guidewires are not twisted together, and that the golden mark on the delivery system is on the correct side.
5. Placement of stent: Hold stiff guidewire and the posterior handle of the delivery system, and pull back the anterior handle to release the small inverted stent bilateral (left upper and lower lobe bronchus) parts in the left main

bronchus. Keeping the relative position of the two handles unchanged, fix the stiff guidewire, and push the upper and lower lobe bronchus parts into the respective bronchi. Resistance is felt when the stent limbs are completely inserted into the respective bronchi.

Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the main bronchus part of stent. Then, hold the posterior handle and quickly pull back the anterior handle to release the main body of the stent into the left main bronchus. The stent is now entirely released. Wait for 1–3 min until patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave one stiff guidewire in place as an intervention pathway for subsequent procedures.

If the patient has breathing difficulty and progressive decline in blood oxygen saturation after releasing the stent, perform fluoroscopy to exclude stent distortion and folding, or non-expansion of the stent. If these complications are ruled out, consider the possibility of blockage of the bronchus by sputum. Insert a sputum suction tube into the left main bronchus, and suck until blood oxygen saturation rises to normal levels.

6. Re-radiography: Introduce a catheter over the guidewire into the left main bronchus and inject 3 ml of 30% iodinated contrast agent to confirm that all stenoses are completely released and that the stent is in the expected location and fully expanded.
7. Sputum suction: Pass a suction tube over the stiff guidewire into the left main bronchus. Apply suction to remove all residual contrast agent and sputum; gently slap the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%. Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation, and apply oral suction to prevent aspiration of saliva.

7.6.5.4 Postoperative Management (See Sect. 7.6.1.4)

7.6.5.5 Prevention and Treatment of Complications (See Sect. 7.6.1.5)

7.6.6 Right Main Bronchial Benign Stenosis

The right main bronchus is only 10–20 mm long, therefore stenosis of this bronchus is usually accompanied with stenosis of the carina area and the right upper and middle lobe bronchi. The previous L-shaped tracheal stent, main bronchus stent, and the large inverted Y-shaped integrated stent cannot be completely released in this short airway without covering the opening of the right upper lobe bronchus; however, the small inverted Y-type stent may cover the left main bronchus. In most cases, a large and a small inverted Y-shaped integrated stent are placed, while the small inverted Y-shaped stent is released into the right middle bronchus—right upper lobe bronchus and right main bronchus; the large Y-shaped stent is released into the right main bronchus—left main bronchus and lower trachea [19].

7.6.6.1 Instrument Preparation

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter (100 cm), 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, two (large and small) inverted Y-shaped coated self-expanding stents (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: Measure the lengths and diameters of the trachea, both main bronchi, and the right upper lobe and right middle bronchi on the chest MSCT cross-sectional image, also measure the angle between the right upper lobe and right middle bronchi. Customize the stents according to these measurements.
3. Small Y-shaped stent: The length of the right main bronchus part of the stent should be the

same as that of the inferior wall of the right main bronchus, and the diameter should be 10% more than that of the right main bronchus. The length of the right upper lobe bronchus and the right middle bronchus parts should be 10 mm; while the diameters should be 10% more than that of the corresponding airways. The angle of the stent bifurcation should match that between the right upper lobe and right middle bronchi.

4. Large Y-shaped stent: The length of the main body (trachea part) of the stent should be 40–50 mm; and the diameter should be 10–20% more than that of the corresponding airway. Also, the length of the left main bronchus part should be 15–20 mm, and the diameter should be 10% more than that of the corresponding airway. The length of the right main bronchus part of the stent should be 10–15 mm (so that the stent does not cover the opening of the right upper lobar bronchus), also the diameter should be 10% more than that of the corresponding airway. The angle of the stent bifurcation should match the angle between the left and right main bronchi.

7.6.6.2 Preoperative Preparation

1. Laboratory examinations (see Sect. 7.6.1.2)
2. Imaging (see Sect. 7.6.1.2)
3. Gastrointestinal preparation (see Sect. 7.6.1.2) (Fig. 7.15)
4. Preoperative medication (see Sect. 7.6.1.2)

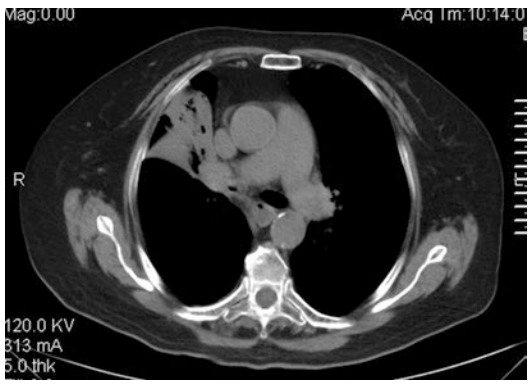

Fig. 7.15 Chest CT scan shows severe stenosis of the right main bronchus

7.6.6.3 Procedure of Placement of Two Inverted Y-Shaped Stents

1. Procedure of placement of small inverted Y-shaped stent
   (a) Patient position: Ask the patient to take off clothes that contain any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. The neck and shoulders should be slightly raised up, and the head tilted backward and turned 20°–30° to the right side. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine, and insert the mouth gag; keep suction apparatus ready to clear airway and oral secretions as necessary.

   Tilt the C-arm 20°–30° to the left (with the head turned 20°–30° to the right, the combined effect is equivalent to turning the body 50° to the right). Adjust the fluoroscopy collimator to include the oropharynx, trachea, and bilateral main bronchus in the field.

   (b) Transcatheter radiography: Under fluoroscopy, insert a hydrophilic guidewire and catheter through the mouth and advance it to the carina region. Fix the catheter and pull out the guidewire. Rapidly inject 2–3 ml of 2% lidocaine through the catheter. Adjust the position of the catheter so that the tip lies in the right main bronchus, and quickly inject 3 ml of 30% iodinated contrast agent to display the tracheobronchial anatomy. Determine the lengths of the stenoses and the relationship between the stenoses and the openings of the right upper and middle lobe bronchi.

   (c) Insertion of stiff guidewire: After completion of radiography, pass a hydrophilic guidewire and catheter through the stenosis into the right lower lobe bronchus. Confirm the catheter's location. Change to a stiff guidewire and fix it in place. Insert a 9F long sheath over the stiff guidewire to the lower end of the trachea. Pull out the inner core of the sheath, and introduce a

catheter through the sheath up to the right upper lobe bronchus and segmental bronchi. Change to another stiff guidewire and fix it in position. Pull out the catheter and sheath. Mark the two stiff guidewires to identify which (right upper or lower lobe) bronchus each one is inserted in.

(d) Balloon pre-dilatation: In severe tracheal scar stenosis, the diameter of the stenosed area may be less than 5–8 mm, and it is difficult to advance the tracheal stent delivery system past the stenosis or to exit it after stent placement. In such situations, perform balloon pre-dilatation. Pass a balloon catheter with a 10–14 mm diameter balloon along the guidewire until the balloon lies across the tracheal stenosis. Rapidly inflate the balloon with 30% iodinated contrast agent and then quickly deflate it and withdraw the catheter.

(e) Insertion of small Y-shaped stent delivery system: Under fluoroscopy monitoring, firmly fix the two stiff guidewires and hold them in position. Load the upper and middle bronchus parts of the small Y-shaped stent on the respective guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Tilt the patient's head backwards as much as possible, and slowly advance the delivery system through the mouth. If resistance is encountered when the delivery system reaches the glottic area, and the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply keeping the glottis open and, during the inhalation, push the delivery system into the trachea and advance it to the carina. Rotate the delivery system so that the upper and middle bronchus parts of the stent are aligned with the corresponding bronchus. Make sure that the two guidewires are not twisted together and the golden mark on the delivery system is on the correct side. Advance the delivery system into the left main bronchus.

(f) Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the Y-shaped stent in the right main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the bronchus part of the stent into the right upper and middle bronchi. When the stent limbs are completely inserted in the respective bronchi, resistance is encountered. Perform fluoroscopy to confirm that the stent bifurcation is at the airway bifurcation.

Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the two bronchus parts of the stent; confirm with fluoroscopy that the stent limbs are correctly in place. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right main bronchus. The small Y-shaped stent is now entirely released. Pull out the stent delivery system slowly, leaving the stiff guidewire in the left lower lobe bronchus so that an intervention pathway is available for subsequent procedures (Fig. 7.16).

2. Procedure of the large inverted Y-shaped stent placement

(a) Insertion of the large inverted Y-shaped stent delivery system (see Sect. 7.6.2.3)

(b) Placement of the large inverted Y-shaped stent (see Sect. 7.6.2.3)

(c) Re-radiography: Introduce the catheter through the guidewire to the carina region, and inject 3–5 ml of 30% iodinated contrast agent to confirm that the stenoses are completely released, the stents are accurately in place and fully expanded, and the two stents fit closely together.

(d) Sputum suction: Severe stenosis of the right main bronchus results in bacterial infection of retained secretions in the alveoli and bronchi. When the stenosis is released, mucus and pus can pour out into the upper bronchi, block the air flow, and cause severe breathing difficulty. Sputum suction is necessary and life-saving. Pass a suction tube over the stiff guidewire into the right main bronchus and especially right lobe bronchus. Apply suction to

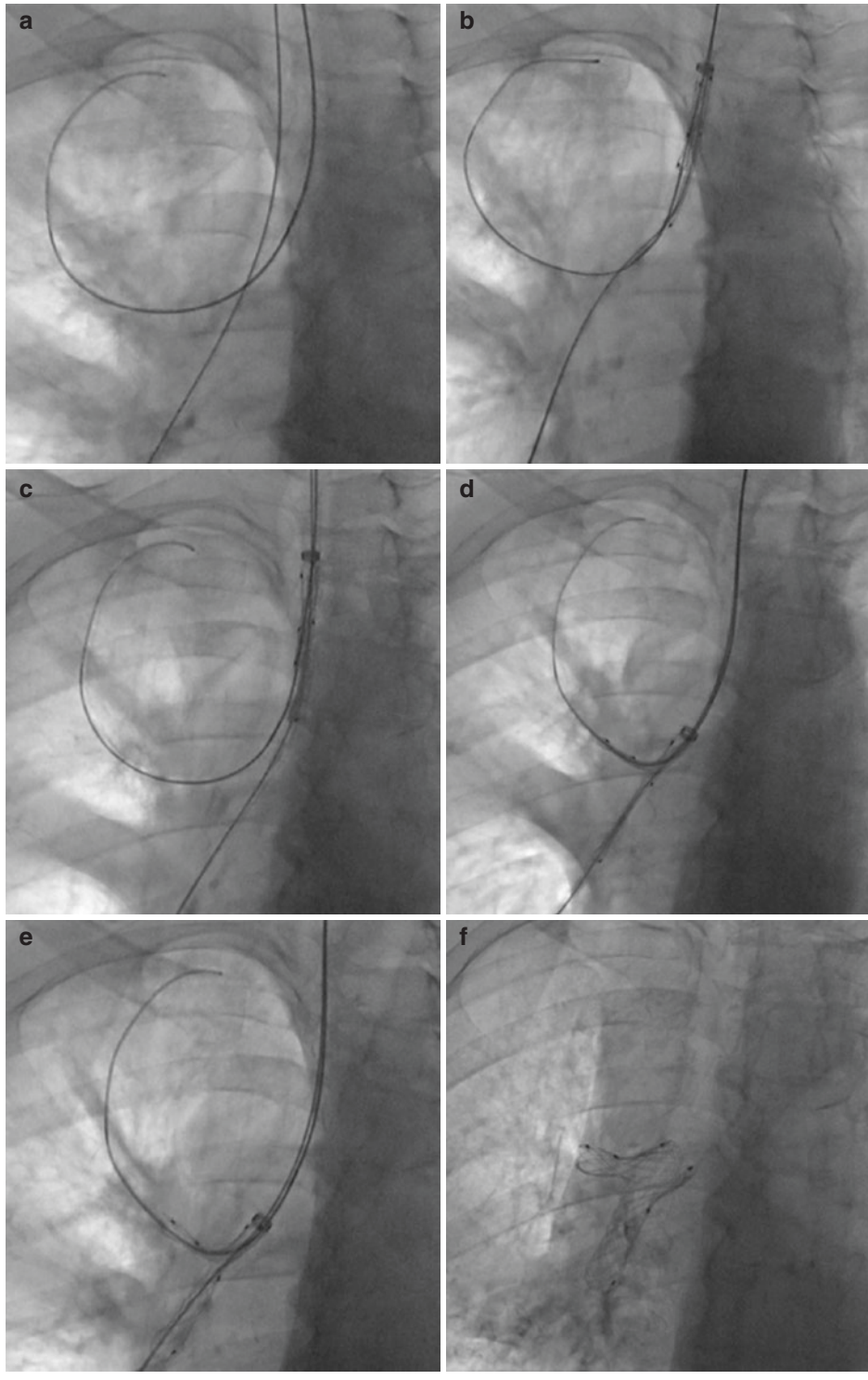

Fig. 7.16 (**a**–**f**) is the process of small Y-shaped airway stent placement. (**a**) The two stiff guidewires inserted into the right upper and right middle bronchial; (**b**) the small Y-type airway stent inserted along the guidewire; (**c**) the delivery system rotated to align the right upper and middle lobe limbs of the stent with the corresponding bronchus; (**d**) the two limbs of the stent inserted into the right upper and middle bronchi; (**e**) the branch and the main body of stent released; (**f**) the fluoroscopy shows good stent position and expansion

remove all residual contrast agent and sputum, and lavage with antibiotics. Gentle slapping on the patient's back and application of postural drainage will help sputum removal. Repeat suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%.

7.6.6.4 Postoperative Management
(See Sect. 7.6.1.4)

7.6.6.5 Complications (See Sect. 7.6.1.5)

7.6.7 Right Upper Lobe Bronchus Benign Stenosis

Isolated right upper lobe bronchial benign stenosis is relatively rare and, when it occurs, it is usually accompanied with stenosis of other bronchi, such as the right main bronchus or right middle lobe bronchus. A small inverted Y-shaped airway stent can be used to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not present the typical complaints of chest tightness, wheezing, and progressive increase in breathing difficulty. Typical signs (cyanosis, three concavities) are also absent. Without the symptoms of obstructive pneumonia, the diagnosis may be missed and treatment delayed. If left upper lobe atelectasis or lung consolidation is present, determine the integrity of the collapsed/consolidated lung and whether normal structure and function can be restored by removing the bronchial obstruction [20, 21].

7.6.7.1 Instrument Preparation
Interventional instruments and stent customization

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, the small inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: Measure the lengths and diameters of the right main bronchus and right upper and middle lobe bronchi on the chest MSCT cross-sectional image, and customize the fully coated small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the right main bronchus part of the stent should be the same as that of the inferior wall of the right main bronchus, and the diameter should be 10% more than the corresponding airway. The length of the right upper lobar bronchus part should be 5 mm more than that of the right upper lobe bronchus stenosis, and the diameter should be 10% more than that of the corresponding airway. The length of the right middle bronchus part of the stent should be 10 mm, and the diameter should be 10% more than that of the corresponding airway. The angle of stent bifurcation should match that between the right middle bronchus and the right upper lobe bronchus.

7.6.7.2 Preoperative Preparation
1. Laboratory investigations (see Sect. 7.6.1.2)
2. Imaging: Perform plain chest CT and enhanced scans to accurately determine the degree and extent of the stenosis and the associated atelectasis. Examine whether the atelectatic lung is uniformly strengthened in the pulmonary arterial phase of the enhanced scan. Uniform enhancement indicates that the lung tissue structure is intact and that complete inflation can be achieved if the obstruction is relieved, and these patients should receive stent implantation. Uneven enhancement or no enhancement indicates that the lung structure (alveoli, alveolar stroma, capillary bed) in the atelectatic part is either destroyed or severely damaged, and normal structure and function cannot be restored by relieving the bronchial stenosis.
3. Gastrointestinal preparation (see Sect. 7.6.1.2)
4. Preoperative medication (see Sect. 7.6.1.2)

7.6.7.3 Procedure of Small Y-Shaped Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. Slightly raise the neck and shoulders; keep the head tilted backwards and turned 20°–30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, anesthetize the throat with lidocaine spray, and insert the mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as necessary.

   Perform fluoroscopy with the C-arm tilted 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°); adjust the fluoroscopy collimator to include the oropharynx, trachea, and bilateral main bronchus in the field.
2. Transcatheter radiography: Under fluoroscopy, pass a hydrophilic guidewire and catheter through the mouth and advance it up to the carina region. Fix the catheter and pull out the guidewire, and then push 2–3 ml of 1% lidocaine solution through the catheter. Adjust the catheter so that the tip lies at the right upper lobe bronchus stenosis. Quickly push 3 ml of 30–40% iodinated contrast agent through the catheter to display the tracheobronchial anatomy. Determine the location and length of the right upper lobe bronchus stenosis and the position of the opening of the right middle bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and catheter through the stenosis into the right upper lobe bronchus and perform radiography to confirm the catheter's location. Change to a stiff guidewire. Repeat the procedure and insert another stiff guidewire into the right lower lobe bronchus. Fix the two stiff guidewires in position.

   An alternative method is as follows. Insert a 9F long sheath over the stiff guidewire to the lower part of the trachea. Pull out the inner core of the sheath, and introduce a catheter through the sheath into the right lower lobe bronchus. Change to stiff guidewire and fix in position.
4. Insertion of stent delivery system: Under fluoroscopy monitoring, firmly fix two stiff guidewires and hold them in position. Load the right upper lobe and right middle lobe bronchi parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding them at the mouth gag and push the delivery system over the guidewire. Tilt the patient's head backwards as much as possible, and slowly advance the delivery system. If resistance is encountered when the delivery system reaches the glottic area, and the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply while keeping the glottis open and push the delivery system into the trachea and advance it to the right main bronchus. Rotate the delivery system so that the right upper lobe and right middle bronchus lobe parts of the stent are aligned with the corresponding bronchus. Make sure that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.
5. Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle of the delivery system to release the right upper lobe and right middle lobe bronchi parts of the stent in the right main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire and push the two limbs of the stent into the respective bronchi. Resistance occurs when the stent limbs are completely inserted into the respective bronchi.

   Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent, then hold the posterior handle and

quickly pull back the anterior handle to release the main body of the stent in the right main bronchus. The small inverted Y-shaped stent is now entirely released. Wait 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one stiff guidewire in place as a pathway for subsequent interventional procedures.

If the patient experiences breathing difficulty and worsening of anoxia after stent deployment, first perform fluoroscopy to exclude distortion, folding, or non-expansion of the stent. Then consider the possibility of blockage of the airway by sputum, exchange to sputum suction tube and clear out the right and left main bronchi, apply suction until blood oxygen saturation returns to normal.

6. Re-radiography: Introduce the catheter over the guidewire and inject 3 ml of 30% water-soluble iodinated contrast agent. Check that the stenosis is completely released, the stent is accurately positioned, and fully expanded.
7. Sputum suction: Pass a suction tube over a stiff guidewire deep into the left main bronchus. Apply suction to remove all residual contrast agent and sputum, while gently slapping the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%.

Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation; apply oral suction to prevent aspiration.

7.6.7.4 Postoperative Management (See Sect. 7.6.1.4)

7.6.7.5 Prevention and Treatment of Complications (See Sect. 7.6.1.5)

7.6.8 Right Middle Bronchial Benign Stenosis

The simple right middle bronchial benign stenosis is relatively rare and usually accompanied with stenosis of other bronchi, such as the right main bronchus or right upper lobe bronchus. The small inverted Y-shaped airway stent can be used to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not present the typical complaints of chest tightness, wheezing, and progressive increase in breathing difficulty. Also, typical signs (cyanosis, three concavities) are absent. Unless the symptoms of obstructive pneumonia appear, the diagnosis may be missed and treatment delayed. If left upper lobe atelectasis or lung consolidation is present, determine the integrity of the collapsed/consolidated lung as well as whether normal structure and function is restored by removing the bronchial obstruction [22].

7.6.8.1 Instrument Preparation

Interventional instruments and stent customization

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, small inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: Measure the diameters and lengths of the right main bronchus and the right upper and middle lobe bronchi on the chest MSCT cross-sectional image, and customize the fully coated small inverted Y-shape integrated self-expanding metal stent according to these measurements. The length of the right main bronchus part of the stent is the same as that of the inferior wall of the right main bronchus, and the diameter is 10% more than that of the corresponding airway. The length of the right middle bronchus part should be 5 mm more than that of the right middle bronchus stenosis; also, the diameter should be 10% bigger than that of the corresponding airway. The length of the right upper lobe bronchus part should be 10 mm; while the diameter should be 10% more than that of the corresponding airway. The angle of stent

bifurcation should match the angle between the right upper lobe and right middle lobe bronchi.

7.6.8.2 Preoperative Preparation

1. Laboratory investigations (see Sect. 7.6.1.2)
2. Imaging: Perform plain chest CT and enhanced scans to accurately determine the degree and extent of the stenosis and the associated atelectasis. Examine whether the atelectatic lung is uniformly strengthened in the pulmonary arterial phase of the enhanced scan. Uniform enhancement indicates that the lung tissue structure is intact and that complete inflation can be achieved if the obstruction is relieved; these patients should receive stent implantation. Uneven enhancement or no enhancement indicates that the lung structure (alveoli, alveolar stroma, capillary bed) in the atelectatic part is destroyed and that normal structure and function cannot be restored by relieving the bronchial stenosis.
3. Gastrointestinal preparation (see Sect. 7.6.1.2)
4. Preoperative medication (see Sect. 7.6.1.2)

7.6.8.3 Procedure for Small Y-Shaped Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. Slightly raise the neck and shoulders; keep the head tilted backwards and turned 20°–30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, anesthetize the throat with lidocaine spray, and insert the mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as and when necessary.

   For fluoroscopy, tilt the C-arm 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body by approximately 50°). Adjust the collimator to include the oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopy, insert a catheter over a hydrophilic guidewire through the mouth, and advance it slowly up to the carina region. Pull out the guidewire, and inject 2–3 ml of 1% lidocaine solution through the catheter. Adjust the position of the catheter so that the tip is at the tracheal stenosis, and rapidly push 3 ml of 30–40% iodinated contrast agent through it to display the tracheobronchial anatomy. Determine the location and length of the stenosis in the right middle bronchus and the position of the opening of the right upper lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, a hydrophilic guidewire and catheter are inserted through the stenosis into the right lower lobe bronchus. Confirm the catheter's location and exchange to stiff guidewire. Using the same procedure, insert another stiff guidewire into the right upper lobe bronchus. Fix the two guidewires in place.

   An alternative method is as follows. Insert a 9F long sheath over the stiff guidewire to the lower part of the trachea. Pull out the inner core of the sheath, and introduce a catheter through the sheath into the right upper lobe bronchus. Change to a stiff guidewire and fix it in position.
4. Insertion of stent delivery system: Firmly fix the two stiff guidewires and hold them in position. Load the right upper lobe and right middle lobe bronchi parts of the Y-shaped stent on the respective guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Insert the stent delivery system over the stiff guidewire under fluoroscopy guidance. Tilt the patient's head backwards as much as possible, and slowly advance the delivery system. If there is resistance when the delivery system reaches the glottic area, and the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply with the glottis open and push the delivery system into the trachea and advance it to the right main bronchus. Rotate the delivery system so that the right upper lobe and right middle lobe limbs of the stent are aligned with the

respective bronchi. Make sure that the two guidewires are not twisted together and that the gold mark on the delivery system is on the correct side.

5. Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right upper lobe and right middle lobe limbs of the stent in the right main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire and push the limbs of the stent into the respective bronchi. Resistance occurs when the limbs of the stent are completely inserted in the respective bronchi.

   Fix the delivery system and guidewire, and pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right main bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one stiff guidewire in place as a pathway for subsequent interventions.

   If the patient experiences breathing difficulty and worsening of anoxia after stent deployment, first perform fluoroscopy to exclude distortion, folding, or non-expansion of the stent. Then consider the possibility of blockage of the airway by sputum: quickly pull out the stent delivery system, exchange for a sputum suction tube and clear out the right and left main bronchi, apply suction until blood oxygen saturation returns to normal.
6. Re-radiography: Introduce the catheter over the guidewire and inject 3 ml of 30% water-soluble iodinated contrast agent. Check that the stenosis is completely released and the stent is accurately positioned and fully expanded.
7. Sputum suction: Pass a suction tube over a stiff guidewire deep into the left and right main bronchi. Apply suction to remove all residual contrast agent and sputum, while gently slapping the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation reaches or is close to 100%. Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation. Apply oral suction to prevent aspiration of accumulated saliva.

7.6.8.4 Postoperative Management (See Sect. 7.6.1.4)

7.6.8.5 Prevention and Treatment of Complications (See Sect. 7.6.1.5)

7.6.9 Right Middle Lobe Bronchus Benign Stenosis

The simple right middle lobe bronchial benign stenosis is relatively rare, and is usually accompanied with stenosis of other bronchi, such as the middle bronchus or the right lower lobe bronchi. The small inverted Y-shaped airway stent can be used to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not present the typical complaints of chest tightness, wheezing, and progressive increase in breathing difficulty. Typical signs (cyanosis, three concavities) are also absent. Unless the symptoms of obstructive pneumonia appear, the diagnosis may be missed and treatment delayed. If left upper lobe atelectasis or lung consolidation is present, determine the integrity of the collapsed/consolidated lung and whether normal structure and function can be restored by removing the bronchial obstruction.

7.6.9.1 Instrument Preparation

Interventional instruments and stent customization

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, small

inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.

2. Choice of stent: Measure the lengths and diameters of the right middle bronchus and the right middle lobe and lower lobe bronchi on the chest MSCT cross-sectional image, and customize the fully coated small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the right middle bronchus part of the stent should be the same as that of the inferior wall of the right middle bronchus, and the diameter should be 10% more than the corresponding airway. The length of the right middle lobe bronchus part should be 5 mm more than the length of the stenosed segment of the right middle lobe bronchus, also, the diameter should be 10% more than that of the stenosed airway. The length of the right lower lobe bronchus part of the stent should be 10 mm; furthermore, the diameter should be 10% more than that of the stenosed airway. The angle of the stent bifurcation should match the angle between the right middle lobe and right lower lobe bronchi.

7.6.9.2 Preoperative Preparation

1. Laboratory investigations (see Sect. 7.6.1.2)
2. Imaging: Perform plain chest CT and enhanced scans to accurately determine the degree and extent of the stenosis and the associated atelectasis. Examine whether the atelectatic lung is uniformly strengthened in the pulmonary arterial phase of the enhanced scan. Uniform enhancement indicates that the lung tissue structure is intact and that complete inflation can be achieved if the obstruction is relieved; these patients should receive stent implantation. Uneven enhancement or no enhancement indicates that the lung structure (alveoli, alveolar stroma, capillary bed) in the atelectatic part is either destroyed or seriously damaged, and normal structure and function cannot be restored by relieving the bronchial stenosis.
3. Gastrointestinal preparation (see Sect. 7.6.1.2)
4. Preoperative medication (see Sect. 7.6.1.2)

7.6.9.3 Procedure of Small Y-Shaped Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. Slightly raise the neck and shoulders; keep the head tilted backwards and turned 20°–30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, anesthetize the throat with lidocaine spray, and insert the mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as necessary.

   For fluoroscopy, tilt the C-arm 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°). Adjust the collimator to include the oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopy, insert a catheter over a hydrophilic guidewire through the mouth, and advance it slowly up to the carina region. Pull out the guidewire, and inject 2–3 ml of 1% lidocaine solution through the catheter. Adjust the position of the catheter so that the tip is at the right middle lobe bronchus stenosis, and rapidly push 3 ml of 30–40% iodinated contrast agent through it to display the tracheobronchial anatomy. Determine the location and length of the stenosis in the right middle lobe bronchus and the position of the opening of the right lower lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, pass a hydrophilic guidewire and catheter through the stenosis into the right middle lobe bronchus. Confirm the catheter's location with radiograph and then exchange to a stiff guidewire. Repeat the procedure and insert another stiff guidewire in the right lower lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method is as follows. Insert a 9F long sheath over the stiff guidewire into the lower part of the trachea. Pull out the inner core of the sheath, and introduce a catheter

through the sheath into the right lower lobe bronchus. Change to a stiff guidewire and fix it in position.

4. Insertion of stent delivery system: Under fluoroscopy monitoring, firmly fix the two stiff guidewires and hold them in position. Load the right middle lobe and right lower lobe bronchi parts of the Y-shaped stent on the respective guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Insert the stent delivery system over the stiff guidewire under fluoroscopy guidance. Tilt the patient's head backwards as much as possible, and slowly advance the delivery system. If resistance occurs when the delivery system reaches the glottic area, and the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply while keeping the glottis open and push the delivery system into the right main bronchus. Rotate the delivery system so that the right middle lobe and right lower lobe bronchi parts of the stent are aligned with the corresponding bronchi. Make sure that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

   Good cooperation between the operator, assistant, nurse, and technician is needed to keep the stiff guidewires fixed, patient position unchanged, and oxygen saturation normal during the procedure.
5. Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right middle lobe and right lower lobe bronchi parts of the stent in the right middle bronchus.

   Keeping the relative positions of the two handles unchanged, push the stent limbs into the right middle lobe and right lower lobe bronchi. Resistance indicates that the stent limbs are fully inserted in the respective bronchi.

   Fix the delivery system and guidewire, and pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right middle bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one stiff guidewire in place as a pathway for subsequent interventions.
6. Re-radiography: Introduce the catheter over the guidewire and inject 3 ml of 30% water-soluble iodinated contrast agent. Check that the stenosis is completely released, the stent is accurately positioned and fully expanded.
7. Sputum suction: Pass a suction tube over a stiff guidewire deep into the right middle bronchus. Apply suction to remove all residual contrast agent and sputum, while gently slapping the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation is close to 100%. Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation; apply oral suction to prevent aspiration.

7.6.9.4 Postoperative Management

(See Sect. 7.6.1.4)

7.6.9.5 Prevention and Treatment of Complications

(See Sect. 7.6.1.5)

7.6.10 Right Lower Lobe Bronchial Stenosis

The isolated benign stenosis of the right lower lobe bronchus is relatively rare, and usually accompanied with stenosis of other bronchi, such as the middle bronchus or right middle lobe bronchus. A small inverted Y-shaped airway stent can be implanted to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not present the typical complaints of chest tightness, wheezing, and progressive increase in breathing difficulty. The typical signs (cyanosis, three concavities) are also

absent. Unless the symptoms of obstructive pneumonia appear, the diagnosis may be missed and treatment delayed. If left upper lobe atelectasis or lung consolidation is present, determine the integrity of the collapsed/consolidated lung and whether normal structure and function can be restored by removing the bronchial obstruction.

7.6.10.1 Instrument Preparation

Interventional instruments and stent customization

1. Interventional instruments: Mouth gag, 5F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9F sheath, small inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: Measure the lengths and diameters of the right middle bronchus and the right middle and lower lobe bronchi on the chest MSCT cross-sectional image, and customize a fully coated small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the right middle bronchus part of the stent should be the same as that of the inferior wall of the right middle bronchus, and the diameter should be 10% more than that of the corresponding airway. The length of the right lower lobe bronchus part of the stent should be 5 mm more than that of the stenosed segment of the right middle lobe bronchus, also the diameter should be 10% more than that of the corresponding airway. The length of the right middle lobe bronchus part of the stent should be 10 mm, and the diameter should be 10% more than that of the corresponding airway. The angle of the stent bifurcation should match the angle between the right middle lobe and the right lower lobe bronchi.

7.6.10.2 Preoperative Preparation

1. Laboratory investigations (see Sect. 7.6.1.2.)
2. Imaging: Perform plain chest CT and enhanced scans to accurately determine the degree and extent of the stenosis and the associated atelectasis. Examine whether the atelectatic lung is uniformly strengthened in the pulmonary arterial phase of the enhanced scan. Uniform enhancement indicates that the lung tissue structure is intact and that complete inflation can be achieved if the obstruction is relieved; these patients should receive stent implantation. Uneven enhancement or no enhancement indicates that the lung structure (alveoli, alveolar stroma, capillary bed) in the atelectatic part is either destroyed or seriously damaged, and normal structure and function cannot be restored by relieving the bronchial stenosis.
3. Gastrointestinal preparation (see Sect. 7.6.1.2.)
4. Preoperative medication (see Sect. 7.6.1.2.)

7.6.10.3 Procedure for Placement of Small Y-Shaped Stent

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (e.g., metal buttons) and to lie relaxed and supine on the fluoroscopy examination table. Slightly raise the neck and shoulders; keep the head tilted backwards and turned 20°–30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, anesthetize the throat with lidocaine spray, and insert the mouth gag. Keep the suction apparatus ready to clear airway and oral secretions as necessary.

   For fluoroscopy, tilt the C-arm 20°–30° to the left (with the head tilted 20°–30° to the right, the combined effect is equivalent to turning the body approximately 50°). Adjust the collimator to include the oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopy, insert a catheter over a hydrophilic guidewire through the mouth, and advance it slowly up to the carina region. Pull out the guidewire, and inject 2–3 ml of 1% lidocaine solution through the catheter. Bring the catheter tip to the right lower lobe bronchus stenosis, and quickly push 3 ml of 30–40%

iodinated contrast agent through the catheter to display tracheal tracheobronchial anatomy. Determine the location and length of the stenosis in the right lower lobe bronchus stenosis and the position of the opening of the right middle lobe bronchus.

3. Insertion of stiff guidewire: After completion of radiography, pass a hydrophilic guidewire and catheter through the stenosis into the right lower lobe bronchus. Confirm the catheter's location with radiography, and exchange to a stiff guidewire. Repeating the procedure, insert another stiff guidewire into the right middle lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method is as follows. Insert a 9F long sheath over the stiff guidewire to the lower part of the trachea. Pull out the inner core of the sheath, and introduce a catheter through the sheath into the right middle lobe bronchus. Change to stiff guidewire and fix in position.
4. Insertion of stent delivery system: Under fluoroscopy monitoring, firmly fix the two stiff guidewires. Load the right middle lobe and right lower lobe bronchi parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Insert the stent delivery system over the stiff guidewire under fluoroscopy guidance. Tilt the patient's head backwards as much as possible, and slowly advance the delivery system. If resistance occurs when the delivery system reaches the glottic area, and the patient coughs or appears to choke, rotate the delivery system so that the two parts assume a position that fits the shape of the rima glottidis. Ask the patient to inhale deeply while keeping the glottis open and push the delivery system up to the right middle bronchus. Rotate the delivery system so that the right middle lobe and right lower lobe bronchi parts of the stent are aligned with the corresponding bronchi. Make sure that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

   Good cooperation between the operator, assistant, nurse, and technician is necessary during the procedure to keep the stiff guidewires fixed, patient position unchanged, and oxygen saturation normal.
5. Placement of the stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right middle lobe and right lower lobe bronchi limbs of the stent in the right middle bronchus. Keeping the relative positions of the two handles unchanged, push the stent limbs into the respective bronchi. Resistance is felt when the stent limbs are fully inserted into the respective bronchi.

   Fix the delivery system and guidewire and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Then hold the posterior handle and quickly pull back the anterior handle to release the main body of the stent in the right middle bronchus. After the stent has been completely released, wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for further intervention.
6. Re-radiography: Introduce the catheter over a guidewire into the right main bronchus and inject 3 ml of 30% iodinated contrast agent to confirm that the stenosis is completely released and that the stent is in position correctly and fully expanded.
7. Sputum suction: Pass a suction tube over a stiff guidewire into the right middle bronchus. Apply suction to remove all residual contrast agent and sputum, while gently slapping the patient on the back to help dislodge tenacious sputum. Apply suction until lung rales disappear and blood oxygen saturation is close to 100%.

   Watch for blood in the phlegm, difficulty in breathing, and decrease in blood oxygen saturation; clear oral secretions to prevent aspiration.

7.6.10.4 Postoperative Management (See Sect. 7.6.1.4)

7.6.10.5 Prevention and Treatment of Complications (See Sect. 7.6.1.5)

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8 Malignant Airway (Trachea/Bronchus) Stenosis Intervention

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8.1 Summary

Lung cancer is the most common malignancy in the world with two million new cases diagnosed each year worldwide. More than one-third of these cases is in China, where the incidence is going to rise. About 20–40% of lung cancer patients will develop airway stenosis or obstruction because of the tumor invasion of the central airway or compression of the airway by metastatic mediastinal lymph nodes [1]. The central airway stenosis may also be caused by tumors of the esophagus, thyroid, thymus, or lung or mediastinal lymph node metastasis from gastric cancer and other malignant tumors. The tracheal stenosis is mostly due to malignant tumors arising in the tracheal lumen.

Patients with airway stenosis present with progressive dyspnea, respiratory failure, and even life-threatening respiratory obstruction. Typically, clinical examination reveals hypoxic cyanosis and the "three concavity sign." In the presence of airway stenosis, sputum clearance is impaired, and obstructive pneumonia or atelectasis may result. As the tumor grows, progressive dyspnea may be related to an irritating cough. Bloody sputum may be present. Tumor erosion of a large blood vessel may cause massive hemoptysis, and blood clots may aggravate airway obstruction and even cause asphyxia.

The small tumors do not cause significant obstruction of the airway, and the treatment of the tumor itself should be focused. However, when the tumor becomes large and seriously compromises airway patency, relief of the obstruction and restoration of normal respiratory air flow take precedence over treatment of the tumor itself.

Severe extensive tracheal stenosis makes tracheal intubation difficult, and surgery has to be postponed. Malignant airway stenosis is usually in the lower trachea and the carina area or in a main bronchus, which causes tracheotomy useless. In 1989, Simonds, for the first time, successfully used a nickel-titanium alloy stent for treatment of tracheal stenosis. Since then the technique has been widely applied, and it is presently the most effective treatment for malignant stenosis of the trachea and bronchus, with the reported success rates over ≥95% [2].

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8.2 Etiology of Airway Malignant Stenosis

Malignant stenosis of the airway is most commonly due to lung cancer and lymph node metastasis. About 90% of cases is due to primary

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bronchogenic cancer [3]. Other malignancies, such as sarcoma, lymphoma, plasmacytoma, carcinoid and gland cystic carcinoma, direct invasion of the airway by esophageal cancer or lymph node metastasis, and thyroid and thymic cancers, account for about 2–3% of cases. Mediastinal lymph node metastasis from cancer of the stomach, colon, rectum, head and neck region, breast, and ovary accounts for another 5–8% of cases [4]. Almost all of malignant tumors arising in the head and neck region, chest, abdomen, retroperitoneum, and pelvic region are likely to metastasize to the mediastinal lymph nodes. Mediastinal lymph nodes in the sternum, followed by large blood vessels, are distributed, but the most concentrated distribution in the central airway is localized around the pipeline, lower trachea, carina, and the main bronchial opening. Once the mediastinal lymph node metastasis occurs, more performance will be achieved for the lower trachea, carina, and left and right main bronchial composite stenosis.

8.3 Mechanism of Malignant Airway Stenosis

Tracheobronchial stenosis may be caused with compression from outside by malignancy in the airway wall or by a growth within the lumen [5].

8.3.1 Compression from Outside

The compression of the trachea or bronchus by tumor is most commonly due to esophageal cancer, thymoma, thyroid tumor, and metastatic mediastinal lymph nodes. The compression of the airway by a malignant tumor can take many forms and affect more regions. Ultimately, serious compression results in tracheobronchial cartilage deformation and degeneration and airway stenosis.

8.3.2 Malignancy of the Airway Wall

Tumor may originate from smooth muscle (leiomyosarcoma), fibrous connective tissue (fibrosarcoma), cartilage, or other components of the airway wall. The damage results in collapse of the wall. The tumor could also grow into the lumen of the airway and cause obstruction.

8.3.3 Tracheobronchial Cavity Tumors

Tumors originating in the bronchial intima or endothelial cells include the various types of bronchogenic carcinomas. The tracheal bronchial tumor in the peripheral bronchioles showed that the peripheral lung cancer did not directly infiltrate the airway. The lungs in the bronchioles, bronchial bronchus, or the main bronchus were directly injected into the tracheal lumen to infiltrate the central airway and block the central airway. Physical obstruction of the respiratory pathway leads to difficulty breathing, or combined with pneumonia, further aggravating dyspnea symptoms.

8.4 Diagnosis of Malignant Airway Stenosis

Central airway stenosis must always be considered in the patient who presents with chest tightness, wheeze, progressive breathing difficulty, orthopnea, and the inspiratory three concavity sign. If there is a past history of chest cancer, these features are highly suspicious of airway stenosis. Under this condition other possibilities must be excluded, especially asthma, allergic reactions, and cardiopulmonary dysfunction. Chest MSCT is the best modality to confirm the diagnosis of airway stenosis, the severity, and treatment planning [6].

8.4.1 Clinical Manifestations

1. Increasing dyspnea: The patient with malignant airway stenosis complains of progressive increase in dyspnea, and in the late stages, there may be dyspnea at rest or orthopnea.
2. Irritating cough: The presence of a tracheobronchial tumor or compression of the airway from

outside results in an irritating cough with or without expectoration of white foamy sputum. This cough usually does not respond to antibiotics, anti-allergy, or anti-asthma treatment.
3. Pulmonary infection: The airway stenosis is likely to cause sputum retention and secondary infection. Then, the patient presents with chills, fever, chest pain, and either a dry cough or cough productive of large amounts of purulent sputum.
4. Hemoptysis: Rapidly growing bronchogenic cancers often have necrotic areas on the surface that may slough off to expose fragile blood vessels. The resulting hemoptysis can range from blood tingeing of sputum to massive life-threatening bleeding.

8.4.2 Physical Examination

Symptoms and signs vary with lesion location and the extent and severity of stenosis. The breathing difficulty includes different forms which some patients present with only inspiratory distress, others with only expiratory distress, and yet others with full-cycle breathing problems. Patients with severe dyspnea may suffer from the typical inspiratory three concavity sign and hypoxic cyanosis. Dyspnea progressive exacerbation of forced sexual position breathing and even sitting oxygen cannot alleviate the severe breathing difficulties with a sense of dying.

Auscultation will reveal high-pitched wheeze and reduced air entry in the affected region, as well as other signs of emphysema or atelectasis. Enlarged metastatic lymph nodes may occur in the neck.

8.4.3 Imaging Examination

It is difficult to study image because patients with severe dyspnea are not able to lie in the supine position. Intravenous injection of corticosteroid drugs (e.g., methylprednisolone 30 mg or dexamethasone 5–10 mg) is helpful for eliminating airway edema and decreasing patient stress.

1. Chest radiography: The plain radiograph of the chest has the limited value in the diagnosis of tracheobronchial stenosis. Some patients may show distortion or kinking of the tracheal or bronchial air shadow. Indirect signs of airway obstruction include atelectasis, pneumonia, and emphysema.
2. MSCT: Thoracic MSCT is an ideal modality to diagnose tracheobronchial stenosis. The MSCT thin layer (<1 mm) continuous scan provides a detailed picture of the tracheobronchial tree and the cause, extent, and severity of any stenosis. The related pulmonary parenchymal disease is also shown. The three-dimensional reconstruction offers the shape and degree of stenosis, depth of tumor invasion, and the relationship with surrounding structures such as large vessels.
3. MRI: The modern MRI, almost as useful as MSCT, determines the location and extent of tracheobronchial stenosis and identifies whether the stenosis is due to a lesion within the airway, in the airway wall, or outside the airway; therefore, it is able to guide the choice of the stent.

8.4.4 Fiberoptic Bronchoscopy

The fiberoptic bronchoscopy is an important modality for diagnosis of central airway stenosis. When history, physical examination, and imaging indicate central airway narrowing, fiberoptic bronchoscopy must be performed unless contraindicated for some reason. With fiberoptic bronchoscopy the stenotic lesion is directly visualized, and biopsy is taken for pathological diagnosis; in addition, retained sputum can be removed and bronchial lavage performed if necessary. However, when the stenosis is severe, the bronchoscope is not able to approach the lesion for biopsy or determine the length of the stenosis. Bronchoscopy and ultrasound-guided needle aspiration biopsy can be performed for diagnosis of lesions compressing the airway from the outside. In fluoroscopy, narrow spectrum lens is helpful for qualitative diagnosis; virtual bronchoscopy can determine the narrow distal bronchial and lung function.

8.4.5 Interventional Radiology Clamp Biopsy

For the patients with tracheobronchial serious stenosis and fiberoptic bronchoscopy cannot pass through. In order to obtain pathological diagnosis of stenosis lesions, especially in the cavity growth of the tumor, the interventional radiology guidewire catheter guide technology should be considered to insert sheath into tracheobronchial, and biopsy forceps through the sheath into the stenosis area, DSA image monitoring, alignment of stenosis lesions clamp biopsy to histopathological examination.

8.4.6 Stenosis Types

The malignant tracheobronchial stenosis is divided into ten types according to the anatomical location of the stenosis [7].

1. Tracheal stenosis: It occurs in the region extending from 1 cm beneath the annular cartilage to 2 cm above the carina crest. It is the most common type due to a malignant tumor within the tracheal cavity or due to compression by tumor of the upper esophagus, thymus, or thyroid or metastatic mediastinal lymph nodes. A tubular self-expanding metal stent can be used to release the stenosis; moreover, a bare stent is used when the stenosis is due to external compression, and a covered stent is for wall and cavity lesions.
2. Carina area (complex) stenosis: The stenosis is in the region comprising the distal 2 cm of the trachea and the proximal left and right main bronchi. There is a simple stenosis involving only one airway or a complex stenosis with stenoses of two or more airways. It is most commonly due to central lung cancer, and the invasion is caused by cancer of the mid-esophagus or compression by metastatic mediastinal lymph nodes. Because of the special anatomical structure of the carina, the treatment involves an inverted Y-type integrated stent or an L-type tracheobronchial anti-skid off stent.
3. Right main bronchus stenosis: The simple right main bronchial stenosis is rare and usually occurs in association with carina stenosis or with right upper lobe or middle lobe bronchi stenosis. Most commonly it is due to right central lung cancer or compression by metastatic mediastinal lymph nodes; and the treatment involves an L-type branched anti-skid off stent or a small Y-type integrated stent.
4. Right upper lobe bronchus stenosis: Simple right upper lobe bronchus stenosis is rare; furthermore, it is usually associated with right main bronchus stenosis or right middle lobe bronchus stenosis. Most commonly it is due to right central lung cancer or compression by metastatic mediastinal lymph nodes. Treatment is performed with placement of a small Y-type integrated stent.
5. Right middle bronchus stenosis: Simple right middle bronchus stenosis is rare; it is usually seen in association with stenosis of the right main bronchus or the right upper lobe bronchus. Most commonly it is due to right central lung cancer or compression by metastatic mediastinal lymph nodes. Treatment is by placement of a small Y-type integrated stent. Some cases of complex stenosis require placement of two inverted Y-type integrated stents.
6. Right middle lobe bronchus stenosis: The simple right middle lobe bronchus stenosis is rare; it is usually seen in association with stenosis of the right lower lobe bronchus or the right middle bronchus. Most commonly it is due to right central lung cancer or compression by metastatic mediastinal lymph nodes. The treatment is performed with placement of a small Y-type integrated stent.
7. Right lower lobe bronchus stenosis: The simple right lower lobe bronchus stenosis is rare; it is usually seen in association with stenosis of the right middle bronchus or right middle lobe bronchus. Most commonly it is due to right central lung cancer or compression by metastatic mediastinal lymph nodes. Treatment is performed with placement of a small Y-type integrated stent.

8. Left main bronchus stenosis: A stenosis of this airway may sometimes be associated with stenosis of the carina or the left upper lobe bronchus. Most commonly it is due to left central lung cancer or compression by metastatic mediastinal lymph nodes. Treatment is performed with placement of an L-type branched anti-skid off stent or a small Y-type integrated stent.
9. Left upper lobe bronchus stenosis: The simple left upper lobe bronchial stenosis is rare; it is usually seen in association with stenosis of the left main bronchus or left lower lobe bronchus. Most commonly it is due to left central lung cancer or compression by metastatic mediastinal lymph nodes. Treatment is performed with placement of a small Y-type integrated stent.
10. Left lower lobe bronchus stenosis: The simple left lower lobe bronchial stenosis is rare; it is usually seen in association with stenosis of the left main bronchus or with the left upper lobe bronchus. Most commonly it is due to left central lung cancer or compression by metastatic mediastinal lymph nodes. Treatment is performed with placement of a small Y-type integrated stent.

8.4.7 Classification According to Degree of Stenosis

The malignant airway stenosis can be classified according to the degree (%) of stenosis, which is calculated as: degree of stenosis = (diameter at stenosed area/normal airway diameter) × 100% [8]. There are five grades, as follows:

1. Grade I: ≤25%; mild stenosis. Patient may have mild cough and other symptoms.
2. Grade II: 26–50%.
3. Grade III: 51–75%; moderate stenosis. Patients with grade II and grade III stenosis may have cough, shortness of breath, and other symptoms.
4. Grade IV: 76–90%.
5. Grade V: 91–100%; severe stenosis. Patients with grade IV and grade V stenosis may present with severe chest tightness, shortness of breath, difficulty breathing, and so on.

This simple classification system does not take into consideration the length of the narrow segment, the degree of distortion of the stenosed segment, the rate of progression of the stenosis, the effects on lung structure and function, as well as whether the stenosis is multiple or complex. It is therefore not useful for clinical diagnosis and selection of treatment.

8.4.8 Classification with the Degree of Dyspnea

A more comprehensive grading system is described in details in Table 8.1. This classification takes into consideration the functional status of the patient's respiratory and cardiovascular systems; therefore, it is a useful guide for treatment decisions. See also 2.1.1.3: Dyspnea grading [9].

Table 8.1 Grading, clinical characteristics and Treatment principles of airway stenosis

Classification	Clinical manifestations	Treatment
I	Difficulty breathing during fast walking	Treatment of primary disease
II	Difficulty breathing during normal walking	Treatment of primary disease
III	Normal walking not possible because of dyspnea	Treatment of primary disease
IV	Difficulty breathing after slight activity	Treatment of primary disease
V	Difficulty breathing when calm and lying down	Early release of airway stenosis
VI	Difficulty breathing when calm and in sitting position	Emergency release of airway stenosis
VII	Difficulty breathing when calm and sitting and oxygen/asphyxia	Emergency release of airway stenosis

8.5 Clinical Treatment of Malignant Airway Stenosis

8.5.1 Medical Treatment

Medical treatment mainly includes the application of supplemental oxygen, postural adjustments to decrease effort of breathing, drugs to improve sputum expectoration, and enhancement of oxygen reserves and tolerance of hypoxia.

1. Oxygen: Oxygen can be delivered via nasal catheter or mask. Noninvasive ventilation or tracheal intubation pulsing positive pressure ventilation increases oxygen saturation if necessary. Humidification of the airway inhibits the formation of obstructive airway sputum.
2. Position: The semi-reclining or sitting position provides some relief for the dyspneic patient because gravity drags down the abdominal organs, allowing free movement of the diaphragm.
3. Mucolytic and expectorant drugs: Severe tracheobronchial stenosis leads to sputum retention and sputum scab formation. Mucolytics and expectorants facilitate sputum clearance from the airway.
4. Nebulization: Drug delivery via nebulization ensures high tracheobronchial drug concentration. Humidification of sputum promotes expectoration and inhibits obstruction of the airway.
5. Elimination of edema: Mannitol, furosemide, and other similar drugs promote tissue dehydration and reduce tracheobronchial edema, thus relieving tracheobronchial stenosis to some extent. Corticosteroid drugs are able to relieve dyspnea through reducing tracheobronchial mucosal edema (especially the localized edema around the lesion) and also by decreasing stress.
6. Antibiotics: Airway stenosis leads to sputum retention in distal bronchi and often results in obstructive pneumonia or atelectasis. The appropriate antibiotics could control infection and protect lung function.
7. Chemotherapy: Patients with good general condition and mild to moderate tracheal stenosis due to chemotherapy-sensitive tumors (e.g., thymic malignancy, lymphoma, small cell lung cancer, and so on) may benefit from chemotherapy. With reduction in tumor volume, the compression of the airway may be alleviated.
8. Assisted breathing: Patients with severe tracheal stenosis may require assisted breathing. Options include laryngeal mask airway, ventilator-assisted breathing, or tracheal intubation across the narrow area and positive pressure ventilation.
9. Fiberoptic bronchoscopy: Microwave ablation, cryoablation, or other techniques can be employed to restore airway patency when the obstruction is due to a tumor within the airway lumen.

8.5.2 Surgical Treatment

Occasionally, tracheobronchial stenosis, especially severe stenosis, can be relieved by surgery, such as stenosis due to compression of the trachea by a thyroid tumor. An intraluminal tumor can sometimes be treated by airway excision and anastomosis [10]. However, in most patients with malignant stenosis, surgery is not feasible for a variety of reasons, e.g., late-stage disease, advanced age, poor cardiopulmonary function, extensive stenosis (which makes endotracheal intubation for anesthesia impossible), and so on.

8.5.3 Radiation Therapy

In most cases, radiation therapy cannot significantly decrease tumor size within a short time. Moreover, radiation therapy can cause reactive edema and tracheobronchial mucosal swelling, which may aggravate the obstruction. For patients with severe stenosis and severe dyspnea, airway stenting should be performed before initiating radiation therapy.

8.6 Interventional Treatment of Malignant Airway Stenosis

8.6.1 Tracheal Malignant Stenosis

Tracheal malignant stenosis may be due to compression by thyroid tumors, thymic tumors, upper esophageal cancer, and mediastinal lymph node metastases or due to obstruction by an intraluminal tumor. The trachea, the longest airway in the respiratory tract, is a single channel without any bypass, and it is fatal if obstruction occurs. The patient with serious tracheal malignant stenosis will have severe dyspnea and will need emergency restoration of air flow. The most effective rescue treatment is placement of a memory alloy self-expanding tracheal stent.

8.6.1.1 Instrument Preparation

Interventional instruments and customization of the stent:

1. Interventional instruments: mouth gag, 5F vertebral artery catheter, 0.035 in. hydrophilic guidewire (150 cm), 0.035 in. stiff guidewire (180–260 cm), partly or fully coated tubal stent (Micro-Tech, Nanjing or Taewoong, Korea), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments
2. Choice of stent: On the chest MSCT cross-sectional (mediastinal-fat window) image, measure the length and diameter (anteroposterior and transverse diameters) of the stenosed segment of the trachea. Customize the stent according to these measurements. Stent diameter should be 10% more than the diameter of the stenosed trachea. The length of the stent should be such that it extends at least 10 mm beyond the stenosis at both ends. Opt for a tubular covered stent when the stenosis is due to a lesion in the tracheal wall or in the lumen and a tubular uncovered stent when the stenosis is due to compression by a lesion outside the airway [11].

If the lesion is in the tracheal lumen or wall, or adjacent to the trachea, and the diameter of tumor is about 10 mm, a radioactive stent is applied to relieve the stenosis and treat the tumor.

8.6.1.2 Preoperative Preparation

1. Laboratory examinations: routine hemogram, liver and kidney function tests, serum electrolyte test, blood coagulation tests, serology for infectious diseases, sputum bacterial culture and drug sensitivity tests, electrocardiogram (ECG), and other relevant tests.
2. Cardiopulmonary function: Obtain an echocardiogram (ECG) to assess cardiac function and reserve; perform multifunctional physiological monitoring to determine lung oxygenation function.
3. Imaging: Perform chest MSCT scan and make full use of multiplanar reformation (MPR), curved planar reformation (CPR), and other post-processing functions to establish the precise location, length, and severity of the stenosis, to check the distribution and severity of lung injury, and to obtain accurate measurements of tracheal and bronchial diameters and lengths. Select the appropriate stent on the basis of these findings.
4. Gastrointestinal preparation: The patient 4–8 h before the procedure should be treated to prevent risk of vomiting and aspiration during stent placement.
5. Preoperative medication: Administer intramuscular stability 10 mg (to reduce patient anxiety) and anisodamine (654-2) 10 mg (to reduce gastrointestinal and respiratory secretions and prevent smooth muscle spasm) 10–30 min before the procedure.

8.6.1.3 Procedure of Tubular Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (such as metal buttons) and to lie down relaxed and supine on the fluoroscopy table. Slightly raise the neck and shoulder; keep the head tilted backward and turned 20° to 30° to the

right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with 1% lidocaine for anesthesia, and place the mouth gag. Keep the suction apparatus ready for clearing the airway and oral secretions as necessary.

Tilt the C-arm 20° to 30° to the left (with head turned 20° to 30° to the right, the combined effect is equivalent to turning the head 50° to the right), and adjust the collimators to include the oropharynx, trachea, and main bronchi in the fluoroscopy field.

2. Transcatheter radiography: Under fluoroscopic guidance, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the tracheal stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the stenosis and its distance from the glottis and carina again.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and catheter past the tracheal stenosis at least 20 mm into the left or the right main bronchus. Pull out the guidewire and inject 1 mL of 30% iodinated contrast agent through the catheter to confirm that the catheter is in the main bronchus. Exchange to a stiff guidewire, and insert it deep into the main bronchus; make sure that the distal end is within the fluoroscopy field. Ask the assistant to fix the stiff guidewire and the mouth gag in place.
4. Insertion of stent delivery system: Insert the stent delivery system over the stiff guidewire. Keeping the stiff guidewire in the main bronchus, slowly push forward the delivery system. Resistance may be encountered at the glottis. Ask the patient to inhale deeply keeping the glottis open, and, during inhalation, push the delivery system past the glottis and into the trachea up to the carina. During the procedure the assistant and nurse should ensure that the patient lies still.
5. Placement of stent: Under fluoroscopy, put the stent at the center of the stenosis. Firmly hold the stiff guidewire and the posterior handle of stent delivery system; then pull back the front handle to release one-third of the stent. Confirm on the fluoroscope that the distal end of the stent is at least 10 mm below the stenosis, and then release the middle third of the stent. Confirm again that the stent covers the entire stenosis, and then quickly release the stent completely. Keeping the stiff guidewire in position, pull out the stent delivery system smoothly.
6. Re-radiography: Introduce the catheter over the guidewire into the right main bronchus. Inject 3 mL of 30% iodinated contrast agent, and check that the stenosis is completely released and the stent is correctly in place and fully expanded. If necessary, adjust the stent position or perform post-dilation.
7. Sputum suction: Pass a suction tube over the stiff guidewire deep into the left and right main bronchi, and apply suction to remove residual contrast agent and sputum. During suction, gently slap the patient's back to dislodge tenacious sputum. Perform suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

8.6.1.4 Postoperative Management

1. Nebulization: After stenting, nebulize twice a day with saline 10 mL + lignocaine 5 mL + ambroxol 30 mg + amikacin 0.2 g for 4–6 weeks. This will encourage sputum discharge and reduce foreign body reaction and inflammation due to the stent.
2. Sputum expectoration: Use postural drainage and chest physiotherapy to help remove infected sputum from the lung. Encourage the patient to cough forcefully and expectorate without worrying about the possibility of stent migration. Use expectorants and mucolytic drugs to facilitate sputum discharge.
3. Antibiotics: Administer antibiotics according to the results of culture and sensitivity tests. Perform bronchial lavage when necessary to remove endobronchial mucus and pus; high concentrations of the appropriate antibiotic can also be administered locally via the bronchoscope.

4. Chest CT: Perform chest MSCT and three-dimensional reconstruction 2–3 days after stent placement. Patients with severe tracheal stenosis may have varying degrees of atelectasis. Relief of the stenosis and rapid reexpansion of the lung may result in pulmonary edema. If the patient complains of chest tightness after stent placement, and chest CT confirms pulmonary edema, treat immediately with corticosteroids to eliminate edema and improve ventilation.
5. Tumor treatment: Stent implantation is only a temporary solution to the problem of malignant tracheal stenosis. The malignancy should also be treated if there is any possibility of recovery. The options include tumor arterial infusion chemotherapy, percutaneous radiofrequency, microwave ablation, radioactive particles implantation, and so on.

8.6.1.5 Prevention and Treatment of Complications

The intraoperative complications include asphyxia, bleeding, and pneumothorax; moreover, incomplete stent expansion may also occur. Postoperative complications include obstruction by secretions, granulation tissue hyperplasia, stent migration, stent fracture, restenosis, and so on.

1. Asphyxia: The patients with tracheal stenosis suffer severe hypoxia before stent placement, and there may be a serious diminution of oxygen reserves. Fluoroscopy-guided tracheal stenting is performed without any ventilatory support, and intraoperative exacerbation of the hypoxia highly occurs. An experienced team with sophisticated skills is indispensible to minimize procedure time and reduce the incidence of asphyxia. Other measures include preoperative administration of 10–20 mg dexamethasone intravenously to improve tolerance of hypoxia and inhalation of 100% oxygen before stent placement to improve oxygen reserves. During this process, all facilities are prepared for tracheal intubation, sputum removal, and auxiliary ventilation if necessary.
2. Hemorrhage: Blood in phlegm is common after airway stenting. Bleeding is usually mild and stops without treatment within 10 min. If hemoptysis persists, and especially if a large amount of blood is being coughed up, inject 2–3 mL of 1:1000 adrenaline in saline through the catheter. This will cause constriction of tracheal mucosal vessels and stop the hemoptysis immediately. The method is effective even if a small peripheral artery has ruptured.
3. Mediastinal and subcutaneous emphysema or pneumothorax: Severe coughing spells may cause tracheobronchial laceration or rupture of preexisting lung bullae and lead to mediastinal or subcutaneous emphysema and pneumothorax. Stent wire damage to lung tissue may also be responsible for pneumothorax. Mild emphysema or pneumothorax requires no more than bed rest and supplemental oxygen.
4. Incomplete stent expansion: The stent may not expand fully if the outward force is not enough to counteract the inward force of tumor tissue. If the stent is incompletely expanded immediately after stent placement, emergency intervention is not necessary, and balloon expansion may be performed only if the stent is still unexpanded after 1–3 days.
5. Stent restenosis: Restenosis is more common with uncovered stents because of tumor in growth through the stent mesh into the stent cavity. Tumor growth beyond the ends of the stent may also cause restenosis. For patients with restenosis due to tumor growth through the stent mesh, remove the stent and replace with a covered stent or a radioactive stent. When the restenosis is due to tumor growth beyond the stent end, place another stent to lift the new stenosis. Tumor arterial infusion chemotherapy or radiotherapy can also be used to suppress the growth.
6. Granulation tissue hyperplasia: Any physiological tube cavity in the body will respond with excessive endothelial cell proliferation after stent placement. In the airway which is an open cavity, airway endothelial cell hyperplasia is particularly obvious. A bare

metal stent is liable to cause hyperplasia all over (though especially at the ends of the stent), whereas hyperplasia caused by a coated stent is solely at the ends. Mild endothelial cell proliferation that does not affect normal breathing can be ignored, but treatment is necessary when breathing and expectoration are affected. Treat with endoscopic ablation (microwave, radio frequency, laser, or thermal ablation). Long-term effect is reported to be best with cryoablation.

Research is underway to develop new internal scaffold materials with better biocompatibility and even biodegradable tracheal stents that would self-degrade after a time and thus avoid long-term complications altogether. New stent weaving technology is also being used to improve the biocompatibility of stents and reduce granulation tissue formation.

7. Stent obstruction by sputum: This is the most common complication with the airway coated stent. The coated stent completely covers the tracheal epithelium and suppresses the normal mucociliary function. Expectoration then relies solely on the force of coughing; if the cough is feeble, sputum will adhere to the stent, to ultimately form a sputum bolt and block the airway lumen. Employ fiberoptic bronchoscopy to remove the sputum bolt as early as possible. It is useful for nursing measures, nebulization, expectoration training, and mucolytic and expectorant drugs to prevent recurrence.
8. Stent migration: Stent migration may occur with improvement of the stenosis, lower forces keeping the stent in place, or because of failure to select a stent of the appropriate size. If stent migration is suspected, immediately perform chest CT or bronchoscopy. If the stent has migrated, adjust the stent position or remove and replace it.
9. Stent rupture: Stent fracture is a rare complication. It is caused by the combination of spasmodic smooth muscle contraction during severe cough and metal wire fatigue. It generally occurs in the tracheal membrane, and usually there is only a localized fracture of a wire; entire stent disintegration is extremely rare. The patient may spit out the fractured metal wire. If stent rupture occurs, make every effort to remove the stent; this is necessary to avoid damage to the surrounding tissue and also to relieve patient anxiety.
10. Chest pain: Chest pain may be related to balloon dilatation, stent placement, or other intraoperative and postoperative interventions. The pain is generally mild and requires no treatment. Oral analgesics are prescribed if necessary.
11. Sore throat and hoarseness: This is related to local irritation of the pharynx, throat, and glottis during stent implantation. It generally subsides within 1–2 days. Nebulization may provide relief.

8.6.2 Carina Compound Stenosis

The carina area is a three-fork structure at the junction of the trachea and the left and right main bronchi. The region contains the highest concentration of mediastinal lymph nodes, which are tribal accumulation distribution. Lymph node metastases are more than a number of lymph nodes swelling at the same time; oppression of the carina and trachea and/or left and right main bronchus leads to complex stenosis, with stenosis in the lower trachea combined with stenoses of the proximal left and/or right main bronchi.

Earlier, treatment of carina area complex stenosis was with three separate tubular stents placed in the lower part of the trachea and the proximal left and right main bronchi. However, the operation was complex and the effect often is affected by problems such as stent docking dislocation or overlapping. Dr. Xinwei Han and his team invented the inverted Y-type stent conveyor (patent name: Airway integrated dual-branch bracket dedicated conveyor; patent number: ZL2006200306639) which could place an inverted Y-type integrated metal self-expanding stent in the carina region [12]. With this technique it has become possible to treat two or more stenosis by placement of a single stent, thus shortening the operation time and decreasing treatment costs.

8.6.2.1 Instrument Preparation

Interventional Instruments and Customization of the Stent

1. Interventional instruments: mouth gag, 5F vertebral artery catheter, 0.035 in. hydrophilic guidewire (150–180 cm), 0.035 in. stiff guidewire (180–260 cm), 0.035 in. metal stiff guidewire (180–260 cm), 9F sheath, inverted Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments
2. Choice of stent: On the chest MSCT cross-sectional (fat window, WW400 HU, WL-50 HU) image, measure the lengths and diameters (anteroposterior and transverse diameters) of the trachea and both main bronchi. Customize the partly coated or fully coated Y-shape integrated self-expanding metal stent according to these measurements. The diameters of the three limbs of the stent should be 10% more than that of the stenosed segment of the corresponding airways, and the lengths of the limbs should be 10 mm more than the lengths of the stenosed segments of the corresponding airways. If the stenosis is adjacent to the opening of the superior bronchus, use two docking inverted Y-type stents to ensure that all airway stenoses are released and the bronchial opening unobstructed.

   Opt for an uncovered stent when the stenosis is due to compression by an external tumor and the intact airway wall, while opt for a covered stent when the tumor is within the airway lumen or involves the airway wall. A radioactive stent is an appropriate option in some cases; it will relieve the stenosis and, at the same time, also serve to treat the tumor.

8.6.2.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: see Sect. 8.6.1.2.
3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.2.3 Procedure of Tubular Stent Placement

1. Patient position: Ask the patient to remove clothes with any radiopaque material (such as metal buttons) and to lie down relaxed and supine on the fluoroscopy table. Slightly raise the neck and shoulder; keep the head tilted backward and turned 20° to 30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine for anesthesia, and place the mouth gag. Keep the suction apparatus ready for clearing the airway and oral secretions as necessary.

   Tilt the C-arm 20° to 30° to the left (with body turned 20° to 30° to the right, the combined effect is equivalent to turning the head 50° to the right), and adjust the collimators to include oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopy, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the tracheal stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location, the length of the carina area stenosis, and its distance from the glottis, as well as the position of the openings of both main bronchi and the upper lobe bronchi.
3. Insertion of stiff guidewire: After completion of bronchography, introduce a hydrophilic and catheter through the stenosis and into the right lower lobe bronchus. Confirm the catheter's location with fluoroscopy, and then exchange to a stiff guidewire. Repeat to insert another stiff guidewire into the left lower lobe bronchus. Mark the two stiff guidewires for identification and fix them in place.

   An alternative method is to insert a 9F long sheath through the stiff guidewire into the lower part of trachea just above the carina. Then pull out the inner core of the sheath, and introduce a guidewire and catheter through

the sheath into the left lower lobe bronchus. Exchange to a stiff guidewire and fix it.

4. Insertion of stent delivery system: Holding the stiff guidewires in position, load the left and right bronchus parts of the Y-shaped stent on the respective guidewires. Connect the side conduit of the stent delivery system to high pressure oxygen. Fix the guidewires at the mouth gag end and introduce the delivery system over the stiff guidewire. With the neck tilted backward as much as possible, slowly push forward the delivery system. If resistance is encountered at the glottic area and the patient appears to choke, rotate the delivery system so that the two parts of the stent assume an anteroposterior position that fits the shape of the rima glottidis. Ask the patient to breathe deeply, keeping the glottis open, and, during inhalation, push the delivery system past the glottis and into the trachea. At the carina, rotate the delivery system so that the left and right bronchus parts of the stent are aligned with the corresponding main bronchi. Check that the two guidewires are not twisted together and that the gold mark on the delivery system is on the correct side.

   Good cooperation among the operator, assistant, nurse, and technician is essential during the procedure, especially to keep the stiff guidewires fixed in place, with the patient position unchanged and oxygen saturation normal.
5. Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the left and right main bronchus parts of the inverted Y-shape stent at the lower part of the trachea. Then, keeping the relative positions of the two handles unchanged, fix the stiff guidewire and push the two parts of the stent into the left and right main bronchi until resistance is felt; this confirms that the two limbs of the stent are completely in the main bronchi. Perform fluoroscopy and confirm that the stent bifurcation is in contact with the carina.

   Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus parts of stent. Then, holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the trachea. The inverted Y-shape stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is up to 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.

   If the patient experiences breathing difficulty and worsening of anoxia after release of the stent, perform fluoroscopy to exclude stent distortion or folding and nonexpansion of the stent. If these problems are ruled out, suspect blockage of the stent by sputum. Quickly pull out the stent delivery system, exchange to a sputum suction tube, and apply suction repeatedly in the left and right main bronchi until blood oxygen saturation rises to normal.
6. Re-radiography: Introduce the catheter over the guidewire into the carina region, and inject 3 mL of 30% iodinated contrast agent, and check that the stenosis is completely released, that the stent is accurately in place and fully expanded, and that both upper lobar bronchi are unobstructed.
7. Sputum suction: Introduce the stiff guidewire, and then pass the suction tube over the guidewire deep into the left and right main bronchi. During suction, gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   During the procedure, watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.2.4 Postoperative Management: See Sect. 8.6.1.4

8.6.2.5 Prevention and Treatment of Complications: See Sect. 8.6.1.5

8.6.3 Left Main Bronchus Stenosis

The left main bronchus (40 ± 3 mm) is much longer than that of the right main bronchus, so the

left main bronchial forms a large operating space when malignant stenosis appears treated by the stent. In the past, tubular stents were used for treating left main bronchus stenosis close to the carina. However, the tubular stent tends to migrate upward to block the right main bronchus or downward to block the opening of the left upper lobe bronchus. Dr. Xinwei Han and his team created the L-type anti-skid stent (main bronchial anti-skid detachable covered stent; Patent NO. ZL03235769.9) to address this problem of stent migration [5]. The branch of the L-type anti-skid stent is put into the main bronchus to release the stenosis, while the main body of the stent in the trachea fixes the stent in place and prevents migration. If the stenosis is in the distal left main bronchus and close to the upper and lower lobe branches, the small inverted Y-type stent can be used, with the main body of the stent placed in the left main bronchus and the limbs in the left upper and lower lobe bronchi.

In patients with left main bronchus stenosis, especially increasing the stenosis, the right lung compensates to some extent for the impaired left lung function. Patients may not present with severe dyspnea or the typical signs (such as the three concavity sign), and the diagnosis of bronchial obstruction and atelectasis may be delayed.

8.6.3.1 Instrument Preparation

1. Interventional instruments: mouth gag, 5F vertebral artery catheter, 0.035 in. hydrophilic guidewire (150–180 cm), 0.035 in. stiff guidewire (180–260 cm), 0.035 in. metal stiff guidewire (180–260 cm), 9F sheath, L-type anti-skid stent or small inverted Y-shaped self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments
2. Choice of stent: Opt for an uncovered stent when the tumor is outside the airway and the wall structure is intact. Opt for a covered stent when the tumor involves the airway wall or is within the lumen of the airway. A radioactive stent can be used if necessary. The left main bronchus is slightly conical in shape, with a thicker proximal part and a relatively thinner distal end; a tubular stent (particularly a covered tubular stent) is not advisable as it would tend to migrate during severe coughing.

   On the chest MSCT cross-sectional (fat window) image, measure the lengths and diameters (anteroposterior and transverse diameters) of the trachea, left main bronchus, and the left upper and left lower lobe bronchi. Measure also the angle between the left upper and lower lobe bronchi. Customize the L-type anti-skid stent or small integrated Y-shape integrated self-expanding metal stent according to these measurements.
   (a) L-type anti-skid stent: This type of stent is suitable for treatment of malignant stenosis of the middle part of the left main bronchus. The diameter of the main body of the stent should be 10% more than that of the trachea; the length should be such that it will extend 40–50 mm above the carina. The diameter of the left main bronchus branch should be 10% more than that of the stenosed segment of the left main bronchus; moreover, the length should such that it will extend at least 10 mm beyond the stenosis.
   (b) Small inverted Y-shaped stent: The length of the left main bronchus part of the stent should be the same as that of the inferior wall of the left main bronchus; at the same condition, the diameter should be 10% more than that of the stenosed part of the airway. The length of left upper lobe bronchus part should be 10 mm±; the diameter should be 10% more than that of the stenosed part of the airway. The length of left lower lobe bronchus part should be 10 mm±; the diameter should be 10% more than that of the stenosed part of the airway. The angle of the stent bifurcation should match the angle between the left upper and lower lobe bronchi.

8.6.3.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: Perform chest MSCT scan and volume scan to assess the site and range of the left main bronchus stenosis. If there is left lung atelectasis or left lung pneumonia, perform enhanced MSCT scan. Uniform

enhancement in the arterial phase indicates that the lung tissue structure is intact and that normal function can be restored by relieving the bronchial stenosis. On the contrary, non-uniform enhancement or no enhancement indicates that the atelectasis has been present for a relatively long time and that lung structure has likely been destroyed by hypoxia-ischemia; stent placement is therefore unlikely to restore lung function.

If infection exists and the treatment with intravenous antibiotics is ineffective, intubate the left main bronchus, and perform lavage with the appropriate antibiotic.

3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.3.3 Procedure of L-Type Anti-skid Partly Covered Stent Placement

1. Patient position: Ask the patient to remove clothes that have any radiopaque material (such as metal buttons) and to lie down relaxed and supine on the fluoroscopy table. Slightly raise the neck and shoulder; keep the head tilted backward and turned 20° to 30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine for anesthesia, and place the mouth gag. Keep the suction apparatus ready for clearing the airway and oral secretions as necessary.

   Tilt the C-arm 20° to 30° to the left (with body turned 20° to 30° to the right, the combined effect is equivalent to turning the head 50° to the right), and adjust the collimators to include oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopic monitoring, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the left main bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the left main bronchus stenosis and the distance from the left upper lobe bronchus opening again.
3. Insertion of stiff guidewire: After completion of bronchography, introduce a hydrophilic guidewire and catheter past the left main bronchus stenosis and into the left lower lobe bronchus. Pull out the guidewire, and inject 1 mL of 30% iodinated contrast agent to confirm that the catheter is in the left lower lobe bronchus. Ask the assistant to keep the position of the guidewire and mouth gag unchanged during the procedure.
4. Insertion of L-shape stent delivery system: Insert the L-shaped stent delivery system over the stiff guidewire into the left main bronchus. Rotate the stent conveyor so that the window between the main body of the stent and the branch is aligned with the opening of the right main bronchus and the gold X-ray mark on the small curvature of the inner bracket is located on the left side edge.
5. Placement of stent: Fix the stiff guidewire and the rear handle of stent conveyor, and slowly pull back the front handle and outer sheath to release the branch part of the L-shaped stent in the left main bronchus, perspective detection when half of the branch released. With continuous monitoring to ensure that the lower end of the stent branch does not cover the upper lobe bronchus opening, and that the upper end does not cover the right main bronchus opening, slowly release two-thirds of the length of the stent. Make sure that the stent branch rides across the stenosis, and then release the entire branch in the left main bronchus. During the release process, constantly adjust the stent conveyor to ensure the window between the main body and the branch aligned with the opening of the right main bronchus.

   Perform fluoroscopy again to confirm that the stent branch is completely released in the left main bronchus and the stent window is aligned with the opening of the right main bronchus. Then, quickly release the main body of the stent in the lower part of the trachea.

   Slowly pull back the conveyor after the stent is released, making sure that the position

of the stent is not disturbed. Leave the guidewire in place as a pathway for subsequent interventions.

6. Re-radiography: Introduce a catheter over the guidewire, and inject 3 mL of 30% iodinated contrast agent. Confirm that the stenosis is completely released, accurately positioned, and fully expanded and the right main bronchus and left upper lobe bronchus are unobstructed. If necessary, adjust stent position or perform post-dilation.
7. Sputum suction: Pass a suction tube over the guidewire deep into the left and right main bronchi. Apply suction to remove any residual contrast agent and sputum. During suction, gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   During the procedure, watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.3.4 Postoperative Management:
See Sect. 8.6.1.4

8.6.3.5 Prevention and Treatment of Complications:
See Sect. 8.6.1.5

8.6.4 Left Upper Lobe Bronchus Stenosis

Isolated malignant stenosis of the left upper lobe bronchus is relatively rare and is usually accompanied by stenosis of the left main bronchus or left lower lobe bronchus. The small inverted Y-shaped airway stent can be used to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not have the typical symptoms of chest tightness, wheezing, and progressive increase in breathing difficulty; and the typical signs (i.e., cyanosis, three concavity sign) may also be absent. If there is no obstructive pneumonia symptoms, the diagnosis may be missed. If left lower lobe atelectasis is found, determine the integrity of the unexpanded lung and whether the normal structure and function can be restored by relieving the stenosis.

8.6.4.1 Instrument Preparation

Interventional Instruments and Customization of the Stent

1. Interventional instruments: mouth gag, 5F vertebral artery catheter, 0.035 in. hydrophilic guidewire (150–180 cm), 0.035 in. stiff guidewire (180–260 cm), 0.035 in. metal stiff guidewire (180–260 cm), 9F sheath, small inverted Y-shaped self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.
2. Choice of stent: On the chest MSCT cross-sectional (fat window, WW400 HU, WL-50 HU) image, measure the lengths and diameters (anteroposterior and transverse diameters) of the stenosed left main bronchus and left upper and lower lobe bronchi. Customize the small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the left main bronchus part of the stent should be the same as that of the inferior wall of the left main bronchus; furthermore, the diameter should be 10% more than that of the stenosed airway. The length of the left upper lobar bronchus part should be 5 mm more than that of stenosed segment of the left upper lobe bronchus; by the way, the diameter should be 10% more than that of the stenosed airway. The length of left lower lobar bronchus part should be 5 mm more than that of stenosed segment of the left lower lobe bronchus; at the same time, the diameter should be 10% more than that of the stenosed airway. The angle of the stent bifurcation should match the angle between the left upper and lower lobe bronchi [13].

8.6.4.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: Perform chest CT scan and enhanced scan to comprehensively evaluate the tracheobronchial tree and lung structure. Determine

the degree and extent of the tracheobronchial stenosis and any related atelectasis. Uniform enhancement in the pulmonary arterial phase of enhanced scan indicates that the lung tissue structure is intact and function can be restored by stent placement to relieve the stenosis. Uneven enhancement or no enhancement indicates that the atelectatic lung tissue is destroyed or seriously damaged and that normal function cannot be restored by treating the stenosis.

3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.4.3 Procedure of Small Y-Shaped Stent Placement

1. Patient position: Ask the patient to remove clothes with any radiopaque material (such as metal buttons) and to lie down relaxed and supine on the fluoroscopy table. Slightly raise the neck and shoulder, and then keep the head tilted backward and turned 20° to 30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine for anesthesia, and place the mouth gag. Keep the suction apparatus ready for clearing the airway and oral secretions as necessary.

   Tilt the C-arm 20° to 30° to the left (with body turned 20° to 30° to the right, the combined effect is equivalent to turning the head 50° to the right), and adjust the collimators to include oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopic monitoring, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position in order to put the tip at the left upper lobe bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the left upper lobe bronchus stenosis and the position of the opening of the left lower lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and pass a catheter over it past the stenosis into the left upper lobe bronchus. Perform radiography again to confirm the catheter's location, and then exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the left lower lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method involves to insert a 9F long sheath through the stiff guidewire into the lower part of trachea just above the carina. Then, pull out the inner core of the sheath, and introduce a guidewire and catheter through the sheath into the left lower lobe bronchus. Exchange to a stiff guidewire and fix it.
4. Insertion of stent delivery system: Under fluoroscopic monitoring, hold the stiff guidewires in position, and load the left upper and lower lobe bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding it at the mouth gag end, and introduce the delivery system over the stiff guidewire. With the neck tilted backward as much as possible, slowly push forward the delivery system. If resistance exists at the glottic area and the patient appears to choke, rotate the delivery system so that the two part of the stent assume an anteroposterior position that fits the shape of rima glottidis. Ask the patient to breathe deeply, keeping the glottis open, and during inhalation, push the delivery system past the glottis and into the left main bronchus. Rotate the delivery system so that the left upper and lower bronchus parts of the stent are aligned with the corresponding bronchus. Check that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

   Good cooperation among the operator, assistant, nurse, and technician is essential during the procedure, especially to keep the stiff guidewires fixed in place, the patient position unchanged, and the oxygen saturation normal.

5. Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the left upper and lower lobe bronchus parts of the inverted Y-shaped stent in the left main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire and push the stent limbs into the respective bronchi till resistance is encountered, confirming that that the stent limbs are fully inserted in the bronchi. Now, fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the left main bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min till the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.

   If the patient experiences breathing difficulty and blood oxygen saturation shows progressive decline after release of the stent, perform fluoroscopy to exclude stent distortion and folding or nonexpansion of the stent. If these complications are ruled out, the possibility exists which bronchus has been blocked by sputum. Quickly pull out the stent delivery system, exchange to a sputum suction tube, and apply suction to the left main bronchus until blood oxygen saturation rises back to normal.
6. Re-radiography: Introduce the catheter over the guidewire into the left main bronchus. Inject 3 mL of 30% iodinated contrast agent, and check that all stenoses are completely released and the stent is correctly in place and fully expanded.
7. Sputum suction: Pass a suction tube over the stiff guidewire into the left main bronchus. Apply suction to remove all residual contrast agent and sputum. Gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   During the procedure, watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.4.4 Postoperative Management:
See Sect. 8.6.1.4

8.6.4.5 Prevention and Treatment of Complications: See Sect. 8.6.1.5

8.6.5 Left Lower Lobe Bronchus Stenosis

Isolated left lower lobe bronchial malignant stenosis is relatively rare and usually accompanied by stenosis of the left main bronchus or left lower lobe bronchus. The small inverted Y-shaped airway stent can be placed to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not have the typical symptoms of chest tightness, wheezing, and progressive increase in breathing difficulty; the typical signs (i.e., cyanosis, three concavity sign) may also be absent. Without the obstructive pneumonia symptoms, the diagnosis may be missed. If right lower lobe atelectasis is found, determine the integrity of the unexpanded lung, and decide whether the normal structure and function can be restored by relieving the stenosis.

8.6.5.1 Instrument Preparation

Interventional Instruments and Customization of the Stent

1. Interventional instruments: See Sect. 8.6.4.1.
2. Choice of stent: On the chest MSCT cross-sectional (fat window, WW400 HU, WL-50 HU) image, measure the lengths and diameters (anteroposterior and transverse diameters) of the left main bronchus and the left upper and lower lobe bronchi. Customize the small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the left main bronchus part of stent should be the same as the length of the

inferior wall of the left main bronchus; the diameter should be 10% more than that of the stenosed airway. The length of the left upper lobe bronchus part should be 5 mm more than the length of the stenosed segment of the left upper lobe bronchus; the diameter should be 10% more than that of the stenosed airway. The length of the left lower lobe bronchus part should be 5 mm more than the length of the stenosed segment of the left lower lobe bronchus; the diameter should be 10% more than that of the stenosed airway. The angle of the stent bifurcation should match the angle between the left upper and lower lobe bronchi.

8.6.5.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: see Sect. 8.6.4.2.
3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.5.3 Procedure of Tubular Stent Placement

1. Patient position: Ask the patient to remove clothes with any radiopaque material (such as metal buttons) and to lie down relaxed and supine on the fluoroscopy table. Slightly raise the neck and shoulder; keep the head tilted backward and turned 20°–30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine for anesthesia, and place the mouth gag. Keep the suction apparatus ready for clearing the airway and oral secretions as necessary.

   Tilt the C-arm 20° to 30° to the left (with body turned 20° to 30° to the right, the combined effect is equivalent to turning the head 50° to the right), and adjust the collimators to include oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.
2. Transcatheter radiography: Under fluoroscopy, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the left lower lobe bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the left lower lobe bronchus stenosis and the position of the opening of the left upper lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and pass a catheter over it past the stenosis into the left lower lobe bronchus. Perform radiography again to confirm the catheter's location, and then exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the left upper lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method is to insert a 9F long sheath through the stiff guidewire into the lower part of trachea just above the carina, then pull out the inner core of the sheath, and introduce a guidewire and catheter through the sheath into the left upper lobe bronchus. Exchange to a stiff guidewire and fix it.
4. Insertion of stent delivery system: Under fluoroscopic monitoring, firmly fix the two stiff guidewires and hold them in position. Load the left upper and lower lobe bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding it at the mouth gag end and introduce the delivery system over the stiff guidewire. With the neck tilted backward as much as possible, slowly push forward the delivery system. If resistance is encountered at the glottic area and the patient appears to choke, rotate the delivery system so that the two parts of the stent assume an anteroposterior position that fits the shape of the rima glottidis. Ask the patient to breathe deeply, keeping the glottis open, and during inhalation, push the delivery system past the glottis and into the trachea and then to the left main bronchus. Rotate the delivery system so that the left upper and lower bronchus parts of the stent are aligned with the corresponding bronchi. Check that

the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

Good cooperation among the operator, assistant, nurse, and technician is essential during the procedure, especially to keep the stiff guidewires fixed in place with the patient position unchanged and oxygen saturation normal.

5. Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the left upper and lower lobe bronchi parts of the small inverted Y-shaped stent in the left main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the bronchus parts into the respective bronchi till resistance is encountered, which is an indication that the stent arms are fully inserted into the bronchi.

   Now, fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the left main bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.

   If the patient experiences breathing difficulty and declining blood oxygen saturation after release of the stent, perform fluoroscopy to exclude stent distortion and folding or nonexpansion of the stent. If these complications are ruled out, it is possible that the bronchial lumen has been blocked by sputum. Quickly pull out the stent delivery system, pass a sputum suction tube into the left main bronchus, and suck repeatedly until blood oxygen saturation rises to normal.
6. Re-radiography: Introduce the catheter over the guidewire into the right main bronchus. Inject 3 mL of 30% iodinated contrast agent, and check that all stenoses are completely released and the stent is correctly in place and fully expanded.
7. Sputum suction: Introduce the stiff guidewire, and then pass the suction tube over the guidewire deep into the left main bronchus. Apply suction to remove all residual contrast agent and sputum. Gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   During the procedure, watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.5.4 Postoperative Management:

See Sect. 8.6.1.4

8.6.5.5 Prevention and Treatment of Complications:

See Sect. 8.6.1.5

8.6.6 Right Main Bronchus Stenosis

The length of the right main bronchus is only 10–20 mm; therefore isolated right main bronchial malignant stenosis is rare. It occurs usually with carina area stenosis or right upper lobe and right middle bronchi stenoses. The simple L-shaped tracheal and main bronchial branch stent or a large inverted Y-type integrated stent cannot completely alleviate the stenosis without covering the opening of the right upper lobe bronchus. The small inverted Y-type airway stent is able to cover the left main bronchus opening. Most cases need the placement of one large and two small inverted Y-shaped integrated stents, in which the small inverted Y-shaped stents is put in the right middle bronchus, right upper lobe bronchus and right main bronchus, and the large Y-shaped stent in the right main bronchus, left main bronchus and lower trachea [14].

8.6.6.1 Instrument Preparation

1. Interventional instruments: mouth gag, 5F vertebral artery catheter (100 cm), 0.035 in.

hydrophilic guidewire (150–180 cm), 0.035 in. stiff guidewire (180–260 cm), 0.035 in. metal stiff guidewire (180–260 cm), 9F sheath, two (large and small) inverted Y-shaped self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14F long sheath, and tracheal intubation instruments.

2. Choice of stent: On the chest MSCT cross-sectional (fat window) image, measure the lengths and diameters (anteroposterior and transverse diameters) of the trachea and both main bronchi. Customize the large Y-shaped integrated self-expanding metal stent according to these measurements. Measure the lengths and diameters (anteroposterior and transverse diameters) of the right main bronchus and right upper lobe and right middle lobe bronchi and the angle between the right upper lobe and right middle lobe bronchi. Customize the small Y-shaped self-expanding metal stent according to these measurements.
   (a) Small Y-shaped stent: The length of the right main bronchus part of the stent is the same as that of the inferior wall of the right main bronchus; at the same time, the diameter should be 10% more than that of the corresponding airway. The length of the right upper lobe bronchus part is 10 mm±, and the diameter is 10% more than that of the corresponding airway. The length of the right middle lobe bronchus part is 10 mm±; the diameter is 10% more than that of the corresponding airway. The angle of the stent bifurcation should match the angle between the right upper lobe and right middle lobe bronchi.
   (b) Large Y-shaped stent: The length of the main body (trachea) of the stent should be 40–50 mm; the diameter should be 10–20% more than that of the corresponding airway. The length of the left main bronchus part is 15–20 mm; and the diameter is 10% more than that of the airway. The length of the right main bronchus part is 10–15 mm (from the opening of right upper lobar bronchus), and the diameter is 10% more than that of the airway. The angle of the stent bifurcation should match the angle between the right and left main bronchi.

8.6.6.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: see Sect. 8.6.1.2.
3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.6.3 Procedure of Placement of Two Inverted Y-Shaped Stents

The two inverted Y-shaped integrated stents are chosen during the same procedure. The small inverted Y-shaped integrated stent is put in first, and then the large inverted Y-shaped integrated stent follows it. The right side branch of the large inverted Y-shaped bracket fits for the main body of the small inverted Y-shaped bracket, and the small inverted Y-shaped inner bracket is pressed and the two inner brackets fit to the bronchus-bronchus complex stenosis without covering the normal tracheobronchial opening. It is an ideal combination of the bracket.

1. The procedure of the small inverted Y-shaped stent placement:
   (a) Patient position: Ask the patient to remove clothes that have any radiopaque material (such as metal buttons) and to lie down relaxed and supine on the fluoroscopy table. Slightly raise the neck and shoulder; keep the head tilted backward and turned 20° to 30° to the right. Drape the patient, fix the nasal oxygen catheter, connect the ECG leads, spray the throat with lidocaine for anesthesia, and place the mouth gag. Keep the suction apparatus ready for clearing the airway and oral secretions as necessary.

   Tilt the C-arm 20° to 30° to the left (with body turned 20° to 30° to the right, the combined effect is equivalent to turning the head 50° to the right), and adjust the collimators to include oropharynx, trachea, and bilateral main bronchus in the fluoroscopy field.

(b) Transcatheter radiography: Under fluoroscopy, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position in order to put the tip at the right main bronchus, and quickly inject 3 mL of 30% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the stenosis and the distance from the openings of the right upper lobe bronchus to the middle lobe bronchus.

(c) Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and catheter to pass through the stenosis into the right lower lobe bronchus. Perform radiography again to confirm the catheter's location, then exchange to a stiff guidewire, and fix it in place. Insert a 9F long sheath over the stiff guidewire to the lower part of the trachea just above the carina. Pull out the inner core of the sheath, and introduce a catheter to pass through the sheath deep into the right main bronchus, the right upper lobe bronchus, and the segmental bronchus. Exchange to another stiff guidewire and fix it, and then pull out the catheter and sheath. Mark the two stiff guidewires for easy identification.

(d) Insertion of small Y-shaped stent delivery system: Firmly fix the two stiff guidewires and hold them in position. Load the upper lobe bronchus and middle lobe bronchus parts of the small Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding it at the mouth gag end. Under fluoroscopic monitoring, introduce the delivery system over the stiff guidewire. With the neck tilted backward as much as possible, slowly push forward the delivery system. If resistance is encountered at the glottic area and the patient appears to choke, rotate the delivery system so that the two parts of the stent assume an anteroposterior position that fits the shape of the rima glottidis. Ask the patient to breathe deeply, keeping the glottis open, and during inhalation, push the delivery system past the glottis and into the trachea. At the carina, rotate the delivery system so that the upper lobe and middle lobe bronchus parts of the stent are aligned with the respective bronchi. Check that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side. Then advance the delivery system into the left main bronchus.

Good cooperation among the operator, assistant, nurse, and technician is important during the procedure, especially to keep the stiff guidewires fixed in place, the patient position unchanged, and the oxygen saturation normal.

(e) Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the Y-shape stent in the right main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the stent limbs into the bronchi till resistance, which indicates the limbs are completely inserted into the respective bronchi. Confirm with fluoroscopy that the stent bifurcation is in contact with the bifurcation of the upper and middle bronchi. Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the two bronchus parts of the stent. Confirm with fluoroscopy that the stent parts are in the correct bronchi. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right main bronchus. The small Y-shaped stent is now entirely released. Leave the stiff guidewire in the right lower lobe bronchus in place as a pathway for subsequent interventions.

2. The procedure of large inverted Y-shaped stent placement:
   (a) The insertion of large inverted Y-shaped stent delivery system: see Sect. 8.6.2.3.
   (b) The placement large inverted Y-shaped stent: see Sect. 8.6.2.3.
   (c) Re-radiography: Introduce the catheter over the guidewire into the carina region. Inject 3–5 mL of 30% iodinated contrast agent, and check that the stenosis is completely released, the stent is accurately in place and fully expanded, and the two stents are fitted closely together.
   (d) Sputum suction: The severe stenosis of the right main bronchus results in a large amount of retained secretions with secondary bacterial infection. When the stenosis is relieved, the accumulated alveolar and bronchial pus and mucus will pour out and block air flow which would cause severe breathing difficulty. Therefore, efficient sputum suction is an indispensable life-saving measure after the covered stent placement.

      Pass a suction tube over the guidewire deep into the right main bronchus and especially the right lower lobe bronchus. Suck thoroughly to remove residual contrast agents and sputum, and then lavage with appropriate antibiotics. Slap the patient's back to dislodge tenacious sputum, and change patient position to help drain sputum. Continue all measures till lung rales disappear and oxygen saturation reaches or is close to 100%.

8.6.6.4 Postoperative Management: See Sect. 8.6.1.4

8.6.6.5 Complications: See Sect. 8.6.1.5

8.6.7 The Right Upper Lobe Bronchus Stenosis

The isolated malignant stenosis of the right upper lobe bronchus is relatively rare and accompanied with stenosis of the other bronchi, such as the right main bronchus or right middle lobe bronchus. A small inverted Y-shaped airway stent is chosen to alleviate all stenoses.

Most patients with dysfunction of only one lobe or one lung do not contain the typical symptoms of chest tightness, such as wheezing and progressive breathing difficulty. However, the typical signs (i.e., cyanosis, three concavity sign) may also be absent. Without the obstructive pneumonia symptoms, the diagnosis could be missed. If right upper lobe atelectasis is found, determine the integrity of the unexpanded lung and whether the normal structure and function can be restored by relieving the stenosis.

8.6.7.1 Instrument Preparation

Interventional Instruments and Customization of the Stent

1. Interventional instruments: see Sect. 8.6.4.1.
2. Choice of stent: On the chest MSCT cross-sectional (fat window, WW400 HU, WL-50 HU) image, measure the lengths and diameters (anteroposterior and transverse diameters) of the right main bronchus diameter and the right upper lobe and middle lobe bronchi. Customize the small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of the right main bronchus part of the stent is the same as that of the inferior wall of the right main bronchus, and the diameter is 10% more than that of the corresponding airway. The length of the right upper lobar bronchus part should be 5 mm more than that of stenosed segment of the right upper lobe bronchus, and the diameter is 10% more than that of the airway. The length of the right middle bronchus part is 10 mm; the diameter is 10% more than that of the airway. The angle of the stent bifurcation should match the angle between the right upper lobe and right middle lobe bronchi.

8.6.7.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: Perform chest CT scan and enhanced scan to comprehensively evaluate the tracheobronchial tree and lung structure. Determine

the degree and extent of the tracheobronchial stenosis and any related atelectasis. Uniform enhancement in the pulmonary arterial phase of enhanced scan indicates that the lung tissue structure is intact and function can be restored by relieving the stenosis. Uneven enhancement or no enhancement indicates that the atelectatic lung tissue is destroyed or seriously damaged and that normal function cannot be restored by treating the stenosis.

3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.7.3 The Procedure of Small Y-Shaped Stent Placement

1. Patient position: see Sect. 8.6.6.3.
2. Transcatheter radiography: Under fluoroscopy, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the right upper lobe bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location, the length of the right upper lobe bronchus stenosis, and the location of the opening of the right middle lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and pass a catheter over it past the stenosis into the right upper lobe bronchus. Perform radiography again to confirm the catheter's location, and then exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the right lower lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method is to insert a 9F long sheath through the stiff guidewire into the lower part of trachea just above the carina. Then pull out the inner core of the sheath, and pass a guidewire and catheter through the sheath into the right lower lobe bronchus. The following step focuses on exchanging to a stiff guidewire and fixing it.
4. Insertion of stent delivery system: Firmly fix the two stiff guidewires in position. Load the right upper lobe and right middle lobe bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding it at the mouth gag end, and introduce the delivery system over the stiff guidewire. With the neck tilted backward as much as possible, slowly push forward the delivery system. If resistance exists at the glottic area and the patient appears to choke, rotate the delivery system in order to localize the two parts of the stent at an anteroposterior position fitting for the shape of the rima glottidis. Ask the patient to breathe deeply, keeping the glottis open, and during inhalation, push the delivery system past the glottis and into the right main bronchus. Rotate the delivery system so that the right upper lobe and right middle lobe bronchus parts of the stent are aligned with the corresponding bronchi. Check that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

   Good cooperation between the operator, assistant, nurse, and technician is very important during the procedure, especially to keep the stiff guidewires in place, the patient position stable, and the oxygen saturation normal.
5. The placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right upper lobe and right middle bronchus parts of the small inverted Y-shaped stent in the right main bronchus. Keeping the relative positions of the two handles unchanged, fix stiff guidewire, and push the stent limbs into the right upper lobe and right middle lobe bronchi until resistance is encountered, which is an indication that the stent limbs are fully inserted in the respective bronchi.

   Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly

pull back the anterior handle to release the main body of the stent in the right main bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.

If the patient experiences breathing difficulty and declining blood oxygen saturation after release of the stent, perform fluoroscopy to exclude stent distortion and folding or non-expansion of the stent. If these complications are ruled out, it is possible that the bronchial lumen has been blocked by sputum. Quickly pull out the stent delivery system, pass a sputum suction tube into the left main bronchus, and suck repeatedly until blood oxygen saturation rises to normal.

6. Re-radiography: Introduce the catheter over the guidewire into the right main bronchus. Inject 3 mL of 30% iodinated contrast agent, and check that all stenoses are completely released and the stent is correctly in place and fully expanded.
7. Sputum suction: Introduce the stiff guidewire, and then pass the suction tube over the guidewire deep into the right main bronchus. Apply suction to remove all residual contrast agent and sputum. During suction, gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

During the procedure, watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.7.4 Postoperative Management: See Sect. 8.6.1.4

8.6.7.5 Prevention and Treatment of Complications: See Sect. 8.6.1.5

8.6.8 The Right Middle Bronchus Stenosis

The isolated malignant stenosis of the right middle bronchus is relatively rare and is usually accompanied by stenosis of other bronchi, such as the right main bronchus or right upper lobe bronchus. The small inverted Y-shaped airway stent is chosen to relieve all stenoses.

Most of the patients with dysfunction of only one lobe or one lung do not suffer from the typical symptoms of chest tightness, wheezing, and progressive breathing difficulty; however, the typical signs (i.e., cyanosis, three concavity sign) may also be absent. Without the obstructive pneumonia symptoms, the diagnosis may be missed. If right lower lobe atelectasis is found, determine the integrity of the unexpanded lung and whether the normal structure and function can be restored by relieving the stenosis [15].

8.6.8.1 Instrument Preparation

Interventional instruments and specially customized stent choice:

1. Interventional instruments: see Sect. 8.6.6.1.
2. Choice of stent: see Sect. 8.6.7.1.

8.6.8.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: Perform chest CT scan and enhanced scan to comprehensively evaluate the tracheobronchial tree and lung structure. Determine the degree and extent of the tracheobronchial stenosis and any related atelectasis. Uniform enhancement in the pulmonary arterial phase of enhanced scan indicates that the lung tissue structure is intact and function can be restored by stent placement to relieve the stenosis. Uneven enhancement or no enhancement indicates that the atelectatic lung tissue is destroyed and normal function cannot be restored by treating the stenosis.
3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.8.3 The Procedure of Small Y-Shaped Stent Placement

1. Patient position: see Sect. 8.6.1.2.
2. Transcatheter radiography: Under fluoroscopy, a hydrophilic guidewire and catheter are passed through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the right middle bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the right middle bronchus stenosis and the position of the opening of the right upper lobe bronchus.
3. Insertion of stiff guidewire: After finishing the radiography, introduce a hydrophilic guidewire and catheter past the stenosis into the right lower lobe bronchus. Perform radiography again to confirm the catheter's location, and then exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the right upper lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method is to insert a 9F long sheath through the stiff guidewire into the lower part of trachea just above the carina. Then pull out the inner core of the sheath, and introduce a guidewire and catheter through the sheath into the right upper lobe bronchus. Exchange to a stiff guidewire and fix it.
4. Insertion of stent delivery system: Firmly fix the two stiff guidewires, and holding them in position, load the right upper lobe and right middle lobe bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding them at the mouth gag end, and introduce the delivery system through the mouth. With the neck tilted backward as much as possible, slowly push forward the delivery system. If resistance exists at the glottic area and the patient appears to choke, rotate the delivery system so that the two parts of the stent assume an anteroposterior position that fits for the shape of the rima glottidis. Ask the patient to breathe deeply, keeping the glottis open, and during inhalation, push the delivery system past the glottis and into the right main bronchus. Rotate the delivery system so that the right upper lobe and right middle lobe bronchus parts of the stent are aligned with the corresponding bronchi. Check that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

   Good cooperation between the operator, assistant, nurse, and technician is essential during the procedure, especially to keep the stiff guidewires fixed in place, the patient position unchanged, as well as the oxygen saturation normal.
5. Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right upper lobe and right middle lobe bronchus parts of the small inverted Y-shaped stent in the right main bronchus. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the stent limbs into the right upper lobe and right middle lobe bronchi until resistance is encountered, confirming that the stent limbs have been fully inserted.

   Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right main bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%; then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.

   If the patient experiences breathing difficulty and declining blood oxygen saturation after release of the stent, perform fluoroscopy to exclude stent distortion and folding or

nonexpansion of the stent. If these complications are ruled out, the possibility is that the bronchial lumen has been blocked by sputum. Quickly pull out the stent delivery system, pass a sputum suction tube into the right upper lobe bronchus, and suck repeatedly until blood oxygen saturation rises to normal.

6. Re-radiography: Introduce the catheter over the guidewire into the right main bronchus. Inject 3 mL of 30% iodinated contrast agent, and check that all stenoses are completely released and the stent is correctly in place and fully expanded.
7. Sputum suction: Introduce the stiff guidewire, and then pass the suction tube over the guidewire deep into the right main bronchus. Apply suction to remove all residual contrast agent and sputum. During suction, gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   During the procedure, watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.8.4 Postoperative Management: See Sect. 8.6.1.4

8.6.8.5 Prevention and Treatment of Complications: See Sect. 8.6.1.5

8.6.9 The Right Middle Lobe Bronchus Stenosis

The isolated malignant stenosis of the right middle lobe bronchus is relatively rare and accompanied by stenosis of other bronchi such as the right middle lobe bronchus or right lower lobe bronchus. The small inverted Y-shaped airway stent can be placed to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not have the typical symptoms of chest tightness, wheezing, and progressive breathing difficulty; however, the typical signs (i.e., cyanosis, three concavity sign) may also be absent. Without obstructive pneumonia symptoms, the diagnosis may be missed. If right lower lobe atelectasis is found, determine the integrity of the unexpanded lung and whether the normal structure and function can be restored by relieving the stenosis.

8.6.9.1 Instrument Preparation

Interventional instruments and customization of the stent:

1. Interventional instruments: see Sect. 8.6.6.1.
2. Choice of stent: On the chest MSCT cross-sectional (fat window, WW400 HU, WL-50 HU) image, measure the length and diameters (anteroposterior and transverse diameters) of the right middle bronchus and the right middle lobe and lower lobe bronchi. Customize the small inverted Y-shaped integrated self-expanding metal stent according to these measurements. The length of right middle bronchus part of the stent should be the same as that of the inferior wall of the right middle bronchus; the diameter should be 10% more than that of the airway. The length of right middle lobe bronchus part is 5 mm more than that of the stenosed segment of the right middle lobe bronchus; the diameter should be 10% more than that of the airway. The length of the right lower lobe bronchus part is 10 mm; the diameter is 10% bigger more than that of the airway. The angle of stent bifurcation should match the angle between the right middle lobe and right lower lobe bronchi.

8.6.9.2 Preoperative Preparation

1. Laboratory examinations: see Sect. 8.6.1.2.
2. Imaging: see Sect. 8.6.6.2.
3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.9.3 Procedure of Small Y-Shaped Stent Placement

1. Patient position: see Sect. 8.6.6.3
2. Transcatheter radiography: Under fluoroscopic guidance, pass a hydrophilic guidewire and catheter through the mouth into the trachea up

to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the right middle lobe bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the right middle lobe bronchus stenosis and the position of opening of the right lower lobe bronchus.

3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and pass a catheter over it past the stenosis into the right middle lobe bronchus. Perform radiography again to confirm the catheter's location, and then exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the right lower lobe bronchus. Fix the two stiff guidewires in place.

   An alternative method is to insert a 9F long sheath through the stiff guidewire into the lower part of trachea just above the carina. Then, pull out the inner core of the sheath, and introduce a guidewire and catheter through the sheath into the right lower lobe bronchus. Exchange to a stiff guidewire and fix it.
4. Insertion of stent delivery system: Firmly fix the two stiff guidewires in position. Load the right middle lobe and right lower lobe bronchus parts of the Y-shaped stent on the respective stiff guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Under fluoroscopic guidance, introduce the delivery system into the mouth. With the head of the patient tilted back as much as possible, slowly push forward the delivery system. If resistance exists at the glottic area and the patient appears to choke, rotate the delivery system so that the two parts of the stent assume an anteroposterior position that fits the shape of the rima glottidis. Ask the patient to breathe deeply with the glottis open, and, during inhalation, advance the delivery system up to the right main bronchus. Rotate the delivery system so that the right middle lobe and right lower lobe bronchus parts of the stent are aligned with the openings of the corresponding bronchi. Make sure that the two guidewires are not twisted together and that the golden mark on the delivery system is on the correct side.

   Good cooperation between the operator, assistant, nurse, and technician is important during the procedure, especially to keep the stiff guidewires fixed in place, the patient position unchanged, and the oxygen saturation normal.
5. Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right middle lobe and right lower lobe bronchus parts of the small inverted Y-shaped stent in the right middle bronchial. Keeping the relative positions of the two handles unchanged, fix the stiff guidewire, and push the stent parts into the respective bronchi till resistance is encountered, confirming that the stent arms are completely inserted into the right middle lobe and right lower lobe bronchi.

   Now, fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right middle bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as a pathway for subsequent interventions.
6. Re-radiography: Introduce the catheter over the guidewire into the right main bronchus. Inject 3 mL of 30% iodinated contrast agent, and perform radiography to check that all stenoses are completely released and the stent is correctly in place and fully expanded.
7. Sputum suction: Introduce the stiff guidewire, and then pass the suction tube over the guidewire deep into the right middle bronchus. Apply suction to remove all residual contrast

agent and sputum. Gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

During the procedure, it is necessary to watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out accumulated mouth secretions to prevent aspiration.

8.6.9.4 Postoperative Management:
See Sect. 8.6.1.4

8.6.9.5 Prevention and Treatment of Complications: See Sect.8.6.1.5

8.6.10 The Right Lower Lobe Bronchus Stenosis

The isolated malignant stenosis of the right lower lobe bronchus is relatively rare and accompanied by other stenosis of other bronchi, such as the middle bronchus or right middle lobe bronchus. The small inverted Y-shaped airway stent can be placed to release all stenoses.

Most patients with dysfunction of only one lobe or one lung do not have the typical symptoms of chest tightness, wheezing, and progressive increase in breathing difficulty; however, the typical signs (i.e., cyanosis, three concavity sign) may also be absent. Without obstructive pneumonia symptoms, the diagnosis may be missed. If right lower lobe atelectasis is found, determine the integrity of the unexpanded lung and whether the normal structure and function can be restored by relieving the stenosis.

8.6.10.1 Instrument Preparation

Interventional instruments and customization of the stent:

1. Interventional instruments: see Sect. 8.6.6.1.
2. Choice of stent: see Sect. 8.6.9.1.

8.6.10.2 Preoperative Preparation

1. Laboratory examinations see Sect. 7.6.1.2.
2. Imaging: Perform chest CT scan and enhanced scan to comprehensively evaluate the tracheobronchial tree and lung structure. Determine the degree and extent of the tracheobronchial stenosis and any related atelectasis. The uniform enhancement in the pulmonary arterial phase of enhanced scan indicates that the lung tissue structure is intact and function can be restored by stent placement to relieve the stenosis. The uneven enhancement or no enhancement indicates that the atelectatic lung tissue is destroyed or seriously damaged and that normal function cannot be restored by treating the stenosis.
3. Gastrointestinal preparation: see Sect. 8.6.1.2.
4. Preoperative medication: see Sect. 8.6.1.2.

8.6.10.3 Procedure of Small Y-Shaped Stent Placement

1. Patient position: see Sect. 8.6.6.3.
2. Transcatheter radiography: Under fluoroscopic guidance, pass a hydrophilic guidewire and catheter through the mouth into the trachea up to the carina region. Fix the catheter and pull out the guidewire. Rapidly push 2–3 mL of 1% lidocaine through the catheter. Then adjust the catheter position so that the tip is at the right lower lobe bronchus stenosis, and quickly push 3 mL of 30–40% iodinated contrast agent to display the tracheobronchial anatomy. Determine the location and length of the right lower lobe bronchus stenosis and the position of the opening of the right middle lobe bronchus.
3. Insertion of stiff guidewire: After completion of radiography, introduce a hydrophilic guidewire and pass a catheter over it past the stenosis into the right lower lobe bronchus. Perform radiography again to confirm the catheter's location, and then exchange to a stiff guidewire. Repeat the procedure to insert another stiff guidewire into the right middle lobe bronchus. Fix the two stiff guidewires in place.

An alternative method is to insert a 9F long sheath over the stiff guidewire into the lower part of trachea just above the carina. Then, pull out the inner core of the sheath, and introduce a guidewire and catheter through the sheath into the right middle lobe bronchus. Exchange to a stiff guidewire and fix it.

4. Insertion of stent delivery system: Firmly fix the two stiff guidewires in position. Load the right middle lobe and right lower lobe bronchus parts of the Y-shaped stent on the respective guidewires. Connect the side conduit of the stent delivery system to high-pressure oxygen. Fix the guidewires by holding them at the mouth gag end, and, under fluoroscopic guidance, introduce the delivery system through the mouth. With the patients head tilted as far back as possible, slowly push forward the delivery system. If resistance is encountered at the glottic area and the patient appears to choke, rotate the delivery system so that the two bronchus parts assume an anteroposterior position that fits the shape of rima glottidis. Ask the patient to breathe deeply with the glottis open; during inhalation, push the delivery system past the glottis and as far as the right middle bronchus. Now rotate the delivery system again so that the right middle lobe and right lower lobe bronchus parts of the stent are aligned with the corresponding bronchi. Make sure that the two guidewires are not twisted together and the golden mark on the delivery system is also on the correct side.

   Good cooperation between the operator, assistant, nurse, and technician is necessary during the procedure, especially to fix the stiff guidewires in place, keep patient position unchanged, and maintain normal oxygen saturation.
5. Placement of stent: Holding the stiff guidewire and the posterior handle of the delivery system, pull back the anterior handle to release the right middle lobe and right lower lobe bronchus parts of the stent in the right middle bronchus. Keeping the relative positions of the two handle unchanged, fix the stiff guidewire and push the two branches of the stent into the respective bronchi till resistance is encountered, confirming that the branches are completely inserted.

   Fix the delivery system and guidewire, and rapidly pull the two bundled silk threads to completely release the bronchus part of the stent; holding the posterior handle, quickly pull back the anterior handle to release the main body of the stent in the right middle bronchus. The small inverted Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and blood oxygen saturation is 90–100%, and then pull out the stent delivery system slowly. Leave at least one endobronchial stiff guidewire in place as an intervention pathway for subsequent procedures.
6. Re-radiography: Introduce the catheter over the guidewire into the right main bronchus. Inject 3 mL of 30% iodinated contrast agent, and check that all stenoses are completely released and the stent is correctly in place and fully expanded.
7. Sputum suction: Introduce the stiff guidewire, and pass the suction tube over it deep into the right middle bronchus. Apply suction to remove all residual contrast agent and sputum. Gently slap the patient's back to help dislodge tenacious sputum. Continue suction till lung rales disappear and blood oxygen saturation reaches or is close to 100%.

   During the procedure, it is necessary to watch for blood in the phlegm, difficulty breathing, and low blood oxygen saturation. Suck out mouth secretions to prevent aspiration.

8.6.10.4 Postoperative Management:
See Sect. 8.6.1.4

8.6.10.5 Prevention and Treatment of Complications:
See Sect. 8.6.1.5

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9 Esophageal-Tracheal/Bronchial Fistula

Hongwu Wang, Huibin Lu, Xinwei Han, and Yonghua Bi

9.1 Introduction

Esophageal-tracheal (bronchial) fistula, a pathological disease, is secondary to congenital alloplasia or diseases where abnormal sinuses exist between the esophagus and trachea. These abnormal sinuses can result in food or digestive liquid flowing into the airway cavity, leading to inhibition of inhalation, severe coughing, refractory lung infection, poor quality of life, and rapid deterioration. The vast majority of adult esophageal-tracheal (bronchial) fistula cases are often secondary to acquired pathological damage, and advanced esophageal carcinoma is the most common cause. This chapter mainly describes the adult-acquired esophageal-tracheal (bronchial) fistula and the application of covered metal stent implantation in the treatment of esophageal-tracheal (bronchial) fistulas.

The adult esophageal fistula is a common but resistant clinical disease, with complex etiology and a high mortality rate. Common causes include tumor invasion, chemotherapy, infection, trauma, and iatrogenic injury, and other causes that have led to the destruction of the esophageal and bronchial wall and the sinus between the esophagus and trachea or bronchial lumen. Oral saliva, food, digestive enzymes, or acidic digestive fluid from the gastric cavity may move into the tracheobronchial fistula, causing irritation and severe coughing. The clinical symptoms include refractory pneumonia, pneumonia (multiple, lobular, segmental, or lobar), eating disorders, severe consumption, malnutrition, and water and electrolyte disorders.

After radiotherapy treatment of the esophageal cancer, tumor necrosis, tumor vascular occlusion, and tumor shrinkage may cause fistulas to form [1]. After three-dimensional conformal radiotherapy with high-dose intracavitary radiation, the incidence of esophagus radiation injury, such as radioactive esophagitis and esophageal perforation, is significantly increased, with a dose-response correlation. Patients experience coughing, fever, hemoptysis, chest tightness, shortness of breath, and other symptoms after consuming liquid food, and will be admitted to hospital. Because of the lack of typical clinical symptoms, this disease is often misdiagnosed as cough, pneumonia, lung abscess, or esophageal-tracheal tumor.

The esophageal-tracheal (bronchial) fistula should be treated as early as possible; a minimally invasive treatment is preferred, such as interventional stenting. Interventional therapy is able to effectively relieve irritating cough symptoms, alleviate pulmonary infection, improve the quality of

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life, and enable patients to receive further treatment for their esophageal cancer, such as transarterial chemotherapy, implantation of radioactive particles or stent with particles, or radiochemotherapy. With an increased understanding about this disease, the clinical detection rate is also increasing. This disease has become a common complication of esophageal carcinoma after radiotherapy.

9.2 Etiology of Esophageal-Tracheal (Bronchial) Fistula

9.2.1 Tumor Invasion

The tumor invades the esophagus wall and/or the airway wall and results in the formation of an esophageal-tracheal (bronchial) fistula [2].

9.2.2 Radiation Injury

After three-dimensional conformal radiotherapy with high-dose intracavitary radiation, the incidence of esophagus radiation injury, such as radioactive esophagitis and esophageal perforation, significantly increases, with a dose-response correlation. The airway wall also suffers from radiation damage, which may induce the esophageal fistula. Because of the radiotherapy, it is difficult to heal the fistula [3].

9.2.3 Bacterial Infection

A mediastinal infection can cause peripheral esophageal lymphadenitis, lymph node necrosis/rupture, invasion of the esophagus and trachea wall, and formation of a esophageal-tracheal (bronchial) fistula [4].

9.2.4 Surgical Operation Injury

A surgical injury involves direct damage to the esophagus wall and/or airway wall and ligation of the surrounding blood vessels resulting in ischemia [5].

9.2.5 Trauma or Physical Damage

Trauma or physical damage to the esophagus and trachea can lead to a sinus tract. Physical damage including ingestion of strongly acidic or alkaline liquids, which can dehydrate the cells of the esophageal mucosa and muscle layers, induce alkali ions and proteins to form basic proteins, can penetrate into deep tissue, generate heat, and cause an esophageal-tracheal (bronchial) fistula.

9.2.6 Iatrogenic Factors

Iatrogenic factors are usually found in patients using long-term mechanical ventilation and nasogastric intubation with a tracheal cuff. The trachea and esophagus wall are compressed by the nasogastric tube, which leads to formation of the fistula and wall necrosis [6, 7]. In most cases, the tracheal cuff injury is found at the level of tracheal wall necrosis.

9.3 Pathology of an Esophageal-Tracheal (Bronchial) Fistula

9.3.1 Radiation Therapy Secondary Injury [3]

The tolerance and treatment dose of esophageal radiation therapy for esophageal cancer is 6,000–7,500 cGy; however, the tolerance dose for the trachea and lung is 3,000–3,500 cGy, equivalent to half of the radiation dose of the esophagus. During esophageal radiation therapy, the trachea and bronchus may become soft and suffocation may occur if the patient receives more than 6,000 cGy.

The tracheobronchial wall (adjacent to the esophagus, the trachea, and the bronchi) cannot be completely excluded from targeted radiation during stereotactic radiotherapy. The radiation causes injury to cartilage and membranes, even resulting in necrosis and perforation after receiving excessive radiation, and the formation of an esophageal-tracheal (bronchial) fistula.

9.3.2 Tumor Invasion and Destruction

The esophageal-tracheal (bronchial) fistula is related to the occurrence or local recurrence of an esophageal tumor, invasion, or destruction of normal tissue. Tumor growth directly erodes the esophagus, causing esophageal perforation and food or digestive fluid overflow. Local tracheal injury from the presence of acidic digestive fluids and local inflammation may result in an esophageal-trachea (bronchial) fistula. A tumor may also destroy the trachea (bronchus) membrane with or without trachea (bronchus) and mediastinal infection or abscess. Esophageal damage caused by esophageal ulcers can also cause an esophageal-tracheal (bronchial) fistula. The recurrence of esophageal cancer can erode the esophagus and trachea (bronchus) wall, and the esophagus and trachea (bronchus) communicate with each other and form a fistula.

9.3.3 Bacterial Infection

An esophageal-tracheal (bronchial) fistula can form from a mediastinal infection with infective purulent cells destroying the esophageal tracheal wall, or esophageal-tracheal peripheral lymphadenitis where the lymph nodes ulcerate and invade the esophageal tracheal wall.

After formation of an esophageal-tracheal (bronchial) fistula, food or saliva can move into the esophagus and cause an irritating and severe cough, which results in patients not eating because they're afraid of choking, coughing, lung injury, and severe infection. The resulting decreased energy consumption leads to poor body disease resistance. If not actively treated, most patients develop severe nutritional disorders, repeated digestion liquid inhalation, bronchospasm, chemical pneumonia, multiple infectious pneumonia, lung abscess, corrosive pneumonia, respiratory function failure, and even death.

A tracheoesophageal (bronchus) fistula should be diagnosed early. Once diagnosed, immediate measures should be taken to avoid lung injury caused by gastric juice flowing into the bronchi. Effective treatment measures include fasting, maintaining a sitting position, introducing a stomach tube through the nasal cavity to relieve pressure in the stomach and drain gastric endocrine fluid, and inserted a nasal jejunal tube to maintain enough intestinal nutrition. The fistula should be plugged by physical methods as soon as possible, completely blocking the digestive fluid and food leaking into the trachea and bronchi.

9.3.4 Physical Damage

Accidental physical damage includes damage caused by strong acidic or alkaline liquid. Strong alkaline liquid dehydrates the esophageal mucosa and causes muscle cell dehydration; alkali ions combined with proteins form basic proteins and these penetrate into deep tissue, producing heat energy, and this can cause an esophageal-tracheal (bronchial) fistula.

When patients with superior segment esophageal carcinoma or history of a lung tumor or mediastinal tumor radiotherapy present with coughing symptoms and refuse to eat food or drink water, an esophageal-tracheal (bronchial) fistula must be suspected. During diagnosis, exclude cough due to swallowing dysfunction, erroneous deglutition, or high esophageal stricture caused by oppressing and injuring the recurrent laryngeal nerve. A digital X-ray, dynamic esophageal angiography performed after administering the oral iodine contrast agent, chest MSCT, bronchoscopy, and/or gastroscope examination are used to confirm the diagnosis.

9.3.5 Clinical Manifestation

9.3.5.1 Cough or Choking Cough

Cough symptoms are mild when the fistula is small and easily ignored. When the fistula is large, the patient coughs irritatingly. This can be treated by fasting, inhibiting the secretion of gastric juices, and maintaining decompression and continuous negative pressure by gastric cavity intubation.

When the fistula is small, a sputum color change can be observed after oral administration

of methylene blue. If the patient coughs up blue sputum, an esophageal fistula may be diagnosed.

9.3.5.2 Expectoration

Patients can have an excessive amount of sputum and the sputum may contain food if the patient is not fasting. Purulent sputum appears in the later stages of the fistula development.

9.3.5.3 Pulmonary Infection

Food, saliva, and digestive liquids can move into the bronchi and pulmonary alveoli through the fistula. This produces severe aspiration pneumonia. A mixture of saliva and food can cause bronchial mucosa and alveolar endothelial injury and increased permeability. A large amount of pulmonary interstitial and alveolar exudates form and this is a good bacterial culture medium. A large number of bacteria from the oral cavity, air passage, esophagus, and food move into the lungs through the fistula and this can lead to secondary multiple pulmonary infection and formation of refractory pneumonia and lung abscesses. Once the pulmonary injury has developed into large lobular pneumonia lesions, controlling the inflammation and infection is extremely difficult. Pulmonary infection is often observed in both lung fields.

9.3.5.4 Dyspnea

When the fistula is large, large amounts of food can drain into the trachea wall simultaneously, which can cause severe spasmodic bronchial asthma. A large amount of exudation caused by excessive alveolar endothelial cell injury, alveolar interstitial injury, and injury of pulmonary capillaries can affect pulmonary ventilation, and if secondary pneumonia aggravates the damage, dyspnea can eventuate. If not controlled, food and digestive fluids will move into the airway, leading to impairment of pulmonary oxygenation function, decreased oxygen saturation, and respiratory failure.

9.3.5.5 Nutritional Failure and Electrolyte Disturbance

Because of the coughing stimulated by eating, patients worry about eating and drinking. This can lead to long-term fasting, fever, and intractable pulmonary infection. In addition, the patient will consume a large amount of water, leading to electrolyte disorders, severe malnutrition, nutritional failure, or other symptoms of cachexia.

9.3.5.6 Fever

Because of the pulmonary infection combined with the lung injury, the esophageal fistula is often accompanied by a high fever. However, it may also be due to general weakness of the body due to inadequate nutrition.

9.3.5.7 Signs

Crackles can be heard on auscultation and this is common in both lungs. Because of long-term fasting, there is often a severe cough, a large amount of expectoration drainage, dyspnea, fever, etc. Electrolyte disorders and severe malnutrition, even cachexia and other symptoms, often appear.

9.3.6 Imaging Examination

9.3.6.1 Digestive Tract Radiography

When patients present with an eating and drinking cough, digestive tract examination is necessary. Gastrointestinal imaging is helpful for diagnosing esophageal fistula and determining the location and size of the fistula. When patients have a suspected esophageal-tracheal (bronchial) fistula, angiography must be carried out with an angiograph or iodine contrast agent. Barium sulfate is forbidden. When using traditional sulfuric acid (especially modern barium mucilage angiography) in the diagnosis of digestive tract fistula, all barium that overflows into the mediastinum and pleural cavity, bronchial, and alveolar cannot be completely excreted. Oral barium treatment carries a large number of oropharyngeal bacteria and when bacteria mixed with barium are deposited in the alveoli, this leads to a refractory pulmonary infection.

A radiograph of the upper digestive tract must be performed by oral administration of 30% iodine contrast medium concentration. This can show if the contrast agent spills into the airway through the esophageal fistula, accompanied by a

severe cough, bronchial tree development, and diffusion into the lungs. Sometimes because of severe coughing, it is not easy for the X-ray point plate to capture the fistula signs. Digital radiography can capture the signs by using continuous photography. The contrast agent travels through the esophagus into the airway and lung, and this displays the specific location of the fistula and can show the specific connected parts according to the position of contrast agent in the airway and indirectly judge the fistula size by the rate and amount of the contrast agent when it moves into the lungs.

The most important point in digestive tract radiography is that the use of barium and barium paste is strictly prohibited for all coughing patients. For the upper digestive tract, a 30% concentration of water-soluble iodine is recommended. Water soluble iodine can be completely absorbed and dissipated after moving into the bronchi and alveoli. Barium, especially barium paste, moves into the bronchi and alveoli and becomes a permanent deposition. Secondary pneumonia in alveoli deposition is very hard to cure (Fig. 9.1; informed consent was obtained from all participating subjects, and the ethics committee of the First Affiliated Hospital of Zhengzhou University approved our study).

9.3.6.2 Chest X–Ray Examination

When lung markings increase in a chest X-ray, intrapulmonary multiple patchy cloudy exudation lesions are usually the diagnosis. In patients with severe illness or a long medical history, cloudy exudation lesions can progress to multiple pulmonary segmental or lobar lesions, predominately in the lower lung. There can be different amounts of pleural effusion.

9.3.6.3 Neck and Chest CT Examination

A neck and chest spiral CT angiography is able to digitally reconstruct the tracheal bronchus, which is helpful to determine the location of the fistula and is a very good non-invasive diagnostic method. Multi-planar reconstruction after spiral CT scan, 3D reconstruction, and virtual endoscopy are reliable for displaying and evaluating the position of the esophageal-tracheal (bronchial) fistula. This provides a more reliable basis of interventional preoperative imaging and preparation for the operation. At the same time, the CT can also show the surrounding damage from the esophageal tumor, the scope and size of the tumor, and the degree of infection of the lungs and mediastinum. Particular attention must be paid to tracheal stenosis, stenosis degree, range and severity of pulmonary infection, which all help to determine the treatment plan.

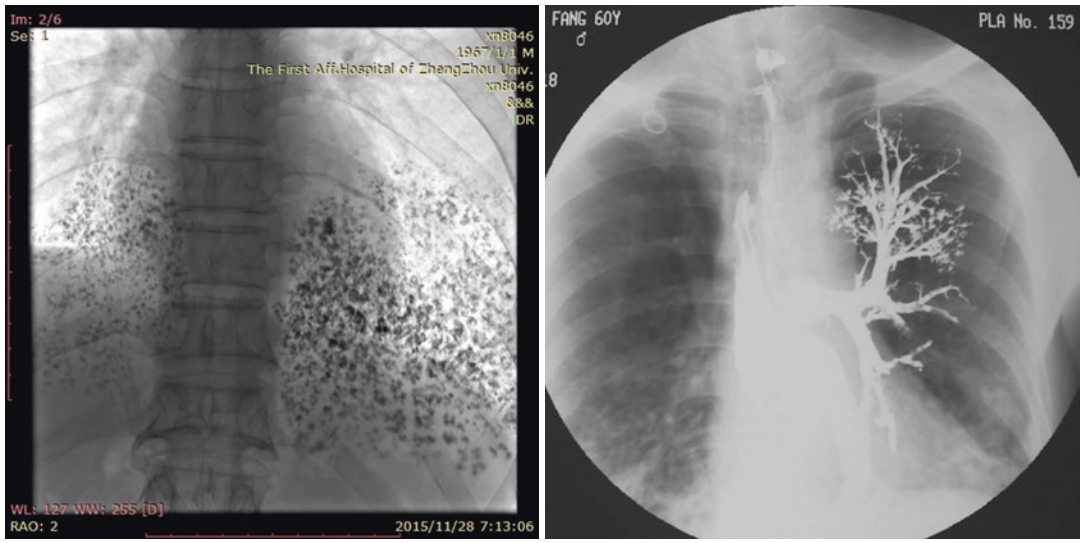

Fig. 9.1 Barium in the trachea, bronchi, and alveoli

The chest MSCT pulmonary window displays two pulmonary diffuse areas of interstitial pulmonary fibrosis, and multiple ranges of patchy lung segment or lobe pulmonary consolidations, and lung consolidation segments. The air bronchogram can be seen in consolidated lung tissue. The larger fistula can be shown in the lung window, with the smaller and tilted or twisted fistula shown in the lung window due to partial volume effect.

The mediastinal window displays the exact location of the fistula, the size of the fistula, and the relationship between the fistula and bronchi. Patients who are thin due to poor nutrition may obtain a false-positive result in the conventional mediastinal window conditions (window width of 400 HU, window level 40 HU) partial volume effect, because the wall of the stomach and trachea bronchial wall become thin due to a lack of adipose tissue in the mediastinum foil.

We recommend using the special mediastinal window—fat window (window width of 400 HU, window level −50 ~ −100 HU) image for processing—because it shows the various structures of the mediastinum, displays the fistula between the esophagus and airway more accurately, and avoids false-positive and false-negative findings, with an accuracy rate above 86%. Spiral CT chest scans can display the esophagobronchial fistula orificium and fistula tract, and this imaging type is the first choice for diagnosis. It is also useful for observing the chest, understanding the detailed anatomical relationship between the fistula and the adjacent structures, accurately measuring the diameter of the esophagus and trachea/bronchi, and providing detailed reference in the methods of interventional radiology to block the fistula by installing an individualized stent treatment (Fig. 9.2).

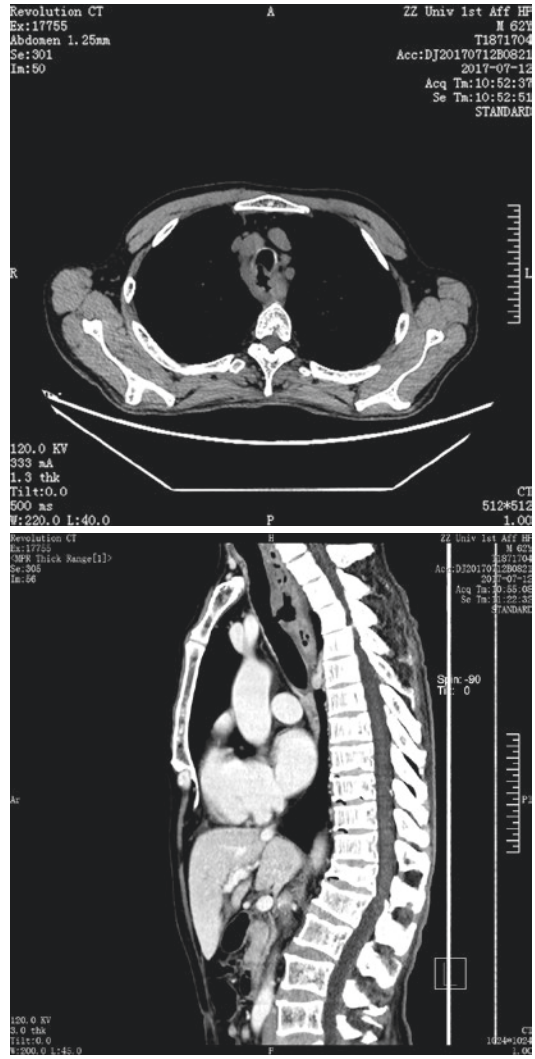

Fig. 9.2 Esophageal-tracheal fistula display on CT scan

9.3.6.4 Bronchoscopy

Bronchoscopy is useful to diagnose an esophageal-tracheal (bronchial) fistula. Bronchoscopy is able to clearly locate the fistula orifice (Fig. 9.3), which shows a defective membranous tracheal wall under the microscope and relates to congestion of the esophagus, edema of surrounding mucosa, and a sinus tract with white moss. A bronchoscope can be used for biopsy around the fistula to confirm the pathology. For an esophageal-tracheal (bronchial) fistula formed by erosive esophagitis, a microscope is needed to observe tissue granulation and inflammatory edema.

After endoscopy in the tracheobronchial diagnosis, it is better to give the patient an endotracheobronchial flushing treatment. A physiological saline solution is injected in each bronchial leaf for lavaging/washing of spilled food and inflammatory exudates, thus reducing corrosion to the lungs caused by digestive liquids and promoting the recovery from pneumonia.

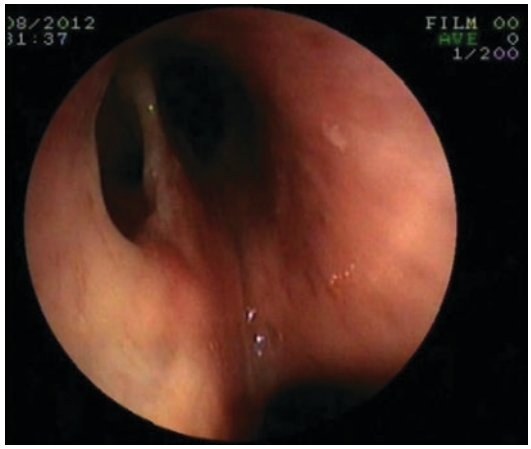

Fig. 9.3 Esophageal-tracheal (bronchial) fistula observed by bronchoscopy

9.3.6.5 Gastroscopy

Gastroscopy can further determine the position of the fistula in the esophagus and the distance between the cardia and throat. Using gastroscopy, it can be seen that the esophageal wall has lost integrity. The size and shape of the fistula can also be seen. If the fistula is caused by tumor invasion or tumor recurrence, it would show sewage moss, and uneven and irregular fistula stoma mucosa. At the fistula orifice, tracheobronchial bubbles are visible and are emitted with each breath. When the sinus is large, cricoid cartilage at the airway can be seen on endoscopy and this provides a definite diagnosis by entering the trachea and bronchus through the fistula orifice.

9.3.7 Types of Fistula

Categorizing the esophageal-tracheal (bronchial) fistulas into different types is meaningful for clinical treatment, particularly in stent interventional radiology treatment. According to the specific location of the esophageal fistula, there are seven types, as follows.

9.3.7.1 The Esophageal-Tracheal (Bronchial) Fistula

The fistula directly communicates with the membranous portion of the posterior wall of the trachea. The upper end of the fistula is over 20 mm away from the glottis, while the lower end of the fistula is over 20 mm away from the carina crest.

9.3.7.2 The Esophageal-Carina Fistula

A fistula of the esophagus directly communicates with the carina, and the fistula communicates with the posterior wall of the carina or the lateral inferior wall, and the fistula is within 2 cm of the carina.

9.3.7.3 The Esophageal–Right Primary Bronchial Fistula

The fistula directly communicates with the right main bronchus, and the anterior wall of the esophagus is linked to the posterior wall or the posterior inferior wall of the right main bronchus.

9.3.7.4 The Esophageal–Left Main Bronchial Fistula

The fistula is directly connected with the left main bronchus, and the anterior wall of the esophagus is linked to the posterior wall of the left main bronchus.

9.3.7.5 The Esophageal–Lobar Bronchial Fistula

The fistula is directly connected to the trunk of any one of the lobar bronchi, communicating with the left, right, upper lobe, middle lobe, or inferior lobe bronchus.

9.3.7.6 The Esophageal–Esophago-Pleural Fistula

The fistula of the esophagus first perforates the pleural cavity and then perforates through the visceral pleura on the surface of the lung, communicating with the alveoli and the distal bronchioles.

9.3.7.7 Other Types

These are also other types lesions, different to the above six types.

9.3.8 Clinical Treatment

The therapeutic principles of esophageal-tracheal (bronchial) fistulas include closure of the fistula,

reconstruction of the digestive tract and the respiratory tract, insertion of a nutritional stent, and control of infection.

The smaller esophageal-tracheal (bronchial) fistula shows slight clinical symptoms. The larger fistula can cause coughing, expectoration, electrolyte disorders, recurrent pulmonary infection, and eating disorders. Repeated lung injury is caused by a recurrent cough, expectoration, and eating. Symptoms of cough and expectoration decrease after fasting. Esophageal-tracheal (bronchial) fistula is a complicated disease, which for most patients is combined with refractory pulmonary infection and eating disorders.

Medical conservative treatment of esophageal-tracheal (bronchial) fistula includes abrosia, inhibition of gastric acid secretion, controlling pulmonary infection, etc. The effect, however, is limited. The traditional surgical treatment involves repairing the fistula orifice by esophageal-tracheal (bronchial) fistula neoplasty (high difficulty and high risk). With new technology continuously emerging in interventional radiology, the fistula is blocked by a covered embranchment stent inserted through the esophagus or airway.

9.3.8.1 Medical Treatment

Medical treatment consists of conservative treatment, including abrosia, inhibition of gastric acid secretion and gastric juice, performing nasal intubation for gastrointestinal decompression and continuous negative pressure drainage, anti-infection treatment, intravenous rehydration treatment, and insertion of a nutritional stent.

Abrosia

Impose a total ban on food and water intake or any swallowing. This stops food, water, and saliva passing into the trachea and bronchus through the esophagus and fistula orifice after swallowing, so that lung infection is avoided.

Use of Antacid Drugs

An acid inhibitor is given intravenously or via an intrajejunal nutrition tube in order to reduce gastric acid secretion and prevent gastric contents from flowing into the esophagus through the fistula orifice as well as reducing bronchial and lung injury.

Gastric Tube Decompression Treatment

Insert a gastric decompression tube via the nose, pump liquid in the stomach with the help of continuous negative pressure, empty the gastric liquid, and prevent gastric acid from flowing backwards into the trachea and bronchus through the esophagus. This treatment is effective in controlling lung inflammation and infection.

Nutrition Treatment of Jejunum

Insert a nasal feeding tube into the upper jejunum through the nasal cavity, pharynx, esophagus, stomach, and duodenum; maintain adequate nutrition by the jejunum. Patients must maintain adequate nutritional stent because of fasting, decompression in the gastric cavity, pulmonary inflammation, consumption, and other factors. Intravenous nutrition is expensive and inconvenient, while internal nutrition is a cheap and convenient solution. Calculate the daily total amount of liquid according to body surface area, total heat, and other elements. Prepare the nutrient solution and inject through the jejunum nutrition tube several times a day.

Anti-infective Therapy

Use sputum cultures to select the appropriate antibiotic therapy for controlling pulmonary infections. However, if the fistula is not blocked, the therapeutic effect is limited.

Fasting, inhibiting gastric acid secretion by drugs and intubation via nasal gastric cavity for continuous negative gastric decompression, internal nutrition through nasal intubation, and anti-infection treatment are effective medical treatment measures. It is very important to alleviate the irritating cough, reduce lung injury and infection, and maintain water intake, electrolyte balance, nutrition, and even normal life. These measures should be performed as early as possible before blocking the fistula by a covered stent.

9.3.8.2 Surgical Treatment

The target of traditional surgical treatment is to repair the esophageal-tracheal (bronchial) fistula, and the operation is difficult and risky [8]. Surgical treatment is not ideal for patients with poor systemic nutritional status, anemia, hypoproteinemia or pulmonary infection, electrolyte

disturbance, radiation injury due to radiation therapy, or intolerance of surgery. General surgical treatment is for fistula neoplasty or resection. This involves direct suture after dissociating the fistula or resecting the esophageal fistula together with one-stage anastomosis. For a larger fistula, a tissue patch is needed to prevent the fistula from forming again. However, postoperative mortality and the complication rate from conventional surgical treatment of esophageal fistula are both high. The "double flap" tracheal defect reconstruction treatment is for esophageal-tracheal (bronchial) fistulas, which simplifies the operation to a certain extent. However, surgical treatment of the esophageal fistula still faces problems such as a big wound, many complications, and a high fatality rate.

9.4 Internal Stent Interventional Radiology Treatment

Advanced esophageal cancer is often associated with an esophageal-tracheal (bronchial) fistula and these patients are mostly unsuitable for surgery. When food or saliva goes into the trachea, the lungs, and mediastinum via the esophageal fistula, this could produce a persistent infection, refractory pneumonia, and malnutrition, which can cause death for patients with advanced esophageal carcinoma complicated with esophageal-tracheal (bronchial) fistula.

Clinical interventional methods mainly refer to inserting a covered stent to block the fistula via the esophagus or trachea [9]. Its purpose is to block the fistula, recover breathing and the independence of the digestive tract, improve the quality of life, encourage quick healing, and effectively control dysphagia and coughing. This method can effectively block the fistula with the advantages of convenience, less trauma, and so on. In patients with a high esophageal fistula or when the fistula merges with tracheobronchial stenosis, if the fistula cannot be blocked by inserting covered stents at the esophagus side, the tracheal bronchus side is an option [10]. Patients with a esophageal-tracheal (bronchial) fistula can undergo covered esophageal stent placement before angiography. It is recommended that there is no use of barium. Instead, use an iodine contrast agent for imaging, and obtain a clear location of the fistula in the operation. The surgical operation should be gentle to avoid causing esophageal injury. If the patient's condition improves after inserting the stent, continue to administer chemoradiotherapy, and the quality of life should improve significantly. The domestic covered stent has a high success rate. The macromolecular surface of the stent has good biocompatibility and corrosion resistance and it can be easily attached after being inserted onto the esophageal wall. This stops the digestive liquid and food from entering the trachea through the fistula. The new organization grows along the stent, reducing the corrosion of tissue around the fistula and finally healing the fistula.

9.4.1 Tracheoesophageal Fistula

According to the seven types of fistula, the tracheoesophageal fistula belongs to the esophageal-tracheal (bronchial) fistula type. For a simple esophageal-tracheal (bronchial) fistula without symptoms of tracheal stenosis, esophageal stent implantation is feasible. If combined with tracheal stenosis, relieve the stenosis before inserting the tracheal stent.

9.4.1.1 Instrument Preparation

The instruments include interventional operation devices and special individual stent specifications.

Interventional Operating Instruments

Mouth gag, 5 F vertebral artery catheter, 0.035 in. hydrophilic membrane wire (150 cm), 0.035 in. stiff guidewire (180–260 cm), tubular covered esophageal or tracheal stent (Nanjing Micro-Tech, TaeWoong Medical, etc.), stent removal hook, sputum suction tube, 14 F long sheathing canal, tracheal intubation equipment, etc.

Stent Selection

The diameter of the esophageal stent is 18–22 mm; it is a covered stent with both ends of the stent 20–30 mm away from the fistula orifice.

Customize individual tracheal tube covered stents according to the anteroposterior diameter (vertical diameter) and left-right diameter (transverse diameter) measured across the cross-section (special mediastinal window—fat window) of the chest MSCT scan. The diameter of the tracheal stent is 15–20% larger than the diameter of the corresponding airway; the two covered ends of the stent should be 20–30 mm away from the fistula.

9.4.1.2 Before Inner-Stent Implantation

Laboratory

Before operation, perform a routine blood check, hepatorenal function test, electrolyte, hemagglutination test, infectious disease test, sputum bacterial culture and drug sensitivity test, electrocardiogram, etc.

Gastrointestinal Preparation

Immediately after the diagnosis, instruct the patient to fast and avoid any swallowing. Implant the gastrointestinal decompression tube and jejunum nutrition tube through the nose as soon as possible (apply single multifunctional catheters that can reduce gastric pressure and supply internal nutrition), enhance nutrition, prevent gastric juice from entering the airway, adjust water and electrolyte disorders, and improve the function of the heart and lungs in order to improve interventional tolerance. Give antacids to reduce gastric acid secretion.

Preoperative Medication

Give a 10 mg diazepam intramuscular injection 10–30 min before the operation to reduce the patient's anxiety and 654–2 10 mg injection to inhibit the secretion of digestive juices, and use hormones to avoid hypoxia or serious breathing difficulties.

9.4.1.3 Surgery for Tubular Stent Interventional Radiology

Esophageal Tubular Covered Stent Implantation

The patient should fast for 4 h preoperatively; administer an intramuscular injection of diazepam 654-2 and oxygen half an hour before surgery. Administer oxygen, prepare ECG monitoring and a sputum suction device, keep the patient in a supine position, give lidocaine gel for oropharyngeal anesthesia, and administer a small amount of iodine contrast agent for angiography preoperatively to determine the scope and location of the fistula. Insert the mouth gag, draw in 0.035 in. hydrophilic film guidewire and 5 F catheter, and pass them into the stomach through the mouth, pharynx, larynx, and esophagus. Remove the guidewire, inject contrast agent through the catheter, and when gastric mucosa is revealed, switch to a 0.035-in. intensive guidewire, withdraw the catheter, insert a stent into the fistula along the intensive guidewire; the center of the stent should be placed at the center of the fistula, the ends of stent should be about 2 cm beyond the lesions. Release the esophageal covered stent fluoroscopically, after the stent has expanded satisfactorily, withdraw the stent conveyor and the guidewire, and administer oral contrast to confirm the position and expansion of the esophageal stent, and condition of the fistula. After surgery, take measures to prevent infection, relieve pain, and administer antacids, protecting the gastrointestinal mucosa. Provide warm liquid to drink 4 h after the operation and administer normal food after 3 days, avoiding hard, thick, and fibrous food. A week after the operation, conduct esophageal radiography to further observe the position and the closure of the fistula (Fig. 9.4).

Tracheal Tubular Stent Implantation

Make sure the patient is positioned supinely on the DSA examination table, institute ECG monitoring, oxygen inhalation, and throat anesthesia by spraying lidocaine, insert mouth gag, and prepare a vacuum extractor to clear airway and oral secretions. Elevate the neck and shoulders, and keep the head backwards and to the right. Insert the 0.035-in. hydrophilic film guidewire and 5 F catheter through the mouth using fluoroscopy, move them to lower the trachea through the oral cavity, pharynx, larynx, and trachea, remove the guidewire, infuse 2 mL of 2% lidocaine through catheter, and reinject 3 mL iohexol for bronchial angiography to observe the site and size of fistula, and the distance

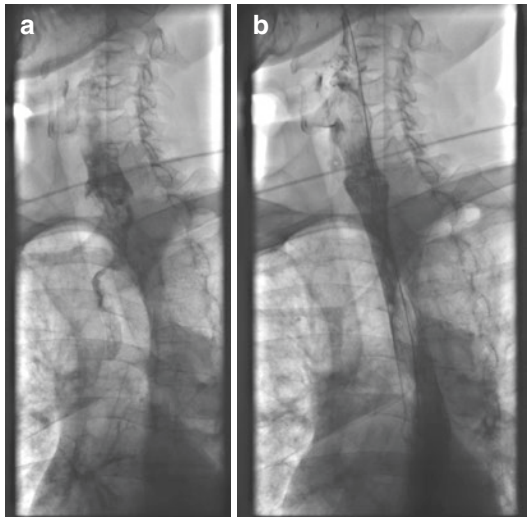

Fig. 9.4 (**a**) Contrast agent flowing to the trachea through the fistula after being swallowed. (**b**) Fistula is occluded by the esophageal covered stent

from the carina. Fix the guidewire and catheter, insert them into the left or the right main bronchus through the fistula, after verifying via angiography, replace with the green hardened wire, insert an individual stent and delivery system along the guidewire to the carina – the stent should be located at the center of the fistula, fix the guidewire and a rear handle firmly, pull back the front handle to completely release the stent, retain the guidewire, and remove it from the stent delivery system. Bring in the catheter, conduct angiography to make sure the left and right main bronchi are unobstructed, and bring in the sputum aspirator along the guidewire to aspirate the residual contrast agent and sputum in the airway. Finally, conduct angiography by taking contrast agent orally to show the closure of the fistula.

During the operation, if the patient has respiratory difficulties and blood oxygen saturation changes, aspirate oral secretions and continue to observe closely.

9.4.1.4 Treatment After Stent Implantation

Administer Convergence Solution Orally

After stent implantation, administer an oral convergence solution daily (saline, 500 mL + lidocaine, 5 mL + adrenaline, 2 mg + gentamicin, two branches) for 4–6 days, in order to alleviate stent stimulation and eliminate local inflammation and edema.

Atomizing Inhalation

Inhale twice a day after stent implantation (normal saline, 10 mL + lidocaine, 5 mL + ambroxol, 30 mg) for 4–6 days to promote the excretion of sputum and reduce irritation and inflammatory response caused by the stent.

Hardening Nutrition

Continue to harden the internal nutrition through the jejunum nutrition tube, and gradually increase the amount of food intake. If eating via the mouth does not stimulate coughing and discomfort, the jejunum nutrition tube can be removed, and continue simple oral intake. Sticky food such as sticky cakes, sweet potato, rice dumplings, and so on, is not recommended.

Relieving Cough and Resolving Phlegm

Administer anti-inflammatory drugs to relieve coughing and phlegm, dilute sputum, and promote expectoration. The patient should be assisted to turn over for a change of position and be patted on the chest and back to discharge sputum in the lungs.

Anti-infection Treatment

According to sputum culture results, choose sensitive anti-infective drugs to control lung infection. If necessary, conduct fibrobronchoscopy for bronchial lavage periodically, eliminate sputum and pus in the bronchus, and apply sensitive antibiotics in high concentration locally.

9.4.1.5 Management of Complications

Pain

Pain is related to swelling and irritation caused by the stent. Mild and general pain does not require special treatment. Painkillers should be given to treat serious pain. Pain is more obvious in patients with higher esophageal stent placement.

Stent Displacement

Stent migration is due to the small diameter and tension of the stent, improper placement of the stent, eating cold food postoperatively, retraction of the stent, severe vomiting, etc. Once the stent migration is confirmed, it is necessary to adjust the stent position immediately or replace it with a new stent after removal of the old stent.

Granulation Tissue Hyperplasia at Both Ends of the Stent

Granulation tissue hyperplasia is the most common complication after inserting esophageal and tracheal stents. Granulation tissue with no clinical symptoms generally does not require treatment. When the trachea or esophagus is obstructed by granulation tissue hyperplasia, use an electric knife, argon knife, or laser to burn and cut the granulation tissue and administer freezing treatment to the root to inhibit the proliferation of granulation tissue, or place a new stent through the esophagus.

Hematemesis or Hemoptysis

Most patients with hematemesis are able to take low doses of epinephrine and thrombin orally. This condition is related to bleeding and unskilled operating skills, muscle injury, high stent tension, cancer tissue erosion after radiotherapy, mucosa ulcer erosion, and increased mechanical pressure in the esophagus aggravating local ischemic necrosis. Close attention should be paid to patients with gradually increased bleeding: monitor blood pressure and pulse, observe acral temperature and hematemesis, etc. Pay attention to the amount of bleeding and the blood color changes; administer an antacid, hemostatic, and gastric mucosal protective agent as needed. A small amount of blood in the sputum is common after inserting the tracheal stent. Bleeding should stop automatically in 10 min without treatment. If hemoptysis is persistent, especially if there is a large amount of blood and expectoration includes blood clumps with little sputum, inject 2–3 mL 1:1000 adrenaline saline through the endotracheal tube to prompt the vasoconstriction of tracheal mucosa and immediately stop hemoptysis, which can achieve effective hemostasis even when suffering with arteriorrhexis.

Compression and Stenosis of Trachea

This condition is caused by the expansion of the esophageal stent, which compresses the trachea. For those with mild compression showing no obvious symptoms of respiratory difficulties, provide temporary observation; if the pressure is heavy, leading to difficulty in breathing, insert a tracheal stent to lift the stenosis.

Sore Throat, Hoarseness

Administer anti-inflammatory and analgesic treatment.

Incomplete Sealing of the Fistula

A small residual fistula remains for a few days with the local foreign body stimulation from the stent, inflammatory reaction, and intimal hyperplasia. With tracheal mucosal edema and further external expansion of the stent, the residual fistula will gradually disappear. Conduct postoperative digestive tract radiography to review the situation. First, determine whether the stent location spans across the fistula, whether the covered parts at the ends of stent are long enough in the normal tracheal segment (more than 15–20 mm); second, confirm if the stent diameter is large enough (15–20% longer than normal tracheal diameter), and whether the expansion capacity of the stent is maintaining good adherence. If the covered stent straddling the normal trachea is not long enough, adjust the position; for an incorrectly placed stent, replace with a stent with a larger diameter.

Stent Obstruction

Esophageal stent clogging is often due to viscous food in the bracket and gastroscope aspiration treatment is necessary. Tracheal stent blockage means that the covered stent completely covers the tracheal epithelium and cilia. This means that the mucus blanket function is completely lost and sputum excretion depends completely on the impact of coughing. If coughing is weak, sputum will gradually adhere to the cover of the stent, then many sputum blots form and the severe obstruction of the trachea leads to tracheal stenosis and dyspnea. The sputum blot and sputum scab should be removed as soon as possible under

bronchoscopy. After the tracheal lumen is clear, start drug inhalation, eliminate phlegm and sputum, and avoid sputum retention.

Enlargement of Fistula or Recurrence of Fistula

With tumor necrosis development or out of control local inflammation, the fistula continues to expand, especially esophageal-tracheal (bronchial) fistulas occurring after radiotherapy. In this situation, tissue surrounding the stoma and fistula receive large doses of radiation, lose tissue growth and regeneration ability and the fistula almost never regenerates, but gradually expands. When designing or selecting stent specifications for occlusion of the fistula, potential hazards such as expanding should be predicted and a stent chosen that is as long as possible (two ends span at least 2 cm across the normal wall). Once the stent loses efficacy in blocking, it needs to be replaced with a longer stent.

9.4.2 Carina Fistula of Esophagus

According to the fistula types based on location, the esophageal fistula– carina fistula belongs to type II of the esophageal-tracheal (bronchial) fistula.

9.4.2.1 Instruments

Equipment for Interventional Surgery

The opening devices include 5 F vertebral artery catheter, 0.035-in. hydrophilic membrane guidewire (150–180 cm), 0.035-in. hydrophilic membrane stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F sheath, esophageal covered stent, or airway inverted Y-shaped tracheal integration partly covered or fully covered expandable metal stent (Nanjing Micro-Tech), stent removal hook, suction tube, 14 F long sheath, tracheal intubation equipment, etc.

Stent Selection Strategy

Generally, an esophageal covered stent of 18–22 mm diameter is chosen where two ends of the stent are 20–30 mm away from the fistula.

According to the fat window of the chest MSCT cross-sectional images (WW 400 HU, WL −50 HU), measure the anteroposterior diameter and transverse diameter of the weasand, measure the anteroposterior diameter and length of bilateral main bronchus, and then select or customize the individual inverted Y-shaped tracheal integration partly covered or fully covered expandable metal stent. The stent parameters should be as follows: diameter of the main bronchial department stent 15–20% larger than the corresponding airway, length of tracheophonesis stent (main body) is 40–50 mm above the knuckle. The length of the right main bronchus is the distance between the carina and right upper lobe bronchus opening edge; the length of the left main bronchus is 20–30 mm.

9.4.2.2 Preparation Before Stent Placement

Laboratory Inspection

Before operation, perform a routine blood check, hepatorenal function test, electrolytes, hemagglutination test, infectious disease check, and conduct sputum bacterial culture and drug sensitivity test to select appropriate anti-infective drugs.

Cardiopulmonary Function Test

Before ECG examinations on cardiac function, the multifunctional physiological monitoring and oxygenation function of the lungs should be checked.

Imaging Examination

Conduct the chest MSCT scan, make full use of MPR, CPR, and other post-processing functions and analyze the images; define the precise location, size, and adjacent relationships of the carina fistula; define distribution and scope of the pulmonary inflammatory lesion and determine the severity of lung injury; measure diameter and length of the tracheobronchial system to customize the stent accurately.

Complete fiberoptic bronchoscopy as far as possible to comprehensively examine the condition of the esophagus and trachea fistula.

Preparation of Gastrointestinal Tract

Establish a nutrition jejunal tube and gastric decompression tube through the nasal cavity as soon as possible, harden internal nutrition to maintain normal metabolism of body, reduce food or saliva in the airway, correct water and electrolyte disturbances, and improve heart and lung function in order to improve tolerance of the intervention operation.

Preoperative Drug Use

Administer 10 mg diazepam intramuscular injection 10–30 min ahead of surgery to eliminate patient anxiety, and an intramuscular injection of 654–2 10 mg to relieve smooth muscle tension, reduce secretion of digestive and respiratory glands, to facilitate interventional radiology operation.

If the patient suffers from severe pulmonary inflammation, poor respiratory function, or low levels of oxygen, intravenous administration of hormone is indicated (10 mg dexamethasone or 30 mg methylprednisolone) to reduce the tracheobronchial and pulmonary exudation and inflammation, improve stress tolerance, and improve patient tolerance to intervention.

9.4.2.3 Operation of Stent Interventional Radiology

Esophageal Stent Implanting Process

Set up oxygen uptake and ECG monitoring, prepare a sputum suction device, maintain the patient in a supine position, administer lidocaine gel for oropharyngeal anesthesia, and administer a small amount of iodine contrast agent for angiography preoperatively to determine the scope and location of the fistula. In the mouth gag, insert a 0.035-in. hydrophilic film guidewire and 5 F catheter, moving them into the stomach through the mouth, pharynx, larynx, and esophagus. Remove the guidewire, inject contrast agent through the catheter, and when the gastric mucosa is revealed, switch to a 0.035-in. intensive guidewire, withdraw the catheter, put the stent into the fistula along the intensive guidewire; the center of stent should be aimed at the center of the fistula, the ends of stent should be about 2 cm beyond the lesions, release esophageal covered stent fluoroscopically, after the stent has expanded satisfactorily, withdraw stent conveyor and the guidewire, give oral contrast again to confirm the position expansion of the esophageal stent, and the condition of the fistula. After surgery, administer measures to prevent infection, relieve pain, prevent gastric juices forming, and protect the gastrointestinal mucosa. Provide warm liquid to drink 4 h after the operation, give normal food after 3 days; avoiding hard, thick, and fibrous food. Conduct esophageal radiography to further observe the position and the closure of the fistula stent a week later.

Make sure the patient lies supinely on the DSA examination table, institute ECG monitoring, oxygen inhalation, throat anesthesia by spraying lidocaine, place a mouth gag, and prepare the vacuum extractor to clear airway and oral secretions. Elevate the neck and shoulders, and keep head backwards and to the right. Draw in a guidewire and catheter through the mouth with fluoroscopy, insert them to the lower trachea through the oral cavity, pharynx, larynx, and trachea, remove the guidewire, infuse 2 mL 2% lidocaine through catheter, reinject 3 mL iohexol for bronchial angiography to observe the site and size of the fistula and the distance from the carina. Fix the guidewire and catheter, conduct them into the right main bronchus through the fistula, and after verifying the angiography, replace with the hydrophilic film stiff guidewire, remove the guidewire, implant a 9 F sheathing canal above the knuckle, remove the inner core, the guidewire, and the sheath together into the left lower lobe bronchus, fix the guidewire after confirmation by radiography, replace with guidewire, keep the guidewire in position and remove the sheathing canal.

Draw in the inner core, loading the left and right branches through the left and right guidewire, respectively. Send in the integrative bicomponent stent and delivery system along the dual guidewire to the carina, adjust the stent position to make sure that the left and right branches lie on the same side as the main bronchus and check that the golden gauge point is located on the left and right edges on both sides. Fix guidewire and the rear handle

firmly, and pull back the front handle to completely release the dual branches of the stent. Fix the rear hand shank of delivery, and pull back front handle to release the trachea, guidewire, and remove the stent delivery system slowly.

During the operation, closely observe if the patient suffers respiratory difficulties and blood oxygen saturation changes. Conduct postoperative airway radiography to check for the closure of the fistula and make sure the stent is clear. Insert the sputum aspirator along the guidewire to aspirate the residual contrast agent and sputum in the airway.

When a patient shows no dyspnea and oxygen saturation changes, this requires a postoperative transcatheter angiography review of airway, airway patency, and understanding of endovascular treatment, and it is recommended to absorb remaining contrast agent and sputum by suction by residual airway guidewire.

Finally, after administering oral 30% iodine contrast agent 20–40 mL and performing an esophageal angiography, carina fistula overflow into the tracheobronchial stent occlusion can be observed by contrast agent, and this is used to confirm if the fistula is complete.

9.4.2.4 See Sect. 9.4.1.4 for Post-processing Operation

Prevention and treatment of complications (see Sects. 9.4.5.7 and 9.4.6.7).

9.4.3 Esophagus–Right Main Bronchial Fistula

According to the types of fistula based on the location of the fistula, the esophagus–right main bronchial fistula belongs to type III of the esophageal-tracheal (bronchial) fistula types.

When a simple esophageal-tracheal (bronchial) fistula without symptoms of tracheal stenosis occurs, esophageal stent implantation is performed to block off the fistula orificium. The right main bronchus is short and thick with a length of 1.5 cm, 1.2–2.0 cm diameter, and angles with the extension line of the trachea longitudinally by approximately 20–30°. The fistula near the opening is close to the carina, while the fistula at the distal segment is adjacent to the middle bronchus or right upper lobe of bronchus. In order to seal the right main bronchial fistula effectively and protect the opening of the right upper lobe bronchus, the large and the small reversed Y-shape full covered airway stent is inserted in most cases, with the small one in the middle-right upper lobe bronchus and right main bronchus, and the large one in the right main bronchus–left main bronchus and trachea.

9.4.3.1 Device Preparation (see also Sect. 9.4.2.1)

Preparation consists of general interventional instruments and covered esophageal stents or individual airway stent models.

Interventional Instruments

The interventional instruments include opening device, 5 F vertebral artery catheter (80–100 cm), 0.035-in. hydrophilic film guidewire (150–180 cm), 0.035-in. hydrophilic membrane stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F sheath, esophageal fully covered stent or two sets of inverted Y-shaped stents partly or fully covered of the appropriate size, the stent removal hook, suction tube, 14 F long sheath, tracheal intubation equipment, etc.

Stent Selection

The diameter of the esophageal stent is 18–22 mm, and the stent is 2–3 cm longer than the fistula. Measure the anteroposterior diameter (vertical diameter) and the left-right diameter (transverse diameter) of the fat window on chest MSCT cross-section, and also the diameter and length of the bilateral main bronchus, choose or customize an appropriate tracheal stent and large integrated covered expandable metal Y-shaped stent. Stent parameters are as follows: trachea, diameter of stent at trachea, and main bronchial department should be 15–20% larger than the corresponding airway caliber, length of tracheophonesis stent (main body) should be 40–50 mm above the knuckle. The length of right main bronchus is the distance between the carina and right

upper lobe bronchus opening edge, and the length of the left main bronchus is 20–30 mm.

Measure the radial line of right main bronchus, right upper lobe, and right middle bronchus, and select or customize a small integrated covered expandable metal Y-shaped stent.

Stent parameters are as follows: the diameter of right upper lobar bronchial branch should be 10% larger than the diameter of the corresponding bronchus, the length being no greate than 80% of the corresponding bronchus. The diameter of right middle bronchial branch is approximately 10% larger than the diameter of the corresponding bronchus, the length being no more than 80% of the total length of the bronchial stent; the diameter of the right main bronchus (main body) is approximately 15% larger than the right main bronchus, and the total length of the wall does not exceed the length of inferior wall of right main bronchus.

9.4.3.2 Preparation of Stent Implantation

(See Sect. 9.4.2.2)

9.4.3.3 Stent Implantation Interventional Radiology Operation

Placement of the Covered Esophageal Stent

Maintain the patient in a supine position with the head to the right, administer oxygen, institute ECG monitoring, prepare sputum aspirator, conduct lidocaine gel oropharyngeal anesthesia, administer a small amount of iodine contrast agent for angiography preoperatively to determine the scope and location of the fistula. Place into the mouth gag the 0.035-in. hydrophilic film guidewire and a 5 F catheter, insert them into the stomach through the mouth, pharynx, larynx, esophagus, remove the guidewire, inject contrast agent through the catheter; when the gastric mucosa is revealed, replace with 0.035-in. intensive guidewire, withdraw the catheter, transfer the stent to the fistula along the intensive guidewire; the center of the stent should be aimed at the center of the fistula, and the ends of the stent should be about 2–3 cm beyond the lesions; release the esophageal covered stent fluoroscopically. After the stent has expanded satisfactorily, withdraw the stent conveyor and guidewire, administer oral contrast again to confirm the position and expansion of the esophageal stent and situation of the fistula. After surgery, administer measures to prevent infection, relieve pain, prevent excessive production of gastric juices, and protect the gastrointestinal mucosa. Provide liquid to drink 4 h after the operation. Administer normal food after 3 days; avoid hard, thick, and fibrous food. Conduct esophageal radiography to observe the position and closure of the fistula a week later.

Implantation of Double Inverted Y–Shaped Tracheal Stent

Implant the two inverted Y-shaped stents during the same operation; generally implant the distal small Y-shaped stent first, then the large one. Set the branch of the large Y-shaped stent into the body of the small Y-shaped stent, then the small stent becomes fixed by the large one.

Patient Position

Keep the patient supine on the DSA examination table; keep the head as close to the end of the DSA examination bed, keep the neck and chest DSA images at an effective monitoring range. The patient must be kept supine without a pillow. Keep the patient's head back and to the right at about 30° (facing the surgeons). Cover the surface with one or two large surgical drapes, administer continuous oxygen through the nose, and continuously monitor multifunctional ECG monitoring of heart and lungs. With the C arm of DSA left positioned obliquely at 20°, and the patient's head angled to the right at 30°, this is equivalent to placing the patient's head approximately 50° to the left anterior. This position helps to show the negative shadow clearly.

Conduct airway throat spray anesthesia and prepare the vacuum extractor to clean the airway and oral secretions as needed.

Transcatheter Angiography

Synchronize the hydrophilic film guidewire and catheter in fluoroscopy, move them to the knuckle

through the oral cavity, pharynx, larynx, and trachea. Remove the guidewire and fix the position of the catheter, infuse 2–3 mL of 2% lidocaine through catheter for tracheal mucosa anesthesia in the region of the knuckle. Adjust the catheter into the right main bronchus, infuse 3 mL 30% iodine contrast agent as fast as possible for airway angiography to further observe the site and size of the fistula in the right main bronchus, the ubiety between the opening of right upper lobe bronchus and middle bronchus, as well as the bilateral main bronchus.

Introduction of Reinforced Wire

Synchronize the guidewire and catheter into the right lower lobe bronchus over the right main bronchial fistula orifice, draw in the metal stiff guidewire after angiography, remove the guidewire and fix the catheter firmly; implant 9 F sheathing canal to hypomere of the trachea or top of the knuckle along the metal guidewire in the right main bronchus, remove the sheath core; the catheter works with the hydrophilic membrane guidewire going into the trachea and right main bronchus through the sheathing canal, insert into the right upper lobe bronchus and deep segment of bronchus, replace the hydrophilic membrane stiff guidewire, remove the catheter and sheath, retain and fix the guidewire, and mark two reinforcing guidewires at the upper and lower lobe.

Introduction of Small Y-Shaped Stent Conveyor

Firmly fix two reinforced guidewires, keep the position of the guidewire unchanged in the bronchus. With the help of up and down stiff wires, draw in up and down cores of the branches carrying the Y-shaped stent conveyor, respectively. Fix the guidewires into place at the extracorporeal gag and end of wire, send the Y-shaped stent delivery conveyor into the mouth smoothly through the mouth gag along the double stiff guidewires.

Fix the stiff guidewires into place, push the conveyor forward into the mouth pharynx through the mouth, maintain the position of the patient's head, and push the conveyor forward into the laryngeal cavity. If vocal resistance and reactive coughing occurs, maintain the thrust and rotate the conveyor, make the orientation of the conveyor's double core fit the anteroposterior diameter of the glottis. Ask the patient to inhale deeply or cough, and when the glottis opens, push the conveyor forward into the trachea until it reaches the knuckle. Rotate to adjust the stent orientation; each branch of the stent should be on the same side as the stiff guidewires at the up and down lobes of the bronchus; ensure the two guidewires are not twisted. Also ensure that the gold marker on the inverted Y-shaped stent is located on the left and right edge, and push the conveyor forward to send the stent's two branches into right main bronchus.

Release of the Small Y-Shaped Stent

Fix the stiff guidewire and rear handle of the conveyor firmly into place, pull back the front handle of the conveyor and sheath to fully release the two branches of the inverted Y-shaped stent into the right main bronchus.

Keep the relative position of the front and back handle constant, harden the stiff guidewire, push two branches of the stent forward into the right upper lobe bronchus and right middle bronchus along the double guidewire carefully and gently, and when confronted with resistance, this means that the stent bifurcation has reached the upper lobe bronchus and the bronchial bifurcation.

Conduct X-ray to further confirm that the stent's bifurcation is at the upper lobe bronchus and the bronchial bifurcation. Fix the conveyor and the stiff guidewire, pull bundling thread at both sides of the branch one after another, conduct X-ray to confirm dual branch position; and then fix the back handle of conveyor, pull back the front handle and the outer sheath quickly to release stent's main part in right main bronchus. After releasing the small inverted Y-shaped stent, remove the conveyor slowly. Retain the metal stiff guidewire in the inferior lobar bronchus to retain the subsequent interventional operation pathway (Fig. 9.5).

Introducing the Large Y-Shaped Inverted Inner Stent Conveyor

Position the catheter and adjust the hydrophilic stiff guidewire in the right upper lobe bronchus to

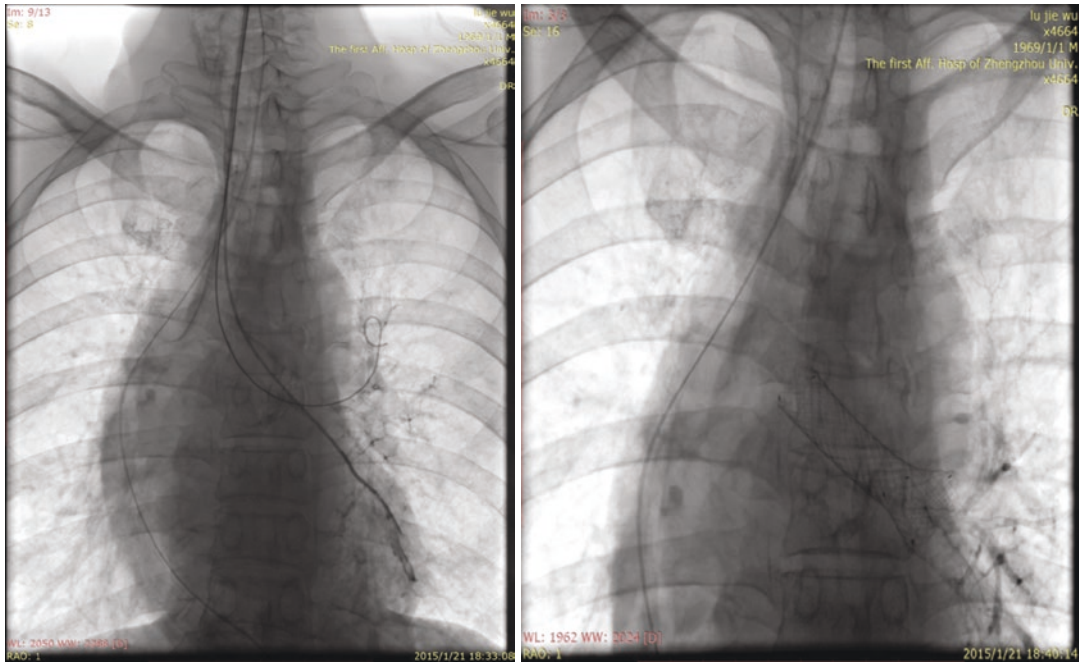

Fig. 9.5 Placement of the distal inverted Y-shaped stent

the left lower lobe bronchus, remove the catheter, fix the stiff guidewire, mark the two stiff guidewires on the left and right bronchial branch.

Fix the two reinforcing wires and maintain the wires' endobronchial position.

Firmly fix two reinforced guidewires, keep the position of the guidewires unchanged in the bronchus. With the help of the left and right stiff guidewires, draw in the left and right cores of the branches carrying the Y-shaped stent conveyor, respectively, connect the conveyor's side arm with high pressure oxygen for oxygen supply. Fix the guidewire at the extracorporeal gag and end of the wire, send the Y-shaped stent delivery conveyor into the mouth along the double stiff guidewires.

Fix the stiff guidewire, push the conveyor forward to the pharynx oralis through the mouth, maintain the position of the patient's head, and push the conveyor into the laryngeal cavity. When encountering vocal resistance and reactive coughing, maintain the forward thrust and rotate the conveyor so that the orientation of the conveyor's double core fits the anteroposterior diameter of the glottis. Ask the patient to inhale deeply or cough and when the glottis opens, push the conveyor to the trachea until the knuckle is reached. Rotate and adjust the conveyor so that the left and right branches of stent are on the same side as the stiff guidewires on the left and right lobe of the bronchi, they should also be facing in the same direction. The two guidewires should be completely separated on both sides without any twisting. Check that the golden marker on the inverted Y-shaped stent is also on the left and right edge.

Fix the stiff guidewire and rear handle of conveyor firmly, pull back the front handle of the conveyor and sheath to fully release the two branches of the inverted Y-shaped stent into the lower tracheal part over the knuckle.

Keep the relative position of the conveyor's front and back handles and artery sheaths constant, strengthen the stiff guidewire, gently push the two branches of the stent forward into the left and right main bronchus and right middle bronchus, respectively, along the guidewire. This process should be conducted under close monitoring. Pay particular attention to the small released Y-shaped stent, ensure it is not pushed to the right side of the big stent. Excluding the above-men-

tioned situation, if resistance exists, then push the Y-shape stent conveyor onwards.

When meeting with resistance during the pushing, this means that the stent's double branches have completely gone into the bilateral main bronchus and that the stent's bifurcation has arrived at the bronchial bifurcation and knuckle bifurcation. Fix the conveyor and strengthen the guidewire; the operator and the patient then rest for 30–60 s, preparing for the next quick action.

Fix the conveyor and strengthen the guidewire, pull the bundling thread at both sides of the branch, fully release the bilateral branch of the stent, fix the back handle of conveyor, pull back the front handle and the outer sheath quickly to release the stent's main part in the bronchus. After releasing the inverted Y-shaped stent, wait for 1–3 min until the patient breathes smoothly, blood oxygen saturation rises to 90–100%, and then remove the conveyor slowly. Retain at least one metal stiff guidewire to retain the subsequent interventional operation pathway (Fig. 9.5).

If symptoms of dyspnea and increased hypoxia occur after release or oxygen saturation decreases progressively, check using fluoroscopy if the obstruction is caused by for example stent kinking or not opening. If there are double lung rales present, consider sputum blocked in bronchus, quickly remove the stent conveyer, replace with a suction tube into the bronchus, conduct sputum suction on left and right sides repeatedly until blood oxygen saturation increases to normal level.

Transcatheter Radiography for Reviewing

Exchange the guidewire, introduce the catheter near the carina, inject iodine 30% 3–5 mL contrast agent by catheter, conduct endotracheal bronchography, see whether the stent is implanted in the correct position, whether the closure of the fistula is complete, whether the double Y–shaped stent fitting is close, and whether stent expansion is complete.

Orally administer 20–40 mL of 30% iodine contrast medium, and use esophageal and esophageal radiography to see if any contrast agent has passed through the right main bronchial fistula into the trachea and bronchi. Further confirmation is needed to see if the stent has expanded fully and the fistula was completely blocked.

9.4.3.4 Postoperative Management

See Sect. 9.4.1.4

9.4.3.5 Prevention and Treatment of Complications

See Sect. 9.5.1.5

9.4.4 Esophagus–Left Main Bronchial Fistula

According to the fistula types based on the different locations of the fistula, the esophagus–left main bronchial fistula belongs to type IV of the esophageal–tracheal bronchial fistula types.

The esophagus–left main bronchial fistula is caused by tumor invasion, radiotherapy, inflammation, infection, trauma or iatrogenic injury and other reasons. It is common in advanced esophageal cancer and lung cancer. After mediastinal lymph node metastasis and mediastinal tumor radiotherapy, patients can develop symptoms of drinking cough, frequent coughing, purulent sputum, fever, chest tightness, shortness of breath, etc. They are often misdiagnosed as having other diseases, such as pneumonia, and the symptoms are often milder than esophageal-tracheal (bronchial) fistula and esophageal fistula, with the symptoms of inflammation of the left lung often being worse.

For esophagus–left main bronchial fistula without tracheal stenosis, esophageal stent implantation is a feasible treatment option. If this condition is combined with tracheal bronchus stenosis, the Y-shaped stent should be used to block the fistula.

The total length of the left main bronchus is 30–40 mm, much longer than the right main bronchus. When a stent is put in the left main bronchus, the operating space is larger. If the fistula mouth occurred in the left main bronchus near the carina, treatment is the same as with esophageal carina fistula, that is, implant a Y-shaped covered metal stent in the trachea and

bilateral main bronchus; if the fistula occurred in the distal left main bronchus near the bifurcation, only insert a small Y-shaped film airway stent in the left main bronchus, left upper lobe bronchus, and left lower lobe bronchus.

9.4.4.1 Instruments

Interventional Devices

These consist of the opening device, 5 F vertebral artery catheter (80–100 cm), 0.035-in. (150–80 cm) hydrophilic membrane guidewire, 0.035-in. hydrophilic membrane stiff guidewire (180–260 mm), 0.035-in. metal stiff guidewire (180–260 mm), 9 F long sheath, esophageal covered stent or tracheal integrated covered expandable metal Y-shaped stent (Nanjing Micro-Tech), stent removal hook, suction tube, 14 F long sheath, tracheal intubation equipment, etc.

Stent Selection

For an esophagus–left main bronchial fistula without tracheal stenosis, esophageal stent implantation is beneficial for eating. If combined with tracheal bronchus stenosis, the Y-shaped stent should be used to block the fistula.

The diameter of the esophageal stent is 18–22 mm. According to the location of fistula, the length of the stent is 2–3 cm longer than that of the orificium fistulae. It is important to select a tracheal stent according to the corresponding tracheobronchial diameter. Measurements are made from the mediastinal window (fat window) in the chest MSCT image. Either select the appropriate size or customize the stent.

Large Y-Shaped Integrated Stent

Measure the anteroposterior and transverse diameter of the trachea, anteroposterior diameter and length of the left and right main bronchus, and the angle between the left main bronchus and right main bronchus. Customize the large inverted integrated fully covered self-expandable Y-shaped metal stent. Stent parameters are as follows: the diameter of the stent is 15–20% greater than diameter of the trachea, the length is 40–50 mm; the diameter of the left branch is greater than 10–15% of the left main bronchus, the length across is 15–20 mm; the right branch diameter is longer than 10–15% of the right main bronchus, the length is 10–15 mm, and the angle of the two branches is equivalent to the angle between the double main bronchus.

Small Y-Shaped Integrated Stent

Measure the anteroposterior and transverse diameter of the principal bronchus, anteroposterior diameter and length of the left upper and right lower bronchus, and the angle between the left main bronchus and right main bronchus. Customize the small inverted integrated fully covered self-expandable Y-shaped metal stent. Stent parameters are as follows: the diameter of the stent is greater than 15–20% of the trachea, the length equals that of the inferior wall of the left main bronchus; the diameter of the left upper branch is greater than 10–15% of the left upper main bronchus, the length across is 10 mm; the left lower branch diameter is longer than 10–15% of the left lower bronchus, the length is 10 mm; the angle of the two branches is equivalent to the angle between the upper and lower bronchus.

9.4.4.2 Preparation of Stent Implantation

(See Sect. 9.4.2.2)

9.4.4.3 Esophageal Covered Stent Implantation Process

In the supine position and with the head to the right, the patient is given oxygen, an ECG, sputum aspirator, lidocaine gel oropharyngeal anesthesia, and a small amount of iodine contrast agent for angiography preoperatively to determine the scope and location of the fistula. Insert the mouth gag, insert a 0.035-in. hydrophilic film guidewire and 5 F catheter, and together insert them into the stomach through the mouth, pharynx, larynx, and esophagus. Remove the guidewire and inject contrast agent through the catheter. When the gastric mucosa is revealed, replace with 0.035-in. intensive guidewire, withdraw the catheter, insert the stent to the fistula along the intensive guidewire, with the center of the stent aimed at the center of the fistula; the ends of the stent should be 2–3 cm beyond the

lesions. Release the esophageal covered stent fluoroscopically. After the stent has expanded satisfactorily, withdraw the stent conveyor and the guidewire, give oral contrast again to confirm the position and expansion of the esophageal stent, and situation of the fistula. After surgery, administer measures to prevent infection, relieve pain, control stomach acid, and protect the gastrointestinal mucosa. Provide warm liquid to drink 4 h after the operation, and administer normal food after 3 days, while avoiding hard, thick, and fibrous food. Conduct esophageal radiography to further observe the position and the closure of the fistula stent a week later.

9.4.4.4 Large Integrated Covered Self-Expandable Metal Y-Shaped Stent Implantation

9.4.4.5 This procedure is the same as esophageal-carina fistula (see Sect. 9.4.2.3).

9.4.4.6 Small Y-Shaped Stent Implantation with Interventional Radiology

Patient Position

Keep the patient supine on the DSA examination table, keep the head close to the end of the DSA examination bed, keep the oropharynx, neck, and chest in the effective monitoring range. The head turns to the right front at an angle of about 30°. Cover the surface with a large surgical drape; administer continuous oxygen through the nose, and provide ECG monitoring. With the C arm of DSA angled obliquely at 20°, and the patient's head angled to the right at 20°, the negative shadow is more clearly shown. Administer the airway throat spray anesthesia, or local transcatheter anesthesia when the catheter goes through the throat chamber. Prepare a vacuum extractor to clear the airway and oral secretions as needed.

Transcatheter Angiography

Insert a mouth gag. Synchronize a hydrophilic guidewire and catheter using fluoroscopy, and move them to the knuckle through the oral cavity, pharynx, larynx, and trachea. Remove the guidewire and keep the catheter inside, infuse 2–3 mL 1% lidocaine through the catheter for tracheal mucosa anesthesia in the region of the knuckle. Adjust the catheter into the right main bronchus, rapidly infuse 3 mL 30% iodine contrast agent for airway angiography to further observe the site and size of the fistula in the left main bronchus, and the degree of connectivity between the knuckle, fistula, and upper lobe bronchus.

Introduction of Reinforced Wire

Synchronize the guidewire and catheter into the left lower lobe bronchus over the left main bronchial fistula orifice, insert the metal stiff guidewire after angiography, remove the guidewire and fix the catheter firmly; implant 9 F sheathing canal in the opening of the left principal bronchus, remove the sheath core; the catheter then works with the hydrophilic membrane guidewire going into the left main bronchus and deep segment of the left upper lobar trachea through the sheathing canal; switch to a hydrophilic membrane stiff guidewire, keep the guidewire and remove the catheter and sheath, marking two reinforced guidewires at the upper and lower lobe.

Introduction of Small Y-Shaped Stent Conveyor

Firmly fix two reinforced guidewires, maintain the unchanged position of guidewires in the bronchus. Draw in both branches carrying the Y-shaped stent conveyor respectively through up and down stiff wires. Fix the guidewires, and send the Y-shaped stent delivery system to the front of the conveyor and through the mouth along the double stiff wires.

Fix the stiff guidewires, push the conveyor forward into the mouth pharynx through the mouth, maintain the position of the patient's head, then push the conveyor forward into the laryngopharynx and cavum laryngis. Rotate and push the conveyor forward after reaching the vocal cords. The double inner core at the front of the conveyor should fit the anteroposterior diameter of the glottis. Encourage the patient to inhale deeply or cough, and then push the conveyor forward into the trachea. Rotate to adjust the stent's

orientation, with the branches of the stent on the same side as the stiff guidewires. The two guidewires should be completely separate and not twisted. Ensure that the golden marker on the inverted Y-shaped stent is also located on the left and right (or up and down) edges, then push the conveyor forward sending the stent's two branches into the left main bronchus.

Release of the Small Y-Shaped Stent

Fix the stiff guidewire and rear handle of conveyor firmly, pull back the front handle of the conveyor and sheath to fully release the two branches of the inverted Y-shaped stent into the left main bronchus.

Keep the relative position of the front and the back handles constant, fix the stiff guidewire, and push the two branches of the stent forward into the left upper and lower lobe bronchus along the double guidewires. When met with resistance during the pushing, this means that the stent's bifurcation has reached the upper and lower lobe bronchial bifurcations.

Fix the conveyor and the stiff guidewire in position and maintain the appropriate thrust, pull the bundling thread at both sides of the two branches one after another and fully release the bilateral branches. Conduct and X-ray to confirm dual branch position; then fix the back handle of conveyor, pull back the outer sheath to release stent's main part in the left main bronchus. Release the small inverted Y-shaped stent, and then remove the conveyor slowly. Be aware that the stent may shift when hooked by the conveyor. Retain the metal stiff guidewire in the inferior lobar bronchus to retain the subsequent interventional operation pathway.

Transcatheter Radiography for Reviewing

Introduce the catheter into the left principal bronchus, inject 3–5 mL of 30% iodine contrast agent by catheter, conduct left bronchography, check whether the stent has implanted in the predicted position, whether the closure of the fistula is complete, whether the branches of the stent have expanded, whether the main part of stent is too long, whether knuckle and the fistula opening are covered, and whether stent expansion is complete (Fig. 9.6).

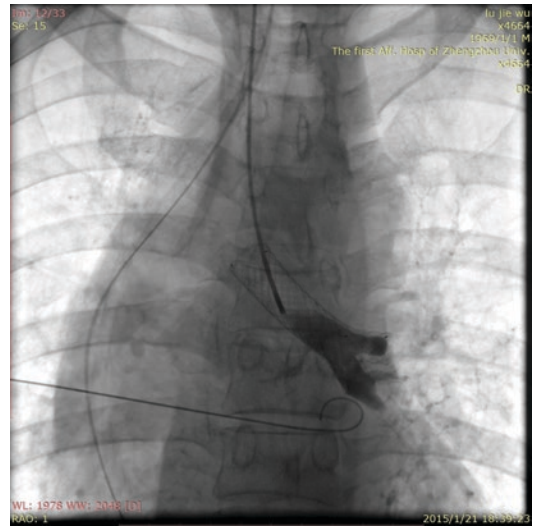

Fig. 9.6 Transcatheter radiography after stenting

Administer orally 20–40 mL of 30% iodine contrast medium for esophageal radiography in order to observe if any contrast agent passes through the right main bronchial fistula into the tracheal bronchus and to confirm that the stent is closed and if the fistula is completely blocked.

Full Sputum Suction

Introduce a sputum suction tube to the left and the right main bronchus, especially the left side of the deep lobe bronchus, by the guidewire and conduct repeated sputum suction. Encourage sputum discharge and sputum suction by administering antibiotics, performing a physiological saline suction, patting the chest and back, switching between the lateral and erect positions, etc.

9.4.4.7 Postoperative Treatment

See Sect. 9.4.1.4

9.4.4.8 Prevention of Complications and Treatment

See Sect. 9.5.1.5

9.4.5 Esophageal–Lobar Bronchial Fistula

According to the fistula types based on different locations, the esophageal–lobar bronchial fistula belongs to type V of the esophageal–tracheal bronchial fistula types. The esophageal fistula interlinks with any one of the main lobe bronchi and communicates with the left and right upper, middle, or lower lobe bronchus.

The esophagus is not a simple, straight pipe, with the most of the esophagus close to the spine. There are three bends in the esophagus. In the lower part of the neck and upper chest, the esophagus is slightly to the left, about 4–6 mm from edge of trachea. Then to the right, the fifth thoracic transits to the midline equivalently, the seventh thoracic esophagus bends to the left anterior again, bypassing the descending aorta, through the diaphragmatic muscle gap to the cardia. In addition to this, the esophagus bends forwards and backwards with a thoracic, cervical curvature. The lobe bronchus lies in the lungs and there is an amount of space between the esophagus and lobe bronchus. It is rare that esophageal perforation directly communicates with lobe bronchus.

Esophageal–lobar bronchial fistula is a rare type of esophageal airway fistula. Esophageal lobe bronchus fistula is always caused by tumor invasion, radiation damage, local chronic inflammation, infection, trauma, etc. For example, middle esophagus carcinoma or left lung with local inflammation or tumor necrosis due to radiotherapy, which is a difficult fistula to treat. The esophagus is adjacent to the lobe bronchus and various causes of lung consolidation, infiltration, and pressure occur after surgery for esophagus cancer, radiation therapy of lung consolidation, etc., and these can give rise to esophageal perforation, corrosion, and communication between the lobe bronchus, thus forming an esophageal–lobe bronchus fistula.

9.4.5.1 Instruments

These include interventional devices and stent selection.

9.4.5.2 Interventional Devices

These consist of the opening device, 5 F vertebral artery catheter (80–100 cm), 0.035-in. (150–180 cm) hydrophilic membrane guidewire, 0.035-in. hydrophilic membrane stiff guidewire (180–260 mm), 0.035-in. metal stiff guidewire (180–260 mm), esophageal covered stent (Nanjing Micro-Tech), stent removal hook, etc.

9.4.5.3 Stent Selection

The diameter of the esophageal stent is 18–22 mm, so the stent should be 2–3 cm longer than that of the fistula.

9.4.5.4 Preparation Before Stent Implantation

(See Sect. 9.4.2.2)

9.4.5.5 Stent Implantation Interventional Radiology

Patients remain in the supine position. Administer oxygen, provide ECG monitoring, prepare sputum suction device, give lidocaine gel for oropharyngeal anesthesia, administer a small amount of iodine contrast agent for angiography preoperatively to determine the scope and location of the fistula. Insert the mouth gag, draw in a 0.035-in. hydrophilic film guidewire and 5 F catheter, and insert them into the stomach through the mouth, pharynx, larynx, and esophagus. Remove the guidewire, inject contrast agent through the catheter, and when the gastric mucosa is revealed, replace it with a 0.035-in. intensive guidewire; withdraw the catheter, insert stent to the fistula along the intensive guidewire, with the center of the stent aimed at the center of the fistula, and the ends of the stent should be 2–3 cm beyond the lesions. Release the esophageal covered stent fluoroscopically, and after the stent has expanded satisfactorily, withdraw stent conveyor and the guidewire. Administer oral contrast again to con-

firm the position expansion of the esophageal stent, and the situation of the fistula. After surgery, administer measures to prevent infection, relieve pain, minimize stomach acid production, and protect the gastrointestinal mucosa. Provide warm liquid to drink 4 h after the operation. Administer normal food after 3 days and avoid hard, thick, and fibrous food. Conduct esophageal radiography to further observe the position and the closure of the fistula stent a week later.

9.4.5.6 Treatment after Stent Implantation

Administer Convergence Solution Orally

After stent implantation, administer an oral convergence solution daily (saline, 500 mL + lidocaine, 5 mL + adrenaline, 2 mg + gentamicin, 2 branches) for 4–6 days to alleviate stent stimulation, and eliminate local inflammation and edema.

Enhance Nutrition

If adherence between the esophagus and stent is insufficient, continue to improve the internal nutrition through the jejunum nutrition tube and gradually increase food intake. If there is no eating cough and discomfort, the jejunum nutrition tube should be removed and simple oral intake continued. It is recommended that patients do not eat sticky food such as sticky cakes, sweet potato, rice dumplings, etc.

9.4.5.7 Complications and Management

Pain

Pain is related to swelling and irritation of the stent. Mild pain and common pain usually do not need special treatment. For serious pain painkillers should be prescribed. Serious pain is more common in patients with higher esophageal stent placement.

Stent Displacement

Stent migration is due to the small diameter and tension of the stent, improper placement of the stent, eating cold food postoperatively, retraction of the stent, severe vomiting, etc. Once the stent migration is confirmed, adjust the stent position or replace it with a new stent after removal of the old stent.

Granulation Tissue Hyperplasia at Both Ends of the Stent

Granulation tissue hyperplasia is the most common complication after esophageal and tracheal stent insertion. Granulation tissue without clinical symptoms generally does not need treatment. When the trachea or esophagus is obstructed by granulation tissue hyperplasia, use an electric knife, argon knife, or laser to burn and cut the granulation tissue, and apply freezing treatment to the root to inhibit the proliferation of granulation tissue, or place a new stent through the esophagus.

Hematemesis or Hemoptysis

Most patients with low levels of hematemesis can take epinephrine and thrombin orally. Hematemesis is caused by bleeding and unskilled operation techniques, muscle injury or high stent tension, especially cancer tissue erosion after radiotherapy, mucosa ulcer erosion, increased mechanical pressure in the esophagus, and aggravating local ischemic necrosis. Pay close attention to patients with gradually increased bleeding, monitor blood pressure, pulse, and observe acral temperature and hematemesis, etc. Pay attention to the amount of bleeding and the blood color changes, administer antacids, hemostatic and gastric mucosal protective agents according to the patient's condition.

Blood-stained sputum is common after inserting a stent. A small amount of blood in the sputum should automatically stop in 10 min without treatment. If hemoptysis is persistent, for example, a large amount of blood and expectoration with blood clumps with little sputum, inject 2–3 mL of 1:1000 adrenaline saline through the endotracheal tube to prompt the vasoconstriction of the tracheal mucosa and immediately stop hemoptysis, which can achieve effective hemostasis even in the presence of arteriorrhexis.

Compression and Stenosis of Trachea

This condition is caused by the expansion of the esophageal stent compressing the trachea. Those patients with mild compression without obvious symptoms of respiratory difficulties are given temporary observation. If the pressure is so high that difficulty with breathing occurs, insert a tracheal stent to lift the stenosis.

Sore Throat, Hoarseness

Administer anti-inflammatory and analgesic treatment.

Incomplete Sealing of the Fistula

A small residual fistula can be observed for a few days postoperatively with local foreign body stimulation from the stent, an inflammatory reaction, and intimal hyperplasia. With tracheal mucosal edema and further external expansion of the stent, the residual fistula will gradually disappear. Conduct postoperative digestive tract radiography to review the situation: first, determine whether the stent location spans across the fistula and whether the covered parts at the ends of stent are longer than the normal tracheal segment (more than 15–20 mm); second, confirm if the stent diameter is large enough (15–20% longer than normal tracheal diameter), and whether the expansion capacity of the stent is maintaining good adherence. If the covered stent at the fistula straddling the normal trachea is not long enough, adjust the position. For stent malposition, replace it with a stent with a larger diameter.

Stent Obstruction

Esophageal stent clogging is often due to viscous food stuck in the bracket. Treat with gastroscope aspiration. The tracheal stent completely covers the tracheal epithelium and cilia and the mucus blanket function is completely lost. Sputum excretion completely depends on the impact of coughing. If the cough is weak, sputum will adhere to the cover of the stent and gradually many sputum blots will form. Severe obstruction of the trachea leads to tracheal stenosis and dyspnea. Bronchoscopy should be performed as soon as possible to remove sputum blot and sputum scab, and clear the tracheal lumen. Thereafter, initiate drug inhalation, eliminate phlegm and sputum, and avoid sputum retention.

Enlargement of Fistula or Recurrence of Fistula

As tumor necrosis develops, or local inflammation is out of control, the fistula continues to expand, especially the esophageal-tracheal (bronchial) fistula after radiotherapy, where tissue surrounding the stoma and fistula receives large doses of radiation, loses tissue growth and regeneration ability, and the fistula almost never regenerates but gradually expands. When designing or selecting stent specifications for occlusion of the fistula, choose as long a stent as possible (two ends spanning at least 2 cm across the normal wall). Once the fistula stent loses efficacy in blocking, it needs to be replaced with a longer stent.

9.4.6 Esophagus–Pleural Cavity–Fine Bronchial Fistula

According to the fistula types based on different locations of fistula, the esophagus-pleural cavity–fine bronchial fistula belongs to type VI of the esophageal–tracheal bronchial fistula types.

The esophageal thoracic–bronchial fistula is a rare type of esophageal fistula. The esophageal airway does not connect with the fistula orifices directly, so the fistulas should be treated separately. The esophageal fistula can be directly blocked by esophageal covered stents. But pleural cavity–fine bronchial fistula closure cannot be directly blocked. If the fistula is small, conduct pleural cavity negative pressure for drainage to force the pleural cavity to shrink and close, thereby the visceral pleura and parietal pleura are forced to fuse and close. If the bronchiolar fistula is large, treatment needs to include the whole airway bullet full covered stent, and this will block the fistula by segmental bronchus. Extend the block from the bronchiole to the center of the airway, until a segmental bronchus of 3–5 mm diameter is obtained. This kind of section bron-

chial block is inevitably accompanied by substantial change and functional disappearance of these pulmonary segments.

9.4.6.1 Instrument Preparation

This includes interventional operation devices and esophageal stent selection.

9.4.6.2 Interventional Operating Instruments

These include a mouth-gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic membrane guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), esophageal covered stent (Nanjing Micro-Tech), pig-tail chest drainage tube, etc.

9.4.6.3 Stent Selection

According to the location of the fistula, the diameter of the esophageal stent should be 18–22 mm, and the length should be 2–3 cm more than the fistula orifice.

9.4.6.4 Preparation of Stent Implantation

(See Sect. 9.4.2.2)

9.4.6.5 Tubular Stent Interventional Radiology

Esophageal Tubular Covered Stent Implantation Process

Patients are kept in the supine position and lidocaine gel is given for oropharyngeal anesthesia. Administer a small amount of iodine contrast agent for angiography preoperatively to determine the scope and location of the fistula. Insert the mouth gag, draw in 0.035-in. hydrophilic film guidewire and 5 F catheter, insert them into the stomach through the mouth, pharynx, larynx, and esophagus. Remove the guidewire, inject contrast agent through the catheter, and when the gastric mucosa is revealed, replace with the 0.035-in. intensive guidewire, withdraw the catheter, and put in the stent to the fistula along the intensive guidewire, with the center of the stent aimed at the center of the fistula, and the ends of the stent should be about 2 cm beyond the lesions. Release the esophageal covered stent fluoroscopically and after the stent has expanded satisfactorily, withdraw the stent conveyor and the guidewire. Administer oral contrast again to confirm the position and expansion of the esophageal stent, and situation of the fistula. After surgery, take measures to prevent infection, pain, excessive production of stomach acid, and to protect the gastrointestinal mucosa. Provide warm liquid to drink 4 h after the operation. Administer normal food after 3 days, but avoid hard, thick, and fibrous food. Conduct esophageal radiography to further observe the position and the closure of the fistula stent a week later.

Process of Intrathoracic Drain Implantation

The patient lies on their back and is administed oxygen, disinfection shop towels, dyna chest CT scan, and the skin puncture point is determined and targeted by inaspace post-processing technology. Design the puncture path and length, administer 2% lidocaine local anesthesia, bring in a 0.035-in. hydrophilic film godet with an 18-g needle puncture, and according to the designed path, remove the puncture needle, bring in 8.5–12 F chest drainage tube by the guidewire, and, finally, remove the guidewire, fasten distal drainage tube into a loop, immobilize the skin, conduct radiography, confirm the tube position is correct, and connect the external drainage pack or negative pressure drainage utensil.

9.4.6.6 Treatment After Stent Implantation

Administer Convergence Solution Orally

After stent implantation, administer oral convergence solution daily (saline 500 mL + lidocaine 5 mL + adrenaline 2 mg + gentamicin 2 branches) for 4–6 days in order to alleviate stent stimulation and eliminate local inflammation and edema.

Enhance Nutrition

If the adherence between the esophagus and stent is not tight, continue to supply the internal nutrition through the jejunum nutrition tube, gradually increasing the amount of food intake. When there is no eating cough or discomfort, the jeju-

num nutrition tube can be removed and a simple oral diet can be continued. Sticky food such as sticky cakes, sweet potato, rice dumplings, etc. are not recommended.

Anti-Infection Treatment

Sensitive anti-infection drugs should be chosen to control lung infection on the basis of sputum bacterial culture results. If necessary, conduct fiber bronchoscope bronchial lavage on a regular basis, remove endobronchial mucus and pus, and apply sensitive antibiotics in high concentrations at the local bronchus.

Suction and Occlusion of Vomica

If there is a large amount of pus in the vomica, conduct a rinse treatment. After the pus cavity is clear, conduct continuous negative pressure suction to narrow and close the cavity.

9.4.6.7 Management of Complications

Pain

Pain is related to swelling and irritation of the stent. Mild pain and common pain usually do not require special treatment. Serious pain can be treated with painkillers. Serious pain is obvious in patients with higher esophageal stent placement.

Stent Displacement

Stent migration is due to the small diameter and tension of the stent, improper placement of the stent, cold food was given postoperatively, the stent was retracted, severe vomiting, etc. Once stent migration is confirmed, adjust the stent position or insert a new stent after removal of the old stent.

Granulation Tissue Hyperplasia at Both Ends of the Stent

Granulation tissue hyperplasia is the most common complication after insertion of esophageal and tracheal stents. Granulation tissue without clinical symptoms generally does not need treatment. When the trachea or esophagus is obstructed by granulation tissue hyperplasia, use an electric knife, argon knife, or laser to burn and cut the granulation tissue, and apply freezing treatment to the root to inhibit the proliferation of granulation tissue, or place a new stent through the esophagus.

Gastrointestinal Bleeding

Most patients with low levels of hematemesis can be administered epinephrine and thrombin orally. Hemorrhage is related to esophageal or chest infections and anti-infection treatment can be administered. It is can also be due to bleeding and unskilled operating skills, muscle injury or high stent tension, especially cancer tissue erosion after radiotherapy, mucosa ulcer erosion, increased mechanical pressure in the esophagus, and aggravation of local ischemic necrosis. Pay close attention to patients with gradually increasing bleeding. Monitor blood pressure and pulse, observe acral temperature and hematemesis, etc., and pay attention to the amount of bleeding and the blood color changes. Administer antacids, and hemostatic and gastric mucosal protective agents as needed.

Compression and Stenosis of Trachea

This condition is caused by the expansion of the esophageal stent compressing the trachea. For those with mild compression showing no obvious symptoms of respiratory difficulties, provide temporary observation. If the pressure is heavy and causes difficulty in breathing, insert a tracheal stent to lift the stenosis.

Sore Throat, Hoarseness

Administer anti-inflammatory and analgesic treatment.

Incomplete Sealing of the Fistula

A small residual fistula can be observed for a few days postoperatively. With the local foreign body stimulation from the stent, inflammatory reaction and intimal hyperplasia, tracheal mucosal edema and further external expansion of stent, the residual fistula will gradually disappear. Conduct postoperative digestive tract radiography to review the situation: first, determine whether the stent location spans across the fistula, i.e., whether the covered parts at the ends of the stent are long enough (more than 15–20 mm); second,

confirm if the stent diameter is large enough (15–20% longer than normal tracheal diameter), and whether the expansion capacity of stent is maintaining good adherence. If the covered stent at the fistula straddling the normal trachea is not long enough, adjust the position; however, for stent malposition, replace with a stent with a larger diameter.

Stent Obstruction

Esophageal stent clogging is often due to viscous food that blocks the bracket. Treat with gastroscope aspiration. Tracheal stent blockage means that the stent completely covers the tracheal epithelium and cilia, and the mucus blanket function is completely lost, so sputum excretion completely depends on the impact of coughing. If the cough is weak, sputum will adhere to the cover of the stent and gradually many sputum blots will form. Severe obstruction of the trachea leads to tracheal stenosis and dyspnea. Sputum blot and sputum scab should be removed under bronchoscopy as soon as possible and the tracheal lumen cleared. Thereafter, provide drug inhalation, eliminating phlegm and sputum, and avoid sputum retention.

Fistula Enlargement or Recurrence of Fistula

As tumor necrosis develops or local inflammation increases out of control, the fistula continues to expand, especially the esophageal-tracheal (bronchial) fistula occurring after radiotherapy. In this case, tissue surrounding the stoma and fistula receive large doses of radiation, and lose tissue growth and regeneration ability. The fistula almost never regenerates, instead it gradually expands. When designing or selecting stent specifications for occlusion of the fistula, choose a stent as long as possible (two ends spanning at least 2 cm across the normal wall). Once the stent loses efficacy in blocking the fistula, it should be replaced with a longer stent.

According to the fistula types (based on location), complicated esophageal-tracheal (bronchial) fistula is a general reference not attributable to the above six typical fistula types, which include three subtypes.

VII -a: multiple fistula with two or more fistulas in the esophagus connecting with the trachea;
VII -b: a multiple fistula with two or more fistulas in the esophagus connecting with the bronchus;
VII -c: a multiple fistula with two or more fistulas in the esophagus connecting with the trachea and bronchus.

The treatment principles for these types of esophageal-tracheal (bronchial) fistulas are the same as those of the above six types.

9.5 Outlook

With the wide application of comprehensive treatments, such as interventional minimally invasive techniques, the awareness of esophageal airway fistulas is increasing, the incidence of successful diagnosis is improving, and therefore the number of clinical cases is increasing. However, there are still many problems to be resolved, like how to further improve interventional treatment of esophageal-tracheal (bronchial) fistulas, and how to effectively avoid the complications caused by contemporary tracheal and esophageal stent implantations. There are many unsolved problems in the long-term efficacy and safety of stent use, but esophageal airway stents have become an effective treatment with a promising future.

The research direction in the future is to develop a new stent with suitable hardness and flexibility for a better curative effect. Esophageal drug coating stents, radioactive stents, and biodegradable stents are currently being developed, in the hope of clinical application in the near future. Clinicians should continue to document the treatments, improve the treatment technology, and

standardize the treatment delivery, thus making stent treatment more safe and effective, so that more esophagobronchial fistula patients can benefit from it.

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Tracheal/Bronchial Rupture

10

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10.1 Overview of Tracheal (Bronchial) Rupture

Tracheal and/or bronchial rupture occurs in severe chest injuries or crush injuries. With more and more traffic accidents in recent years, closed tracheal and bronchial ruptures have become more common and one of the reasons for early death after chest trauma. Tracheal and main bronchial rupture occurs mainly in closed and opened trauma of the neck and chest. Of the 200 cases of closed tracheal and main bronchial rupture found in the reported literature, the mortality rate was 30%, and more than half of those deaths were within 1 h after injury. With the increase in vehicle trauma, this type of damage has become more common. Tracheal rupture itself is not the direct cause of death, but the tracheal rupture is generally accompanied by peripheral vascular and tissue damage, which easily leads to suffocation by clotting or foreign matter inhalation in the ruptured trachea. Mediastinum emphysema is secondary to rupture, and the increasing emphysema pressure can compress the airway, leading to tracheal stenosis. If these patients are not treated in time, they will die from hypoxia.

Penetrating trauma (sharp or blunt) can cause tracheal injuries. Penetrating tracheal wounds are generally in the neck. The trachea is in the central chest and is vulnerable to shooting or other types of penetrating injury. A strong external strike can be sufficient to cause tracheal injury in the neck, and the first rupture point is at the joint between the tracheal cartilage and membranous part. The typical tear is annular and incomplete, and a rare tear is perpendicular to the cartilage ring along the tracheal membrane. Trachea detachment is very rare; however, trachea detachment caused by kite wire or various wire body cutting neck has also been reported in recent years.

10.2 Etiology of Tracheal (Bronchial) Rupture

10.2.1 Traumatic Tracheal Bronchial Injury [1]

This injury can be caused by a car accident, injury from a fall from height, injury from a sharp object, neck injury, chest rupture, etc.

10.2.2 Iatrogenic Injury

This is an airway injury or radiotherapy damage caused by tracheal intubation, tracheostomy, or balloon dilation [2–5].

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10.2.3 Tracheal Foreign Body Damage

Tracheal bronchial rupture is mostly due to severe choking or a sharp foreign body piercing the bronchial membrane. The local rupture is generally not large.

10.2.4 Tumor Invasion

Tracheal bronchial rupture is common after invasion of the tracheal membrane or carina in esophageal cancer. The tumor directly infiltrates to destroy the tracheal (bronchial) wall and cause ischemic necrosis perforation. Alternatively, chemotherapy, arterial infusion chemotherapy, or radiotherapy can cause rapid breakdown of the growing tumor, and the normal surrounding tissue repairs slowly. Tracheal (bronchial) perforation develops into tracheal bronchial rupture.

10.2.5 Spontaneous Bronchial Rupture [6, 7]

Spontaneous tracheal rupture is rare and most patients are caused by breath-holding, only reported in a small number of cases.

10.2.6 Radioactive Injury

Patients with the gastric wall in the esophageal radiation field for mediastinal tumor can suffer radiation damage. The tracheal (bronchial) wall can be damaged, or the trachea (bronchial) wall suffers radiation damage during radiotherapy after esophageal cancer surgery, which is the main cause of tracheal (bronchial) rupture.

10.3 Tracheal (Bronchial) Rupture Pathology

Tracheal and/or bronchial injury is mostly caused by blunt or penetrating injuries, with iatrogenic injuries occasionally being reported. The tracheal neck, mediastinal structure, and bronchi lie completely within the mediastinum. The posterior cervical trachea is protected by the vertebral body, with the front in a superficial position. A neck-penetrating injury or blunt injury can lead to tracheal rupture. The thoracic trachea, carina, and bronchus lie between the sternum and thoracic spine, where the two sides are protected by the lungs and the chance of injury is minimal. It has been reported that about 80% of intracavitary tracheobronchus (trachea, carina, and main bronchus) injuries occurred in a range of 2.5 cm from the crest. This can be explained by the following theories: (1) traction theory: the thorax was subjected to a strong external pressure, the thoracic diameter was significantly increased, the two lungs were moved to the sides forming an outward pulling force at the tracheal carina, and when the pulling force exceeded a certain limit, there was a bronchial rupture near the tracheal carina; (2) shear theory: the body and the lungs suddenly slowed down, a greater shear force arose at the tracheal fixation point, tracheal knuckle, and so the bronchus snapped with the internal pressure; (3) pressure theory: the glottis closed at the moment of injury, bronchial pressure surged, the pressure was transmitted to the distal small airway, and then the bronchus was broken by a reverse force produced at the tracheal bifurcation.

10.4 Tracheal (Bronchial) Rupture Diagnostics

The following points describe the diagnostic basis of early injury: (1) a short period of time after chest trauma, extreme dyspnea, cyanosis, and severe mediastinal and subcutaneous emphysema occurred; (2) a large amount of gas escaped over a short time via closed thoracic drainage, the lungs cannot recover quickly, dyspnea remains unimproved; (3) breath sounds in the injured lung sound low or disappear; (3) “Hang lung sign” can be observed on chest X-ray. Line fiberoptic bronchoscopy is essential for early diagnosis and positioning, as are blood and secretions from the bronchial cavity.

Advanced diagnosis of bronchial rupture: for patients with a history of acute airway injury, bronchial rupture of an advanced stage is

presented with chest tightness, breath shortness, lung infection, and long-term injured lung atelectasis. Chest X-ray and CT examination show lung consolidation and atelectasis, for example, pleural effusion can be seen in a secondary infection. Fiberoptic bronchoscopy shows the bronchial stenosis at the injured side, closing the formed caecum.

10.4.1 Clinical Manifestations

The manifestations of tracheal rupture after chest trauma include dyspnea, subcutaneous or mediastinal emphysema, pneumothorax or tension pneumothorax, blood pneumothorax, and cyanosis. Dyspnea is a prominent symptom of traumatic tracheal or bronchial rupture. Patients may have hemoptysis of a slight to moderate degree. Pneumothorax generally appears immediately after the tracheal and main bronchus rupture. According to the rupture site, pneumothorax can be unilateral or bilateral, and rapidly develops into tension pneumothorax. For some patients with tracheal laceration but complete mediastinal pleura, only mediastinal and subcutaneous emphysema appears with the pneumothorax. Mediastinal and subcutaneous emphysema are the common symptoms of tracheal rupture, and these conditions appear above the sternal marks on the anterior neck. They then develop rapidly, spreading to the entire neck, chest, shoulder and abdomen, even up to the lower limbs when it is severe. A small number of casualties occur, for example, a resulting coma due to severe hypoxia.

The tracheal injury is often combined with bleeding of varying°. When the patient comes into the emergency room, most of the tracheal hemorrhage has stopped or has not been emptied; the patient shows hemoptysis symptoms only when the hemorrhage is massive. The above clinical symptoms depend on the location and size of the tear, whether tracheal peripheral vessels have torn, and whether the mediastinal pleura are complete or not.

Some patients fail to be diagnosed in the early stages, because the trachea or bronchial rupture is obstructed by blood clots or soft tissue. After the acute phase, the rupture site forms scar tissue and stenosis, or is even completely obstructed by atelectasis. It can be diagnosed within several months or years. Patients often have chest tightness, shortness of breath, suffocation, and cyanosis or other performance-reducing respiratory symptoms. In addition to the respiratory area being reduced due to pulmonary atelectasis, the lung has a right to left shunt, and the right to left shunt is only functioning at 20–30% when encountering unilateral atelectasis. Symptoms of infection appear in the presence of a concurrent infection. When the trachea is shifted to the affected side, on examination percussion can be heard and breathing sounds disappear.

10.4.2 Imaging Examination

10.4.2.1 Chest X-Ray Examination

The major X-ray changes in early trachea rupture or fracture are massive pneumothorax; subcutaneous, mediastinal, and deep neck emphysema; upside thoracic rib fractures; tracheal truncation or discontinuity; tracheal translocation; atelectasis; lung falling signs; etc.

10.4.2.2 Chest MSCT Examination

Chest CT examination is helpful to determine the location and extent of injury, especially spiral CT or ultra-high-speed CT, which can conduct tracheal, main bronchial stent stereo imaging, and describe the shape, location, and length of the rupture (Fig. 10.1, Informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study). This type of scan shows in detail the direct signs of tracheal fracture, deformation and discontinuity of the tracheal translucent band, and even reveals dislocation signs.

Thoracic MSCT with continuous thin-layer scanning, multi-window width post-processing images, and lung window (window width 1,000 HU, window level –700 HU) can show lung damage such as pneumonia and can also show ruptures with a larger diameter. The mediastinum window (window width 400–

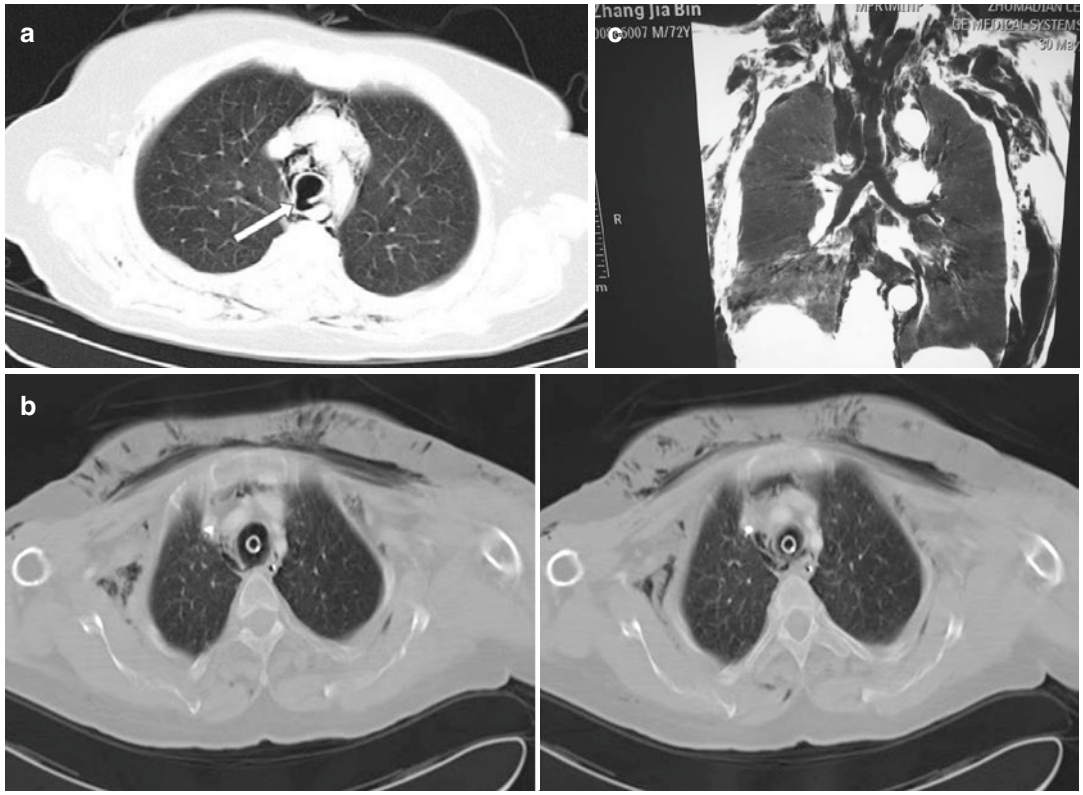

Fig. 10.1 CT examination of the tracheal rupture

500 HU, window level 50 HU) or fat window (window width 500 HU, window level −50 to −100 HU) can show the tracheal-bronchial structure and size and location of the rupture. This allows for measurement of the size of the rupture.

10.4.3 Fiberoptic Bronchoscopy

With suspected diagnosis, fiber bronchoscopy is helpful for both diagnosis and treatment. Bronchoscopy can detect the tracheal rupture and the site and degree of stenosis. It has a certain diagnostic value for early or late cases and the existence of tracheal rupture can be ruled out by negative results. Severe hemoptysis after thoracic injury is a symptom of tracheal rupture, and even if there are no other indications of tracheal disconnection, bronchial microscopy should immediately be considered.

10.4.4 Classification of Rupture

The classification of tracheal (bronchial) ruptures guides the clinical treatment, especially interventional radiology with stent blocking. There are eight rupture types according to the specific anatomical site of tracheobronchial rupture.

1. Tracheal rupture: Rupture of the thoracic cavity directly connects to the trachea. It is secondary to upper thoracic esophageal cancer surgery. Thoracic-stomach front wall directly connecting with the membranous part of the tracheal anterior wall is more common. The upper end of the rupture is 20 mm above the glottis, the lower is more than 20 mm from the Juga crest.
2. The knuckle rupture: The thoracic-stomach rupture directly connects with the carina, which is secondary to middle thoracic esophageal cancer surgery. The thoracic-stomach

posterior wall connecting to the carinal posterior and lower-lateral wall is more common, about 2 cm from the Juga crest in airway.
3. The main bronchial rupture: Thoracic-stomach rupture directly interlinks to the right main bronchus, secondary to middle thoracic esophageal cancer surgery. The gastric front wall connecting to the right main bronchial posterior or inferior wall is more common. Because the right main bronchus is limited in length, the stent graft is more complex. The right main bronchial rupture is type III-a, and the left main bronchus rupture is type III-b.
4. Other types of bronchial rupture: These differ from the above three typical lesions.

10.4.5 Clinical Treatment

Tracheal, main bronchial rupture and injury should be diagnosed and treated as early as possible. The current treatment strategy of tracheal rupture mainly involves intervention, surgical treatment, or conservative medical treatment.

Clinical treatment involves surgical treatment. In general, the majority of patients after early treatment are able to recover well.

If the symptoms are not very obvious and the injury range is less than 1 cm under bronchoscopy, conduct conservative treatment and measures including anti-infection, subcutaneous tissue incision, closed drainage, and other combined treatments. Rapid and effective surgical treatment is the most rational treatment for these diseases. Try to avoid the lungs and intrathoracic infection, and protect the lung function. In general, patients recover well after surgery, anti-infective treatment is generally required after surgery, and attention needs to be paid to granulation tissue hyperplasia and tracheal stenosis, which may occur after surgery.

The intervention method used to block the rupture is by placing tracheal stents to restore the airflow. If the rupture is large, the stent allows the patient to garner strength for further surgery. Stents are significantly effective for rupture blocking, because the treatment is simple and presents fewer complications.

10.4.5.1 Conservative Treatment

A tracheal bronchial injury with a range of less than 1 cm is treated with conservative treatment. Conservative measures include anti-infection, subcutaneous tissue incision or puncture exhaust, closed drainage, and other combined treatments.

1. Anti–infection treatment. Once the tracheal bronchial rupture occurs, airway secretions may enter the rupture. At this time, patients should be given anti-infection treatment to control the mediastinal infection [8].
2. Subcutaneous tissue incision or puncture exhaust. Pneumoderm is often due to gas entering the subcutaneous layer along the rupture through the mediastinal space. If the patient suffers severe subcutaneous emphysema symptoms, cut the skin or use a large needle to puncture the emphysema site and remove air.
3. Thoracic close drainage. If the patient suffers extreme difficulty with breathing, they could have severe subcutaneous mediastinal emphysema. It is difficult to identify the side of the pneumothorax, and bilateral thoracic closed drainage should be conducted immediately, do not delay by waiting for the chest X-ray.
4. Tracheal intubation. For patients with suspected tracheal bronchial injury, tracheal intubation is a very effective treatment for the following reasons: (1) it can ensure that the airway is smooth and is conducive to removal of blood and secretions; (2) it facilitates the emergency fiber bronchoscopy; (3) it is conducive to administration of surgical anesthesia.

10.4.5.2 Surgical Treatment

Once bronchial rupture is diagnosed or highly suspected, conduct surgical investigation as soon as possible. Early surgical repair reduces the difficulty of the operation, the possibility of lung resection, and mortality. Inflammation of the broken and surrounding tissue is reduced at the early stage and it is easy to anastomose and recover lung function. Infection and pulmonary fibrosis in the late stage may lead to a lobectomy due to reduced lung function, which can be avoided by

early surgery. If surgery is delayed because of fibrosis at the bronchial rupture, it is more difficult to find and separate the damaged tissue ends and easier to cause bleeding, especially on the left side of the bronchus. Most of the left side of the bronchus hides behind the aortic arch and is in close adhesion to the pulmonary artery. This area should be dissected carefully.

The key to a successful operation is: (1) pruning at both ends of the edge should be neat, and the caliber of both ends should be as consistent as possible; (2) thread or non-absorbable prolene line may cause a stenosis, therefore an absorbable line can reduce tissue reaction; (3) sever the lower lung ligament to reduce the anastomotic tension; (4) leakage at the anastomotic stoma can be repaired by pedicled mediastinal pleura; (5) for patients with delayed diagnosis, locating the wound ends accurately is the key to the success of the operation; the site of the most serious adhesion or scar is often the site of tracheal bronchial rupture. Separate the normal trachea or bronchus from the adhesions. Combined intraoperative fiberoptic bronchoscopy can help to find the wound edges; (6) completely remove granulation tissue and membranous scars to ensure that the anastomosis is at the normal airway mucosa, or postoperative restenosis is prone to recur; (7) squeeze the lung tissue as needed and remove excess airway mucus.

10.5 Internal Stent Interventional Radiotherapy

With intervention for tracheal bronchial rupture, it is important that for patients with smaller or incomplete ruptures the tracheal covered stent is used to block the rupture, prevent further leakage of gas, and promote the healing of rupture and vomica. When rupture and vomica are completely healed, remove the stent. For patients with complete tracheal disconnection, a tracheal stent graft can also be used to prevent the leakage of gas from the rupture to the mediastinum or chest, and improve blood oxygen saturation to create an opportunity for further surgery.

For the knuckle or bronchial rupture, the application of a Y-shaped tracheal stent graft effectively blocks the breach and reduces mediastinal and subcutaneous emphysema. The silicone film coated on the surface of the stent has good biocompatibility; corrosion resistance; can be a good paste on the tracheal wall so that sputum and gas cannot pass through the breach, reduce the surrounding tissue infection, and create further opportunity for surgery [9].

Perform bronchoscopy 2–3 weeks after the surgery. If stenosis has occurred, a tracheal stent should be used to expand it.

10.5.1 Tracheal Rupture

According to the types of rupture based on the rupture location, tracheal rupture is type I.

10.5.1.1 Equipment Preparation

This includes interventional operation equipment and special individualized stent specifications.

1. Interventional operating instrument. Mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic membrane wire (150 cm), 0.035-in. stiff guidewire (180–260 cm), tubular covered stent (Nanjing Micro-tech, Tae Woong Medical, etc), sputum suction tube, etc.
2. Stent selection. Customize individualized tracheal tube covered stents according to the anteroposterior diameter (vertical diameter) and left-right diameter (transverse diameter) measured across the cross-section (special mediastinal window—fat window) of chest MSCT. The diameter of a tracheal stent is 15–20% larger than the diameter of the corresponding airway, and the two covered ends of the stent should be at least 15 mm away from the rupture.

10.5.1.2 Before Stent Implantation

1. Laboratory. Check routine blood tests, hepatorenal function, electrolytes, hemagglutination test, four infectious diseases, arterial blood gases, electrocardiogram, etc.

2. Preoperative medication. Administer a 10 mg diazepam intramuscular injection 10–30 min before the operation to relieve the patient's anxiety, and 654-2 10 mg injected to block the secretion of digestive juice.

10.5.1.3 Tubular Stent Implantation Interventional Radiology

1. Patient position. Keep patient supine on the DSA examination table without a pillow, elevate the neck and shoulders slightly, and keep the head as far back as possible, angled to the right at 20–30°. Cover the surface with a large surgical drape, fix a nasal oxygen tube, and connect multifunctional ECG. Administer throat anesthesia by spraying lidocaine, place a mouth gag, prepare a vacuum extractor to clear airway and oral secretions as needed.

   Incline a C arm obliquely towards the left at 20–30° (equivalent to placing patients at 50° to the right anterior, with the patient's head angled to the right at 20–30°), adjust the DSA X-ray vision to include oropharynx, trachea, and bilateral main bronchus.
2. Transcatheter angiography. Place a mouth gag in the fluoroscopy field, synchronize the hydrophilic film guidewire and catheter, insert them into the trachea through the oral cavity, pharynx, larynx, glottidis atrium, and infraglottic cavity successively along the radiolucent gas until they reach the lower tracheal knuckle, remove the guidewire and maintain the position of the catheter, infuse 2–3 mL 1% lidocaine through the catheter for tracheal mucosa anesthesia. Adjust the end of the catheter to the area near the tracheal crevasse, infuse 3 mL 30–40% iodine contrast agent for airway angiography to further observe the site and size of the tracheal crevasse, the ubiety between airway knuckle and rupture, and the ubiety between rupture and glottis.
3. The introduction of reinforced wire. After angiography, insert the hydrophilic membrane guidewire through the catheter; guidewire and catheter enter the left or right main bronchus for at least 20 mm, remove the guidewire and retain the catheter, inject 30% 1 mL iodine contrast agent for angiography to confirm that the catheter is located in the main bronchus, replace with a stiff guidewire deep into the main bronchus, ensure that the distal end of the stiff guidewire is in the X-ray monitor field. Firmly fix the guidewire to the opening device.
4. Introduction of stent conveyor. Send in the conveyor package by loading the tracheal covered stent along the stiff guidewire, fix the guidewire in the main bronchus using monitoring, push the conveyor forward slowly to the throat glottis area passing through the oral and pharyngeal cavity. When the patient takes a breath, push the trachea above the bulge, taking advantage of the opportunity.
5. Stent release. Under monitoring, position the stent over the rupture, with the rupture centered, fix the stiff guidewire and stent conveyor firmly, pull the front handle of the conveyor to release 1/3 front stent, conduct fluoroscopy again to confirm the front end of the stent is over the rupture correctly for at least 20 mm, release the stent rapidly. Fix and retain the stiff wire guide, remove the delivery system.
6. Angiography review. Insert the catheter along the stiff guidewire, inject 30% iodine contrast agent for bronchography to see whether closure of the rupture is complete, whether the stent position is accurate, whether the stent expands fully, whether the knuckle and two main bronchi are unobstructed, etc. Adjust the position of the stent or conduct the expansion again, if necessary.
7. Full suction. Again insert a stiff guidewire through the catheter, bring in the suction tube deep into the left and right main bronchus, clear the left and right main bronchial of the residual contrast agent and sputum, until the sound in the lung disappears and oxygen saturation reaches or approaches 100%.
8. Insert the chest drainage tube. If the patient develops pneumothorax, a chest drainage tube is necessary. Puncture the ipsilateral thoracic cavity under fluoroscopy or guidance of Dyan CT and insert the 10.2 F drainage tube for adequate aspiration.

10.5.1.4 Management After Implantation of Stents

1. Aerosol inhalation. Inhale twice a day after inner-stenting (saline 10 mL + lidocaine 5 mL + ambroxol 30 mg + gentamicin 1 branch) to promote sputum discharge and reduce foreign body stimulation and inflammatory response.
2. Expectoration and eliminating phlegm. Tell patients to turn over to change their position, and pat the chest and back to completely discharge infectious sputum from the lungs. Administer expectorant, sputum thinner, etc., in order to encourage coughing up sputum.
3. Anti-infective treatment. Depending on the results of sputum bacterial cultures, sensitive anti-infectious drugs are applied to control lung infection. Perform regular bronchoscopic bronchial lavage, if necessary, to remove bronchial sputum and pus. Local bronchial use of high concentrations of sensitive antibiotics is recommended.

10.5.1.5 Complications and Treatment

Complications in stenting of bronchial rupture include intraoperative bleeding, chest pain, incomplete stent expansion, etc. Postoperative complications include lax rupture closure, both ends of stent stenosis, stent displacement, etc.

1. Chest pain. This generally does not require special treatment. Postoperative chest pain is related to stimulation by stent implantation and other interventional therapy. Serious pain can be treated with painkillers.
2. Stent migration. This is due to severe coughing and the stent will need to be adjusted as soon as possible. Either remove and reposition the stent, or replace with a new stent after removing the old stent.
3. Bleeding injury. Injury to the mediastinal artery near the rupture during surgery may lead to major bleeding and the operator should be aware of this. The operating room should be routinely equipped with cardiopulmonary resuscitation instruments, tracheal intubation, and simple artificial respirators to reduce occurrence of various fatal complications. Blood-stained sputum is very common during stent placement but should stop automatically within 10 mins and does not need treatment. If hemoptysis continues, especially when there is a large amount of blood and there are blood clumps in the sputum, inject 1:1000 2–3 mL adrenaline saline through the tube in the trachea to promote tracheal mucosal vasoconstriction and immediately stop the hemoptysis. This treatment can even stop bleeding of the peripheral artery with a hemorrhage per rhexis.
4. Cough, sputum. Treatment is necessary to relieve coughing and reduce sputum. Atomization treatment is recommended.
5. Fever and lung infection. If the body temperature is over 38.5°, administer anti-infection drugs.
6. Stent obstruction by sputum retention. This is the most common complication for covered tracheal stent implantation. The stent completely covers the tracheal intimal epithelium and epithelial cilia movement and the mucus blanket function disappears completely. Therefore sputum excretion completely depends on coughing strength; if the cough is weak, thick phlegm will gradually adhere to the stent film, and this can form a sputum thrombosis, which will obstruct the tracheal cavity forming a tracheal stenosis, and dyspnea may develop. Perform fiber bronchoscopy as soon as possible to clear the phlegm thrombosis and sputum scab, and restore tracheal patency, and then administer aerosol inhalation, expelling phlegm by use of drugs and expectoration training to avoid sputum retention.
7. Tracheal granulation tissue hyperblastosis stenosis. This condition refers to reactive endothelial cell hyperplasia after stent implantation. Hyperplasia is mainly located at both ends. There is almost no hyperplasia between the ends of the stent but both ends are prone to hyperplasia forming scarring stenosis. If mild tracheal stenosis does not affect the normal breath, it does not need treatment; however, if severe stenosis affects the respiratory and

expectoration function, it needs prompt treatment. For general endoscopic ablation therapy, perform microwave, radio frequency, laser and other thermal ablation therapies. Freezing ablation is also possible and studies have shown that the long-term effect of freezing ablation is better. Remove the stent as soon as possible after healing of the rupture.

10.5.2 Trachea Carina Rupture

10.5.2.1 Equipment Preparation

1. Interventional operating instruments
   These consist of a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic membrane guidewire (150–180 cm), 0.035-in. hydrophilic membrane stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F long sheath, fully or partly covered metal expandable Y-shaped integrated stent appropriate for diameter and length of trachea and bilateral main bronchus (Nanjing Micro-Tech), suction tube, etc.
2. Stent selection. Measure the anteroposterior diameter (vertical diameter) and left-right diameter (transverse diameter) of the trachea, measure anteroposterior diameter and length of bilateral main bronchus according to the fat window on the cross-section (window width 400 HU, window level −50 HU) of chest MSCT, choose or customize individualized covered metal expandable reversed Y-shaped integrated stent. Stent parameters: tracheal, main bronchial stent diameter is 15–20% larger than that of the corresponding airway, tracheal stent (subject) length is about 40–50 mm above the knuckle. The length of the right main bronchial part is the distance between the right upper lobe bronchus and superior border of the knuckle edge; the length of left main bronchus is generally 20–30 mm.

10.5.2.2 Preparation of Stent Implantation

1. Laboratory inspection. Check for infectious disease, perform routine blood tests, hepatorenal function tests, electrolytes, hemagglutination test, arterial blood gases, etc. Perform sputum bacterial culture and a drug sensitivity test to select sensitive anti-infective drugs.
2. Image. Perform the chest MSCT scan, make full use of MPR, CPR, and other post-processing functions, analyze the images, define the precise location, size, and adjacent relationships of the carina rupture; define the distribution and scope of the pulmonary inflammatory lesion, determine the severity of lung injury; measure the diameter and length of tracheobronchial area accurately to choose specifications of the stent.
3. Preoperative medication. Administer 10–30 mg diazepam intramuscular injection 10–30 min ahead of operation to eliminate patient anxiety, intramuscular injection of 654-2 10 mg to relieve smooth muscle tension and reduce secretion of sputum to facilitate respiratory tract interventional radiology operation.

10.5.2.3 Y-Shaped Stent Interventional Radiology Operation

1. Patient position. Keep the patient supine on the DSA examination table; keep the neck and chest within the effective monitoring range. Remove the pillow, elevate the shoulders slightly, keep the head as far back as possible, angled to the right at 20–30°. Cover the surface with surgical drapes, give continuous oxygen through the nose, and connect a multifunctional ECG. Incline a C arm obliquely towards left at 25–30° with the patient's head angled to the right at 25–30°. Administer throat anesthesia with lidocaine spray, and prepare a vacuum extractor to clear airway and oral secretions as needed.
2. Airway radiography. Insert a mouth gag, synchronize a hydrophilic film guidewire and catheter using fluoroscopy, insert into the knuckle through the oral cavity, pharynx, larynx, and trachea. Remove the guidewire, infuse 2–3 mL 1% lidocaine through catheter for knuckle mucous membrane anesthesia. Infuse 30–40% iodine contrast agent for airway angiography to further observe the site and size of the knuckle crevasse, the ubiety between the bilateral main bronchus and rup-

ture, and the mouth position of bilateral main bronchus and upper lobe branch. Select and retain the path diagram of the internal stent interventional radiology operation.

3. The introduction of reinforced wire. Insert the guidewire, which should be coordinated with the catheter, and enter the right lower lobar bronchus over the knuckle, bring in hydrophilic membrane stiff guidewire after angiography, remove the guidewire and retain the catheter firmly in place; in the same way, introduce another metal stiff guidewire into left lower lobar bronchus, then retain and fix it.

   Insert a 9 F long sheath into the lower trachea, the trachea, or above the knuckle along the hydrophilic membrane stiff guidewire in the main bronchus, remove the sheathing canal core. The hydrophilic membrane guidewire and catheter enter the trachea through the sheathing canal, then enter into the left lower bronchial leaf, exchange with metal stiff guidewire, remove the catheter and the sheath, retain and fix the guidewire, then mark the left and right stiff guidewires.
4. Introduction of stent conveyor. Firmly fix two reinforced guidewires, keep the position of the guidewires unchanged in the bronchus. With help of left and right stiff guidewires, draw in left and right cores of the branches carrying the inverted Y-shaped stent conveyor, respectively. Fix the guidewires, send a Y-shaped stent delivery conveyor to the mouth along the double stiff guidewires.

   Fix the stiff guidewire under monitoring, push the conveyor forward into the pharynx oralis through the mouth, encourage the patient to keep the head back, and push the conveyor forward into the laryngopharynx oral cavity, then the cavum laryngis. Ask the patient to cough, and when the glottis opens, push the conveyor to the trachea until it is over the knuckle. Rotate and adjust the stent so that the left and right branches of the stent are on the same side as the stiff guidewires in the left and right lobe of the bronchi. Thus, the branches should be in the same direction as the guidewires. The two guidewires should be completely separated and not twisted.
5. Release the stent. Fix stiff guidewire and rear conveyor handle firmly, pull back front handle and outer sheath to fully release two branches of the inverted Y-shaped stent into the lower tracheal part over the knuckle.

   Keep the relative position of the conveyor's front and back handles constant, strengthen the stiff guidewire, and push the two branches of stent forward into the left and right main bronchus and right middle bronchus, respectively, along the guidewire. Push the conveyor to the trachea until it reaches the upside of the knuckle. Further confirm that the stent branches have reached the tracheal knuckle tightly under monitoring.

   Fix the conveyor and the stiff guidewire, pull the bundling thread at both sides of the branch, respectively, release the bilateral branches fully, then fix the back handle of conveyor, pull back the front handle and the outer sheath quickly to release the tracheal stent's main part. After releasing the stent, remove the stent conveyor slowly. Retain at least one bronchial hardened guidewire to retain the subsequent interventional operation pathway.
6. Angiographic reviewing. Replace the guidewire, introduce the catheter near the carina, inject iodine 30% contrast agent by catheter, conduct bronchography to see whether the stent is implanted in the predicted position, whether the closure of the rupture is complete, whether opening of bronchial double superior lobes is not covered by stent, and whether stent expansion is complete.
7. Sputum suction. Insert the stiff guidewire again through the catheter, bring in a suction tube through the catheter deep into the left and right main bronchus, clear the left and right main bronchus of residual contrast agent and sputum, until the lung rales disappear and blood oxygen saturation reaches or approaches 100%.
8. Insert the chest drainage tube. If the patient develops pneumothorax; a chest drainage tube is needed. Puncture the ipsilateral thoracic cavity under fluoroscopy or guidance of Dyan CT and insert the 10.2 F drainage tube for adequate aspiration.

10.5.2.4 Postoperative Management

See Sect. 10.5.1.4

10.5.2.5 Complication Prevention and Treatment

See Sect. 10.5.1.5

10.5.2.6 Postoperative Treatment

See Sect. 10.5.1.4

10.5.2.7 Prevention and Treatment of Complications

See Sect. 10.5.1.5

10.5.3 Right Main Bronchus Rupture

According to the rupture types based on rupture location, the right main bronchus rupture is type III a.

The main bronchus is short (ranging from 10 to 20 mm), and the breach of the proximal segment of the open area is adjacent to the carina. The distal end is adjacent to the middle bronchus or superior right lobe bronchus. In order to block the right main bronchial rupture effectively and protect the right upper lobe bronchial opening, a large and a small Y-shaped airway fully covered stent need to be used in most cases. The small stent is inserted into the middle bronchus, the right upper lobe bronchus, and the right main bronchus; and the large stent is placed into the right main bronchus, the left main bronchus, and the trachea.

10.5.3.1 Equipment Preparation

1. Interventional operating instruments. These include a mouth gag, 5 F vertebral artery catheter (80–100 cm), 0.035-in. hydrophilic membrane guidewire (150–180 cm), 0.035-in. hydrophilic membrane stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F long sheath, two sets of fully covered expandable Y-shaped stents with appropriate specification, etc.
2. Y-shaped stent selection. Measure the anteroposterior diameter (vertical diameter) and left-right diameter (transverse diameter) of the trachea, measure the anteroposterior diameter and length of the bilateral main bronchus according to the fat window on the cross-section of chest MSCT, choose or customize tracheal and double main bronchial individualized covered metal expandable reversed large integrated Y-shaped stent. Stent parameters are as follows: tracheal, main bronchial stent diameter is 15–20% larger than that of the corresponding airway, tracheal stent (subject) length is about 40–50 mm above the knuckle. The length of the right main bronchial part is the distance between the right upper lobe bronchus and superior border of knuckle edge, the left main bronchial part is generally 20–30 mm.

   Measure the radial line between the right main bronchus with the right upper lobe and the right medial bronchus, select or customize the individualized small inverted Y-shaped integrated self-expanding metal stent. Stent parameters: the diameter of the upper right lobe bronchial stent branch is 10% larger than that of the corresponding bronchus, the length should be no more than 80% of the length of the corresponding bronchus; diameter of the right middle bronchial stent branch is 10% larger than that of the corresponding bronchus, the length should be no more than 80% of the length of the corresponding bronchus. The diameter of the stent section at the right main bronchus (subject) is 15% larger than that of the right main bronchus; the length should be no more than that of right main bronchial inferior wall.

10.5.3.2 Preparation for Stent Installation

(See Sect. 10.5.2.2)

10.5.3.3 Interventional Radiology Preparation of Two Y-Shaped Stents

Implant two inverted Y-shaped stents during the same operation; generally implant the distal small inverted Y-shaped stent first, then the large one. Set the branch of the large Y-shaped stent into body of the small Y-shaped stent, then the small stent becomes fixed by the large stent.

Keep the patient supine on the DSA examination table; keep the head as close as possible to the end of DSA examination bed, keep neck and chest DSA images within range of the operators. The neck and shoulders should be properly cushioned without a pillow. Keep the patient head back and angled to the right at about 30° (facing the operators). Cover the surface with surgical drapes, administer continuous oxygen through the nose, and connect a multifunctional ECG for continuous monitoring of the function of the heart and lungs. The C arm of the DSA is angled obliquely at 20° with the patient's head angled to the right at 30°, which is equivalent to angling patients at 50° to the left anterior. This position helps to clearly show the negative shadow.

Administer airway throat spray anesthesia, and prepare a vacuum extractor to clear airway and oral secretions.

1. The airway radiography. Insert a mouth gag, synchronize the hydrophilic film guidewire and catheter in fluoroscopy, insert them into the knuckle through the oral cavity, pharynx, larynx, and trachea. Remove the guidewire, retain the catheter, infuse 2–3 mL 1% lidocaine through the catheter for knuckle mucous membrane anesthesia. Infuse 30% iodine contrast agent for airway angiography to further observe the site and size of the right main bronchial rupture, the ubiety between mouth of right upper lobe bronchus and middle bronchus, and to show bilateral main bronchus. Select the best image, choose and retain the path diagram of the internal stent interventional radiology operation.
2. Introduction of reinforced wire: Synchronize the guidewire and catheter going into the right lower lobe bronchus over the right main bronchial fistula orifice, draw in the metal stiff guidewire after angiography, remove the guidewire and fix the catheter firmly; implant a 9 F sheathing canal to hypomere of the trachea or top of the knuckle along the metal guidewire in the right main bronchus, remove the sheath core; the catheter works with the hydrophilic membrane guidewire going into the trachea, right main bronchus through the sheathing canal, into the right upper lobe bronchus and deep segment of the bronchus. Switch to a hydrophilic membrane stiff guidewire, remove the catheter and sheath, retain and fix the guidewire, and mark two reinforcing guidewires at the upper and lower lobe.
3. Introduction of the small inverted Y-shaped stent conveyor: Fix two reinforced guidewires firmly in fluoroscopy, and maintain the position of the guidewires unchanged in the bronchus. With the help of up and down stiff guidewires, draw in the cores of both lobes carrying the inverted Y-shaped stent conveyor. Fix the guidewires at the mouth gag and end of the guidewire, and send a Y-shaped stent delivery conveyor into the mouth through the mouth gag along the double stiff guidewires.

   Fix the stiff guidewires in fluoroscopy, and push the conveyor forward into the mouth pharynx through the mouth, encourage the patient to keep the head back, push the conveyor forward into the laryngopharynx and laryngeal cavity, encourage the patient to cough, and when the glottis opens, push the conveyor to the trachea until over the knuckle. Rotate and adjust the stent aligning the left and right branches of the stent on the same side as the stiff guidewires in the left and right lobes of the bronchus. The two guidewires should be completely separated on the left and right side. The gold marker on the inverted Y-shaped stent should also be on the left and right edges, push the conveyor forward until the stent's two branches move into the right main bronchus.
4. Release of the small inverted Y-shaped stent: Fix a stiff guidewire and rear handle of conveyor firmly, pull back the front handle of the conveyor and sheath to fully release two branches of the inverted Y-shaped stent into right main bronchus. Keep the relative position of the front and back handle constant, fix the stiff guidewire, push the two branches of the stent forward into the right upper lobe bronchus and right middle bronchus, respectively, along the double guidewire, when meeting resistance during the pushing, confirm that the stent branches have reached the upper lobe

bifurcation and middle bronchial bifurcation with monitoring. Fix the conveyor and the stiff guidewire, pull the bundling thread at both branches one after another to release the bilateral branch fully, carry out an X-ray to confirm the dual branch position is correct, then fix the back handle of conveyor, and pull back the front handle and the outer sheath quickly to release stent's main part in right main bronchus. After releasing the small inverted Y-shaped stent, remove the conveyor slowly. Retain the metal stiff guidewire in bronchus.

5. Introduction of large Y-shaped inverted stent conveyor: Coordinate the catheter, adjust the hydrophilic membrane stiff guidewire in the right upper lobe bronchus to the left lower lobe bronchus, remove the catheter, fix the stiff guidewire, and mark the two stiff guidewires on the left and right side of the bronchus. Using monitoring, fix two reinforcing wires, and maintain the wires' endobronchial position. With the help of left and right stiff guidewires, draw in the left and right cores of the branches carrying the large inverted Y-shaped stent conveyor, respectively, fix the guidewire at the mouth gag and end of the guidewire, insert the conveyor into the mouth along the double stiff guidewires.

   Push the conveyor forward to the pharynx oralis through the mouth using fluoroscopy before fixing the stiff guidewires, encourage the patient to keep the head back, push the conveyor into the glottis through the laryngopharynx and the cavum laryngis, maintain the proper thrust and rotate the conveyor, change the orientation of the conveyor's double core to fit the anteroposterior diameter of the glottis. Ask the patient to inhale deeply or cough, and when the glottis opens, push the conveyor into the knuckle through the trachea. Rotate and adjust the conveyor, adjust the stent's position in the conveyor, make sure that the left and right branches of the stent are on the same side as the stiff guidewires in the left and right bronchi. The two guidewires should be completely separated on both sides without any twisting. Gold markers on the inverted Y- shaped stent are also located on the left and right edges.

   Release the large inverted Y-shaped stent: Fix the stiff guidewire and rear handle of conveyor, pull back the front handle of the conveyor and sheath to fully release two branches of inverted Y-shaped stent into lower tracheal part over the knuckle. Keep the relative position of the conveyor's front and back handles and artery sheaths constant, strengthen the stiff guidewire, gently push two the branches of the stent forward into the left and right main bronchus and right middle bronchus, respectively, along the guidewire. This should be conducted under constant monitoring. Pay attention to the small released inverted Y-shaped stent and make sure it not pushed to the right side of the larger stent. When encountering resistance during the pushing, exclude the above possible causes through monitoring, and then push the inverted Y-shaped stent conveyor onwards. When resistance stops during the pushing, pull the bundling thread at both sides of the two branches one after another; make sure the stent's bifurcation has reached the tracheal knuckle under monitoring. Fix the guidewire and conveyor, pull the bundling thread at both sides of the two branches one after another, and fully release the bilateral branches. Fix the back handle of the conveyor; pull back the front handle and outer sheath to release the stent's main part in the trachea. After releasing the inverted Y-shaped stent, remove the conveyor slowly. Retain one stiff guidewire in the bronchus.

6. Airway radiography re-examination: Introduce the catheter near the knuckle, inject 30% 3–5 mL iodine contrast agent rapidly via catheter, conduct tracheal bronchial radiography to see whether the stent has been implanted in the predicted position, whether the closure of the rupture is complete, whether gomphosis between the two inverted Y-shaped stents is tight, and whether stent expansion is complete.
7. Full suction: Insert the suction tube into the left and right main bronchus and deep lobar bronchus, especially the right bronchus, and clear sputum repeatedly, until the oxygen saturation rises or approaches normal and the sound in the lungs disappears or lessens significantly.

10.5.3.4 Postoperative Treatment

See Sect. 10.5.1.4

10.5.3.5 Prevention of Complications and Treatment

See Sect. 10.5.1.5

10.5.4 Left Main Bronchus Rupture

According to the rupture types based on rupture location, the left main bronchus rupture is type IIIa of the bronchial rupture.

The length of the left main bronchus is about 40 mm, which is much longer than that of the right main bronchus. Therefore, there is a large operation space when the stent is inserted in left main bronchial lesions. If the left main bronchus rupture occurred at the left peribronchus near the knuckle, and knuckle rupture occurs during operation, a large inverted Y-shaped covered airway stent is inserted in the trachea and bilateral main bronchus. If rupture occurs in a distal segment of the left main bronchus near the bifurcation of the upper and lower lobe of the left main bronchus, use a small inverted Y-shaped covered airway stent in the left main bronchus and left upper and lower lobe bronchus.

The blockage of a left main bronchial rupture is different to that of the right main bronchial rupture, and the latter often leads to the use of two large inverted Y-shaped stents for blocking. The left main bronchial rupture generally requires a single large or a single small Y-shaped stent.

10.5.4.1 Equipment Preparation

1. Interventional Operating Instruments
   These include a mouth gag, 5 F vertebral artery catheter (80–100 cm), 0.035-in. hydrophilic membrane guidewire (150–180 cm), 0.035-in. hydrophilic membrane stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F long sheath, small or large covered metal integrated expandable Y-shaped stent (Nanjing Micro-Tech), suction tube, etc.
2. Stent selection. Measure the corresponding tracheal bronchial radial line according to special mediastinal window (fat window) of chest MSCT image, then select or customize the stent.

Small Inverted Y-Shaped Integrated Stent

Measure the anteroposterior and transverse diameter of the left principal bronchus, anteroposterior diameter, and length of the left upper and left lower bronchus, angle of the left upper lobe and left lower lobe. Customize the individual small inverted fully covered self-expandable Y-shaped metal stent. Stent parameters are as follows: length of stent main body equals that of the left main bronchial inferior wall, the diameter is more than 15–20% of the left main bronchus diameter, and the diameter of the upper left branch is more than 10–15% of that of the upper left branch, the length is 10 mm±, the left lower main bronchus is 10–15% larger than that of the left lower branch, the length is 10 mm, the angle of the stent's two branches is equivalent to the angle between the upper and lower lobe bronchus.

Large Y-Shaped Integrated Stent

Measure the anteroposterior and transverse diameter of the trachea, anteroposterior diameter and length of the left and right main bronchus, the angle between the left and right main bronchi. Customize the large integrated fully covered self-expandable inverted Y-shaped metal stent. The stent parameters are as follows: the diameter of stent is 15–20% greater than the tracheal diameter, the length is 40–50 mm; the diameter of the left branch is 10–15% greater than the left main bronchial diameter, the length is 15–20 mm; the right branch diameter is 10–15% greater than the right main bronchial diameter, the length is 10–15 mm, the angle between the two branches is equivalent to the angle between the two main bronchi.

10.5.4.2 Preparation for Stent Implantation

(See Sect. 10.5.2.2)

10.5.4.3 Small Y-Shaped Stent Interventional Radiology Operation

1. Patient position
   Keep the patient supine on the DSA examination table, keep the head as close as possible the to end of DSA examination table, keep the neck and chest within the effective monitoring range. Remove the pillow, keep the head back and angled to the front right at about 30° (patient faces the operators). Cover the surface with large surgical drapes. Administer continuous oxygen through the nose; connect a multifunctional physiological monitor to monitor cardiac and respiratory function continuously. Incline the C arm obliquely towards the left at an angle of about 20° with the patient's head angled to the right at 30°, which is equivalent to placing the patient's head at about 50° to the left anterior. This position helps to clearly show the negative shadow.

   Administer airway throat spray anesthesia or local transcatheter anesthesia when the catheter goes through throat chamber; the latter may reduce discomfort of the tongue and mouth pharynx. Prepare a vacuum extractor to clear airway and oral secretions.
2. Airway radiography. Insert a mouth gag, insert a hydrophilic film guidewire and catheter with head of catheter coming out for 1–2 cm in fluoroscopy, insert them into the knuckle through the oral cavity, pharynx, larynx, and trachea. Remove the guidewire, retain the catheter, infuse 2–3 mL 1% lidocaine through catheter for knuckle mucous membrane anesthesia. Adjust the catheter into the left main bronchus; infuse 3 mL 30% iodine contrast agent for airway angiography to further observe the site and size of the left main bronchial rupture and the ubiety between rupture, upper lobe bronchus and knuckle. Select the best image of the tracheal hypomere, bilateral main bronchus, left upper and lower lobe bronchus as the path diagram of the internal stent interventional radiology operation.
3. Introduction of reinforced guidewire. Synchronize the guidewire and catheter going into the left lower lobe bronchus over the right main bronchial fistula orifice, draw in the metal stiff guidewire to deep lower lobe bronchus after angiography, remove the guidewire and fix the catheter firmly; implant a 9 F sheathing canal in the opening of the left main bronchus, remove the sheath core, the catheter works with guidewire going into the left main bronchus, upper left lobe bronchus, deep bronchus, replace with a hydrophilic membrane stiff guidewire, keep and fix the hydrophilic membrane stiff guidewire, remove the catheter and sheath, retain and fix the guidewire, mark two reinforcing guidewires at the upper and lower lobe.
4. Introduction of small Y-shaped stent conveyor. Fix two reinforced guidewires firmly, maintain the position of the guidewire unchanged in the bronchus with fluoroscopy. With the help of up and down stiff guidewires, draw in the cores of the up and down lobes carrying the inverted Y-shaped stent conveyor, respectively. Fix the guidewire at the mouth gag and end of the guidewire, insert the Y-shaped stent delivery conveyor into the mouth through the mouth gag along the double stiff guidewires. Intervention operators, assistant, nurses, and technicians are to provide complete support in fixing the stiff guidewires, maintaining the patient's position, maintaining oxygen supply, and clearing sputum as needed.

   Fix the stiff guidewire under monitoring, push the conveyor forward into the pharynx oralis through the oral cavity, encourage the patient to keep the head back, and push the conveyor forward into the laryngopharynx and cavum laryngis. When the front of the conveyor encounters resistance at the glottis, the patient coughs reactively; maintain the proper thrust and rotate the conveyor, adjust the position of the double core at the front of the conveyor to fit the anteroposterior diameter of the glottis. Ask the patient to inhale deeply or cough, and when the glottis opens,

push the conveyor into the trachea, taking advantage of the opportunity, then into the left main bronchus. Rotate and adjust the conveyor to align the left and right branches of the stent to be on the same side as the stiff guidewires in the left and right lobe bronchi; the two guidewires are in the left and right (or up and down) sides and the two sides are completely separate and not twisted. Golden markers on the inverted Y-shaped stent are located on the left and right edges. Push the conveyor forward, causing most of the stent's two branches to enter the left main bronchus.

5. Release of the Y-shaped stent. Fix the stiff guidewire and rear handle of the conveyor firmly, pull back the front handle of the conveyor and sheath to fully release two branches of inverted Y-shaped stent into left main bronchus.

   Keep the relative position of the front and back handle constant, fix the stiff guidewire, carefully and gently push the two branches of the stent forward into the left upper and lower lobe bronchus, respectively, along the double guidewire. When resistance is encountered, this means that the stent branches have completely entered the upper and lower lobe bronchi, and stent bifurcation has been reached at the bifurcation of the upper and lower lobe bronchi. Further confirm this through monitoring.

   Fix the stiff guidewire and conveyor totally, maintain an appropriate forward force, pull the bundling thread at both sides of the stent's two branches, one after another, release the bilateral branches fully, and conduct fluoroscopy to verify the location of stent's two branches. Fix the back handle of the conveyor; pull back the front handle and outer sheath to release stent's main part in left main bronchus.
6. Airway radiography re-examination. Introduce the catheter near the left main bronchus by the stiff guidewire, remove the guidewire and retain the catheter, inject 3–5 mL 30% iodine contrast agent rapidly via catheter, conduct left bronchial radiography and check to see whether the stent has been implanted in the predicted position, whether the closure of the rupture is complete, whether the stent branches are unobstructed, whether the stent is too long, whether the stent covers the knuckle and the opening of the right main bronchus, and whether the stent's expansion is complete.
7. Postoperative sputum suction. Insert the stiff guidewire again through the catheter, bring in a suction tube through the catheter to the left and right main deep bronchus, clear the left and right main bronchus of residual contrast agent and sputum until the lung rales disappear and blood oxygen saturation reaches or approaches normal.
8. If the patient develops pneumothorax, a chest drainage tube is needed. Puncture the ipsilateral thoracic cavity under fluoroscopy or guidance of Dyan CT, insert the 10.2 F drainage tube for adequate aspiration.

10.5.4.4 Interventional Radiology Preparation for a Large Y-Shaped Stent

1. Patient position. Keep the patient supine on the DSA examination table; keep the neck and chest DSA images within an effective monitoring range. The shoulders should be properly cushioned without a pillow. Maintain the head back and to the right at about 25–30° (facing the operators). Cover the surface with surgical drapes, administer continuous oxygen through the nose, and connect multifunctional ECG for continuous monitoring of heart and lung function. The C arm of the DSA is angled obliquely at 25–30° with the patient's head angled to the right at 25–30°.

   Administer airway throat spray anesthesia and prepare vacuum extractor to clear the airway and oral secretions as needed.
2. Airway radiography. Insert a mouth gag, synchronize the hydrophilic film guidewire and catheter with fluoroscopy, insert them into the knuckle through the oral cavity, pharynx, larynx, and trachea. Remove the guidewire, retain the catheter, infuse 2–3 mL 1% lidocaine through athe catheter for knuckle mucous membrane anesthesia. Infuse 30%

iodine contrast agent for airway angiography to further observe the site and size of the left main bronchial rupture and the ubiety of bilateral main bronchus and upper lobe bronchial opening. Select the best image, choose and retain the path diagram of the internal stent interventional radiology operation.

3. Introduction of reinforced wire. Synchronize the guidewire and catheter and insert them into the right lower lobe bronchus over the rupture, insert the stiff guidewire after angiography, remove the guidewire and fix the catheter firmly; insert another metal stiff guidewire in the left lower lobe bronchus in the same way, then retain and fix it. 9 F sheathing canal is inserted into the hypomere of the trachea or top of the knuckle along the hydrophilic film stiff guidewire in the right main bronchus. Remove the sheath core; the catheter travels with the hydrophilic membrane guidewire going into the trachea, left lower lobe bronchus, replace with a metal stiff guidewire, remove the catheter and sheathing canal, retain and fix the guidewire, and mark the two left and right reinforced guidewires.
4. Introduction of stent conveyor. Fix two reinforced guidewires firmly in position using fluoroscopy, maintain the position of the guidewires unchanged in the bronchus. With help of left and right stiff guidewires, insert cores of the left and right lobes carrying the inverted Y-shaped stent conveyor. Fix the guidewires, send a Y-shaped stent delivery conveyor into the mouth gag along the double stiff guidewires.

   Fix the stiff guidewire in position using fluoroscopy, push the conveyor forward into the mouth pharynx through the mouth, encourage the patient to keep the head back, push the conveyor forward into the laryngopharynx and laryngeal cavity, encourage the patient to cough, and when the glottis opens, push the conveyor to the trachea until over the knuckle. Rotate and adjust the stent to make the left and right branches of the stent on the same side as the stiff guidewires in the left and right lobes of the bronchus. The two guidewires should be completely separated and not twisted.
5. Release the stent. Fix stiff guidewire and rear handle of the conveyor, pull back the front handle of the conveyor and outer sheathing canal to fully release two branches of inverted Y-shaped stent into the lower tracheal part over the knuckle.

   Keep the relative position of the conveyor's front and back handles and artery sheaths constant, push two branches of the stent forward into the left and right main bronchus along the stiff guidewires, confirm that the stent bifurcation has reached the tracheal knuckle under monitoring.

   Fix the conveyor and stiff guidewire, release the stent's bilateral branches, pull the left and right bundling thread of the stent, release the bilateral branches fully, then fix the back handle of conveyor, pull back the front handle and outer sheath to release the stent's main part in the trachea. After releasing the stent, remove the stent conveyor slowly. Retain at least one bronchial stiff guidewire to retain the interventional operation pathway.
6. Angiographic reviewing. Exchange the guidewire, introduce the catheter near the carina, inject 30% iodine contrast agent by catheter, perform bronchography to see whether the stent has implanted in the predicted position, whether the closure of the rupture is complete, whether the opening of bronchial double superior lobes is not covered by stent, and whether stent expansion is complete.
7. Sputum suction. Insert the stiff guidewire again through the catheter, insert a suction tube through the catheter deep into the left and right main bronchus, and clear the left and right main bronchus of residual contrast agent and sputum, until the lung rales disappear and blood oxygen saturation reaches or approaches 100%.
8. Chest drainage tube. If the patient develops pneumothorax, a chest drainage tube is needed. Puncture the ipsilateral thoracic cavity under fluoroscopy or guidance of a Dyan CT and insert the 10.2 F drainage tube for adequate aspiration.

10.5.4.5 Postoperative Treatment

See Sect. 10.5.1.4

10.5.4.6 Prevention and Treatment of Complications

See Sect. 10.5.1.5

10.6 Outlook

Tracheal and/or bronchial rupture often occurs in severe chest injuries or crush injuries. In recent years, with the number of traffic accidents increasing, closed tracheal and bronchial rupture has become more common and is one of the reasons for early death after chest trauma. Chest injuries from sharp objects or firearms also cause tracheal and bronchial injury. Rupture occurs in any part of the trachea and bronchus, and is generally consistent with the injury site. This type of wound is often associated with large vascular injury, which is often very serious and lethal. In addition, very few cases are iatrogenic, such as bronchoscopy to remove nails, pins, and other foreign bodies causing tracheal perforation. There are even cases of tracheal rupture caused by anesthesia tracheal cuff over-expansion or anesthetic gas tracheal explosion.

As a minimally invasive method, the airway stent is used in the treatment of tracheal bronchial rupture. For patients with an incomplete tear or divided rupture, the stent is able to completely block the break and promote healing of the rupture and abscess. The stent is removed after complete healing. For a completely divided or large rupture, the stent is applied to prevent gas from escaping and to strengthen the patient for surgery. However, there are many challenges to correct stent placement. The unresolved problems in the long-term efficacy and safety of the airway implantation method include the method itself, preventing the displacement and expectoration difficulties after stent implantation, and avoiding long-term granulation tissue proliferation.

With the advancement of science and technology, a biodegradable scaffold that does not need to be removed after implantation can be completely absorbed and decomposed in the body, and can promote healing of tracheal ruptures, is being developed. The developers are hoping to subject this to clinical trials in the near future.

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11 Thoracostomach–Airway (Trachea/Bronchus) Fistula

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11.1 Summary

For many years, earlier stages of esophageal cancer and cardiac cancers have been treated using extensive reconstruction. Reconstruction of the upper alimentary tract through the stomach is one of the most important procedures after reconstruction of the esophagus. In 1933, Ohsawa conducted surgery in which the stomach was used for the reconstruction of the resected esophagus. The stomach has become the favoured organ to use for reconstruction after extensive resection of the esophagus because it makes the operation much easier and results in lower mortality and complication rates. At present, in surgeries that involve the esophagus, extensive resection of the esophagus is widely accepted together with esophagogastrostomy above the aortic arch or at the neck. It is performed by pulling up the stomach to the post mediastinum in which the esophagus is located (Fig. 11.1). However, the blood supply and innervation of the thoracostomach are significantly changed after this surgery, and, in addition, tumor residue, recurrence, and injury caused by postoperative cancer can result in various thoracostomach complications.

Thoracostomach–airway fistula is one of the most common complications after resection of the esophagus (replacement of the esophagus with a gastric component). After the surgery, the stomach is pulled up to post mediastinum and tightly packed with the trachea, carina, and both the main bronchus and middle bronchus. Thus, bleeding, exudation, inflammation, and fibrosis can cause thoracostomach adhesion with the trachea, carina, and both the main bronchus and middle bronchus (Fig. 11.2, informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study). Many factors are able to destroy the wall of the stomach and the airway and result in joining of the stomach and the airway. The gastric juices leak into the airway causing a severe burning sensation and irritating cough [1]. If the patient is in the supine position, gastric juices easily leak into the airway and aggravate the cough. If the patient is in the sitting or standing position, gastric juice does not easily leak into the airway. Therefore, patients should always be in a sitting or standing position. Patients can also present with intractable pneumonia, which can be multiple, lobular, segmental, or lobar. Symptoms such as loss of appetite, refusal to

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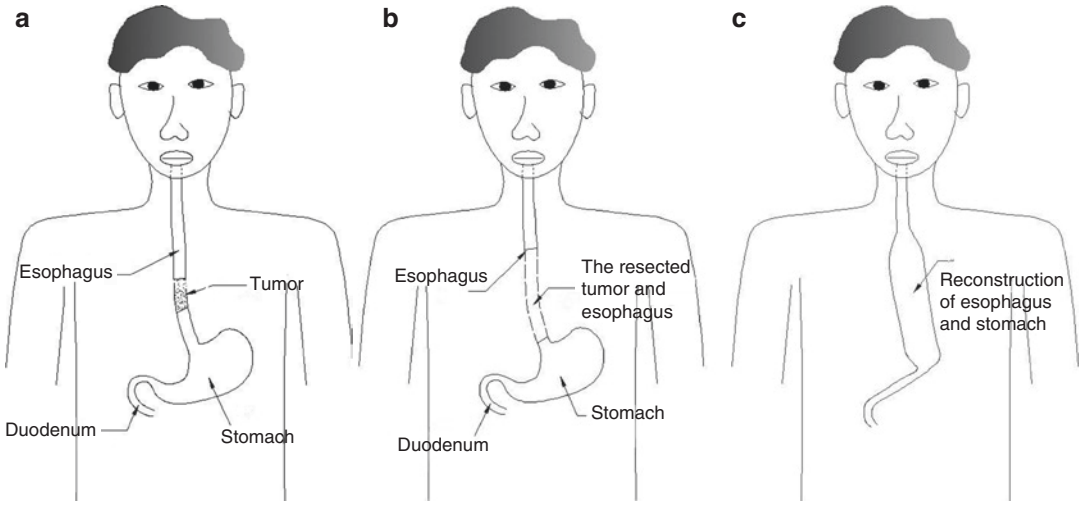

Fig. 11.1 Diagram of the extensive resection of the esophagus and thoracostomach. (**a**) Middle esophageal cancer. (**b**) Extensive resection of thoracic esophagus. (**c**) The stomach is pulled up to the chest, as the thoracostomach

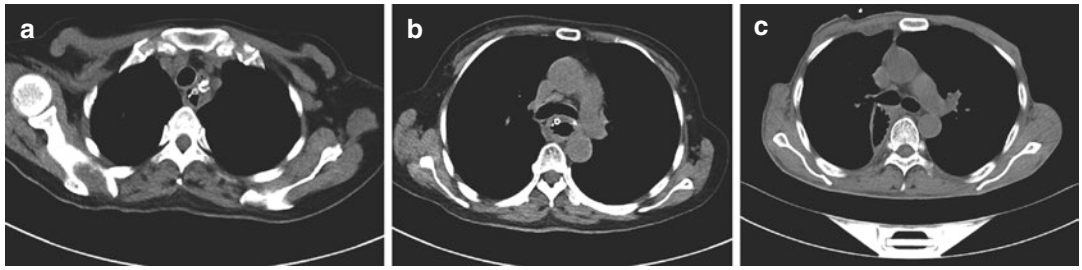

Fig. 11.2 (**a**) Thoracostomach adhesion with the trachea; (**b**) thoracostomach adhesion with the carina; (**c**) thoracostomach adhesion with the right main bronchus

eat, dyscrasia, and electrolyte disturbances also exist [2].

Thoracostomach–airway fistula is rarely seen nowadays due to the introduction of esophageal resection. However, a patient's life can be in danger if the prognosis is poor. Up until 2002, there were only approximately 40 studies dealing with this disease. Each of these studies was a case study and few large sample analyses were found. This disease is not completely understood by physicians and has previously been misdiagnosed as epiglottis dysfunction, deglutition disorder, tracheoesophageal fistula, or radiation pneumonitis, and thus correct treatment was delayed.

When the patient is in the supine position, gastric juices leak into the airway and cause a burning sensation, which can cause lung tissue injury and multiple lung infections. Patients often fear coughing after eating, which might lead to eating disorders and dyscrasia, and thus the fatality rate is high. Cases of surgery treating esophageal cancer are growing. Stereotactic radiotherapy (intensity-modulated conformal therapy, X-knife, and gamma knife) towards the esophagus bed after surgery is also becoming more common, whereby the thoracostomach receives a large amount of radiation, which can cause fistulas. Moreover, paying more attention to the symptoms of this disease can help with early detection. Currently, the thoracostomach–airway fistula has become one of the most common complications after esophageal surgery.

11.2 Etiology

11.2.1 Surgical Injury

Surgery can directly damage the stomach and airway wall. Insufficient stitching of the narrowed stomach can lead to a stomach fistula. A penetrating stomach ulcer exists before surgery. Excessive artery ligation can cause ischemic necrosis in the stomach and airway wall. The blood supply of the stomach is restrained when it is pulled up, and necrosis and perforation can occur.

11.2.2 Bacterial Infection

Bacterial infection occurs at the esophagus bed and an abscess can destroy the wall of the stomach and airway. An abscess can also originate from the subphrenic region and extend to the esophageal region.

11.2.3 Gastric Ulcer Perforation

Various factors lead to the stress response; internal and exogenous injury can cause damage to the stomach wall, the stomach wall undergoes necrosis and perforation, digestive juices leak out and corrode the nearby airway wall, causing the association of the stomach cavity with the trachea (bronchus).

11.2.4 Tumor Recurrence

Tumor residue after resection or local tumor recurrence can lead to a thoracostomach–airway fistula. The tumor infiltrates and causes damage to the wall of the stomach and/or airway and this leads to avascular necrosis and perforation. Moreover, arterial perfusion chemotherapy, radiotherapy, or chemotherapy causes rapid tumor necrosis. Normal tissue repair is relatively slow. Perforation forms between the stomach and the trachea (bronchus) and a fistula forms.

11.2.5 Radiation Injury

Surgery is not always accurate in the case of later tumor stages and tumor adhesion can form within the trachea, the descending aorta, and other important tissue structures. Thus, conventionally additional radiation therapies, especially three-dimensional radiotherapy, are conducted where the esophageal bed receives an overdose of radiation and this causes damage. Thereafter, stomach ulcers, necrosis, gastric acid, and pepsin aggravate the stomach wall injury and the stomach wall perforates. The trachea (bronchus) wall also suffers radiation damage, which is the main cause of the thoracostomach–airway fistula.

The esophageal cancer radiotherapy dose and normal esophageal tolerance dose of radiation is 6,000–7,000 cGy, but the tolerance of the stomach is only half of this (3,000–4,000 cGy). The intrathoracic stomach is subject to excessive radiation injury and ulcers, necrosis, perforation, and airway wall injury occur. Gastric acid and pepsin cause chemical stimulation and local inflammation, which aggravates the damage. The stomach and trachea (bronchus) join to form the fistula. With this type of fistula caused by excessive radiation, the cells around the fistula lose their normal regeneration function and the fistula has difficulty healing.

To treat esophageal cancer, surgery, and not radiation, should be chosen. The operation includes total removal of the tumor and avoids three-dimensional radiation therapy towards the esophageal bed after surgical resection.

11.3 Pathology

11.3.1 Residual Tumor Invasion

The formation of the thoracostomach–airway fistula is related to tumor residue and recurrence, in which the tumor cells infiltrate and enter normal tissue.

Surgical indication selection is not always accurate; preoperative tumor staging is not accurate; surgical resection can lead to errors. All of the above factors can make the operation unsuccessful and result in incomplete removal of the tumor. A residual tumor directly erodes into the wall of the stomach and then perforates the stomach. There is gastric fluid injury and local inflammatory damage to the airway wall, resulting in the formation of thoracostomach–airway fistula. The tumor may destroy the airway wall first and cause mediastinal inflammation, infection, and abscesses. The wall of the stomach also gets damaged, from the outer layer of the wall to the inner wall, and this speeds up the formation of the fistula. The wall of the stomach and airway can be damaged at the same time.

11.3.2 Radiation Injury

As mentioned above, the esophageal cancer radiotherapy dose and normal esophageal tolerance dose of radiation is 6,000–7,000 cGy, but the tolerance dose of the stomach is only half that of the esophagus. Esophageal cancer surgery cannot completely achieve radical excision, so tumor residue or recurrence is common. To eliminate the residual tumor, routine radiotherapy towards the tumor area on the original esophageal bed is needed.

After the operation, the thoracic stomach is located at the original esophagus bed area in the mediastinum and three-dimensional radiation therapy targets this area. It is difficult to exclude the stomach completely from this radiation therapy zone. The thoracic stomach receives excessive radiation and the wall of the stomach is injured (mucosal damage, muscle layer injury, serous layer damage), resulting in in necrosis, perforation, peptic gastric juice spillover, corrosion, breaking of the tracheal/bronchial wall, and the formation of a thoracostomach–airway fistula. The trachea (bronchus) is also within the radiation field and radiation may also cause tracheal and bronchial wall damage at the same time and result in a fistula.

11.3.3 Physiological Disorders

The stomach has an automatic secretion function. Every day, with or without food, the stomach produces nearly 1,000 ml of gastric acid and pepsin. Gastric acid and pepsin can corrode and damage the stomach wall; in addition, postoperative thoracic gastric emptying disorders occur easily and prolong the duration of gastric acid and pepsin in the stomach. The stomach mucosa loses the protection of the muscular layer, and then the stomach and tracheal bronchus wall perforate, which promotes the formation of a thoracostomach–airway fistula.

11.3.4 Lung Injury

Continuous large amounts of gastric juices and peptic acid move into the alkaline environment of the tracheal bronchus and alveoli to produce complex chemical corrosion and lung injury, and a secondary pulmonary infection (multiple infections) further aggravates lung damage. Radiation damage to the stomach and airway is difficult to heal. Gastric contents entering the airway cause strong acid stimulation, bronchial bronchospasm, and a stubborn choking cough. The bronchial epithelium shows acute inflammation and inflammatory cells infiltrate around the bronchus. When the acid spreads quickly into the surrounding lung interstitial tissue, the bronchial epithelium and alveolar epithelial cells degenerate and this can involve interstitial tissue such as the capillary wall. This leads to the increased permeability of blood vessel walls and alveolar capillary wall damage forms an interstitial edema and alveolar pulmonary edema. Pulmonary edema reduces the lung tissue elasticity and compliance, reduces lung capacity, damages alveolar type II cells, reduces pulmonary surfactant production, and causes small airway closure. The alveolar walls break down and atelectasis develops. The lack of alveolar ventilation causes hypoxemia and can even cause acute respiratory distress syndrome. Endovascular liquid, large leakage, or reflective vasodilation, systemic effective circulating blood volume reduce. If the blood volume is reduced by over 35%, this results in low blood pressure and affects blood circulation.

The severity of pneumonia is determined by the pH value of gastric juice, flow amount and velocity of gastric juice, secondary infection, and distribution of gastric juice in the lung and bronchus. Gastric juice with a pH of < 2.5 severely damages the lung tissue. A flow amount of 50 ml causes severe lung damage, and the wider the distribution, the more severe the lung damage.

Gastric juice and gastric contents moving into the airway cause a severe burning sensation, which is hard to tolerate, causes a choking cough, and patients cannot eat. Lung injury and severe infection increase the body's energy consumption and lead to poor overall health and disease resistance. If active treatments are not carried out, most patients will suffer severe nutritional disorders, repeated gastric acid aspiration and bronchospasm, chemical pneumonia, corrosive pneumonia, multiple infectious pneumonia, lung abscesses, respiratory function failure, multiple organ system failures, and eventually death.

A thoracostomach–airway fistula should be confirmed as early as possible. Once the diagnosis is confirmed, measures should be taken immediately to prevent gastric juice spill into the airway. Effective measures include maintaining a sitting position, gastrointestinal decompression, fasting (no solids and liquids), and a nasal jejunum nutrition tube for maintaining sufficient nutrition. To prevent gastric juice from spilling into the airway, the fistula can by physically blocked.

11.3.5 Gastric Motility Disorders

Bavry put forward the stomach gas expansion theory, which indicates that after the stomach is pulled up to the chest, blood supply, nerve control, and tension of the stomach becomes abnormal. The gastric mucous membrane is stretched thinly, which promotes gastric acid secretion; then peptic ulcer disease and stomach perforation occur, and a high level of gastrin is released; the vagus nerve is lost, and the bile reflux and gastric emptying processes are delayed. This prolongs the gastric acid and pepsin damage to the gastric mucosa and can cause ulcer perforation and a fistula.

11.4 Diagnosis

The majority of thoracostomach–airway fistulas occur after esophageal cancer surgery. The fistula can appear at different times after the surgery. It is characterized by a sudden and intense excitant choking cough and a burning sensation when in the supine position. These symptoms are not linked to eating. The symptoms lessen in the sitting position; thus the patient is forced to sit and is not allowed to lie down.

If the patient has a history of esophageal reconstruction (where the stomach takes the place of the esophagus), a history of three-dimensional radiotherapy for tumor residue or recurrence, and a sudden burning sensation and excitant choking cough when in the supine position and when not eating, a thoracostomach–airway fistula should be strongly suspected [3]. Differential diagnosis involves the exclusion of mediastinal lymph node metastasis oppressing a recurrent laryngeal nerve that causes swallowing dysfunction, aspiration, high esophageal stenosis, esophageal–tracheal fistula, esophageal anastomotic stricture, and/or fistula and other choking cough diseases. Oral iodine water dynamic esophageal radiography, chest MSCT, fiberoptic bronchoscopy, and/or gastroscopy can aid in accurate diagnosis.

11.4.1 Clinical Features

11.4.1.1 Choking Cough

Patients present with a sudden burning sensation and excitant choking cough. When breathing, there is a lot of gas in the airway and this enters the gastric cavity through the fistula, which results in stomach intake illusion, gastric lumen capacity expansion, and reflexive gastric juice secretion. At the end of inspiration, the lung volume expansion oppresses the stomach, acidic gastric juice spills into the alkaline environment of the tracheal bronchus, and the lung then generates a violent burning sensation and an intolerable excitant choke and cough. In the supine position, the stomach liquid spills into the tracheal bronchus more easily, thus aggravating the

choking cough. The sitting and standing position causes the stomach liquid to settle in the lower cavity of the stomach and gastric antrum and it does not easily enter the tracheal bronchus, and there is relief from the choking cough. This is the characteristic clinical manifestation of the thoracostomach–airway fistula, also called the "supine position burning and excitant choking cough syndrome." This syndrome cannot be cured by simply fasting. Inhibition of gastric juice secretion and gastrointestinal decompression are effective in treatment of this syndrome.

The syndrome of supine position burning and excitant choking cough includes the gastrointestinal and respiratory syndromes. The gastrointestinal syndrome includes excitant choking and coughing (caused by or aggravated after swallowing food and liquid), fear of eating, nutrition disorders, water electrolyte disorders, and other illnesses. The respiratory syndrome has nothing to do with eating but manifests as a burning sensation and excitant choke while in the supine position, gastric juice spills into the tracheal bronchus and lung tissue causing severe asthma, dyspnea, serious choking and coughing, an accumulation of a large amount of liquid or gastric contents, high fever, chills, being forced to sit, lung injury, refractory multiple lung infection, and a series of other pathological changes.

11.4.1.2 Lung Infection

Large amounts of acidic gastric juice spill into the alkaline environment of the tracheal bronchus and alveoli to produce complex chemical corrosion and lung injury. Gastric contents include saliva, food, and gastric juice (which has multiple digestive functions for protein and starch), causing injury to and permeability of the tracheal bronchus mucous membrane and alveolar endothelium to increase. A large amount of exudate in the pulmonary interstitium and alveoli creates a good medium for bacteria culture, and a large number of bacteria in food, the oral cavity, airway, and esophagus enter the lungs through the fistula and cause secondary multiple lung infection. Corrosive pneumonia interacts with the multiple pulmonary infection causing more and more bronchial and lung injury. This results in refractory pneumonia and a lung abscess. Once lung damage progresses into lobar pneumonia, the inflammation and infection are difficult to control.

11.4.1.3 Dyspnea

Acid stimulation from stomach acids in the lungs causes serious spasmodic bronchial asthma. Stomach acid and digestive enzymes corrode and damage a large number of alveolar endothelial cells, and cause alveolar interstitial and pulmonary capillary injury. This damage stimulates production of a large amount of exudate, which impacts pulmonary ventilation and air exchange. Secondary pneumonia aggravates the damage and dyspnea can occur. If acid in the airway is not treated, the oxygenation function can be impaired, which can lead to oxygen deprivation and respiratory function failure.

11.4.1.4 Fever

Lung injury is always related to lung infection; thus fever and chills are one of the common symptoms. But if the patient's body is malnourished and in a poor condition, it will be too weak for a body response and the temperature won't rise. In this case, the patient probably has severe dyscrasia and/or a severe infection.

11.4.1.5 Expectoration

When excessive sputum is present, it can present a variety of characteristics. It is often accompanied by a large amount of gastric juice. Without fasting, sputum may carry food ingredients.

11.4.1.6 Dyscrasia, and Fluid and Electrolyte Imbalance

When a patient has a thoracostomach–airway fistula, there are many complications that take energy from the patient and lead to poor overall health. This includes severe water electrolyte disorders, malnutrition, nutrition failure, and cachexia.

11.4.2 Imaging

11.4.2.1 Chest X-Ray

Once an excitant choking cough occurs, a chest X-ray plain film is preferred for the patient. The images of the X-ray will most likely show increased lung markings and multiple patchy cloud-like shadows. Lesions are also present according to the location of the fistula: the thoracostomach–tracheal fistula and thoracostomach–carina fistula show up as multiple distributions of lesions in both lungs; the thoracostomach–left main bronchial fistula has lesions in the left lung; the thoracostomach–the right main bronchial fistula shows lesions in the right lung; the thoracostomach–middle bronchial fistula manifests as right lower lung lesions. A serious or long history of cloud-like shadow lesions can advance to multiple segmental or lobar solid lesions, often in the lower lobe. Different amounts of pleural fluid may exist. If a small amount of pleural effusion exists in the left lung, pleural thickening after transthoracic esophageal surgery should be considered.

If choking and coughing symptoms are worse in the supine position and improve when the patient is sitting and standing, a thoracostomach–airway fistula should be strongly suspected. A chest MSCT or fiber gastroscope should be performed as soon as possible for diagnosis.

11.4.2.2 Upper Gastrointestinal Contrast

Traditional diagnosis of the digestive tract fistula relies on barium meal testing, where contrast agent overflows to the digestive tract to show a positive diagnosis of a digestive tract fistula. Once the barium sulfates, especially barium mucilage, spill into the mediastinum, pleural cavity, bronchi, or alveoli, it is difficult to discharge out of the body. Oral barium meal carries a large number of bacteria from the oropharyngeal and esophagus area. Bacteria mixing with the barium deposit in the alveolar area will result in refractory pulmonary infections.

For diagnosis of a digestive tract fistula, an oral 30% concentration water iodine contrast agent for upper gastrointestinal radiography should be used. The contrast agent passes through the esophagus into the stomach cavity, then spills into the airway through the fistula. Thereafter, an intense choking cough spreads the contrast agent all over the lungs. The bronchial tree shadow in one or both lungs shows up on the imaging. A severe choking cough makes the contrast agent spill into the airway too fast and a static X-ray image might not capture the moment when the contrast agent moves through the fistula. Digital dynamic imaging used with a video camera can capture the moment when the contrast agent moves through the fistula. Dynamic imaging can observe how the contrast medium spills from the stomach into the airway, and displays the location of the entrance (on the stomach side) and exit (on the airway side) of the fistula. Generally, it is difficult to measure the size of the fistula, but the flow rate and amount of contrast agent flowing through can be used to speculate the size of the fistula. Gastrointestinal radiography is not the first choice for diagnosis of a thoracostomach–airway fistula.

In all choking cough patients, barium and barium mucilage should not be used for upper gastrointestinal contrast and imaging. Instead, it is recommended to use 30% water-soluble iodine. Water iodine in the bronchi and alveoli can be completely absorbed, while barium and barium mucilage will remain permanently in the bronchi and alveoli surface. Secondary alveolar sedimentary pneumonia is difficult to cure (Fig. 11.3). Barium gastrointestinal radiography is strictly prohibited for the diagnosis of a thoracostomach-airway fistula.

11.4.2.3 Chest MSCT

If the syndrome of supine position burning and excitant choking cough syndrome is present, a thoracostomach-airway fistula is suspected. The first step in diagnosis is a chest MSCT (plain scan). The benefits of using a chest MSCT scan include not needing to use a contrast agent (thus there is no need for the patient to swallow contrast agent and stimulate choking and coughing),

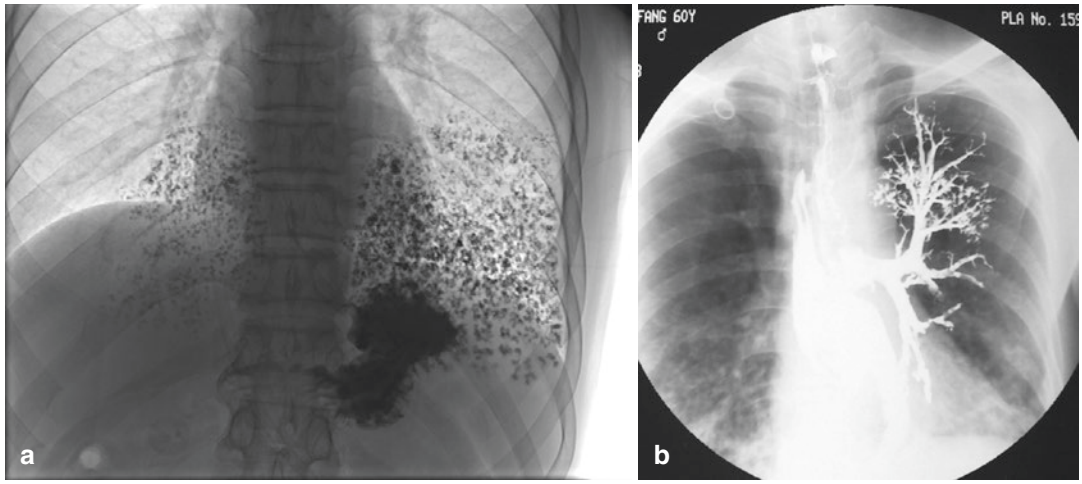

Fig. 11.3 (**a**) Barium sediment in both lower lobes after barium meal examination. (**b**) Left bronchus tree casted by barium

obtaining a clear image regardless of the patients' agitation, and there is no aggravation of lung inflammation and lung injury [4]. Before the chest MSCT, it is recommended that the patient undergoes gastrointestinal decompression, where the gastric contents are continuously pumped out and the stomach fluid is emptied to prevent stomach contents flowing into the tracheal bronchus when patient is in the supine position. Then the patient is ready to receive the chest MSCT examination as coughing will be prevented and imaging won't be affected.

If the chest MSCT image of the lung window shows two pulmonary diffuse interstitial fibrosis, several different sizes of wedge or flake shadows in the pulmonary segments or lobe. The diseased lung segment and lobe do not narrow and air bronchogram signs can be seen in the consolidation tissue. Generally, the fistula can be clearly seen in the lung window; but smaller, tilted or distorted fistulas are covered in the pulmonary window because of the partial volume effect.

The mediastinal window shows the fistula more clearly, both the location and size of the fistula and the positional relationship between the fistula and the airway. Patients with poor nutrition have insufficient fat tissue for setting off the mediastinum, and the stomach and trachea bronchial wall is thin. In this condition, the conventional mediastinal window (window width 400 HU, window level 40 HU) is likely to show false positive signs of the fistula because of the partial volume effect. To accurately display the fistula and accurately measure the tracheal bronchus diameters, it is recommended to use the special mediastinal-fat window (window width 400 HU, window level −50 to −100 HU) as it displays the mediastinum structure and the fistula between the gastric system and the airway in a more accurate manner. This window avoids a false positive and a false negative result and accuracy is more than 86% (Fig. 11.4). In addition, unilateral or bilateral pleural effusion and pericardial effusion can also be seen on the image [5, 6].

Chest spiral CT scans visually display the fistula. This type of imaging should be the first choice of diagnosis method for a thoracostomach-airway fistula. It presents the chest conditions in detail and can be used to analyze the fistula's anatomic relationship with the adjacent structures. This type of scan also allows for the accurate measurement of the tracheal/bronchial diameter and provides detailed data for individualized tracheal stenting and other interventional therapy (Fig. 11.5).

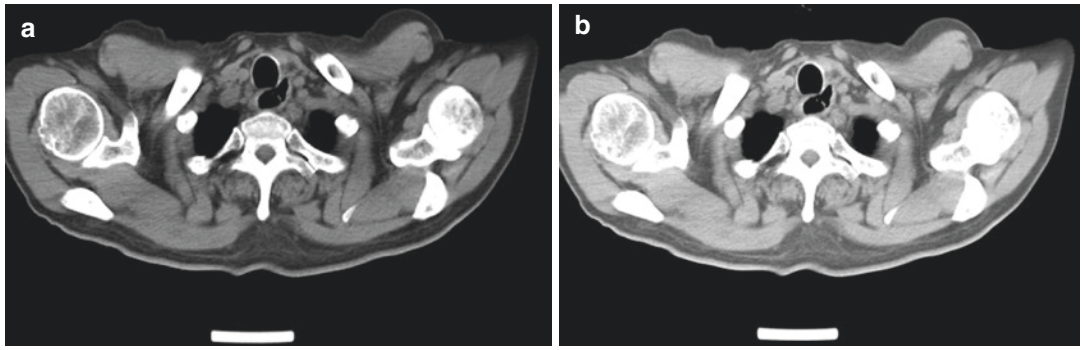

Fig. 11.4 Image of thoracostomach-airway fistula. (**a**) Mediastinal window shows (window width 400 HU, window level 40 HU) suspected fistula between thoracic stomach and trachea; (**b**) fat window (window width 400 HU, window level −50 HU) shows blurry fistula between thoracic stomach and trachea

11.4.3 Endoscopy

Before performing fiber endoscopy, such as chest MSCT, we should first undertake gastrointestinal decompression. Lying down for the scan can cause severe coughing and the examination can be hard to perform if decompression is not performed.

11.4.3.1 Fiber Gastroscopy

An electronic fiber gastroscope is inserted through the residual esophagus, gastroesophageal anastomosis, and into the thoracic stomach. The operator will be able to see how the stomach anterior wall has lost integrity and that there are different sizes and shapes of holes, namely fistulas. If the fistula is caused by tumor invasion or tumor recurrence, there might be white furry, bumpy, and irregular mucosa. Along with the breath, the fistula can have bubbles from the tracheal bronchus. If the fistula is large, airway cricoid cartilage can be seen via the gastroscope. Endoscopy can be introduced into the tracheal bronchus and the fistula diagnosis confirmed (Fig. 11.6).

11.4.3.2 Fiber Bronchoscopy

An electronic fiber bronchoscope passes through the throat into the trachea and bronchi, and the posterior wall of the tracheal bronchus can be checked for a fistula. There will be mucosal hyperemia and edema found surrounding the fistula. If the fistula is caused by a tumor invasion or recurrence, there will be bumpy and irregular mucosa around the fistula and a gastric mucosa fold can be seen via bronchoscopy; thus the diagnosis is confirmed. With fiberoptic endoscopy, we can carry out a biopsy of the tissue around the fistula in order to clarify the pathological reasons of the fistula (Fig. 11.7). After diagnosis, it is recommended to conduct a tracheal bronchus washing treatment by endoscope: inject saline or antibiotic saline into each bronchial lobe, drain the gastric juice and inflammatory exudate, alleviate acid corrosion, and promote pneumonia recovery [7].

11.4.4 Types of Fistulas

Classification of the thoracostomach–airway fistula is based on the location of the fistula. The "supine position burning and excitant choking cough syndrome" is classified into the following eight types of fistula.

11.4.4.1 Thoracostomach–Trachea Fistula

The fistula connects directly with the trachea. The fistula occurs after upper thoracic esophageal carcinoma surgery. The anterior wall of the thoracic stomach is joined directly to the poste-

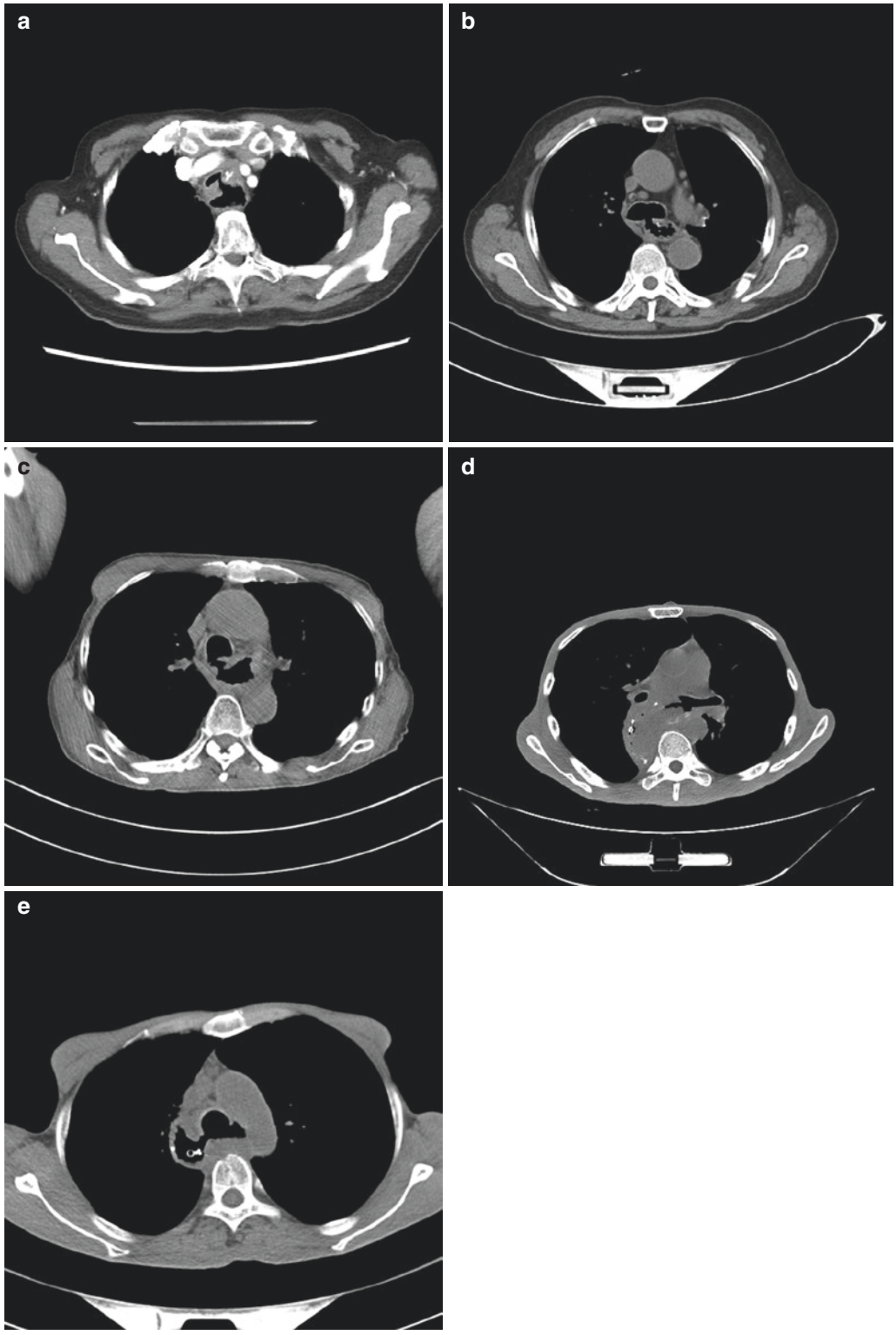

Fig. 11.5 Several kinds of thoracostomach–airway fistula, CT image. (**a**) Thoracostomach–tracheal fistula; (**b**) thoracostomach–carina fistula; (**c**) thoracostomach–right main bronchial fistula; (**d**) thoracostomach–left main bronchial fistula; (**e**) thoracostomach–mediastinal–tracheal fistula

rior wall of the trachea. The upper border of the fistula is at least 20 mm from the glottis and the inferior border is at least 20 mm from the carina.

11.4.4.2 Thoracostomach–Carina Fistula

The thoracostomach fistula connects with the carina and is secondary to middle thoracic esophageal carcinoma surgery. The gastric anterior wall and the posterior or side wall of the carina are connected with each other. The distance between the fistula and carina crest is less than 2 cm.

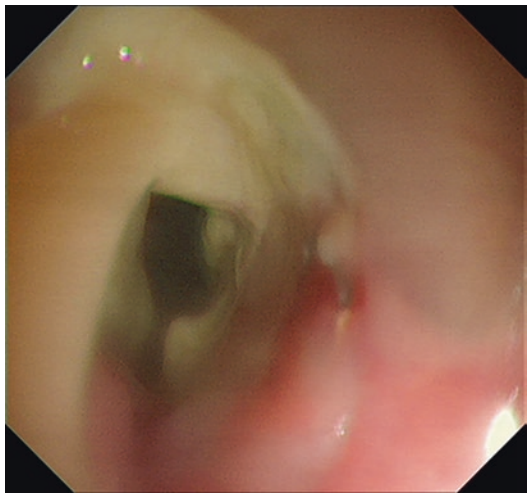

Fig. 11.6 Fiber gastroscope images of thoracostomach–airway fistula

11.4.4.3 Thoracostomach–Right Main Bronchus Fistula

The thoracostomach fistula connects with the right main bronchus and is secondary to middle thoracic esophageal carcinoma surgery. The gastric anterior wall and the posterior or inferior posterior wall of the right main bronchi are connected with each other. Because the length of the right main bronchus is short, stenting is more complicated.

11.4.4.4 Thoracostomach–Left Main Bronchus Fistula

The thoracostomach fistula connects with the left main bronchus and is secondary to middle thoracic esophageal carcinoma surgery. The gastric anterior wall and the posterior or inferior posterior wall of the left main bronchi are connected with each other.

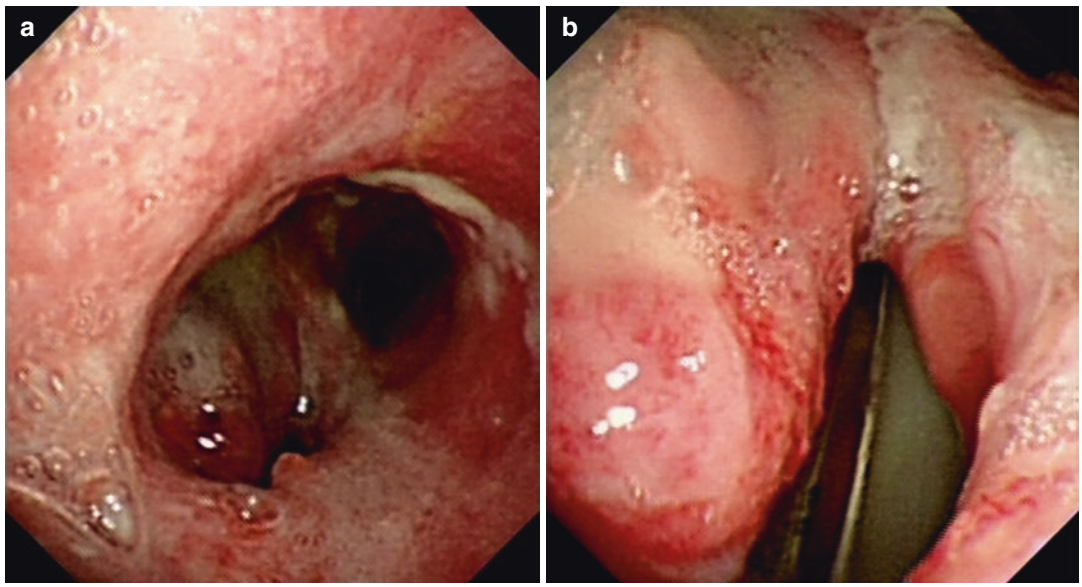

Fig. 11.7 Fiber bronchoscopy images of thoracostomach–airway fistula. (**a**) Fistula on the posterior wall of trachea; (**b**) gastric tube can be seen through the fistula

11.4.4.5 Thoracostomach–Right Middle Bronchus Fistula

The thoracostomach fistula connects with the right middle bronchus and is secondary to middle-lower thoracic esophageal carcinoma surgery. The gastric anterior wall and the posterior or inferior wall of the right middle bronchus connect with each other.

11.4.4.6 Thoracostomach–Lobar Bronchus Fistula

The thoracostomach fistula is connected with any one of the lobar bronchi, including the left, right upper, middle, and lower lobar bronchi.

11.4.4.7 Thoracostomach–Bronchiole – Pleural Cavity Fistula

The stomach fistula first perforates the mediastinal parietal pleura and connects with the pleural cavity, then perforates the visceral pleura and connects with the alveoli and peripheral alveolar bronchioles.

11.4.4.8 Complex Thoracostomach–Airway Fistula

The fistula types that cannot be classified as one of the seven types above include:

VII-a: multiple fistula, two fistulas or more.
VII-b: fistula connects with two or more parts of the airway.
VII-c: presents typical "supine position burning and excitant choking cough syndrome", but the fistula cannot be determined on image examination. The tract of the fistula travels for a long way through the mediastinum.

11.5 Treatment

Serious corrosive lung damage, intractable pulmonary infection, and eating disorders caused by a thoracostomach–airway fistula are the main causes of death for this condition [1]. The severity and stubbornness of the lung injury and infection lies in the fact that regardless of whether the patient eats or not, the stomach has sustained automatic secretion of peptic gastric juice and this continuously passes through the fistula to spill into the airway and cause sustainable and irreversible, corrosive, peptic lung injury.

Traditional internal medicine conservative treatment involves fasting water, inhibition of gastric acid secretion, and lung infection control measures. Treatment with medicine cannot completely stop the gastric juice spilling into the tracheal bronchus so its effect is limited. Surgical repair of the fistula is not effective because of the patient's poor physique and tolerance, severe infection around the fistula, radiation damage, or chance of surgical failure where the fistula continues to exist [6].

In recent years, with the constantly emerging new technologies of interventional therapy, coated stent sealing of fistulas has been widely used. Although the gastric cavity has large variability and the stent cannot be fixed, the stent can be placed on the other side of the fistula, namely the airway, to seal the fistula. Airway stent placement technology progression and improvement of the material and knitting craft enables tracheal or bronchial stents to be used more successfully in clinical application and comprehensive therapy. Airway stenting has obtained the ideal curative effect.

11.5.1 Medicine

Conservative treatment includes fasting, inhibition of gastric acid secretion using drugs, continuous gastrointestinal decompression, intravenous rehydration, and nutritional support treatment.

11.5.1.1 Fasting

Without oral intake of food and water, there is no swallowing movement. After eating and swallowing, gastric juices move through the fistula into the tracheal bronchus, causing corrosive damage to the bronchus and lung tissue.

11.5.1.2 Inhibit Gastric Acid Secretion using Drugs

Administer acid inhibitors via intravenous delivery or via the nutrition tube to reduce gastric acid secretion, reduce gastric juice volume passing

through the fistula, relieve the choking cough, and reduce the amount of bronchial and lung damage.

11.5.1.3 Gastrointestinal Decompression

Insert a gastric decompression tube through the nose for negative pressure suction of the liquid in the stomach, aim to empty the stomach, reduce the gastric acid spilling into the tracheal bronchus, reduce the irritating choking cough, reduce the bronchus and lung injury, and control lung inflammation and infection.

11.5.1.4 Nasal Jejunal Nutrition

Insert the nutrition tube through the nasal cavity, pharynx, esophagus, stomach, and duodenum to the jejunum to maintain adequate nutrition. Enough nutrition support is essential because the patient is fasting, undergoing gastrointestinal decompression, has lung inflammation, and massive consumption. Parenteral nutrition is expensive and inconvenient, whereas jejunum nutrition is low cost and easy to use. Calculate the total daily liquid requirements, total quantity of heat, and other elements according to the body surface area. Compound the nutrient solution and inject this through the jejunum nutrition tube several times a day.

11.5.1.5 Sitting and Standing Position

Remain in the sitting and standing position as long as possible to reduce the gastric juice overflow into the tracheal bronchus, ease the excitant choking cough, and reduce lung damage.

Jian Xie reported three cases of non-radiation thoracostomach–airway fistulas, including two cases treated with conservative treatment and one case treated by surgical repair. All three cases were cured completely and this shows that non-radiation thoracostomach–airway fistulas should first take the conservative treatment option. Thereafter, surgical treatment may be chosen when the conservative treatment is invalid and the patient can tolerate such procedures. Jun-Feng Wang reported one case of a thoracostomach–airway fistula after esophagectomy that was cured by using tracheal stents, but he believed that the patient could not tolerate general anesthesia and major surgery again. Therefore, conservative treatment should be the first choice. If the conservative treatment is invalid, choose tracheal coated stents as the second choice.

Effective medical treatment measures include fasting, inhibition of the secretion of gastric acid, gastrointestinal decompression, and nasal jejunum nutrition. It is very important to ease the excitant choking cough to reduce lung injury and infection, maintain normal nutrition and water and electrolyte balance and even prevent death. After diagnosis, especially if the fistula is secondary to radiation treatment, treatment should start as early as possible before using a coated stent.

11.5.2 Surgery

Surgery should be performed carefully when the fistula is secondary to cancer surgery or a recurrent tumor receiving radiotherapy after esophagectomy. Surgical methods include direct suture of fistula and sealing the fistula with muscle flap transplantation.

Okuyama treated one case of a thoracostomach–airway fistula after esophagectomy using two successful pectoralis major muscle flap transplantations to repair the fistula. The fistula healed and epithelization was seen. It was concluded that muscle flap transplantation is effective for patients in good physical condition. However, successful surgery treatment of a fistula that was secondary to radiotherapy was not reported.

Many patients have serious lung infections, nutritional disorders, a depleted physical condition, and cannot tolerate surgery. Radiotherapy causes the loss of tissue regeneration ability and after surgical repair, the fistula is difficult to heal.

Use of a coated stent has become an effective treatment of various kinds of fistulas. Due to the large stomach cavity, especially the gastric lumen, the diameter varies hugely during systole and diastole. It is difficult to design an appropriately sized and shaped stent for the gastrointesti-

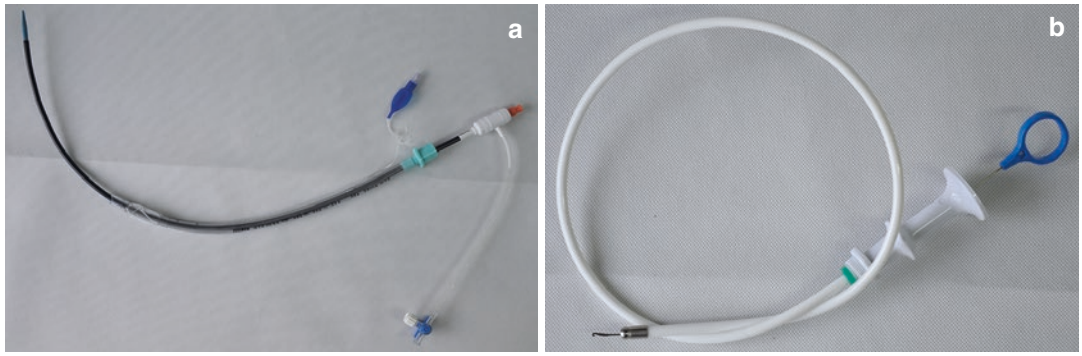

Fig. 11.8 Tubal airway stent inserting instrument. (**a**) A 14 F sheath is slipped over a trachea cannula. (**b**) Stent retrieval hook

nal tract. The relationship between the adjacent thoracic stomach and tracheal bronchus changes after the operation: the stomach and airway are organized and fixed as one structure. Because the tracheal bronchus diameter is constant, an airway stent can successfully seal the fistula.

New airway stents have been designed in recent years. Due to the progression of new technology in materials and knitting craft, airway stents have been more widely applied in clinical treatments. In interventional radiology theory, to seal the fistula between the stomach and airway and prevent gastric juice spilling into the airway, the fistula should be sealed from the stomach side, but it is difficult to completely seal the fistula using a stomach stent. However, the stent can be applied on the airway side and this is regarded as an acceptable treatment. In the next section, we are going to introduce the steps and methods of interventional treatment in detail according to different types of thoracostomach–airway fistulas.

11.6 Intervention Treatment

11.6.1 Thoracostomach–Trachea Fistula

Thoracostomach–trachea fistula belongs to type I fistula.

11.6.1.1 Instrument Preparation

Interventional instruments and customized stent choice are presented below.

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150 cm), 0.035-in. stiff guidewire (180–260 cm), tubal partly or totally coated stent (Micro-Tech, Nanjing or taewoong, Korea), stent retrieval hook, sputum suction tube, 14 F long sheath, tracheal intubation instruments (Fig. 11.8).

Choice of Stent

According to the chest MSCT cross-sectional (mediastinal-fat window) image, measure the airway diameter (longitudinal and transverse diameter) and customize the partly coated or fully coated tubal stent. Stent diameter should be 15–20% bigger than the corresponding airway and the length of the coated part of the stent should extend at least 15 mm beyond both ends of the fistula [8–10].

11.6.1.2 Preoperative Preparation

Laboratory Examinations

Check blood for routine tests, liver and kidney function, electrolytes, blood coagulation tests, and infectious diseases, and conduct a sputum bacterial culture and drug-sensitive test to select appropriate anti-infection drugs.

Gastrointestinal Preparation

After diagnosis, fast the patient, forbid any swallowing, perform gastrointestinal decompression and jejunum nutrition as soon as possible (if possible using a single multifunction catheter),

enhance enteral nutrition, reduce the amount of gastric juice spilling into the airway, correct the water electrolyte disorder, and improve the cardiopulmonary function to improve the patient's ability to tolerate the upcoming procedure.

Administer an intramuscular injection of antacid agents or administer via the jejunum nutrition tube. This will reduce gastric juice production and gastric acid secretion.

Premedication

At 10–30 min before the operation, 10 mg diazepam should be intramuscularly injected to reduce tension. Administer anisodamine 10 mg via intramuscular injection to inhibit digestive gland secretion. Administer hormones when anoxia or serious breathing difficulties occur.

11.6.1.3 Tubular Stent Placement Procedure

Patient Position

The patient should remove all clothes that have X-ray foreign bodies (such as metal buttons), lie on the DSA examination table in a supine position, remove the pillow, neck and shoulders slightly raised, head hypokinetic and turned to the right side about 20–30°. Cover with a large surgical drape, fix a nasal oxygen tube, connect ECG monitoring, administer lidocaine throat anesthesia spray, insert a mouth gag and have a vacuum extractor ready to clear airway and oral secretions as necessary.

The C arm is angled to the left at 20–30° (with the patient's head angled right at 20–30°, this is equivalent to the body angled right at 50°), adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Transcatheter Radiography

Under fluoroscopy, insert the mouth gag, and a hydrophilic guidewire and catheter are inserted through the mouth, oropharynx, aryngopharynx, larynx vestibule, glottis, glottis inferior vena, tracheal, and carina region. Fix the catheter and pull out the guidewire. Through the catheter, rapidly inject 1% lidocaine 2–3 ml, adjust the position of the catheter tip toward the tracheal fistula, and through the catheter, quickly inject 30–40% iodine water contrast agent 3 ml to display the tracheal bronchus on angiography. Use this to determine the location and size of the tracheal fistula and the distance from the glottis and carina region.

Insertion of Stiff Guidewire

After completion of radiography, introduce a hydrophilic guidewire. The guidewire and catheter pass over the fistula into the left or right main bronchus to a depth of at least 20 mm. Remove the guidewire. Administer a transcatheter injection of 30% of the iodine contrast agent 1 ml to confirm that the catheter is in the main bronchi. Exchange to a stiff guidewire and insert deep into the main bronchus, making sure that the distal region is within the effective visual field of the X-ray fluoroscopy. The assistant should firmly fix the stiff guidewire and mouth gag and maintain the position of the guidewire and mouth gag.

Insertion of a Stent Delivery System

A stent delivery system is inserted using the stiff guidewire. Keep the stiff guidewire in the main bronchi position and slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When you encounter resistance and the patient appears to have a choking cough response and agitation, the assistant or nurse should monitor closely. Ask the patient to inhale deeply and keep the patient's body in a fixed posture; the glottis opens when deep inhaling is performed. At this time, push the delivery system to above the carina. Stop the operation with the delivery system and guidewire position fixed. The operator and the patient rest for 30–60 s.

Placement of the Stent

Under fluoroscopy, the location of the stent should be centered over the fistula. Firmly hold the stiff guidewire and the posterior handle of the stent delivery system in front of the operator's chest, pull back the front handle and release a third of the stent. Confirm on the fluoroscope that the distal end of the stent is below the fistula by at least 20 mm, then release the middle third of the

stent, confirm again that the stent is covering the fistula, then quickly release the stent completely.

Keep the stiff guidewire in position and pull out the stent delivery system smoothly.

Re–radiography

Introduce the catheter using the guidewire and inject 30% water iodine contrast agent 3 ml to confirm if the fistula is completely sealed, the stent is placed accurately, the stent has expanded fully, and the carina and main bronchus are unobstructed. If necessary, adjust the stent position.

Sputum Suction

Introduce a stiff guidewire and then, using the guidewire, a suction tube is inserted into the left and right main bronchi. Thoroughly suction the residual contrast agent and sputum. At the same time, slap the patient's back to dislodge sputum until the lung rales disappear and blood oxygen saturation reaches or approaches 100%.

During the operation, closely observe whether there is blood in the phlegm, difficulty in breathing, or low blood oxygen saturation. If present, promptly clear mouth secretions (Fig. 11.9).

11.6.1.4 Postoperative Management

Aerosol Inhalation

Aerosol inhalation should be administered twice a day after stenting (saline 10 ml + lignocaine 5 ml + ambroxol 30 mg + amikacin 0.2 g), for 4–6

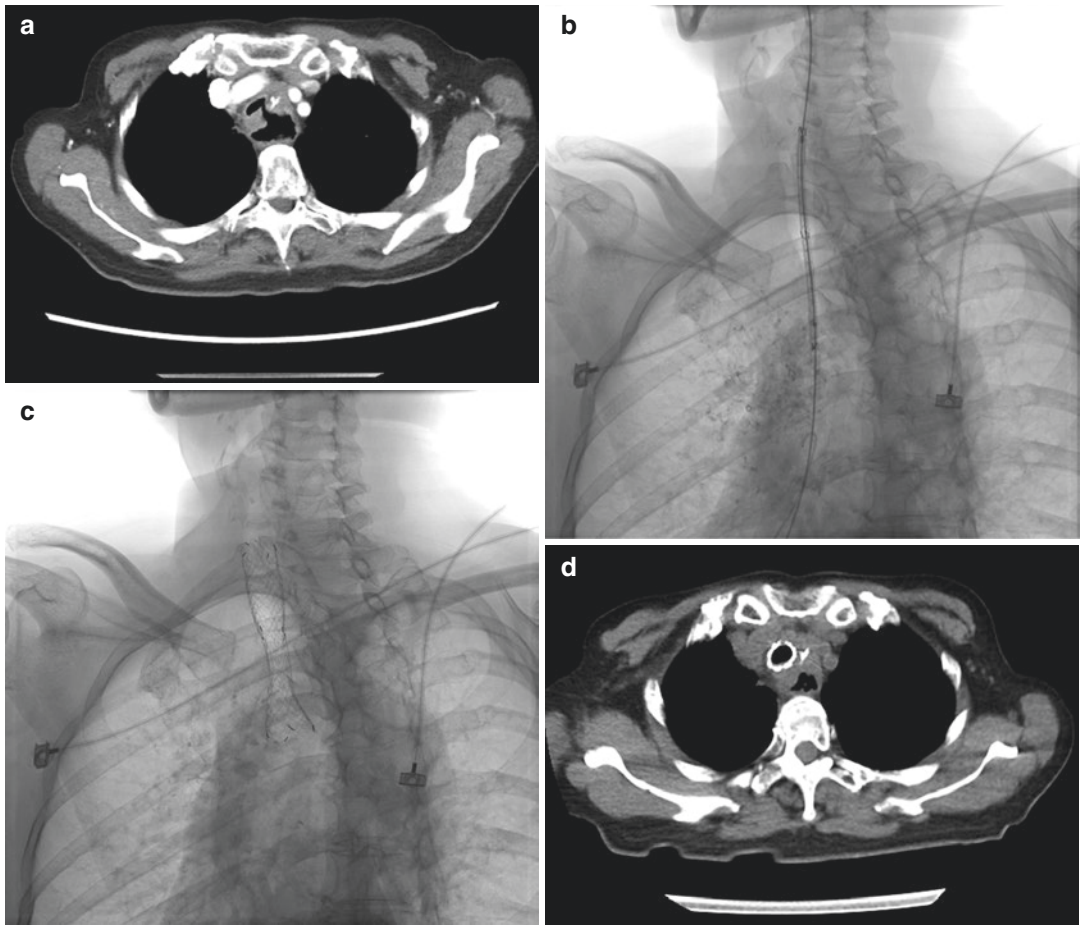

Fig. 11.9 Stenting procedure for thoracostomach–airway fistula. (**a**) Preoperative chest CT shows thoracostomach–airway fistula. (**b**) Tubal coated airway stent is inserted using a guidewire. (**c**) Stent placed. (**d**) CT shows the fistula sealed by stent

weeks, to prompt sputum discharge and reduce stent foreign body reaction and inflammation.

Expectoration

Regularly roll the patient over to change position, pat their back to help discharge the infectious sputum in the lungs. This patting will not cause stent displacement. Encourage the patient to cough and expectorate hard as this will prompt lung any inflammation and infection to heal. To facilitate sputum discharge, use expectorants, sputum thinners, etc.

Antibiotics

According to the results of the bacterial cultures, choose sensitive anti-infection drugs to control the lung infection. Perform regular fiber bronchoscope bronchial lavage, if necessary, to remove endobronchial mucus and pus. High concentrations of sensitive antibiotics can be administered locally in the bronchi.

Nutritional Support

Continue the use of the jejunum nutrition tube to enhance enteral nutrition while slowly increasing food intake through the mouth. If eating does not stimulate the choking and cough, the jejunum nutrition tube can be removed.

11.6.1.5 Complications [9]

Hemorrhage

It is common to find blood in the phlegm after airway stenting. This small amount of blood in the sputum will generally stop 10 min after the operation and needs no treatment. If there is continued hemoptysis, especially with a large amount of blood, blood masses, and a little sputum, then inject 2–3 ml of 1:1000 adrenaline saline via catheter. This causes the tracheal mucosa vessels to constrict and the hemoptysis will stop immediately. This treatment is successful even if a small peripheral artery is ruptured.

Bucking

Bucking (straining) is caused by stimulation of the tracheal stent and deep airway and a large amount of sputum gushing out of the trachea. If the patient has an irritating cough, administer a local injection of 1–2% lidocaine 2–3 ml through the catheter to anesthetize the sensitive tracheal intima. If large amounts of sputum gush out of the trachea, slap the patient's chest and back and encourage the patient to forcibly cough phlegm. If the patient is weak and cannot cough, introduce a sputum suction tube into the airway using the guidewire, which should be deeply intubated into the left and right bronchial; clear the sputum and promote deep sputum discharge out of the bronchi and alveoli. If the sputum is too thick to suck out, a fiberoptic bronchoscopy lavage can be conducted. Aim to thoroughly remove all excess sputum and prevent phlegm retention.

Asphyxia

If the stent seals the fistula successfully, the integrity of the airway is restored and the patient can breathe normally and efficient oxygenation exchange can occur. If dyspnea occurs immediately after stent implantation, under fluoroscopy and airway radiography determine whether the coated stent has slid down and blocked both sides of the main bronchus. If found to be so, immediately introduce the stent retrieval hook to adjust the stent location or remove the stent.

Breathing should be improved after stent placement but if a sudden difficulty in breathing occurs after a severe cough, and after stent displacement is excluded, check if there is excessive sputum obstructing the large airway. On both sides of the chest, a wet lung rale will be audible. If this is the case, introduce a sputum suction tube immediately into the left and right bronchi deeply and remove the sputum (Fig. 11.10).

Insufficient Sealing of Fistula

To confirm if the stent has sealed the fistula successfully, administer 30% iodine contrast agent orally and if the contrast agent passes from the thoracic stomach into the airway, the stent has not completely sealed the fistula. First check whether the stent is located across the fistula and whether both ends of the coated part are long enough (extending more than 15–20 mm beyond the fistula). Second, check if the stent diameter is

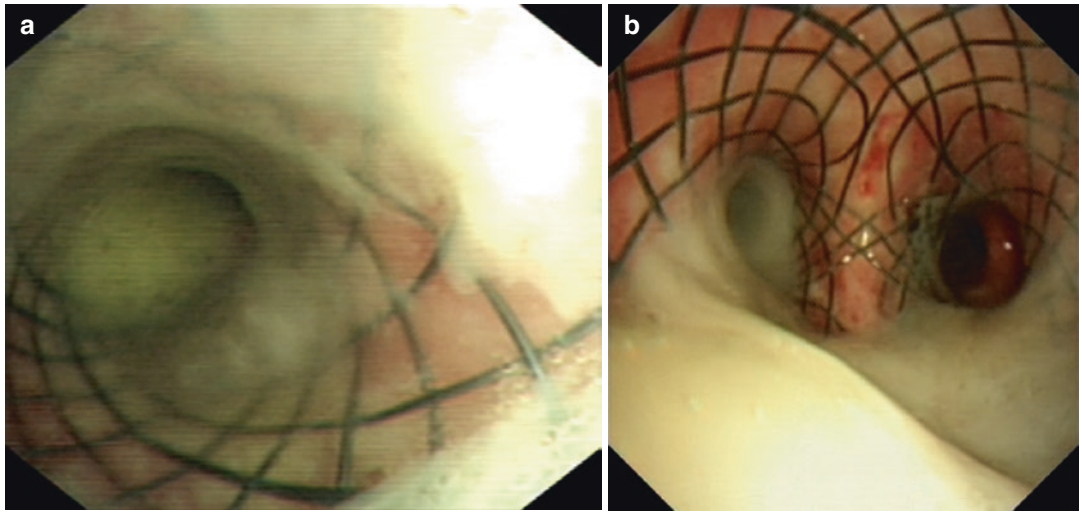

Fig. 11.10 Picture of bronchus intubation and sputum suction (**a**) the massive sputum obstruct the large airway (**b**) the massive sputum obstruct the left and right bronchial

large enough (15–20% larger than the normal trachea diameter). The stent should have enough expansion force to maintain sufficient adherence. If the stent does not cover the fistula fully, adjust the stent position. If the stent does not adhere to the airway wall sufficiently, replace with a larger diameter stent. A small residual fistula can disappear in a few days and does not need to be treated. This is due to the foreign body stimulation, inflammatory reaction, endometrial hyperplasia, and tracheal mucosa edema, which lead to the continuous expansion force of the stent that can make the surrounding tissue and stent push against each other and this closes the fistula.

Stent Not in Place or Dislocation

If the stent is not placed at the ideal location, the fistula is not fully sealed or the main bronchus is blocked. Excessive coughing can also move the stent. Adjust the stent location or remove the stent and replace with a new stent.

Stent Obstructed by Sputum

This is the most common complication of an airway coated stent. The stent completely covers the trachea epithelium and epithelial cilia movement and the mucus blanket function are completely lost. Expectoration relies solely on coughing and if the patient has a weak cough, sputum will adhere to the stent and forms a sputum bolt, which will severely block the airway lumen and cause tracheal stenosis with the patients experiencing a difficulty in breathing. Use fiber bronchoscopy to remove the sputum bolt as soon as possible and restore endotracheal cavity flow. Then administer medical treatment and nursing methods such as atomization inhalation, expectorants, and expectoration training to avoid phlegm retention.

Stent Obstructed by Granulation Tissue

Any physiological tube cavity in the body produces excess endothelial cell proliferation after the placement of stents. As an open cavity with stent stimulation and inflammatory reaction, airway endothelial cell hyperplasia is more obvious. Metal stents cause hyperplasia for the full length of the stent and even more at both ends. The coated part of coated stents hardly causes any hyperplasia, but both ends of these stents tend to form scar stenosis. Mild cell proliferation without affecting normal breathing does not require treatment. But severe stenosis affects breathing and expectoration and this should be treated. Generally, endoscopic ablation is used to treat hyperplasia. The ablation could be microwave, radio frequency, laser, other thermal ablation, or cryoablation. Studies show that cryoablation treatment is best.

Thoracostomach–airway fistula patients who undergo tracheal stenting, especially with a coated stent, have a lower incidence of excessive granulation tissue hyperplasia than that of benign and malignant airway stenoses. We speculate that factors such as a local mixed infection or gastric acid can limit excessive proliferation of endothelial cells.

Fistula Enlarged

A variety of factors damage the wall of the stomach, which perforates and causes a new thoracostomach–tracheal fistula. Corrosion by stomach acid causes fistulas to enlarge. Especially the thoracostomach–airway fistula after radiation treatment. The fistula and surrounding tissues receive an excessive dose of radiation, which causes the loss of tissue growth and regeneration, resulting in the slowed healing of the fistula, slow necrosis, and subsequent enlargement of the fistula.

When customizing a stent, choose a longer stent (the length of the coated part of the stent should extend at least 20 mm beyond both ends of the fistula) to allow for the possibility of fistula enlargement. After stenting, administer acid inhibitory drugs and anti-ulcer treatment to protect the fistula from enlarging and to promote healing. Once the fistula becomes enlarged and the stent sealing has failed, insert a longer stent.

Fever and Lung Infection

With a thoracostomach–airway fistula, a large amount of gastric juice spills into the tracheal bronchus and lung tissue. This stimulates bronchospasm, affects normal breathing and secretions (expectoration), and causes corrosion damage to the bronchial and alveolar epithelium and deep lung tissue. A large amount of inflammatory exudates form interstitial and alveolar edemas with the edema fluid creating a very good bacterial growth environment. This can result in segmental and lobe infection, or multiple infections, etc. After bacterial culture, choose sensitive anti-infection drugs and conduct lung lavage therapy on a regular basis.

It is important to diagnose a thoracostomach–tracheal fistula early and this should be followed by early treatment (such as fasting water and gastrointestinal decompression). This will assist in the prevention or reduction of lung corrosive injuries and secondary infection [10].

11.6.2 Thoracostomach–Carina Fistula

Thoracostomach–carina fistula is a type II fistula.

11.6.2.1 Instrument Preparation

Interventional instruments and customized stent choice are outlined below.

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F sheath, Y-shaped (appropriate for the shape of the carina region) coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14 F long sheath, tracheal intubation instruments.

Choice of Stent

According to the chest MSCT cross-sectional (fat window, window width 400 HU, window length -50 HU) image, measure the trachea and both the main bronchi diameters (longitudinal and transverse diameter), customize the partly coated or fully coated Y-shaped integrated self-expanding metal stent. Stent parameters are as follows: stent diameter should be 15–20% bigger than the corresponding airway, the length of the trachea part of the stent should be 40–50 mm above the carina, the length of the right main bronchus part should be the same as the distance between the carina and right upper lobar bronchus opening, the length of left main bronchus part is 20–30 mm.

11.6.2.2 Preoperative Preparation

Laboratory Examinations

Check blood for routine tests, liver and kidney function, electrolyte levels, blood coagulation tests, and infectious diseases test. Conduct a

sputum bacterial culture and drug sensitive test to select appropriate anti-infection drugs.

Cardiopulmonary Function

Use an ECG to determine the cardiac function and use multi-functional physiological monitoring to estimate the pulmonary oxygenation function.

Imaging

Use chest MSCT scanning and make full use of the post-processing functions such as MPR and CPR to define the precise location, size, and surrounding tissue relationships. Use the imaging to define the lung inflammatory lesion distribution and judge the severity of the lung injury. Accurately measure the length and the diameter of the trachea and main bronchus to choose an appropriate stent.

Perform fiber bronchoscope and gastroscope, if possible, to understand the relationship of the thoracic stomach and tracheal bronchus and to remove endobronchial retention.

Gastrointestinal Preparation

After diagnosis, enforce fasting and forbid any swallowing. Perform gastrointestinal decompression and jejunum nutrition as soon as possible (using the interventional methods) to enhance the enteral nutrition, reduce gastric juice spilling into the airway, correct the water electrolyte disorder, and improve cardiopulmonary function to improve the patient's ability to tolerate surgery.

Premedication

At 10–30 min before the operation, administer 10 mg diazepam intramuscularly to reduce tension. Also inject anisodamine 10 mg to inhibit digestive gland secretion and decrease smooth muscle tension, thus making it easier for interventional operation.

If the patient suffers from serious lung inflammation, has poor respiratory function, and a low blood oxygen level, administer intravenous hormones (dexamethasone 10 mg, or methyl prednisolone 30 mg) to decrease the tracheal bronchus and lung exudation and inflammation, improve stress tolerance, and improve the patient's tolerance for intervention.

11.6.2.3 Y-Shaped Stent Placement Procedure

Patient Position

The patient should remove clothes that have X-ray foreign bodies (such as metal buttons), lie on the DSA examination table in a supine position, remove the pillow, have neck and shoulders slightly raised, head in hypokinesis and turned to the right (toward the operator) angled at 25–30°. Cover with a large surgical drape, fix nasal oxygen tube, connect ECG monitoring. The C arm is angled to the left at 25–30° (with the patient's head angled right at 25–30°, this is equivalent to the body angled to the right at 50°and this position shows the airway negative shadows more clearly), adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Administer lidocaine throat anesthesia spray, insert the mouth gag, and have the vacuum extractor ready to clear airway and oral secretions, as necessary.

Transcatheter Radiography

Under fluoroscopy, insert the mouth gag. A hydrophilic guidewire and catheter are inserted through the mouth, oropharynx, laryngopharynx, larynx vestibule, glottis, glottis inferior vena, and tracheal and carina region. Fix the catheter and pull out the guidewire. Through the catheter, rapidly inject 1% lidocaine injection 2–3 ml, adjust the position of the catheter tip toward the fistula. Through the catheter, quickly inject 30% iodine water contrast agent 3 ml to display the tracheal bronchus angiography. Use this to determine the location and size of the carina fistula and the location of both of the main bronchi and upper lobar bronchus. Choose the best radiography image for use as an operation map.

Insertion of Stiff Guidewire

After completion of radiography, introduce a hydrophilic guidewire. The guidewire and catheter pass over the fistula into the right lower bronchus. Use radiography to confirm the catheter's location and exchange to a stiff guidewire.

Using the same procedure, insert another stiff guidewire into the left lower bronchus. The two stiff guidewires are fixed in location.

An alternative operation method is as follows: insert a 9 F long sheath using the stiff guidewire to the lower part of the trachea or above the carina, pull out the inner core of the sheath. Introduce the guidewire and catheter through the sheath into the left lower lobar bronchus, exchange to a stiff guidewire and fix in position.

The two stiff guidewires should be marked differently to define which (left or right) bronchus each is located-in.

Insertion of Stent Delivery System

Under fluoroscopy monitoring, firmly fix the two stiff guidewires and hold them in position. The left and right bronchus parts of the Y-shaped stent are loaded on the left and right stiff guidewires, respectively. Connect the stent delivery system to high pressure oxygen. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The operator team should cooperate in the procedure, especially when fixing the stiff guidewires, keeping the patient's position unchanged, and maintaining a normal oxyhemoglobin saturation level.

Insert the stent delivery system using the stiff guidewires. Ensure the patient's head is in hypokinesis. Slowly push the delivery system through the oral cavity and pharynx cavity to the glottic area. When you encounter resistance and the patient shows a choking cough response, rotate the delivery system to make the two bronchi parts in the anteroposterior position fit the shape of the rima glottides. Ask the patient to breathe deeply and the glottis will open with deep inhalation. When the glottis opens, push the delivery system through to above the carina. Rotate the delivery system to make the left and right bronchus part of the stent correspond to the main bronchus, and make sure that the two guidewires are not twisted together. The golden mark on the delivery system should also be on the correct side.

Placement of Stent

Hold the stiff guidewire and the posterior handle of the delivery system, pull back the delivery system anterior handle to release the Y-shaped stent bilaterally (left and right main bronchus) at the lower part of trachea.

Keep the relative position of the two handles unchanged, fix the stiff guidewire, push the bronchus part into the left and right main bronchi. If you encounter resistance, this means that the bronchus part is completely within the main bronchi and the stent bifurcation has arrived at the carina. Fluoroscopy further confirms that the stent bifurcation is at the carina. Pause the operation with the delivery system and guidewire position fixed. The operator and the patient should rest for 30–60 s.

Fix the delivery system and guidewire. Rapidly pull the two bundled silk threads to completely release the bronchus part of the stent. Hold the posterior handle and quickly pull back the anterior handle to release the stent main body in the trachea. The Y-shaped stent is now entirely released. Wait for 1–3 min until the patient is breathing smoothly and the blood oxygen saturation is 90–100% and then slowly pull out the stent delivery system. Keep at least one stiff guidewire in place as a subsequent intervention operation pathway (Fig. 11.11).

If the patient is suffering from breathing difficulties, anoxic symptoms are aggravated, and the blood oxygen saturation declines, re-examine under the fluoroscopy to exclude stent distortion and folding or an unopened stent. Then consider a sputum block in the bronchus. Quickly remove the stent delivery system, replace with a sputum suction tube into the left and right bronchi, and suction repeatedly until the blood oxygen saturation rises to a normal level.

Re–radiography

Introduce the catheter through the guidewire to the carina region, inject 30% water iodine contrast agent 3 ml to confirm that the fistula is completely sealed, the stent is in the correct location, whether the stent has expanded fully, and both the upper lobar bronchi are unobstructed, etc.

At the same time, administer 30% iodine contrast agent 20–40 ml water to the patient orally to conduct esophagus and stomach radiography. Observe whether the contrast agent moves through the fistula to spill into the tracheal bronchus and confirm complete stent sealing.

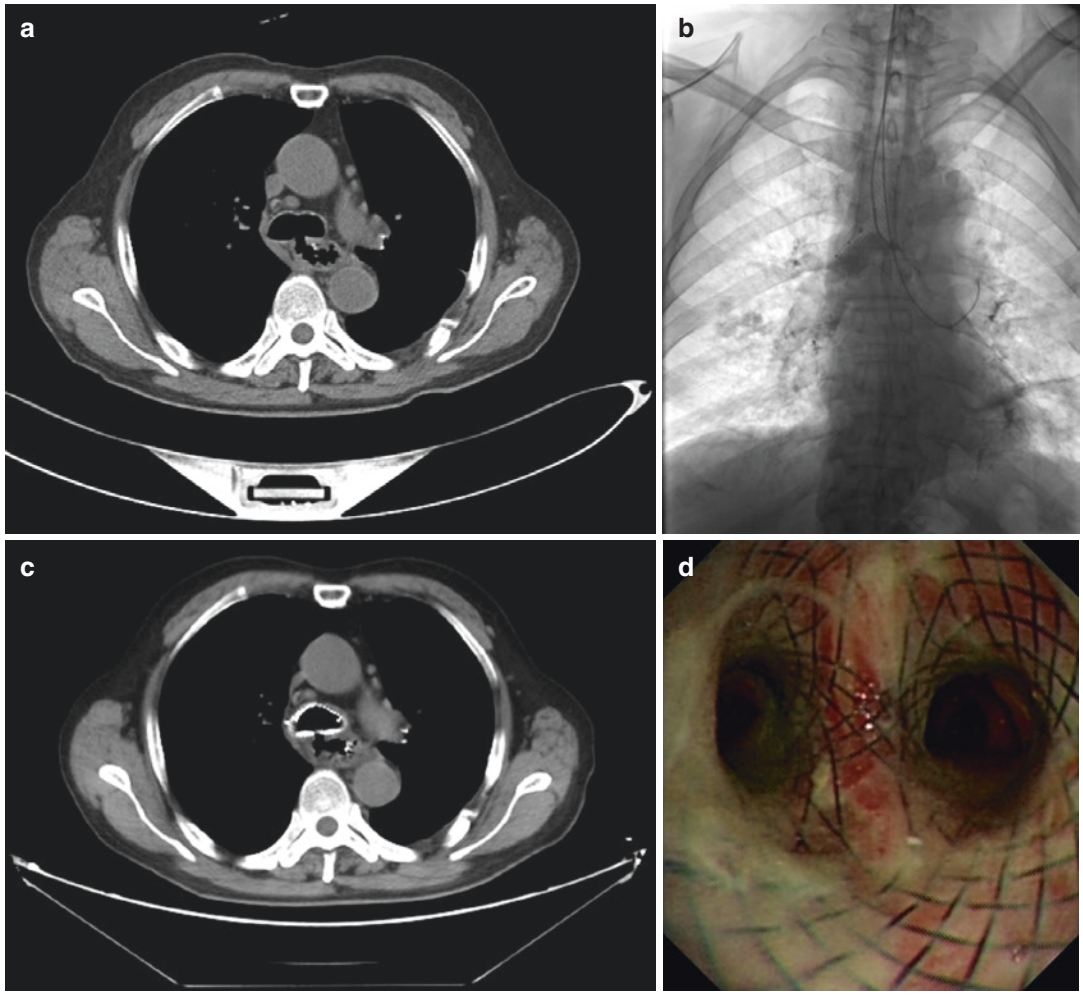

Fig. 11.11 (**a**) Preoperative chest CT scan showing thoracostomach–carina fistula; (**b**) insertion of the Y-shaped stent; (**c**) postoperative chest CT scan shows the completely sealed fistula; (**d**) bronchoscope shows that the fistula was sealed completely

Sputum Suction

This is a necessary and effective measure used to save the patient's life after the placement of a tracheal bronchus coated stent. A thoracostomach–carina fistula causes gastric juice to spill into the tracheal bronchus, corrosion and chemical stimulis that cause a large amount of effusion and secondary bacterial infections. The alveolar and bronchial tissue have different characteristics of mucus and pus production. Once the coated stent has sealed the fistula and restored the integrity of the tracheal bronchus and its negative pressure, alveolar and thin bronchial secretions will flow out to the bronchi, blocking the air flow, causing more severe breathing difficulties.

Introduce a stiff guidewire and then the suction tube should be intubated using the guidewire deep inside the left and right main bronchi and lobar bronchi. Thoroughly clear the residual contrast agent and sputum, and follow this with lavage with antibiotics. At the same time as the sputum suction, slap the patient's back to dislodge the sputum, and change the patient's position to expel sputum more easily until the lung rales disappear and the blood oxygen saturation level reaches or is close to 100%.

11.6.2.4 Postoperative Management

See Sect. 11.6.1.4

11.6.2.5 Complications

See Sect. 11.6.1.5

11.6.3 Thoracostomach–Right Main Bronchus Fistula

Thoracostomach–right main bronchus fistula is a type III thoracostomach–airway fistula.

Because of the short right main bronchus (total length of 10–20 mm), a proximal fistula would be adjacent to the carina and a distal fistula would be adjacent to the middle bronchus or adjacent to the upper lobe bronchus. In order to effectively seal a right main bronchial fistula and to protect the upper lobe bronchus, we generally need to insert a large and a small Y-shaped airway coated stent. The small Y-shaped stent is placed at the middle lobe bronchus, right upper lobe bronchus, and right main bronchus. The large Y-shaped stent is placed at the right main bronchus, left main bronchus, and trachea.

11.6.3.1 Instrument Preparation (Similar to Sect. 11.6.2.1)

Interventional instruments and customized stent choice are outlined below [11].

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 9 F sheath, two (large and small) Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14 F long sheath, tracheal intubation instruments.

Choice of Stent

According to the chest MSCT cross-sectional (fat window) image, measure the trachea and both main bronchus diameter (longitudinal and transverse diameter) and length to customize a coated large integrated Y-shaped self-expanding metal stent. Stent parameters should be as follows: stent diameter should be 15% larger than the corresponding airway. The length of the trachea part of the stent should reach 40–50 mm above the carina, the length of the right main bronchus part should be the same as the distance between the carina and right upper lobar bronchus opening. The length of the left main bronchus part is 20–30 mm.

Measure the right main bronchus and right upper and middle lobar bronchus diameter and length, customize a coated small Y-shaped integrated self-expanding metal stent. Stent parameters should be as follows: the diameter of the right upper lobe part of the stent should be 10% larger than the corresponding airway, and the length should be less than 80% of the total length of the corresponding airway; the diameter of the right middle lobe part of the stent should be 10% larger than the corresponding airway, and the length should be less than 80% of the total length of the corresponding airway; the diameter of the right main bronchus part of the stent should be 15% larger than the corresponding airway, and the length should be less than the total length of the inferior wall of the right main bronchus.

11.6.3.2 Preoperative Preparation

See Sect. 11.6.2.2

11.6.3.3 Placement Procedure of Two Y-Shaped Stents

The order of placement of both of the Y-shaped stents is first the small Y-shaped stent on the distal side and then the large Y-shaped stent on the proximal side. The large Y-shaped stent fixes the small stent in position.

Patient's Position

The patient should remove clothes that have X-ray foreign bodies (such as metal buttons), lie on the DSA examination table in a supine position, remove the pillow, have the neck and shoulders slightly raised, head in hypokinesis and turned to the right side (toward the operator) at an angle of about 20–30°. Cover with one or two large surgical drapes, fix nasal oxygen tube, con-

nect ECG monitoring. The C arm is angled left at 20–30° (with the patient's head turning right at 20–30°, this is equivalent to angling the body to the right at 50°), adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Administer throat lidocaine anesthesia spray, insert a mouth gag and have the vacuum extractor ready to clear the airway and oral secretions, as necessary.

Transcatheter Radiography

Under fluoroscopy, insert the mouth gag and insert a hydrophilic guidewire and catheter through the mouth, oropharynx, laryngopharynx, larynx vestibule, glottis, glottis inferior vena and tracheal and carina region. Fix the catheter and pull out the guidewire. Rapidly inject through the catheter 1% lidocaine injection 2–3 ml, adjust the position of the catheter tip to the right main bronchus. Rapidly inject through the catheter 30% iodine water contrast agent 3 ml to display the tracheal bronchus angiography. Use this to determine the location and size of the carina fistula and relationship between the right upper lobar bronchus opening and middle lobar bronchus. Choose the best image as the road map for subsequent intervention operation.

Insertion of Stiff Guidewire

After completion of radiography, introduce the hydrophilic guidewire. The guidewire and catheter pass through the fistula into the right middle bronchus. Use radiography again to confirm the catheter's location, then replace this with a stiff guidewire. The stiff guidewire is left in location and fixed. Insert a 9 F long sheath, using the stiff guidewire, to the lower part of the trachea or above the carina, pull out the inner core of the sheath. The guidewire and catheter are introduced through the sheath deep into the right main bronchus, the right upper lobar bronchus, and the segmental bronchus. Replace with another stiff guidewire and fix it in position. Pull out the catheter and sheath. The two stiff guidewires should be marked differently to define which (right upper or middle lobar) bronchus each is located-in.

Insertion of Small Y-Shaped Stent Delivery System

Under fluoroscopy, firmly fix the two stiff guidewires and hold them in position. The upper and lower bronchus part of the small Y-shaped stent is loaded on the upper and lower (right middle bronchus) stiff guidewire. The side conduit of the stent delivery system is connected to high pressure oxygen. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The operator team should cooperate in the procedure, especially in fixing the stiff guidewires, keeping the patient's position unchanged, and maintaining the oxyhemoglobin saturation level at normal.

The stent delivery system is inserted using the stiff guidewires. Maintain the patient's head in hypokinesis as much as possible, and slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When resistance is encountered and the patient produces a choking cough response, rotate the delivery system to make the two bronchi parts in the anteroposterior position fit the shape of the rima glottides. Ask the patient to take a deep breath and when the glottis opens during deep inhalation, push the delivery system to above the carina. Rotate the delivery system to make the upper and middle bronchus parts of the stent align with the corresponding bronchus and make sure the two guidewires are not twisted. Ensure that the golden mark on the delivery system is also on the correct side. Push the delivery system forward into the right main bronchus.

Placement of Stent

Hold the stiff guidewire and the delivery system's posterior handle, and pull back the delivery system's anterior handle to release the small Y-shaped stent in the right main bronchus.

Keep the position of the two handles unchanged. Fix the stiff guidewire, push the bronchus part into the right upper and middle bronchi. When resistance is encountered, this confirms that the bronchus part is completely in the right upper and middle lobar bronchi and that the stent bifurcate has reached the bifurcate of the

upper and middle lobar bronchus. Fluoroscopy further confirms that the stent has reached the bifurcate of the upper and middle lobar bronchus. Fix the delivery system and guidewire in place, and rapidly pull off the two bundled silk threads, which will completely release the lobar bronchus part of the stent. Fluoroscopy will confirm that the stent parts are in the correct lobar bronchus; hold the posterior handle and quickly pull back the anterior handle to release the stent main body in the right main bronchus. The small Y-shaped stent is now entirely released. Pull out the stent delivery system slowly. Retain the left middle lobar bronchus stiff guidewire in position as a subsequent intervention operation pathway (Fig. 11.12).

Insertion of the Large Y-Shaped Stent Delivery System

Use the catheter to change the upper lobe bronchus stiff guidewire position to the left lower lobe bronchus. Fix the position of the left stiff guidewire. Mark the left and right side of endobronchial stiff guidewires.

Under fluoroscopy, firmly fix the two stiff guidewires and hold them in position. The left and right bronchus parts of the large Y-shaped stent are respectively loaded on the left and right bronchus stiff guidewires. The side conduit of the stent delivery system is connected to high pressure oxygen. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The operator team should cooperate in this procedure, especially with fixing of the stiff guidewires, keeping the patient's position unchanged, and maintaining the oxyhemoglobin saturation at normal levels.

The stent delivery system is inserted using the stiff guidewires. Ensure the patient's head is in hypokinesis as much as possible. Slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When resistance is encountered and the patient responds with a choking cough response, rotate the delivery system to align the two bronchus parts in the anteroposterior position to fit the shape of the rima glottides. Ask the patient to breathe deeply and the glottis will open with a deep inhalation. At this moment, push the delivery system to above the carina. Rotate the delivery system to align the left and right main bronchus part of the stent with the corresponding bronchus and make sure that the two guidewires are not twisted. Ensure that the golden mark on the delivery system is also on the correct side.

Stent Placement

Hold the stiff guidewire and delivery system's posterior handle and pull back the delivery system's anterior handle to release the large Y-shaped stent at the trachea above the carina.

Keep the position of the two handles relatively unchanged and fix the stiff guidewire. Push the bronchus part into the right and left main bronchi. When pushing the stent branches into the main bronchus, this must be performed under fluoroscopy monitoring and the operator should ensure that the main body of the small Y-shaped stent is not pushed by the right bronchus part of the large Y-shaped stent. If resistance is encountered when you push the delivery system forward, confirm under fluoroscopy that the small Y-shaped stent has not been pushed away by the large Y-shaped stent. Only then can you continue to push the large Y-shaped stent delivery system forward.

Resistance confirms that the bronchus parts are in the right and left bronchi, and the stent bifurcation have arrived at the carina. Fluoroscopy can further confirm that the stent bifurcation has reached the carina. Pause the operation and fix the position of the delivery system and guidewire. The operator and patient rest for 30–60 s.

Fix the delivery system and guidewire. Rapidly pull the two bundled silk threads to completely release the lobar bronchus part of the stent. Hold the posterior handle and quickly pull back the anterior handle to release the stent main body at the trachea. The large Y-shaped stent is entirely released. Wait for 1–3 min until the patient breathes smoothly and the blood oxygen saturation returns to 90–100%, and then pull out the stent delivery system slowly. Keep one stiff guidewire in place as a subsequent intervention operation pathway (Fig. 11.12).

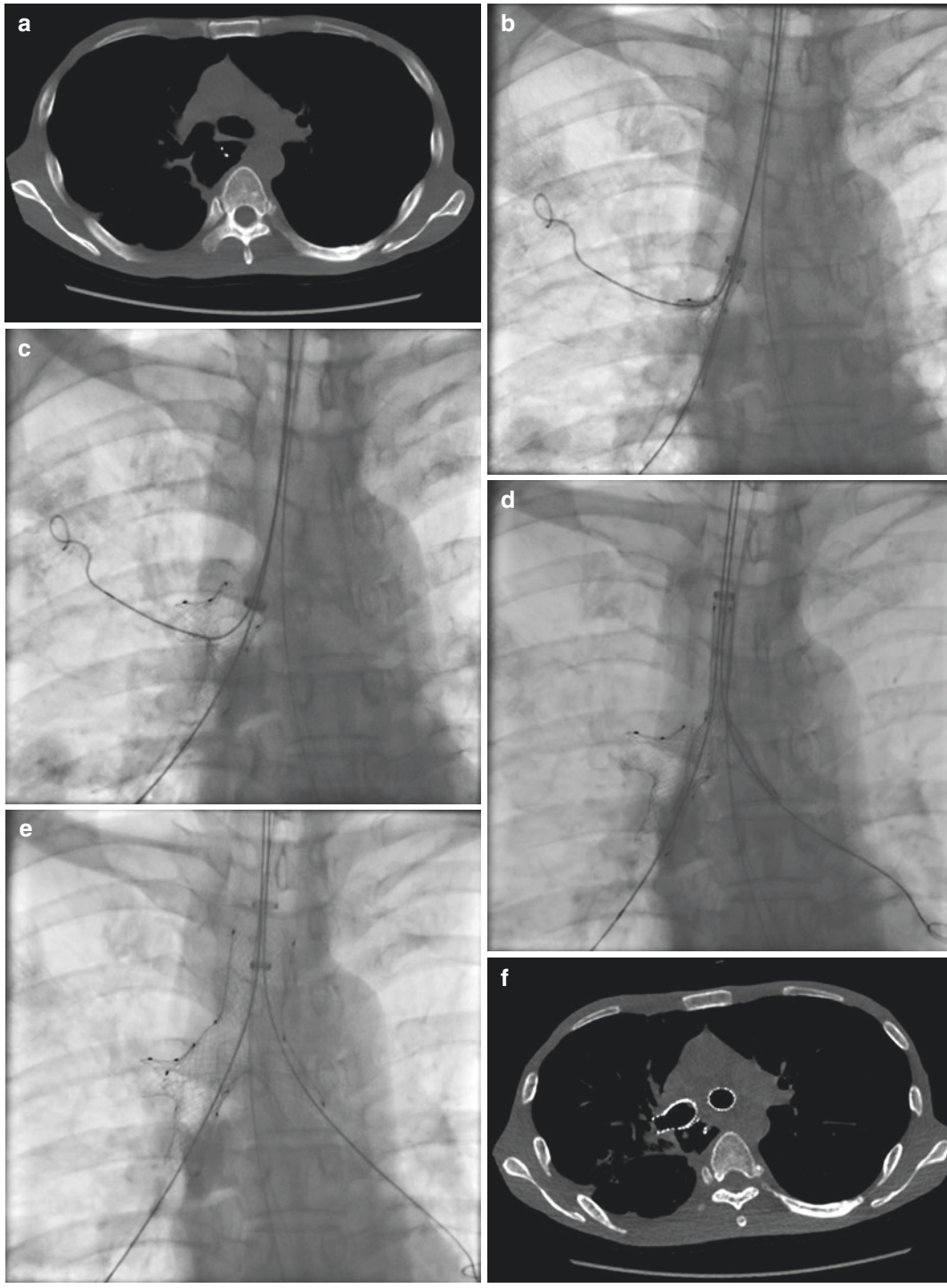

Fig. 11.12 The procedure for thoracostomach–right main bronchus fistula stenting. (**a**) Preoperative chest CT scan showing thoracostomach–right main bronchus fistula; (**b**–**c**) insertion of the small Y-shaped stent; (**d**-**e**) insertion of the large Y-shaped stent; (**f**) postoperative chest CT scan shows the completely sealed fistula

If the patient has breathing difficulties and anoxic symptoms after release of the stent or if the blood oxygen saturation level progressively declines, use fluoroscopy to exclude stent distortion and folding or unopened stent. Then consider a sputum block in the bronchus. Quickly pull out the stent delivery system and replace with a sputum suction tube into the left and right bronchi and suction repeatedly until the blood oxygen saturation rises to a normal level [12].

Re-radiography

Using a guidewire, introduce the catheter to the carina region, inject 30% water iodine contrast agent 3–5 ml to confirm if the fistula is completely sealed, if the stent is in the correct location, whether the stent has expanded fully, and if the two stents are closely fitted, etc.

At the same time, administer 30% iodine contrast agent 20–40 ml water to the patient orally to conduct esophagus and stomach radiography. Observe whether any contrast agent moves through the fistula to spill into the tracheal bronchus and confirm if the stent has sealed completely.

Sputum Suction

Sputum suction is an important and effective measure to treat the patient after tracheal bronchus covered stent placement. A thoracostomach–carina fistula causes gastric juice to spill into the tracheal bronchus, which causes corrosion and chemical stimulus and a large amount of effusion and secondary bacterial infections. The alveolar and bronchial tissues all have different properties of mucus and pus production. Once a coated stent seals the fistula, the integrity of the tracheal bronchus and its negative pressure is restored. Then the alveolar and thin bronchial secretions are poured out into the bronchi, thus blocking the air flow and causing more severe breathing difficulties.

Introduce a stiff guidewire, then a suction tube is intubated using the guidewire deep inside the left and right main bronchi and lobar bronchus. The residual contrast agent and sputum is thoroughly cleared and this is followed by lavage with antibiotics. Slap the patient's back at the same time to dislodge stubborn sputum and change the patient's position to expel the sputum until the lung rales disappear and the blood oxygen saturation reaches or approaches 100%.

11.6.3.4 Postoperative Management

See Sect. 11.6.1.4

11.6.3.5 Complications

See Sect. 11.6.1.5

11.6.4 Thoracostomach–Left Main Bronchus Fistula

The thoracostomach–left main bronchus fistula is a type IV thoracostomach–airway fistula.

Because the left main bronchus is much longer (±40 mm) than the right main bronchus, when the left main bronchus undergoes stenting it occupies a larger operation space. If the fistula is in the proximal section of the left main bronchus and is close to the carina, one large Y-shaped airway coated stent should be used. At the same time as this operation, the thoracostomach–carina fistula should be treated. If the fistula is in the distal section of the left bronchus and close to the left upper and lower lobar bifurcate, one single small Y-shaped stent can be placed at the left lower lobar bronchus, left upper lobar bronchus, and left main bronchus.

Sealing the thoracostomach–left main bronchial fistula is different to the sealing of the thoracostomach–right main bronchial fistula. The latter fistula often needs to use the small and large double Y-shaped stent. But, in most cases, the former only needs the single inverted Y-shaped stent, a single large, or a single small Y-shaped stent.

11.6.4.1 Instrument Preparation

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm),

0.035-in. metal stiff guidewire (180–260 cm), 9 F sheath, two (large and small) Y-shaped coated self-expanding stent (Micro-Tech, Nanjing), stent retrieval hook, sputum suction tube, 14 F long sheath, tracheal intubation instruments.

Choice of Stent

Using the chest MSCT cross-sectional (fat window) image, measure the trachea and the lengths and diameters of both of the main bronchi (longitudinal and transverse diameter). Use these measurements to customize the coated large integrated Y-shaped self-expanding metal stent. Stent parameters should be as follows: the stent diameter should be 15% larger than the corresponding airway, the length of the trachea part of the stent should reach to 40–50 mm above the carina, the length of the right main bronchus part is the same as the distance from carina to the right upper lobar bronchus opening, and the length of the left main bronchus part is 20–30 mm.

Small Y-Shaped Stent

Measure the diameter the lengths of the left main bronchus, left upper and lower lobar bronchus (longitudinal and transverse diameter). Measure the angle between the left upper and lower lobar bronchus and customize the coated small Y-shaped self-expanding metal stent. Stent parameters should be as follows: the length of the left main bronchus part of the stent should be the same as the length of the left main bronchus inferior wall; the diameter should be 15–20% larger than the corresponding airway; the length of the left upper lobar bronchus part should be ±10 mm; the diameter should be 10–15% larger than the corresponding airway; the length of the left lower lobar bronchus part should be ±10 mm; the diameter should be 10–15% larger than the corresponding airway. The angle of stent bifurcate equals the angle between the left upper and lower bronchus.

Large Y-Shaped Stent

Measure the diameters and lengths of the trachea and left and right main bronchus (longitudinal and transverse diameter). Measure the angle between the left and right main bronchus and use these measurements to customize a coated large integrated Y-shaped self-expanding metal stent. Stent parameters should be as follows: the length of the main body (trachea) part of the stent should be 40–50 mm; the diameter should be 15–20% larger than the corresponding airway; the length of the left main bronchus part should extend 15–20 mm beyond the fistula; the diameter should be 10–15% larger than the corresponding airway; the length of the right main bronchus part should be 10–15 mm (keep away from or close to the opening of the right upper lobar bronchus); the diameter should be 10–15% larger than the corresponding airway. The angle of the stent bifurcation should equal that of the left upper and lower lobar bronchus [13, 14].

The large Y-shaped stent placement procedure is the same as for the thoracostomach–carina fistula (see Sect. 11.6.2.3).

11.6.4.2 Preoperative Preparation

See Sect. 11.6.2.2

11.6.4.3 Small Y-Shaped Stent Placement Procedure

Patient Position

The patient removes clothes that have X-ray foreign bodies (such as metal buttons), lies on DSA examination table in a supine position, removes the pillow, has neck and shoulders slightly raised, head at hypokinesis and turned to the right (toward the operator) angled at 20–30°. Cover with one or two large surgical drapes, fix nasal oxygen tube, connect ECG monitoring. The C - arm is turned to the left and angled at 20–30° (with the patient's head turning right at 20–30°, this is equivalent to the body inclining to the right at 50°). Adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Administer lidocaine throat anesthesia spray, insert the mouth gag and have the vacuum extractor ready to clear the airway and oral secretions, as necessary.

Transcatheter Radiography

Under fluoroscopy, insert the mouth gag and insert a hydrophilic guidewire and catheter through the mouth, oropharynx, laryngopharynx, larynx vestibule, glottis, glottis inferior vena, and tracheal and carina region. Fix the catheter and pull out the guidewire. Through the catheter, rapidly inject 1% lidocaine 2–3 ml and adjust the position of the catheter tip to the right main bronchus. Through the catheter, quickly inject 30% iodine water contrast agent 3 ml to display the tracheal bronchus angiography. Use this to determine the location and size of the carina fistula and the relationship between the right upper lobar bronchus opening and the middle lobar bronchus. Choose the best radiography image that includes the lower segment of the trachea, both the main bronchi, and the left upper and lower lobar bronchi as the road map for subsequent intervention operation.

Insertion of Stiff Guidewire

After completion of radiography, introduce a hydrophilic guidewire. The guidewire and catheter pass through the fistula into the left lower lobar bronchus. Use radiography again to confirm the catheter's location and then exchange to a stiff guidewire. Fix the stiff guidewire in location. Insert a 9 F long sheath, using the stiff guidewire, to the lower part of the trachea or to above the carina. Pull out the inner core of the sheath. The guidewire and catheter are introduced through the sheath deep into the left main bronchus, left upper lobar bronchus, and the segmental bronchus. Exchange to another stiff guidewire and fix this in position. Pull out the catheter and sheath. The two stiff guidewires should be marked differentiate which (left upper or lower lobar) bronchus each is located-in.

Insertion of the Small Y-Shaped Stent Delivery System

Under fluoroscopy, firmly fix the two stiff guidewires and hold them in position. The upper and lower bronchus parts of the small Y-shaped stent are loaded onto the upper and lower (left middle bronchus) stiff guidewires, respectively. The side conduit of the stent delivery system is connected to high pressure oxygen. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The operator team should cooperate during the procedure, especially when fixing the stiff guidewires, keeping the patient's position unchanged, and maintaining the oxyhemoglobin saturation at normal levels.

The stent delivery system is inserted using the stiff guidewires. Maintain patient's head in hypokinesis as much as possible. Slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When you encounter resistance and the patient appears to have a choking cough response, rotate the delivery system to align the two bronchi parts in an anteroposterior position that fits the shape of the rima glottides. Ask the patient to take a deep breath and this will force the glottis to open during deep inhalation. At this moment, push the delivery system to above the carina. Rotate the delivery system to align the upper and middle bronchus part of the stent with the corresponding bronchus, and make sure that the two guidewires are not twisted. Ensure that the golden mark on the delivery system is also on the correct side. Push the delivery system forward into the left main bronchus.

Placement of Stent

Hold the stiff guidewire and the delivery system's posterior handle, pull back the delivery system's anterior handle to release the Y-shaped stent at the left main bronchus.

Keep the position of the two handles unchanged, fix the stiff guidewire, push the bronchus part into the left upper and middle bronchi. Resistance confirms that the bronchus part is completely in the left upper and lower bronchi and the stent bifurcation has arrived at the bifurcation of the upper and lower bronchus. Fluoroscopy further confirms that the stent bifurcation has reached the bifurcation of the upper and lower bronchus. Fix the delivery system and guidewire, rapidly pull the two bundled silk threads, completely release the lobar bronchus

part of the stent. Fluoroscopy confirms that the stent parts are in the correct lobar bronchus. Hold the posterior handle and quickly pull back the anterior handle to release the main body of the stent in the right main bronchus. The small Y-shaped stent is entirely released. Pull out the stent delivery system slowly. Retain the lower lobar bronchus stiff guidewire in position as a subsequent intervention operation pathway.

Re–radiography

Introduce the catheter using the guidewire to the carina region, inject 30% water iodine contrast agent 3–5 ml to confirm that the fistula is completely sealed, the stent is in the correct position, whether the stent has expanded fully, and if the two stents are closely fitted, etc. (Fig. 11.13).

At the same time, administer 30% iodine contrast agent 20–40 ml water to the patient orally to conduct esophagus and stomach radiography. Observe whether any contrast agent moves through the fistula to spill into the tracheal bronchus. Confirm if the stent has sealed the fistula completely.

Sputum Suction

Sputum suction is an important and effective measure that aids the patient after tracheal bronchus covered stent placement. A thoracostomach–left main bronchus fistula causes gastric juice to spill into the tracheal bronchus, corrosion and chemical stimulus, which cause a large amount of effusion and secondary bacterial infections. Alveolar and bronchial tissue have different properties of mucus and pus production. Once the coated stent has sealed the fistula and restored the integrity of the tracheal bronchus and its negative pressure, the alveolar and thin bronchial secretions will move out to the bronchi, block the air flow, and cause more severe breathing difficulties.

Introduce a stiff guidewire. Insert a suction tube, using the guidewire, into the left and right main bronchi and especially the left lobar bronchus. Apply suction thoroughly to clear residual contrast agent and sputum and perform lavage with antibiotics. At the same time as this procedure, slap the patient's back to dislodge stubborn sputum, and change the patient's position to expel sputum until the lung rales disappear and blood oxygen saturation reaches or approaches 100%.

11.6.4.4 Postoperative Management

See Sect. 11.6.1.4

11.6.4.5 Complications

See Sect. 11.6.1.5

11.6.5 Thoracostomach–Right Middle Bronchus Fistula

The thoracostomach–right middle bronchus fistula is type V thoracostomach–airway fistula.

The total length of the right middle bronchus is 20–30 mm, which is longer than the right main bronchus. Above the right middle bronchus is the right upper lobar bronchus. Below the right middle bronchus is the right upper lobar bronchus and the lower lobar bronchus. It is difficult to fix a tubal stent in the 20–30 mm space and even harder if a coated tubal stent is used to seal a fistula.

The middle bronchus length of 20–30 mm is a relatively large space for a stenting operation. The small Y-shaped stent is used to seal limited fistulas in the middle bronchus. If the fistula is at the distal or middle-distal section of the middle bronchus, a small Y-shaped stent can be placed at the middle and lower lobe bronchus and the middle bronchus (Fig. 11.14). If the fistula is at the proximal section of the middle bronchus, the small Y-shaped stent is placed at the middle bronchus, upper bronchus, and right main bronchus (Fig. 11.15). If the fistula involves most of the middle bronchus, choose the two small Y-shaped coated stents mentioned above as they can cover each other to ensure adequate coverage of the fistula; the first stent is in the middle and lower lobe bronchus, and middle bronchus, the second stent is in the middle bronchus, upper lobar bronchus, and right main bronchus (Fig. 11.16) .

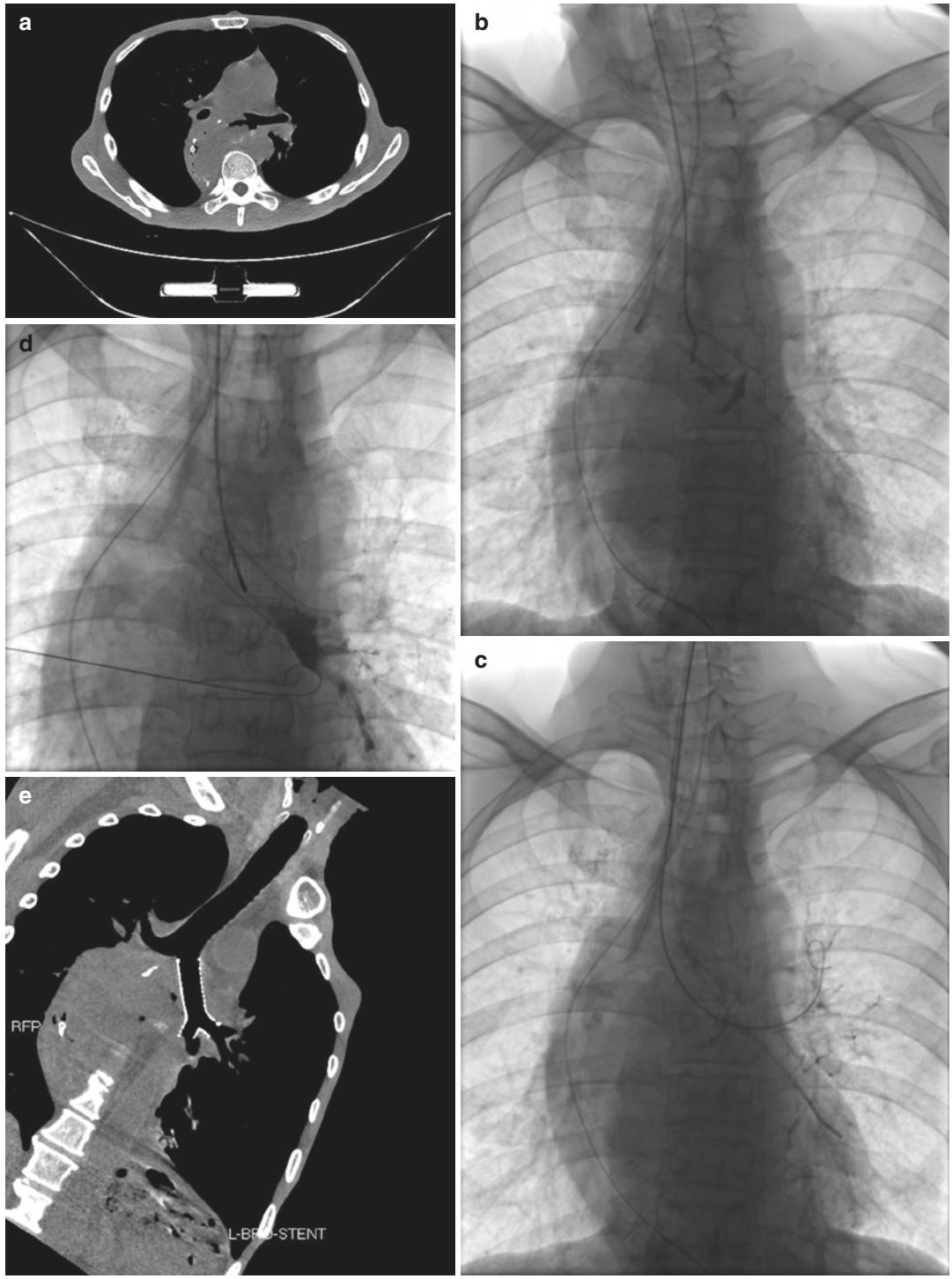

Fig. 11.13 The procedure for thoracostomach–left main bronchus fistula stenting. (**a**) Preoperative chest CT scan shows thoracostomach–left main bronchus fistula; (**b**) the fistula is revealed by radiograph; (**c**) introduce two guidewires; (**d**) inserted stent and re-radiograph shows that the fistula was sealed completely. (**e**) postoperative chest CT scan shows that the fistula was sealed completely

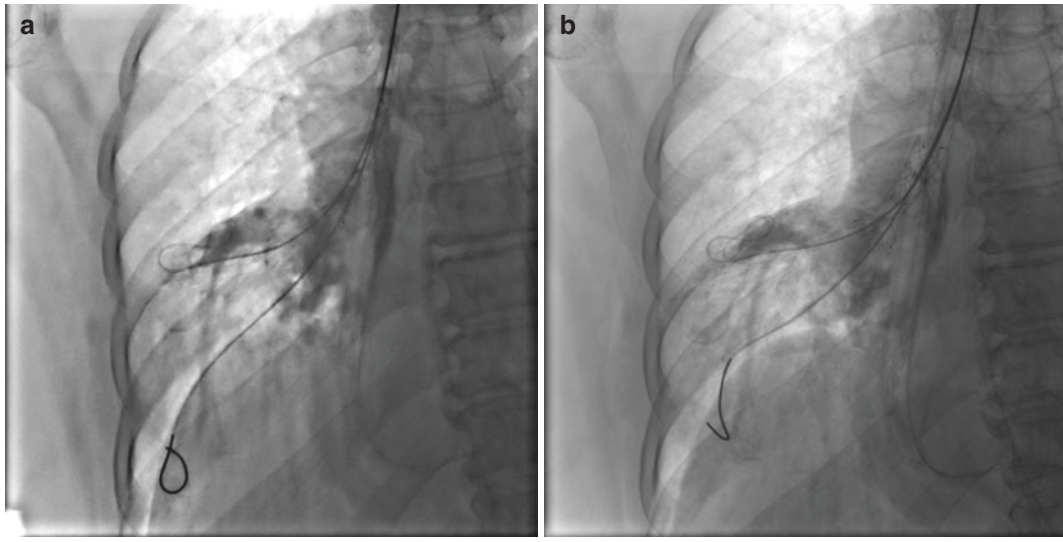

Fig. 11.14 The small Y-shaped stent in the middle and lower lobe bronchus and middle bronchus (**a**) fully expanded the two branch parts of the small Y-shaped stent (**b**) fully expanded the main body of the small Y-shaped stent

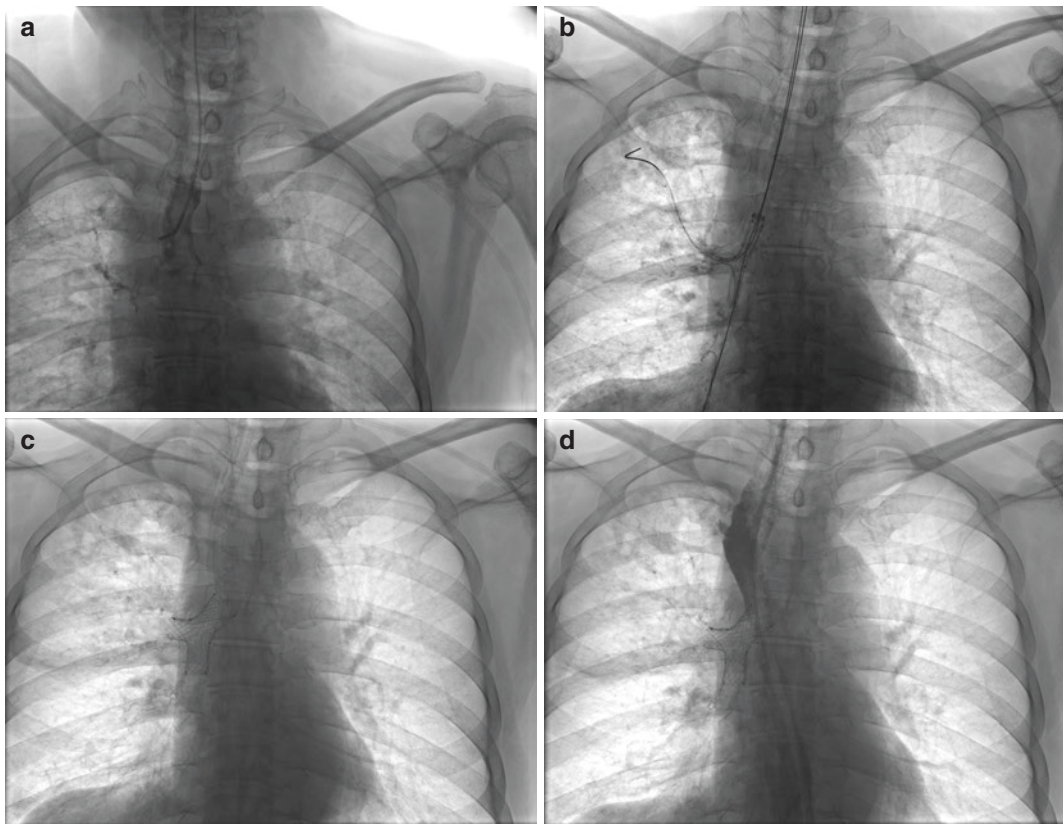

Fig. 11.15 The treatment of one case of thoracostomach–right bronchus fistula (one small Y-stent inserted) (**a**) airway radiography showed a thoracostomach–right bronchus fistula (**b**-**c**) a small Y-stent insertion in the middle bronchus, upper lobar bronchus and right main bronchus (**d**) upper gastrointestinal contrastshowed that the fistula had disappeared

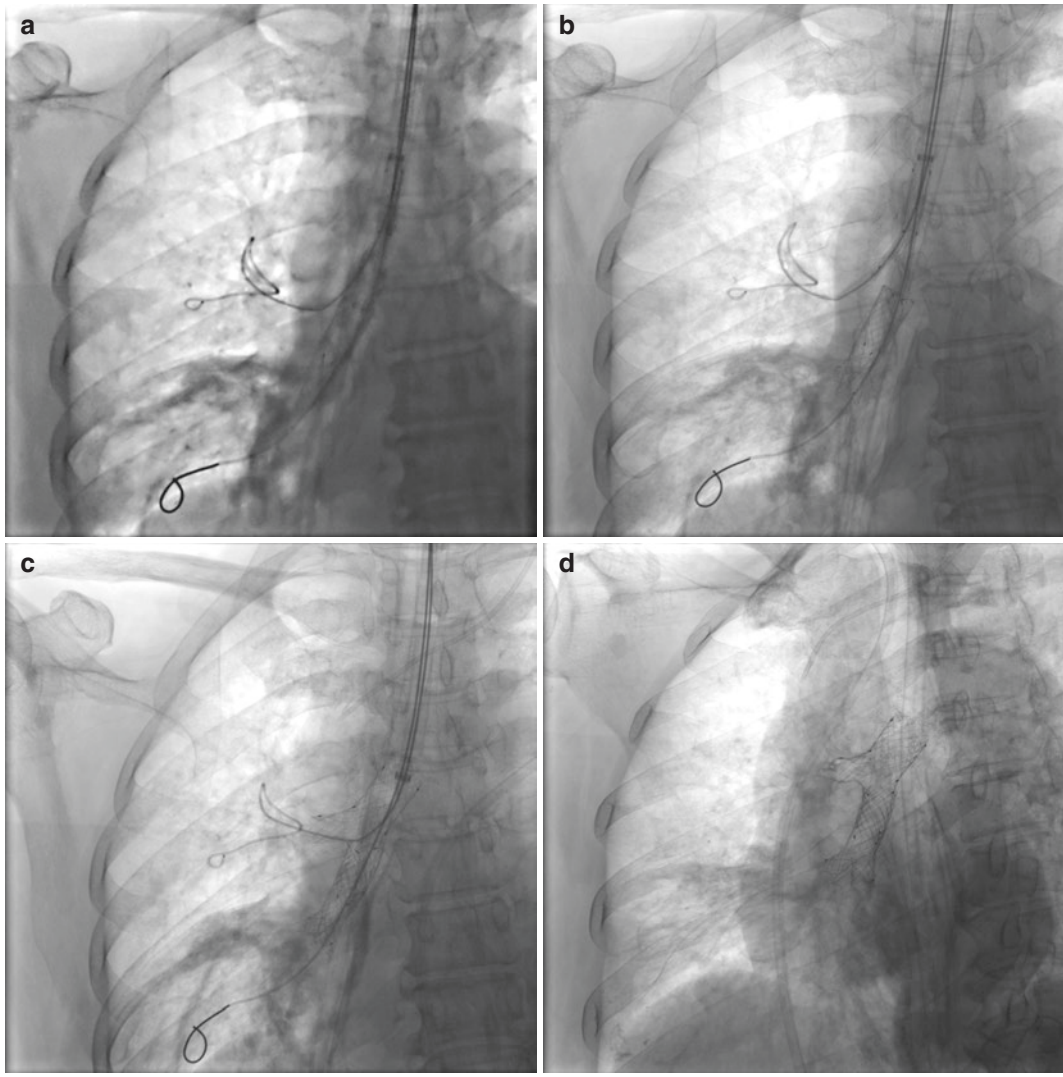

Fig. 11.16 The treatment of one case of thoracostomach–right bronchus fistula (two small Y-stents inserted) (**a**-**b**) one small Y stent is in the middle and lower lobe bronchus and middle bronchus (**c**-**d**) the other one is in the middle bronchus, upper lobar bronchus and right main bronchus

11.6.5.1 Instrument Preparation

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (180–260 cm), 0.035-in. metal stiff guidewire (180–260 cm), 10 F sheath, Y-shaped coated self-expanding stent (Micro-Tech, Nanjing).

Choice of Small Y-Shaped Stent

According to the chest MSCT cross-sectional (fat window) image, measure the diameters and the lengths of the right main bronchus, the right lobar bronchus, and the middle bronchus (longitudinal and transverse diameter). Use these measurements to customize the coated small Y-shaped integrated self-expanding metal stents.

The Small Y-Shaped Stent (Main Body in Middle Bronchus)

Measure the diameters and the lengths of the middle bronchus, the left middle, and the lower lobar bronchus (longitudinal and transverse diameter). Measure the angle between the left middle and lower bronchus and use these measurements to customize a coated small integrated Y-shaped self-expanding metal stent that fits the shape of the middle bronchus, the left middle and the lower lobar bronchus. The stent parameters should be as follows: the length of the middle bronchus part of the stent should be ±90% of the length of the middle bronchus. The diameter should be ±15% larger than the corresponding airway. The length of the lobar bronchi part should be ±10 mm. The diameter should be 10–15% larger than the corresponding airway. The angle of the stent bifurcation should equal that of the middle and lower lobar bronchus.

The Small Y-Shaped Stent (Main Body in Right Main Bronchus)

Measure the diameters and the lengths of the middle bronchus, the upper lobar bronchus, and the right main bronchus (longitudinal and transverse diameter). Use these measurements to customize a coated large integrated Y-shaped self-expanding metal stent to fit the shape of the middle bronchus, upper lobar bronchus, and right main bronchus. The stent parameters should be as follows: the length of the main body (right main bronchus) part of the stent should be 90–100% of the inferior wall of the right main bronchus. The diameter should be 15–20% larger than the corresponding airway. The length of the upper lobar bronchus part should be ±10 mm. The diameter should be 10–15% larger than the corresponding airway. The length of middle bronchus part should be smaller than the total length of the middle bronchus and the diameter should be ±15% larger than the corresponding airway. The angle of the stent bifurcation should equal the angle between the middle bronchus and the upper lobar bronchus.

11.6.5.2 Preoperative Preparation

See Sect. 11.6.2.2

11.6.5.3 Small Y-Shaped Stent Placement Procedure

The thoracostomach–middle bronchus proximal fistula is treated by placing a small Y-shaped stent in the right main bronchus, right upper bronchus, and middle bronchus. The operation procedure is the same as that of the small Y-shaped stent placement for the thoracostomach–right main bronchus fistula (see Sect. 11.6.3.3).

A thoracostomach–middle bronchus distal and distal-middle fistula is treated by placing a small Y-shaped stent in the right middle and lower lobar bronchus and the middle bronchus, and the operation procedure is as below:

Patient Position

The patient remove clothes that have X-ray foreign bodies (such as metal buttons), lies on the DSA examination table in a supine position, removes the pillow, has neck and shoulders slightly raised, head in hypokinesis, and turns to the right side (toward the operator) angled at about 20–30°. Cover with one or two large surgical drapes, fix the nasal oxygen tube and connect the ECG monitoring. The C - arm is turned to the left at an angle of 20–30° (with the patient's head angled to the right at 20–30°, this is equivalent to a body angled to the right at 50°). Adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Administer lidocaine throat anesthesia spray, insert the mouth gag and have the vacuum extractor ready to clear airway and oral secretions, as necessary.

Transcatheter Radiography

Under fluoroscopy, insert the mouth gag and insert a hydrophilic guidewire and catheter through the mouth, oropharynx, laryngopharynx, larynx vestibule, glottis, glottis inferior vena, trachea, carina region, and opening of the right main bronchus. Fix the catheter and pull out the guidewire. Through the catheter, rapidly inject 1% lidocaine 2–3 ml and adjust the position of the catheter tip to the right main bronchus. Through the catheter, quickly inject 30% iodine water contrast agent 3 ml to display the tracheal bronchus angiography. Use this to determine the location

and size of the fistula and the relationship between the fistula and the right upper, middle, and lower lobar bronchus. Choose the best right main bronchus, right upper, middle and lower lobar bronchus, and middle bronchus image as a road map for subsequent intervention operation.

Insertion of Stiff Guidewire

After completion of radiography, introduce a hydrophilic guidewire. The guidewire and catheter pass over the fistula into the right middle bronchus. Use radiography again to confirm the catheter's location and then exchange to a stiff guidewire. The stiff guidewire is left in location and fixed. Insert a 9 F long sheath through the stiff guidewire to the lower part of the trachea or to above the carina, pull out the inner core of the sheath. The guidewire and catheter are introduced through the sheath deep into the right main bronchus, the right upper lobar bronchus, and the segmental bronchus. Exchange to another stiff guidewire and fix it in position. Pull out the catheter and sheath. The two stiff guidewires should be marked differently to define which (right middle or middle lobar) bronchus they are each in.

Insertion of Small Y-Shaped Stent Delivery System

Under fluoroscopy, firmly fix the two stiff guidewires and hold them in position. The middle and lower lobar bronchus part of the small Y-shaped stent is loaded on the middle and lower stiff guidewire. The side conduit of the stent delivery system is connected to high pressure oxygen. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The medical team should work together during the procedure, especially when fixing the stiff guidewires, keeping the patient's position unchanged, and maintaining the oxyhemoglobin saturation level at normal.

The stent delivery system is inserted using the stiff guidewires. Maintain the patient's hypokinesis as much as possible and slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When you encounter resistance and the patient appears to have a choking cough response, rotate the delivery system to align the two bronchus parts at an anteroposterior position that fits the shape of the rima glottides. Ask the patient to take a deep breath and the glottis will open during the deep inhalation. At this moment, push the delivery system through to the right main bronchus. Rotate the delivery system to align the middle and lower lobar bronchus part of the stent to the corresponding bronchus. Make sure the two guidewires are not twisted together. Ensure the golden mark on the delivery system is also on the correct side. Push forward the delivery system into the right main bronchus.

Placement of Small Y-Shaped Stent

Hold the stiff guidewire and the delivery system's posterior handle, pull back the delivery system's anterior handle to release the Y-shaped stent in the right main bronchus.

Keep the position of the two handles unchanged. Fix the stiff guidewire and push the bronchus part into the right middle and lower lobar bronchi. When you encounter resistance, this confirms that the bronchus part is completely in the right middle and lower lobar bronchi, and that the stent bifurcation has arrived at the bifurcation of the middle and lower lobar bronchus. Fluoroscopy can further confirm if the stent bifurcation has reached the bifurcation of the middle and lower lobar bronchus. Fix the delivery system and guidewire and rapidly pull the two bundled silk threads to completely release the lobar bronchus part of the stent. Use fluoroscopy to confirm that the stent parts are in the correct lobar bronchus. Hold the posterior handle and quickly pull back the anterior handle to release the stent main body in the right middle bronchus. The small Y-shaped stent is entirely released. Pull out the stent delivery system slowly. Retain the lower lobar bronchus stiff guidewire in position as a subsequent intervention operation pathway.

Re-radiography

Introduce the catheter using the guidewire to the right middle bronchus, inject 30% water iodine contrast agent 3–5 ml to confirm if the fistula is completely sealed, the stent is in the correct position, and whether the stents have fully expanded, etc. (Fig. 11.17) .

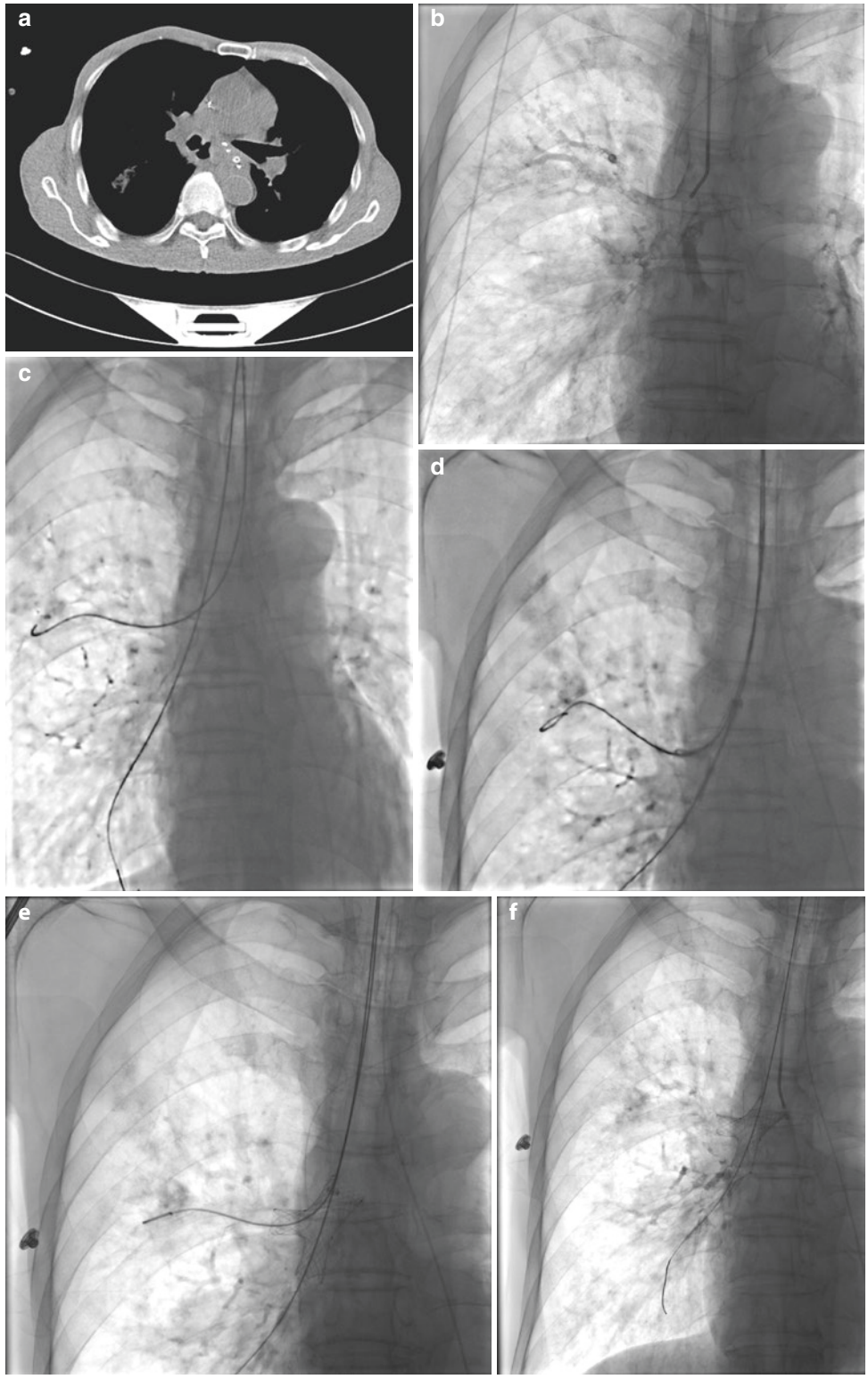

Fig. 11.17 The treatment of one case of thoracostomach - right middle bronchus fistula (**a**) chest spiral computed tomography (SCT) before intervention showed a thoracostomach–right middle bronchus fistula (**b**) airway radiography showed features of the fistula similar to those seen on SCT (**c**-**e**) a small Y-stent insertion (**f**) airway radiography showed that the fistula had disappeared

At the same time, administer 30% iodine contrast agent 20–40 ml water to the patient orally to conduct esophagus and stomach radiography. Observe whether any contrast agent passes through the fistula to spill into the tracheal bronchus and whether stent sealing is complete.

Sputum Suction

Sputum suction is an important and effective measure to aid the patient after tracheal bronchus covered stent placement. A thoracostomach–airway fistula causes gastric juice to spill into the tracheal bronchus, corrosion and chemical stimulus that cause a large amount of effusion, and secondary bacterial infections. Alveolar and bronchial tissue have different properties of mucus and pus production. Once the coated stent has sealed the fistula and restored the integrity of the tracheal bronchus and its negative pressure, the alveolar and thin bronchial secretions will move out into the bronchi, blocking the air flow, and causing more severe breathing difficulties.

Introduce a stiff guidewire and then the suction tube is intubated, using the guidewire, deep into the left and right main bronchi and especially the left lobar bronchus. Suction the residual contrast agent and sputum, and follow this with lavage with antibiotics. Slap the patient's back to dislodge stubborn sputum at the same time and change the patient's position to expel sputum until the lung rales disappear and blood oxygen saturation reaches or approaches 100%.

11.6.5.4 Postoperative Management

See Sect. 11.6.1.4

11.6.5.5 Complications

See Sect. 11.6.1.5

11.6.6 Thoracostomach–Lobar Bronchus Fistula

The thoracostomach–right main bronchi fistula is a type VI thoracostomach–airway fistula. The fistula connects with any of the lobar bronchi, such as the left or right upper, middle, or lower lobar bronchus.

Upper gastrointestinal tract reconstruction after esophageal resection moves the thoracic stomach into the posterior mediastinum and it comes into direct contact with the trachea, carina, left and right main bronchus, and middle bronchus. But because the lobar bronchi are in the lungs, there is a certain distance between the thoracic stomach and the lobar bronchus, direct communication with the lobar bronchi is rare.

After esophageal cancer surgery, a variety of factors can cause solidification of the lung, local tumor recurrence infiltrating the lung tissue, or a radiotherapy injury of the lung. This can lead to the thoracic stomach being close to the lobe bronchus and if chest gastric perforation occurs, gastric acid will corrode the nearby cells and the lobe bronchus will join to the thoracostomach. Then a thoracostomach–lobar bronchus fistula is formed. The fistula can be a thoracostomach–right lower lobe bronchus fistula, a thoracostomach–left lower lobe bronchus fistula, or a thoracostomach–right middle bronchial fistula. A thoracostomach–the left/right upper lobe bronchus fistula is rare.

11.6.6.1 Instrument Preparation

Including interventional instruments and stent.

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (260 cm), 0.035-in. metal stiff guidewire (260 cm), 9 F sheath, Y-shaped single plugged coated self-expanding stent.

Choice of Stent

The total length of each lobe bronchus is about 10 mm. If a thoracostomach–lobe bronchus fistula involves almost the whole of the lobe bronchus, trying to seal the lobe bronchus fistula with a tubular coated stent or a Y-shaped stent is almost impossible. In order to reduce the fistula's damage and reduce lung damage to a minimum range, this type of fistula can be palliatively treated by blocking the diseased lobe bronchus and the lobe and only allow the gastric juice spillover into the single lobe bronchus and the lobe. Thereby sacrificing this lobe to protect the majority of the lung tissue.

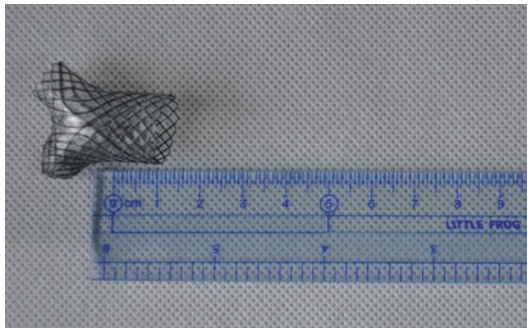

Fig. 11.18 The small Y-shaped single plugged coated self-expanding stent

Using the small Y-shaped single plugged coated self-expanding stent, the single plugged branch can seal the fistula and block the diseased lobe bronchus. The plugged branch of the Y-shaped stent is the dead end and the stent delivery inner core or guidewire cannot get through. This is unlike an ordinary stent that uses guidewire inside the stent or push technology to push forward through the guidewire. Xin-wei Han invented a stent delivery system that combines the stent bundling and stent push technology and this has successfully solved this problem. The two branch parts are loaded in the bundle mode (the delivery system inner core and guidewire need not move through the single plugged part, but tie the single plugged part at the side of the delivery system inner core), the main body of the stent is loaded in the traditional push mode (Fig. 11.18).

1. Thoracostomach–right lower lobar bronchus fistula. Use a small Y-shaped single plugged coated self-expanding stent. The single plugged part (dead end) seals the right lower lobar bronchus. The stent parameters should be as follows: according to the chest MSCT cross-sectional (fat window) image, measure the diameters and lengths of the middle bronchus, right middle and lower lobar bronchus (longitudinal and transverse diameter). Measure the angle between the right middle and lower bronchus. The length of main body of stent should be ±90% of the length of the middle bronchus. The diameter should be 10–15% larger than the corresponding airway. The length of the lower lobar bronchi part (the single plugged part) should be the same as the right lower lobar bronchus. The diameter should be 15–20% larger than the corresponding airway. The length of the middle lobar bronchi part (tubal) should be 80–90% of the length of the right middle lobar bronchus. The diameter should be 10–15% larger than the corresponding airway. The angle of the stent bifurcation should equal that of the middle and lower lobar bronchus. The stent is fully coated.
2. Thoracostomach–right middle lobar bronchus fistula. Use the small Y-shaped single plugged coated self-expanding stent. The single plugged part (dead end) seals the right middle lobar bronchus. The stent parameters should be as follows: according to the chest MSCT cross-sectional (fat window) image, measure the diameters and the lengths of the middle bronchus, the right middle and lower lobar bronchus (longitudinal and transverse diameter). Measure the angle between the right middle and lower bronchus. The length of the main body of the stent should be ±90% of that of the middle bronchus. The diameter should be 10–15% larger than the corresponding airway. The length of the middle lobar bronchi part (the single plugged part) should be the same as the right lower lobar bronchus. The diameter should be 15–20% larger than the corresponding airway. The length of the lower lobar bronchi part (tubal) should be 80–90% of the length of the right middle lobar bronchus. The diameter should be 10–15% larger than the corresponding airway. The angle of the stent bifurcation should equal the angle between the middle and lower lobar bronchus. The stent is fully coated.
3. Thoracostomach–left lower lobar bronchus fistula. Use a small Y-shaped single plugged coated self-expanding stent. The single plugged part (dead end) seals the left lower lobar bronchus. The stent parameters should be as follows: according to the chest MSCT cross-sectional (fat window) image, measure the diameters and the lengths of the left upper and lower lobar bronchus, the right main

bronchus diameter (longitudinal and transverse diameter). Measure the angle between the left upper and lower bronchus. The length of the main body of the stent should be ±90% of the length of the left main bronchus. The diameter should be 10–15% larger than the corresponding airway. The length of the left lower lobar bronchi part (the single plugged part) should be the same as the right lower lobar bronchus. The diameter should be 15–20% larger than the corresponding airway. The length of the left upper lobar bronchi part (tubal) should be 80–90% of that of the right middle lobar bronchus. The diameter should be 10–15% larger than the corresponding airway. The angle of the stent bifurcation should equal the angle between the upper and lower lobar bronchus. The stent is fully coated.

11.6.6.2 Preoperative Preparation

See Sect. 11.6.2.2

11.6.6.3 Small Y-Shaped Single Plugged Coated Self-Expanding Stent Placement Procedure

A thoracostomach–right lower lobar fistula can be treated using a small Y-shaped single plugged coated self-expanding stent (for short, Y-shaped single plugged stent) placed in the right middle and lower lobar bronchus and middle bronchus. The operation procedure is described below.

Patient Position

The patient must remove clothes that have X-ray foreign bodies (such as metal buttons), lies on the DSA examination table in a supine position, removes the pillow, has neck and shoulders slightly raised, head in hypokinesis, and turned to the right (toward the operator) at an angle of about 20–30°. Cover with one or two large surgical drapes, fix nasal oxygen tube, and connect ECG monitoring. The C arm is turned to the left at 20–30° (with the patient's head turned to the right at 20–30°, this is equivalent to the body angled to the right at 50°). Adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Administer lidocaine throat anesthesia spray, insert the mouth gag and have the vacuum extractor ready to clear airway and oral secretions, as necessary.

Transcatheter Radiography

Under fluoroscopy, insert the mouth gag and insert a hydrophilic guidewire and catheter through the mouth, oropharynx, laryngopharynx, larynx vestibule, glottis, glottis inferior vena, trachea, carina region, and opening of the right main bronchus. Fix the catheter and pull out the guidewire. Through the catheter, rapidly inject 1% lidocaine 2–3 ml and adjust the position of the catheter tip to the right main bronchus. Through the catheter, quickly inject 30% iodine water contrast agent 3 ml to display the tracheal bronchus angiography. Use this to determine the location and size of the fistula as well as the relationship between the fistula and the right upper, middle, and lower lobar bronchus. Choose the best right main bronchus, right upper, middle and lower lobar bronchus, and middle bronchus image to use as a road map for subsequent intervention operation.

The thoracostomach–right lower lobe bronchus fistula is treated with a Y-shaped single plugged stent, which seals the diseased right lower lobe bronchus and the lobe with the plugged part. Its purpose is to block the right lower lobe bronchus fistula or block communication between the right lower lobar bronchus and other normal bronchial tree branches. Even if gastric juice continues to overflow into the right lower lobe bronchus, it can only go into the right lower lobe bronchus and the lower right lung tissue. To prevent or reduce a right lower lobe pulmonary infection, adjust the catheter into the right lower lobe bronchus. Confirm the position by catheter angiography and then administer through the catheter an appropriate dose of sensitive antibiotics and saline. Flush the solution and leave some of the antibiotics in the right lower lobe to prevent or treat infection.

Insertion of Stiff Guidewire

After completion of radiography, introduce a hydrophilic guidewire. The guidewire and catheter pass over the fistula into the right lower bronchus.

Use radiography to confirm the catheter's location and then exchange to a stiff guidewire. The stiff guidewires are left in location and fixed. Insert a 9 F long sheath using the stiff guidewire into the right main bronchus opening. Pull out the inner core of the sheath. Insert another guidewire and introduce the catheter through the sheath deep into the right main bronchus, right middle lobar bronchus, and segmental bronchus. Exchange this to another stiff guidewire and fix it in position. Pull out the catheter and sheath. The two stiff guidewires should be marked differently to define which (right middle or lower lobar) bronchus they are each-in.

Insertion of the Small Y-Shaped Stent Delivery System

Under fluoroscopy, firmly fix two stiff guidewires and hold them in position. The middle and lower lobar bronchus parts of the small Y-shaped stent are loaded on the middle and lower stiff guidewires. The side conduit of the stent delivery system is connected to high pressure oxygen. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The operator team should cooperate during this procedure, especially when fixing the stiff guidewires, keeping the patient position unchanged, and maintaining the oxyhemoglobin saturation level at normal.

The stent delivery system is inserted using the stiff guidewire. Maintain the patient's hypokinesis as much as possible and slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When you encounter resistance and the patient appears to have a choking cough response, rotate the delivery system to align the two bronchus parts at an anteroposterior position that fits the shape of the rima glottides. Ask the patient to take a deep breath and the glottis will open during the deep inhalation. At this moment, push the delivery system forward to the right main bronchus. Rotate the delivery system to align the middle and lower lobar bronchus parts of the stent toward the corresponding bronchus and make sure that the two guidewires are not twisted. Ensure that the golden mark on the delivery system is also on the correct side. Push the delivery system forward into the right main bronchus.

Placement of the Small Y-Shaped Single Plugged Stent

Hold the stiff guidewire and delivery system's posterior handle, pull back the delivery system's anterior handle to release the Y-shaped stent in the right main bronchus.

Keep the position of the two handles unchanged. Fix the stiff guidewire and push the bronchus part and single plugged part into the right middle and lower lobar bronchi. When you encounter resistance, this confirms that the two parts are completely in the right middle and lower lobar bronchi and that the stent bifurcation has arrived at the bifurcation of the middle and lower lobar bronchus. Fluoroscopy can further confirm that the stent bifurcation has reached the bifurcation of the middle and lower lobar bronchus. Fix the delivery system and guidewire and rapidly pull the two bundled silk threads to completely release the lobar bronchus part of the stent. Use fluoroscopy to confirm that the stent parts are in the correct lobar bronchus. Hold the posterior handle and quickly pull back the anterior handle to release the stent main body in the right middle bronchus. The small Y-shaped stent is entirely released. Pull out the stent delivery system and then the guidewire from the right lower lobar bronchus (compressed by the plugged part) slowly. Avoid hooking out the plugged part out of the right lower lobar bronchus. Retain the middle lobar bronchus stiff guidewire in position as a subsequent intervention operation pathway.

Re–radiography

Introduce the catheter, using the guidewire, to the main body of the Y-shaped single plugged stent, inject 30% water iodine contrast agent 3–5 ml to confirm if the fistula is completely sealed, if the stent is in the correct location, and whether the stents have expanded fully and have not blocked the right upper lobar bronchus, etc. (Fig. 11.19).

At the same time, administer 30% iodine contrast agent 20–40 ml water to the patient orally to conduct esophagus and stomach radiography. Observe whether the contrast agent moves through the fistula to spill into the tracheal bronchus and confirm if the stent has sealed the fistula completely.

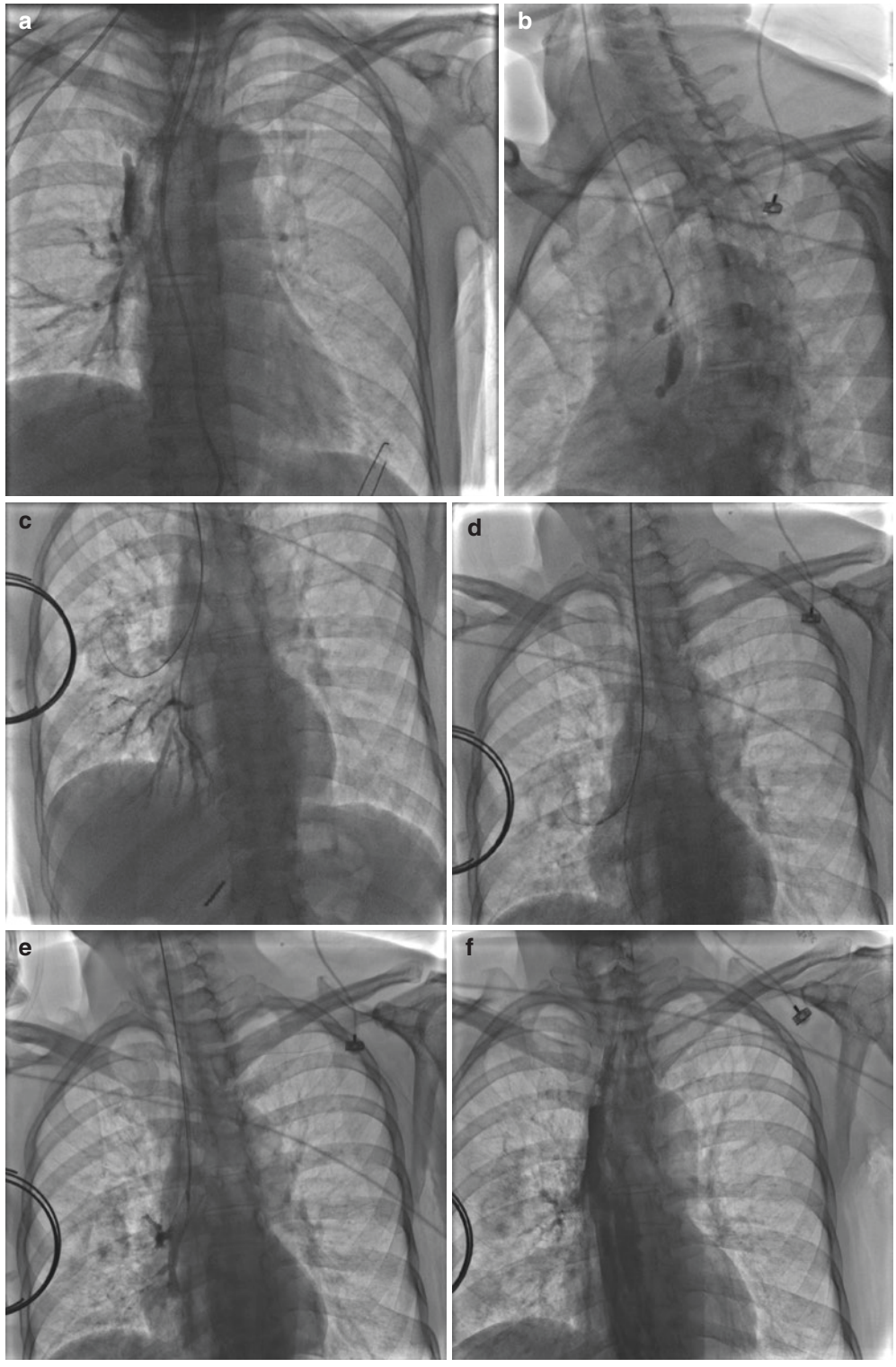

Fig. 11.19 The procedure of thoracostomach–right lower lobar bronchus fistula stenting. (**a**) Oral intake of contrast agent flows into the right lower bronchus. (**b**) Right bronchus angiography. (**c**) Insertion of stiff guidewire. (**d**) Insertion of stent. (**e**) Repeat angiography of right bronchus. (**f**) No bronchus shown during the process of oral intake contrast agent

Sputum Suction

Sputum suction as an important and effective measure to aid the patient after tracheal bronchus covered stent placement. The thoracostomach–airway fistula causes gastric juice to spill into the tracheal bronchus, corrosion and chemical stimulus that causes a large amount of effusion, and secondary bacterial infections. Alveolar and bronchial tissue have different properties of mucus and pus production. Once a coated stent has sealed a fistula and restored the integrity of the tracheal bronchus and its negative pressure, the alveolar and thin bronchial secretions will move into the bronchi, blocking the air flow and causing more severe breathing difficulties.

Introduce a stiff guidewire and then insert a suction tube using the guidewire deep into the left and right main bronchi and especially the left lobar bronchus. Suction the area thoroughly and remove all residual contrast agent and sputum. Follow this with a lavage with antibiotics. At the same time as this procedure, slap the patient's back to dislodge stubborn sputum and change the patient's position to expel sputum until the lung rales disappear and the blood oxygen saturation level reaches or approaches 100%.

11.6.6.4 Postoperative Management

See Sect. 11.6.1.4

11.6.6.5 Complications

See Sect. 11.6.1.5

11.6.7 Thoracostomach – Bronchiole – Pleura Cavity Fistula

Thoracostomach–bronchiole–pleura cavity fistula is a type VII thoracostomach–airway fistula, a rare type.

Thoracostomach–pleural cavity–bronchiole fistula is a gastric ulcer perforation, which wears down the mediastinal pleura through into the pleural cavity, and then wears out the visceral pleura and peripheral lung tissue, thus communicating with the alveolar bronchiole. Due to the gastric fistula and bronchial fistula not being directly connected, both sides of the fistula need to be handled individually. Currently, there is no slim stent delivery system that can access the sub-segmental bronchi, bronchia, and bronchioles. There is also no suitable stent being used in these regions, let alone a coated stent that seals the fistula directly. Generally, the segment bronchial is 3–5 mm in diameter. Design a plugged coated stent that will indirectly seal the bronchiole fistula. This is done by sealing the superior level segment bronchus to block the gastric contents from passing through the fistula into the normal lung segment and lung.

This kind of segmental bronchial level sealing is inevitably accompanied by a change to the segmental lung tissue and a degree of function loss. Due to the large stomach cavity and stomach cavity changes in systole and diastole, stent implantation cannot occur on the side of the stomach. Instead, the stomach cavity should be decompressed with a tube and continuous suction. This removes the gastric contents, prompting the fistula, parietal pleura, and visceral pleura adhesion and healing. A jejunum nutrition tube is inserted at the same time to maintain adequate nutrition.

A thoracostomach–bronchiole in left lower lobar basal segment fistula is used as an example to introduce this stenting technology.

11.6.7.1 Instrument Preparation

Including interventional instruments and stent.

Interventional Instruments

These include a mouth gag, 5 F vertebral artery catheter, 0.035-in. hydrophilic guidewire (150–180 cm), 0.035-in. stiff guidewire (260 cm), 0.035-in. metal stiff guidewire (260 cm), 9 F sheath, 8–10 F multiple function drainage tube package, plugged coated self-expanding stent and delivery system (Fig. 11.20).

Choice of Stent

The length of each bronchial segment is 10–20 mm (average 15 mm). In the thoracostomach–left lower lobar basal segment bronchiole fistula, according to the chest MSCT image, in the thoracic gastric fistula adjacent area, the left pleural cavity near the mediastinal area has pneumatosis,

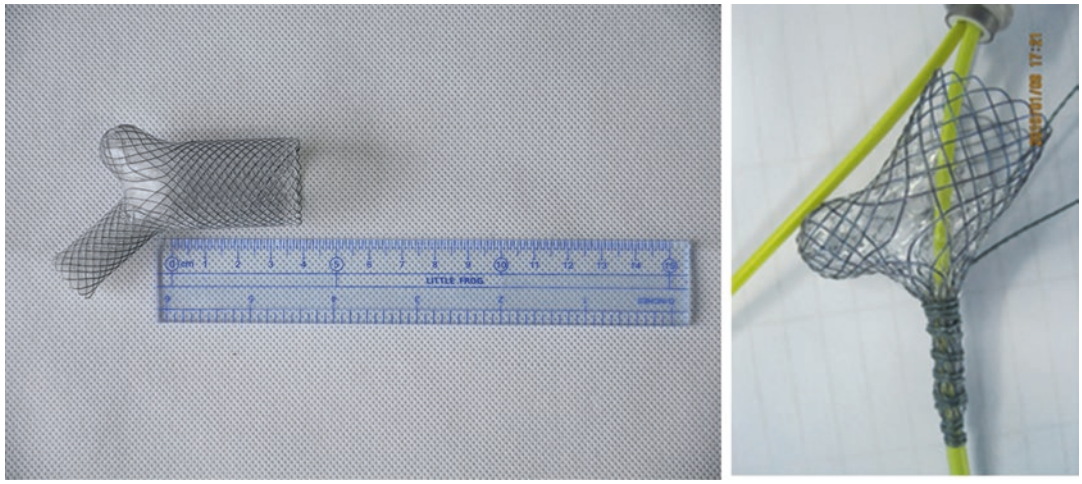

Fig. 11.20 The plugged coated self-expanding stent and delivery system

effusion, or local adhesion. According to the thin layer MSCT image (multiple window width condition continuous observation), there is continuous tracing of the bronchial tree from the fistula to the bronchioles, bronchia, sub-segmental bronchus, basal segment bronchus, and the left lower lobar bronchus. In order to reduce lung injury caused by the fistula, seal the superior level basal segment bronchus and basal segment lung tissue as the palliative treatment option. This only allows the gastric juice to move through the fistula into the basal bronchus and the basal segment lung tissue, thus sacrificing this lung segment to protect the other pulmonary lung tissue.

The plugged coated self-expanding stent seals the bronchiole fistula, blocking the diseased segmental bronchus. The plugged stent has a dead end and the stent delivery inner core or guidewire cannot pass through. It is unlike an ordinary stent that uses a guidewire from inside the stent or push technology to push forward through the guidewire. Dr. Xinwei Han invented a plugged stent delivery system, which uses stent bundling technology and which has successfully solved this problem. The stent is loaded in the bundle mode (delivery system inner core and guidewire need not pass through the head of the plugged stent, but tie the plugged stent at the side of the delivery system inner core).

The plugged coated self-expanding stent blocks the left lower lobar bronchiole belonging to the basal segmental bronchus. The stent parameters should be as follows: according to the chest MSCT cross-sectional (fat window) image, measure the diameter and length of the left lower lobar basal segmental bronchus (longitudinal and transverse diameter). The length of the stent should be no more than the length of the segmental bronchus. The diameter should be 10–15% larger than the corresponding airway. The stent is fully coated.

11.6.7.2 Preoperative Preparation

See Sect. 11.6.2.2

11.6.7.3 Plugged Stent Placement Procedure

Patient Position

The patient remove clothes that have X-ray foreign bodies (such as metal buttons), lies on the DSA examination table in a supine position, removes the pillow, has neck and shoulders slightly raised, head in hypokinesis and turned to the right side (toward the operator) at an angle of about 30–40°. Cover with one or two large surgical drapes, fix nasal oxygen tube, and connect ECG monitoring. Adjust the DSA X-ray vision field to include the oropharynx, trachea, and bilateral main bronchus.

Have the vacuum extractor ready to clear airway and oral secretions, as necessary.

Transcatheter Radiography

Under fluoroscopy, insert a mouth gag and insert a hydrophilic guidewire and catheter through the mouth, oropharynx, laryngopharynx, larynx vestibule, glottis, glottis inferior vena, trachea, carina region, and the opening of the left main bronchus. Fix the catheter and pull out the guidewire. Through the catheter, rapidly inject 1% lidocaine 2–3 ml and adjust the position of the catheter tip to the right main bronchus. Through the catheter, quickly inject 30% iodine water contrast agent 3 ml to display the tracheal bronchus angiography. Use this to determine the location and size of the fistula within the left lower lobar lung tissue. Choose the best left lower lobar bronchus and basal segmental bronchus image to use as a road map for subsequent intervention operation.

Insertion of Stiff Guidewire

After completion of radiography, introduce a hydrophilic guidewire. The guidewire and catheter are inserted into the left lower basal segmental bronchus, sub-segmental bronchus, bronchia, bronchioles, and fistula into the left pleural cavity. The stiff guidewires are left in location and fixed. Insert a 9F long sheath through the stiff guidewire to the left main bronchus opening, pull out the inner core of the sheath. Insert another guidewire and introduce a catheter through the sheath, deep into another segmental bronchus. Exchange to a stiff guidewire and fix it in position. Pull out the catheter and sheath. The two stiff guidewires are marked differently to define which (basal segmental or the another) bronchus each is in.

Insertion of Plugged Stent Y-Shaped Delivery System

Under fluoroscopy, firmly fix two stiff guidewires and hold them in position. The two parts of the Y-shaped delivery system are loaded on the corresponding stiff guidewire. Make it clear which bundled plugged stent is on the basal segmental stiff guidewire. Fix the guidewires by holding them at the mouth gag and outer end. Push the delivery system into the mouth.

The operator team should cooperate in the procedure, especially when fixing the stiff guidewires, keeping the patient's position unchanged, and maintaining the oxyhemoglobin saturation level at normal.

Insert the stent delivery system using the stiff guidewires, maintain the patient's hypokinesis as much as possible and slowly push the delivery system forward through the oral cavity and pharynx cavity to the glottic area. When you encounter resistance and the patient appears to have a choking cough response, rotate the delivery system to align the two bronchus parts at an anteroposterior position that fits the shape of the rima glottides. Ask the patient to take a deep breath. The glottis opens during deep inhalation so, at this moment, push the delivery system through to the right main bronchus. Rotate the delivery system to align the middle and lower lobar bronchus parts of the stent toward the corresponding bronchus and make sure that the two guidewires are not twisted together. The plugged stent is in the basal segmental bronchus.

Placement of the Small Y-Shaped Single Plugged Stent

Hold the stiff guidewire and the delivery system's posterior handle, pull back the delivery system's anterior handle to release the Y-shaped stent in the left main bronchus.

Keep the position of the two handles unchanged and fix the stiff guidewire. Push the delivery system into the basal segmental bronchus. Use fluoroscopy to confirm that the stent is in the basal segmental bronchus.

Fix the delivery system and guidewire and rapidly pull the two bundled silk threads to completely release the stent. Use fluoroscopy to confirm that the stent parts are in the correct bronchus. The plugged stent is entirely released. Pull out the stent delivery system and then the guidewire in the right lower lobar bronchus (compressed by the plugged stent) slowly and avoid hooking the stent out of the basal segmental bronchus. Retain a segmental bronchus stiff guidewire in position as a subsequent intervention operation pathway.

Re–radiography

Introduce the catheter, using a guidewire, to the plugged stent and inject a 30% water iodine contrast agent 3–5 ml to confirm if the fistula is completely sealed, if the stent is in the correct position, and whether the stents have expanded fully and have not blocked the right upper lobar bronchus, etc..

At the same time, administer 30% iodine contrast agent 20–40 ml water to the patient orally to conduct esophagus and stomach radiography. Observe whether any contrast agent passes through the fistula to spill into the tracheal bronchus and confirm if the stent has sealed the fistula completely.

Sputum Suction

Sputum suction is an important and effective measure to aid the patient after tracheal bronchus stent placement. The thoracostomach - airway fistula causes gastric juice to spill into the tracheal bronchus, corrosion and chemical stimulus result in a large amount of effusion, and secondary bacterial infections. Alveolar and bronchial tissue have different properties of mucus and pus production. Once a coated stent has sealed a fistula and restored the integrity of the tracheal bronchus and its negative pressure, the alveolar and thin bronchial secretions will move out into the bronchi, blocking the air flow and causing more severe breathing difficulties.

Introduce a stiff guidewire. Then a suction tube is intubated through the guidewire deep into the left and right main bronchi and especially the left lobar bronchus. Suction the area thoroughly to clear all residual contrast agent and sputum. Following this, lavage with antibiotics. At the same time, slap the patient's back to dislodge stubborn sputum, and change the patient's position to expel sputum until the lung rales disappear and blood oxygen saturation reaches or approaches 100%.

Continuous Gastrointestinal Depression

Fasting, inserting a gastric tube for continuous gastric decompression, and emptying the stomach contents cause the anterior and posterior wall of the stomach to press together and close the fistula. This stops gastric contents spilling into the pleural cavity and maintains the pleural cavity suction, prompting pleural adhesion, fusion, organization, and healing.

Pleural Cavity Drainage

When gastric juice spills into the pleural cavity, sputum leaks into the pleural cavity, pleura and lung tissue are damaged by corrosion, and secondary infections occur. If the pleural cavity vomica is large, the degree of natural healing may be small. For treatment, the operator can conduct a dorsal thoracic puncture into the pleural cavity and insert a drainage tube. This will maintain the negative pressure and allow the visceral and parietal pleura to make contact and heal.

11.6.7.4 Postoperative Management

See Sect. 11.6.1.4

11.6.7.5 Complications

See Sect. 11.6.1.5

11.6.8 Complex Thoracostomach–Airway Fistula

This type of fistula cannot be classified in one of the seven types above. There are three subtypes:

VIII-a: multiple fistulas, two fistulas, or more.
VIII-b: fistula joins two or more parts of the airway.
VIII-c: has typical "supine position burning and excitant choking cough syndrome" but the fistula cannot be determined on image examination.

The tract of the fistula travels a long way through the mediastinum.

Type VIII fistulas need airway-coated stent treatment. The stenting technique is the same as described in the above sections.

11.6.8.1 VIII-a Fistula

This type describes multiple fistulas on the thoracic stomach. Regardless of how many fistulas

are on the wall of thoracic stomach; they all join with the tracheal bronchus and create a confluence as one large or two fistulas on the airway wall. Whether there is one large fistula or two adjacent fistulas (close or far), all of them are treated with an airway-coated stent.

1. The trachea large fistula (or two fistulas) generally uses a tubal-coated airway stent. If the fistula is close to the carina, use a large Y-shaped stent. The Y-shaped stent sits on the carina and covers most or all of the trachea.
2. The carina large fistula (or two fistulas) uses a large Y-shaped stent. The Y-shaped stent sits on the carina and covers most or all of both of the main bronchus.
3. The left main bronchus large fistula (or two fistulas) uses a large Y-shaped stent for the proximal fistula and a small Y-shaped stent for the distal fistula. The stent main body is at the left main bronchus and this seals the fistula. The branches are fixed at the middle and lower lobar bronchus.
4. The right main bronchus large fistula (or two fistulas) uses a large Y-shaped stent for the proximal fistula at the trachea, left main bronchus, and right main bronchus. The distal fistula uses a small Y-shaped stent with the main body at right main bronchus. This seals the fistula with the branches fixed at the middle and upper lobar bronchus.
5. The right middle bronchus large fistula (or two fistula). The proximal fistula uses a small Y-shaped stent with the stent main body at the right main bronchus, with the branches fixed at the middle and upper lobar bronchus. The distal fistula uses a small Y-shaped stent with the main body in the right middle bronchus and this seals the fistula with the branches fixed in the middle and lower lobar bronchus.

11.6.8.2 VIII–b Fistula

The large fistula (or two fistulas) joins with two or more parts of the airway. The fistula involves two or more parts of the tracheal bronchus. Treatment is with an airway-coated stent, but most cases need two or more stents joining together.

1. The lower trachea fistulas (two or more): use a large Y-shaped stent with the main body at the trachea. This seals the fistula with the branches covering the carina fistula.
2. The carina fistulas (two or more): use a large Y-shaped stent and a small Y-shaped stent. The small Y-shaped stent is first placed at the right upper lobar bronchus, right middle bronchus, and right main bronchus. Then the large Y-shaped stent is placed at the trachea and both main bronchi. The main body of the small Y-shaped stent and the branch of the large Y-shaped stent cover each other and seal the right main bronchus fistula.
3. The carina and left main bronchus fistula (two or more): because the left main bronchus is long, use a large Y-shaped stent. If the left main bronchus fistula is far from the carina fistula and the left main bronchus fistula is adjacent to middle and lower lobar bronchus, use a large Y-shaped stent combined with a small Y-shaped stent. The small Y-shaped stent is first placed at the left upper lobar bronchus, left lower lobar bronchus, and left main bronchus. Then the large Y-shaped stent is placed at the trachea and both main bronchi. The main body of the small Y-shaped stent and the branch of the large Y-shaped stent cover each other and this seals the carina and the left main bronchus fistula.
4. The right main bronchus and middle bronchus fistula (two or more): if the two fistulas are close to each other (right main bronchus distal fistula, middle bronchus proximal fistula), use a small Y-shaped stent. If the two fistulas are far from each other (right main bronchus distal fistula, middle bronchus distal fistula), use two small Y-shaped stents: one in the right lower and middle lobar bronchus, and middle bronchus and the other in the right upper and middle lobar bronchus, and right main bronchus. If the two fistulas are further apart (right main bronchus proximal fistula, middle bronchus distal fistula), use two small and one large Y-shaped stents joined together: one small Y-shaped stent at the right lower lobar bronchus, right middle lobar bronchus, and middle bronchus and the other small Y-shaped

stent at the right upper and middle lobar bronchus, and right main bronchus, and the large Y-shaped stent placed at trachea and both main bronchi.

5. If a carina and both main bronchi large fistula or multiple fistulas exist, use three Y-shaped stents; one large and two small. First place one small Y-shaped stent at the right main bronchus, right upper, and middle lobar bronchus, then one small Y-shaped stent at the left upper and lower lobar bronchus and left main bronchus, and the large Y-shaped stent at the trachea and both main bronchi. The branches of the large Y-shaped stent are covered within the two small Y-shaped stent main bodies. The three stents should be joined tightly.

11.6.8.3 VIII–c Fistula

This fistula type describes a typical "supine position burning and excitant choking cough syndrome" but the fistula cannot be determined on an image examination (chest MSCT, upper gastrointestinal contrast). Additional fiber bronchoscopy can show abnormalities of the tracheal bronchus wall, such as local bubbling, white furry substance, and the fistula structure. These can be more clearly seen after washing. Mark the fistula location using bronchoscopy and seal it using different stents.

11.7 Outlook

With advances in the development of esophageal cancer surgery with every passing day and the wide application of three-dimensional radiation and other comprehensive treatments, further understanding of the thoracostomach–airway fistula and its diagnosis have gradually improved. There are more and more clinical cases, and airway stents are being used more and more often. But there are still many problems that need to be solved: how to further improve the understanding of the disease, how to improve early diagnosis of the disease, what method is effective for the treatment of chemical lung damage and multiple lung infection, airway stents being treated as foreign bodies, and the long-term effect of stent implantation and security.

An ideal airway stent is easy to insert and remove, and it should have enough expansion ability and not inflict damage to the airway mucosa. In addition, it should be available in many different sizes and shapes that are suitable for all kinds of airway fistulas. It should fix tightly in the airway and not shift or stimulate the airway mucosa, not increase infection, and not promote excessive formation of granulation tissue, block the airway branch, or inhibit cilia movement and clearance of secretions.

Developing a stent with suitable hardness and flexibility and a better curative effect is the direction of future research. Stents that are currently in development and undergoing clinical trials include drug-coated stents, electrical decomposition stents, radioactive stents, and biodegradable stents. For stents to be applied in clinical use in the near future, clinicians should continue to familiarize themselves with the treatment advances, perfect the technology used, standardize the operation procedure, make stenting more safe and effective, and help more thoracostomach–airway fistula patients benefit from these advancements.

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Bronchopleural Fistula

12

Xinwei Han, Quanhui Zhang, and Gang Wu

12.1 Introduction

Lung cancer is one of the most serious types of malignant tumor, threatening human health. In recent years, the incidence of lung cancer has increased significantly in China, and lung cancer is responsible for most malignant tumors in some developed areas. Tuberculosis is a chronic disease. China is one of the 22 countries with (Bangladesh, Brazil, Cambodia, China, Democratic Republic of the Congo, Ethiopia, India, Indonesia, Kenya, Mozambique, Myanmar, Nigeria, Uganda, Pakistan, Philippines, Russian Federation, South Africa, Thailand, United Republic of Tanzania, Vietnam, Brazil and Zimbabwe) with high incidence of tuberculosis. Lobectomy or total pneumonectomy is currently the main treatment for lung cancer, cavitary pulmonary tuberculosis, localized bronchiectasis, and destruction of the lung [1, 2]. Bronchopleural fistula (BPF) is one of the serious complications that can occur after a pneumonectomy. It can endanger the patient's life if not treated properly. The incidence of BPF after pneumonectomy is 0.8–12.5% in the rest of the world, but in China the incidence of BPF after pneumonectomy is low, only 0.7–1.7%. The mortality rate for patients with BPF after traditional treatment for BPF is high, ranging from 12–71.2% [3, 4].

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BPFs can occur in the airway branches of the trachea, the main bronchi, the bronchi, the segmental bronchi, the bronchioles, or the alveolar ducts, which are all part of the pleural cavity. In recent years, understanding of BPFs by thoracic surgeons has improved, surgical treatment has been optimized, efficient antibiotics are available, nutrition can be adequately supported, and this has resulted in the incidence of BPFs decreasing significantly after pulmonary resection, and particularly after total pneumonectomy.

12.2 Etiology of Bronchopleural Fistula

12.2.1 Improper Treatment of the Bronchial Stump

Improper treatment of the bronchial stump after pneumonectomy is the main reason for the early occurrence of a BPF, and consist of four common types:

1. Bronchial stumps are improperly handled during surgery. For example, when the stump is too long (> 10 mm) sputum easily accumulates in the bronchial stump, which causes an anastomotic infection of the stump and leads to a BPF.
2. If the stump was sutured too densely or sparsely, and the suture line was knotted too

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tightly or too loosely, this might lead to the stump of the bronchus connecting with the thoracic cavity. Sputum containing bacteria can enter the pleural cavity through the fistula and repeated infection leads to the formation of a sinus.

3. The excessive separation of the trachea and hilum results in a stump ischemia, for example, the bronchial vessel is excessively peeled in the operation or excessive use of electrocoagulation during the operation leads to thermal injury of bronchial vessels, which will affect wound healing and lead to a BPF.
4. Excessive crushing of the stump can result in incomplete closure of the stump and slower healing of the bronchial stump can lead to a BPF.

12.2.2 Residual Tumor

The formation of BPF is also related to the recurrence of a residual tumor of the bronchial stump and local invasion and destruction of normal tissue.

The formation of a BPF can be the result of many factors, for example, surgical indications are not appropriate; preoperative judgment of tumor staging is not accurate; the resectability of the tumor is incorrectly predicted; surgery cannot completely remove the tumor, which leads to a residual tumor of the bronchial stump; local recurrence and direct invasion of cancer cause bronchial wall damage and ischemic necrosis or perforation. Chemotherapy, arterial infusion chemotherapy, and radiation therapy lead to rapid tumor necrosis, slow repair of normal tissue, and bronchial wall perforation.

12.2.3 Tuberculous Invasion

Destructive pulmonary tuberculosis, especially pulmonary tuberculosis with positive sputum cultures, causes chronic hypoproteinemia and malnutrition in patients with a long medical history of tuberculosis. The residual lesion of the bronchial stump or the active stage of tuberculosis results in caseous necrosis of the bronchial stump after lung resection, and this can cause a BPF. Pomerantz et al. reported a 10.5% incidence of BPF in 85 patients with drug-resistant pulmonary tuberculosis after pneumonectomy.

12.2.4 Neoadjuvant Chemoradiotherapy

Preoperative radiotherapy or chemotherapy and excessive intraoperative removal of tissue around the bronchial stump can lead to ischemia of the bronchial stump and a decrease of mucosal blood flow, thus affecting the healing rate and increasing the possibility of a BPF forming. It has been reported that the preoperative bronchial tissue can receive more than 5,000 cGy of irradiation and this puts that tissue at risk for a BPF.

12.2.5 Infection

A systemic infection, especially poor chest drainage resulting in a chest infection, causes surrounding tissue necrosis of the bronchial stump and hyperplasia fibrosis, which will affect the tissular blood supply of the bronchial stump. The over-reaction of the inflammatory tissue increases the rejection by the body of the surgical suncture and stapler. This can lead to a BPF forming.

12.2.6 Other Etiologies

Systemic diseases such as diabetes mellitus, long-term use of corticosteroids, hypoproteinemia, advanced age, etc. cause delayed healing of the bronchial stump, which can also result in a BPF after pneumonectomy. Postoperative mechanical ventilation is also an important cause of BPFs [5]. During an operation, blood transfusion [6], a decrease of FEV1 percentage [5, 6] and carbon monoxide diffusion (DLCO) in the lung, infectious diseases, and the prolongation of drainage time can all cause a BPF.

12.3 Diagnosing a Bronchopleural Fistula

12.3.1 Clinical Symptoms

It has been reported that the occurrence time of a BPF ranges from a few days to a few years. The characteristic clinical manifestations are an irritating cough, a pleural watery sputum obvious in the lateral decubitus position, persistent high fever, hemoptysis, closed thoracic drainage tube continuing to expel a large amount of gas, and a large amount of ipsilateral thoracic purulent discharge through the bronchial fistula into the contralateral lung tissue leading to aspiration pneumonia, sepsis, and respiratory failure. Different stages of a BPF have different pathophysiological characteristics. Due to the size of the fistula and the different levels of tolerance, the clinical manifestations are different but traditional treatment is the same. More patients die from infections or multiple organ failure.

12.3.2 Imaging Examination

12.3.2.1 Chest Radiography

The early signs of a BPF include fluid pneumothorax and the level of pleural fluid dropping obviously or rising after a decline (not caused by a pleural puncture). One to 2 mL of methylene blue is injected into the thoracic drainage tube, and the diagnosis can be confirmed when the sputum turns bluish violet. Patients with poor diagnosis need to receive an aerosol inhalation of radionuclide, and diagnosis can be confirmed when the intrathoracic radioactivity being scanned.

12.3.2.2 Thoracic Multislice Spiral CT

For patients suspected of having a large BPF according to the clinical symptoms, a chest MSCT scan should be performed. The scanning scope is from the second cervical vertebra to the diaphragm. For the axial plane, the multiwindow width under the coronal, sagittal, and 3D reconstruction is used. For the transverse plane, the coronal, sagittal, and 3D reconstruction are performed under the condition of multiwindow width. The lung window (window width 1,000 HU, window level −700 HU) can show pneumonia and other lung damage (Fig. 12.1), and a larger BPF can also be found. Smaller, sloping, or twisted fistulas may be covered by the pulmonary window because of the partial volume effect. The mediastinal window (window width 400–500 HU, window level 50 HU) or diaphragm window–fat window (window width 400 HU, window level −50 to −100 HU) can display a

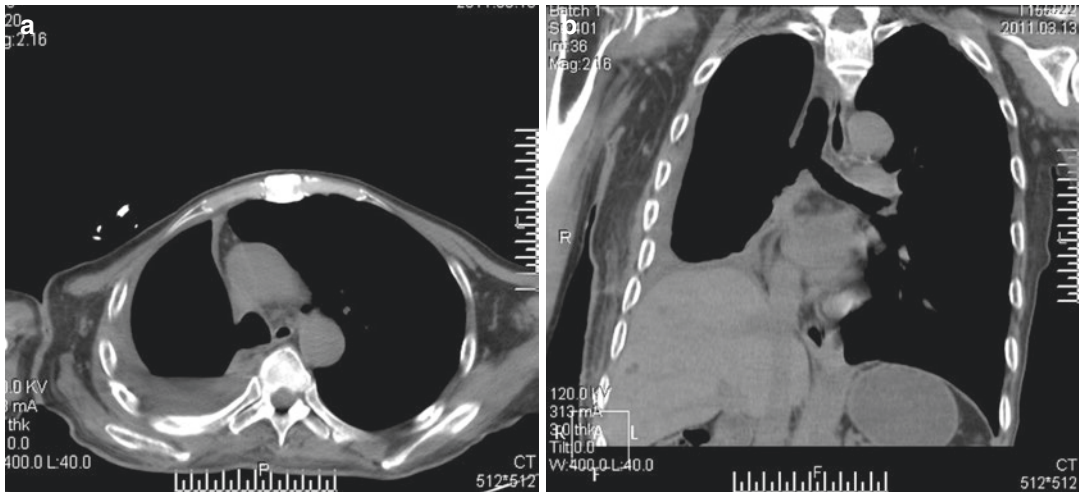

Fig. 12.1 Chest MSCT scan and reconstruction image, (**a**) Mediastinum window–fat window shows right bronchial stump fistula, (**b**) right BPF coronal image reconstruction

variety of structures in the mediastinum, pleural residual space, and airway fistula, which is more accurate and can avoid false-positive and false-negative results to the maximum extent. The accuracy rate is over 86% (Fig. 12.1a, informed consent was obtained from all participating subjects, and the ethics committee of the first affiliated hospital of Zhengzhou University approved our study). An MSCT scan can clearly show the trachea, the bronchial structure, the bronchial fistula, and the position and size of the fistula. The transverse, coronal (Fig. 12.1b), sagittal, and 3D reconstruction can display the location and size of the BPF, the length of the bronchial stump, the prevalence of pleural effusion and pulmonary infection on the affected side, and the location of the adjacent tissues around the fistula. The MSCT scan can be used to measure airway diameter, length, and angle, and this information will direct the clinical treatment and customization of the BPF closure stent to ensure that the fistula is completely blocked [7].

12.3.2.3 Airway Angiography

Airway angiography refers to the dynamic acquisition tracheography image in DSA and this is obtained by inserting the catheter into the mouth, epiglottis, glottis, and air tube. Here it can be observed that the contrast medium overflows into the contralateral pleural cavity or diffuses into the pleural cavity through the bronchial stump fistula (or the early stage of the bronchial stump fistula). This can be clearly demonstrated in the anatomical relationship between the fistula, trachea, bronchi, and pleural residual cavity and allows for the customization of an individual airway stent. This is especially important for the bronchial and bronchopleural fistula, which are poorly displayed on the MSCT scan.

Because tracheography (Fig. 12.2) is invasive, it is not used as a common examination method but only to confirm the location of the BPF and its relationship with the adjacent tissues (Fig. 12.2a). It can also be used for the qualitative diagnosis of a pleural fistula of the lobar bronchus and segmental bronchus when the MSCT scan is poor (Fig. 12.2b).

12.3.3 Fiberoptic Bronchoscopy

Fiberoptic bronchoscopy can be used to observe the location of the fistula, the size, and the relationship between the fistula and trachea. Thirty min before the fiberoptic bronchoscopy, patients are injected with diazepam 10 mg, anisodaminen 10 mg, and dexamethasone 10 mg to alleviate airway hyper-responsiveness and reduce airway secretions. After

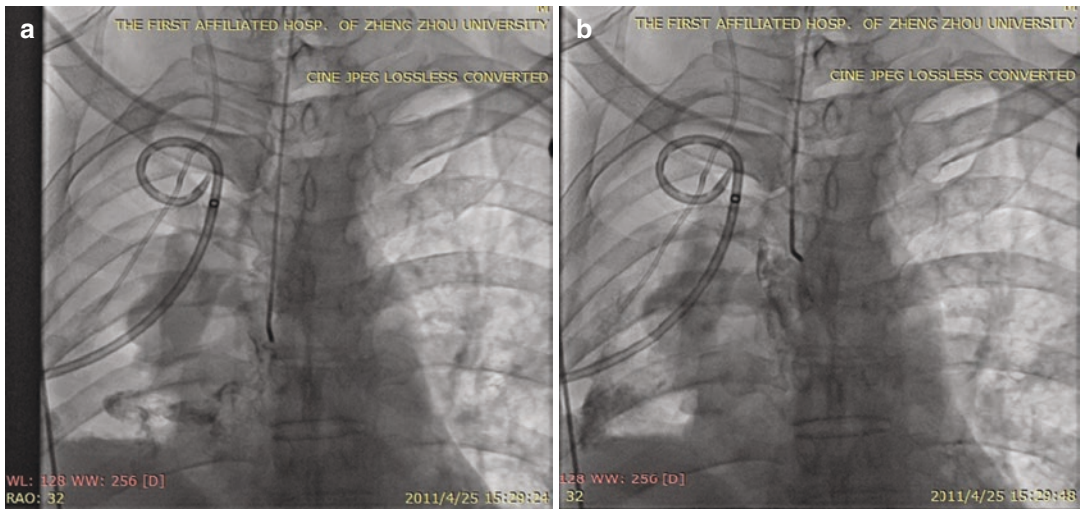

Fig. 12.2 Bronchial angiogram: (**a**) the right upper lobe bronchus with opening proximal fistula, (**b**) intubation to the right upper lobe endobronchial angiography

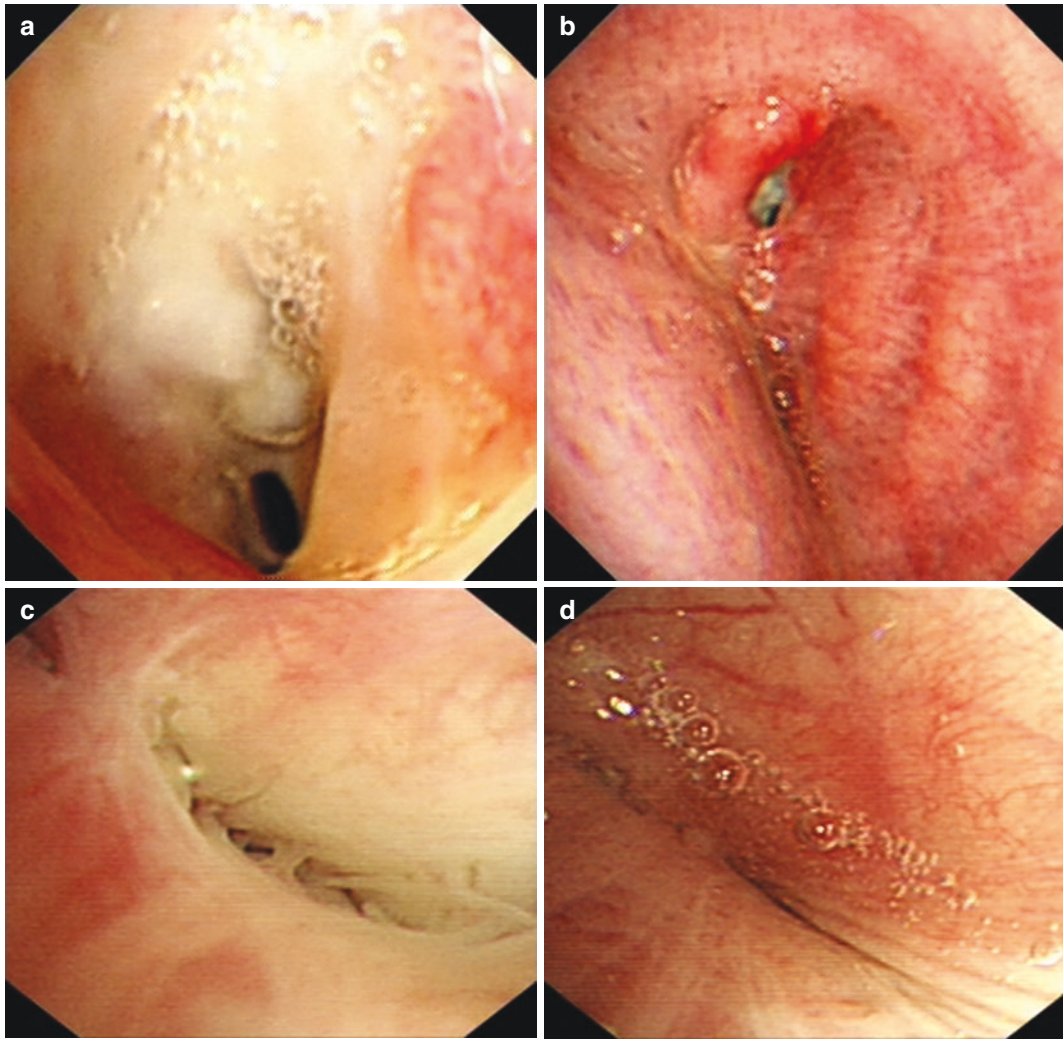

Fig. 12.3 Image of a bronchoscopy. (**a**, **b**) The white fur on the stump of the bronchus seen under bronchoscopy, with a partial tear. (**c**, **d**) Bubbles flow through the fistula when coughing

anesthesia by thyrocricoid puncture through the mouth and into the trachea and glottis bronchial, the fistula can be directly observed with the edematous mucosa around the fistula and a visible white fur attached in the sinus (Fig. 12.3a, b). If the patient is asked to cough, bubbles can be seen to overflow through the fistula. Chest liquid enters the airway and the larger fistula can be directly observed in the bronchus, connected to the pleural cavity (Fig. 12.3c, d). After the fiberoptic bronchoscopy, it is best to perform a rinse treatment in the airway and bronchus with a saline injection or a saline solution with antibiotics to lavage each side and each leaf of the bronchus in order to promote recovery from pulmonary inflammation and improve the patient's health.

12.4 Staging and Types of BPF

12.4.1 Stages of BPF According to Time to Formation

These stages include: early BPF (forms 7 days after surgery), medium-term BPF (forms 8–30 days after surgery), and advanced BPF (forms 30 days after surgery).

An early BPF forms within 1 week of surgical pneumonectomy. Patients present with a mediastinal swing (mediastinal flutter), which affects the heart blood circulation and is accompanied by chest tightness, contralateral lung infection, and other symptoms. When examining the bottle from the thoracic closed drainage, continuous leakage is seen and this is accompanied by subcutaneous emphysema. The mid-term BPF forms 8–30 days after a pneumonectomy. Most patients suffer from aspiration pneumonia, pleural infection, coughing, expectoration, emaciation, and poor physique. An advanced BPF forms 30 days or more after the pneumonectomy. Symptoms include weight loss, fatigue, poor physique, repeated infection of the lungs or pleural cavity, respiratory failure, and multiple organ failure.

12.4.2 Types of BPF According to the Location

For the minimally invasive interventional radiotherapy, a self-expandable stent made of memory alloy was selected to facilitate the development of an individualized airway memory alloy self-expandable stent occlusion treatment regimen. The BPFs are divided into 11 types based on the location of the BPF in the body:

Type 1 carina BPF: A carina BPF forms between the airway and pleural cavity in the carina after a pneumonectomy.

Type 2 left main BPF: A left main BPF forms between the left bronchial stump and the pleural cavity after left pneumonectomy.

Type 3 right main BPF: A right main BPF forms between the right bronchial stump and the pleural cavity after right pneumonectomy.

Type 4 right middle segmental BPF: Right middle segmental BPF forms between the right middle segmental bronchial stump and the pleural cavity after right middle and lower lobe pneumonectomy.

Type 5 right upper lobe BPF: A right upper lobe BPF forms between the right upper lobe bronchial stump and the pleural cavity after right upper lobe pneumonectomy.

Type 6 right middle lobe BPF: A right middle lobe BPF forms between the right middle lobe bronchial stump and the pleural cavity after right middle lobe pneumonectomy.

Type 7 right lower lobe BPF: A right lower lobe BPF forms between the right lower lobe bronchial stump and the pleural cavity after right lower lobe pneumonectomy.

Type 8 left upper lobe BPF: A left upper lobe BPF forms between the left upper lobe bronchial stump and the pleural cavity after left upper lobe pneumonectomy.

Type 9 left lower lobe BPF: A left lower lobe BPF forms between the left lower lobe bronchial stump and the pleural cavity after left lower lobe pneumonectomy.

Type 10 segmental BPF: A segmental BPF forms between the segmental bronchial stump and the pleural cavity after segmental pneumonectomy. The reasons for the BPF forming may include pleural cavity infection, trauma, or operation. This results in rupture of the visceral pleura and damage to the pulmonary lobe and lung segment. This causes the segmental bronchial to communicate with the pleural cavity.

Type 11 terminal BPF: A terminal BPF can occur following pneumonectomy or other surgery in the pleural cavity. When the residual cavity is refractory to healing, pus can corrode the lung surface and cause pulmonary layers, pleura, alveoli, and bronchioles to communicate with the pleural cavity. The pus from the gastroesophageal anastomotic stoma or the pus from an encapsulated empyema corrode the surface of the lung and cause the terminal bronchioles to communicate with the pleural cavity. Trauma and rupture of the bullae can also lead to the formation of a BPF between the terminal bronchiole and the pleural cavity.

12.5 Clinical Treatment of a BPF

Infection, asphyxia, and respiratory failure are the main causes of death in patients with a BPF. Once a BPF forms, a large amount of sputum enters the pleural cavity through the fistula, which causes a residual pleural infection. The infection is aggravated with expansion of the

fistula. A large amount of purulent pleural effusion in the pleural cavity can enter the airway or the uninjured side of the lung through the stoma when the patient coughs or changes position, which causes coughing, liquid accumulation in the chest, excessive sputum, fever, and other symptoms. Purulent pleural effusion entering the lower lobe of the lung can cause pneumonia and aggravated infection. When the pleural cavity is large, purulent pleural effusion increases the size of the void and causes respiratory dysfunction. Therefore, after a pneumonectomy, immediate closed thoracic drainage is necessary when a BPF is found. Ensure patients remain in the lateral position to prevent ipsilateral pleural effusion entering the trachea through the sinus as this will cause a bronchial obstruction and could lead to death in patients with hypoxia [1, 2, 7]. In order to improve respiratory function, use targeted antibiotics according to the results of the pleural fluid culture, administer a high protein diet, and, if necessary, administer an intravenous drip of human albumin, which can promote healing of the fistula.

The majority of surgical treatments require fenestration drainage, chest molding, and various fistula repairs. The operation is complicated, causes in large wounds, requires optimal patient tolerance, results in a high disability and postoperative recurrence rate, and it also has a high failure rate. Because of the severe infection of the bronchial stump fistula, the failure rate of the operation in this infected environment is higher than that under aseptic conditions. So a BPF cannot be repaired by a surgical approach. Moreover, due to long-term consumption, infection, and poor physique, patients with advanced BPFs cannot tolerate multiple operations.

In recent years, there have been many reports on the successful treatment of BPFs (< 3 mm) using bronchoscopy, laser treatment, bronchial stump submucosal sclerotherapy, and other treatment methods.

12.5.1 Medical Therapy

Conservative treatment using internally administered drugs is the basis of all treatment, including pleural aspiration, continuous closed thoracic drainage, anti-infection, phlegm drugs, nutritional support, etc. Examples of conservative treatments are:

1. *Aspiration of pus by pleural puncture and continuous closed thoracic drainage*. Once a BPF forms, the pleural cavity should be drained of the residual purulent secretion and gas using pleural aspiration (liquid) or implantation of a closed thoracic drainage system. This can prevent the occurrence of aspiration pneumonia or suffocation with a large amount of purulent fluid flowing into the airway.
2. *Anti-infective therapy*. As the pleural cavity is connected to the airway, a large number of bacteria enter the pleural cavity and reproduce. This can result in an intractable infection. Perform a bacterial culture and drug sensitivity test on pleural fluid or sputum. Before the result of the drug sensitivity test is known, it is necessary to administer broad-spectrum antibiotics to control the infection.
3. *Reducing phlegm*. Patients with a BPF are generally physically weak with a limited ability to expectorate, thus expectorant drugs or aerosolized inhalation drugs are administered. Diluting the sputum is a good way to reduce inflammation of the contralateral lung, provide respiratory care, and prevent sputum retention.
4. *Nutritional support*. Patients with a BPF generally suffer some symptoms of chronic consumption, fever, and persistent weakness, which often leads to malnutrition and poor healing of the bronchial stump. It is important to strengthen the patient with nutritional support. Offer a high protein, high vitamin diet and also administer intravenous nutritional support in accordance with specific circumstances, which can enhance physical fitness and promote the healing of the fistula.
5. *Position*. It is necessary to encourage and train the patients to cough. Position the head high and the feet low, and this will prevent the purulent reflux from entering the healthy lung and causing aspiration pneumonia and suffocation.

12.5.2 Surgical Treatment

Surgical treatment involves timely and effective closure of the BPF, complete drainage of the pleural cavity, and effective control of the pleural infection, which can then promote fistula healing and eventually eliminates the ipsilateral pleural cavity. These steps are currently the only effective treatment principles in the treatment of a BPF. The traditional method of surgical treatment of a BPF mainly included: (1) Pleural pneumonectomy or resection and suture of bronchial stump; (2) Sternal incision, retreatment of the mediastinal bronchial stump [6]; (3) Repair of bronchial stump fistula with pedicled thoracic muscle flap;(4) Repair of bronchial fistula with pedicled greater momentum in thoracic cavity; or (5) Repair of the bronchial fistula with transfer of the scapular muscle flap [8, 9].

Most of the surgical treatment methods should be performed close to the fistula, such as fenestrated drainage, thoracic plasty, and repair. Patients often miss the opportunity to undergo surgical treatment due to complicated operations, large wounds, inability to tolerate surgery, a high disability rate, a high rate of wound infection, severe infection, poor health, and other reasons.

With the popularization of minimally invasive technology, the improvement of interventional equipment, and the invention of new interventional instruments, interventional technology has been significantly improved. In 2001, Watanabe reported one successful case of airway stenting to treat a BPF, which provided the basis for interventional radiology in the treatment of BPFs. In recent years, with the improvement of interventional techniques and material technology, application of interventional radiology in airway diseases is more and more widely seen, but the treatment method of BPFs using shape memory alloy self-expandable stent closure is still rarely reported in the literature. Dr. Xinwei Han, et al. [7, 10] designed a series of shape memory alloy self-expandable plastic stents for BPFs and successfully secured the national patent based on the anatomical characteristics, and physiological and pathological changes of the BPF after surgery, combined with the characteristics of the airway stent in the medical market. The clinical applications of this type of BPF stent were satisfactory.

12.6 Interventional Radiological Treatment with a Stent

12.6.1 Carina BPF

A carina BPF forms between the carina airway and the pleural cavity after pulmonary resection. Based on the special anatomical structure and lesion characteristics of the carina area, Dr. Xinwei Han and colleagues designed the L-shaped branch single-bullet, Y-shaped branch single-bullet, and memory self-expandable covered metallic airway stent for the treatment of a carina BPF.

12.6.1.1 Equipment Preparation

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation*. 5 F single-bend tube 1 root, 0.035-in. hydrophilic membrane guidewire 1 root, 0.035-in. reinforced guidewire 1, customized L-shaped branch single-bullet airway stent (Fig. 12.4a) or Y-shaped branch

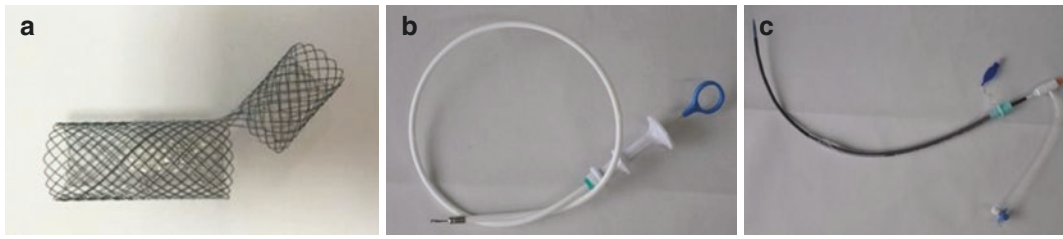

Fig. 12.4 Interventional operating equipment and special individualized stent. (**a**) Customized L-shaped airway stent; (**b**) stent retrieval hook; (**c**) tracheal intubation inserted into 14 F sheath

single-bullet memory self-expandable covered metallic stent and the stent delivery system, stent recovery hook (Fig. 12.4b), mouth gag 1, 14 F long sheath, tracheal intubation (Fig. 12.4c), suction device, ventilator, and other rescue equipment.

2. *Stent selection*. According to the chest MSCT cross-section image of the fat window (window width 400 HU, window length -50 HU), measure the tracheal anteroposterior diameter and transverse diameter. Measure the diameter and length of the bilateral bronchus. Select or customize an L-shaped or inverted Y-shaped integrated self-expandable covered metallic stent. Stent parameters should be as follows: the diameters of the trachea, main bronchial stent are generally 12–20% greater than the diameter of the corresponding airway, the length of the trachea (main body) is 40–50 mm larger than the carina. The length of the right main bronchus is equal to the distance of the carina from the upper margin of the upper right lobe bronchial opening, the length of the left main bronchus is generally 20–30 mm.

12.6.1.2 Preoperative Preparation

1. *Laboratory exam*. Routine blood, urine, stool, liver function, renal function, blood glucose, electrolytes, coagulation test, pulmonary function tests, bacterial culture and drug sensitivity of sputum or pleural cavity secretions, and ECG before the treatment.
2. *Imaging*. Perform a chest MSCT scan and make full use of MPR, CPR, and other post-processing functions. Analyze the image to define the exact location, size and surrounding adjacent relationship of the carina BPF. Define the distribution and extent of pulmonary inflammatory lesions and determine the severity of lung injury. Use this scan to accurately measure the tracheal main bronchial diameter and length and then select the stent specifications.

As far as possible, perform fiberoptic bronchoscopy and fiber gastroscopy and use this to comprehensively understand the condition of the chest and tracheal-bronchus. Remove as many of blockages as possible or excessive phlegm or sputum within the bronchus.

3. *Cardiopulmonary function*. Use an ECG to understand the cardiac function and reserves, and to monitor pulmonary oxygenation function by multifunction physiological monitoring.
4. *Premedication*. 10–30 min before the interventional procedure (before the patient is admitted to the operation room), intramuscular diazepam 10 mg is administered to relieve the patient's anxiety. An intramuscular injection of anisodamine 10 mg relieves smooth muscle tension, reduces secretion of digestive glands and respiratory glands, and facilitates airway interventional radiology procedures. If the patient has severe pulmonary inflammation, poor respiratory function, or low levels of oxygen, administer an intravenous injection of hormones (dexamethasone 10 mg, or methylprednisolone 30 mg) to reduce the tracheobronchial and pulmonary exudation and inflammation, and to improve the stress coping ability as well as improve the patient's tolerance to intervention.

12.6.1.3 Interventional Radiology for L–Shaped Airway Stent Implantation Procedure

1. *Patient position*. The patient relaxes the body, removes clothing containing items not compatible with X-ray (for example, a metal buckle) from the upper body and lies in a supine position on the DSA inspection table. Remove the pillow and slightly elevate the neck and shoulders. Try to angle the head back and to the right at 20–30°. The patient is covered with a large surgical drape. Fix a nasal oxygen tube and connect the multi-channel ECG monitoring. The procedure is performed after administration of lidocaine spray for local throat anesthesia. Insert the mouth gag into the patient's mouth and prepare the negative pressure suction device to clear the airway and oral secretions as needed.

The left side of the C-arm is tilted 20–30°(with the right deviation of the head at 20–30°, this is equivalent to turning the patient about 50° to the right). Adjust the X-ray visual field of the DSA to include the oropharynx, trachea, and bilateral main bronchi.

2. *Transcatheter angiography*. Under fluoroscopy, insert a 0.035-in. hydrophilic membrane guidewire and 5 F vertebral artery catheter through the mouth into the oropharynx. Move the catheter tip to above the throat and hypopharynx. Ask the patient to cough or to inhale, and when the glottis is open, use the guidewire to move the catheter across the laryngeal cavity, then to the trachea. Remove the guidewire. Inject 2–3 mL of 2% lidocaine for airway mucosa anesthesia and 1–2 mL of 0.1% epinephrine solution to prevent airway mucosal injury from bleeding (Fig. 12.5a). Via the catheter, inject a water-soluble contrast (3 mL) to show the length of the main bronchial stump, the location and size of the fistula, the length of the main bronchus, and the position of the upper lobe opening.
3. *Introduce reinforced guidewire*. After the completion of angiography, the catheter is introduced into the hydrophilic membrane guidewire. The guidewire and catheter move through the fistula into the left or right main bronchus at a depth of at least 20 mm. Then remove the guidewire and retain the catheter in position. Via the catheter, inject 30% water-soluble contrast (1 mL) to confirm the location of the catheter at the main bronchus. The exchange is introduced into the bronchial trunk of the lower side of the uninjured side by adding the reinforced guidewire. The DSA X-ray field of vision is adjusted to include the guidewire, throat, and chest. The surgical assistants must ensure that the position of the reinforced guidewire and the opener remain unchanged at this time.
4. *Introduce the stent delivery system*. Insert the stent and its delivery system along the reinforced guidewire and gently maneuver through the glottis to avoid damage to the glottis (Fig. 12.5b). Use fluoroscopy to ensure that the reinforced guidewire is in the main bronchial position. Push the delivery system forward slowly through the mouth, pharynx, and to the throat glottis. When you encounter resistance or the patient coughs or is agitated, ask the patient to inhale deeply and ensure that they are not moving. When the glottis opens during deep inhalation, take the opportunity to advance to the trachea. Stop operating and fix the delivery system and guidewire position and allow the operator and patient to rest for 30–60 s and adjust the position slightly.
5. *Release stent*. Under X-ray monitoring, the position of the stent is adjusted so that the three landmarks of the lateral wall of the stent are located at the lateral wall of the airway (Fig. 12.5c), and the arc transition section is aligned with the opening of the main bronchial orifice of the affected side (that is, the fistula area). After accurate positioning, the stent is released slowly into the main bronchi and trachea (Fig. 12.5d). After the stent is fully released, the guidewire is retained and the stent delivery system is carefully removed (Fig. 12.5e).
6. *Transcatheter review of angiography*. After the introduction of the guidewire into the catheter, the catheter is injected with 3–5 mL of 30% water-soluble contrast to determine whether the fistula has been completely blocked. Ask the patient to cough or breathe deeply and observe if there is an overflow of gas into the closed drainage bottle. If there is still a continuous flow of bubbles, the closure of the fistula is not complete. If there is a small bubble overflow that gradually reduces and disappears, this indicates that fistula closure is successful.
7. *Full suction and hemostasis*. Insert the catheter and the loach guidewire into the contralateral distal bronchial. Remove the catheter and insert a suction tube along the guidewire. Thoroughly suction the endobronchial residual contrast agent and sputum and pat the chest and back to assist with sputum discharge. Do this until the sputum and pulmonary rales disappear and the oxygen saturation reaches or approaches 100%. The patient is encouraged to cough and undergo repeated

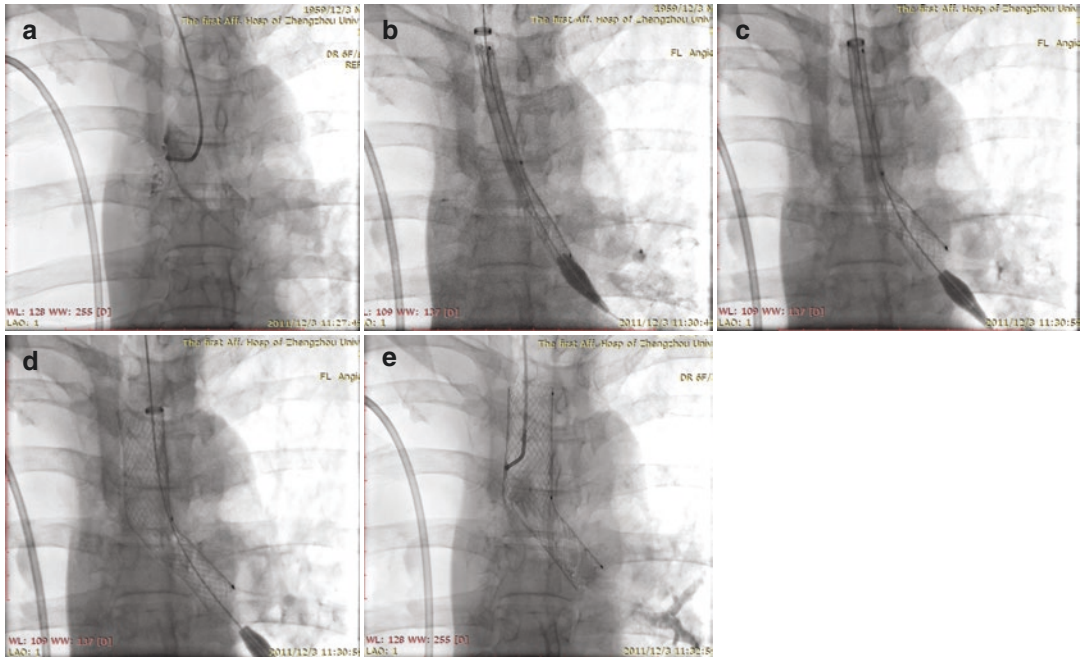

Fig. 12.5 Interventional placement of L-shaped airway stent. (**a**) Transcatheter tracheal angiography is used to determine the carina fistula and right main bronchus; (**b**) insert the L-shaped stent delivery system along the reinforced guidewire; (**c**) the three lateral markers of the lateral wall of the stent are located on the lateral wall of the airway; (**d**) release the stent slowly into the main bronchi and trachea; (**e**) remove the stent delivery system and retain the guidewire as a suction channel

suctioning, and, if necessary, dilute the sputum with 3–5 mL physiological saline and aspirate. If there is blood in the sputum, administer 1–2 mL of 0.1% epinephrine solution hemostatic through a catheter. Withdraw the catheter when no more blood is found in the sputum.

8. *Replacement of thoracic closed drainage*. After stent occlusion of the fistula, the closed thoracic drainage tube can be changed to a multifunctional drainage tube in the interventional department (8.5–12 F). With a purse string suture around the drainage tube, an external negative pressure suction device is adopted to cause a certain amount of negative pressure suction in the chest cavity to promote the displacement of the mediastinum and diaphragm, the collapse of the thorax, and the closure of the pleural cavity. If necessary, the pleural cavity can be flushed or filled with antibiotics through a multifunctional drainage tube to control infection and promote healing.

12.6.1.4 Management after Stenting

1. *Aerosol inhalation*: Aerosol inhalation (normal saline 10 mL + lidocaine 5 mL + ambroxol 30 mg + Amikacin 0.2 g) is administered twice a day for 4–6 weeks after stenting, which prompts the excretion of sputum and reduces the stent foreign body irritation and inflammatory response.
2. *Expectoration and expectorant*: The patient should change position regularly and be assisted by slapping their back to completely remove the infectious sputum in the lungs. The slapping will not shift the stent. The patient should cough and expectorate with great force to promote the removal of phlegm and sputum.
3. *Anti-infection*: According to the results of the bacterial culture, prescribe targeted anti-infectious drugs to control the lung infection. If necessary, regular fiberoptic bronchoscopy is performed with bronchial lavage to remove sputum and pus in the bronchi. High

concentrations of targeted antibiotics could also be used in local application within the bronchi.
4. *Enhance nutrition*: Administer enteral nutrition through the jejunum nutrient tube and gradually increase the amount of oral intake. If choking is not stimulated by eating and other discomfort occurs, the jejunum nutrient tube can be removed to restore normal oral intake and improve the quality of life.

12.6.1.5 Management of Complications

1. *Hemoptysis*: A small amount of blood in the sputum is common after stenting. This normally automatically stops in 10 min without treatment. If there is persistent hemoptysis, especially a large amount of blood or clots of blood, inject 2–3 mL 1:1,000 adrenergic saline through the endotracheal tube to prompt vasoconstriction of the tracheal mucosa and immediately stop hemoptysis. This works even if the peripheral arteries are ruptured and bleeding.
2. *Bucking*: Generally, the foreign body reaction is stimulated by placing the stent in the trachea. After the stent is inserted, a large amount of sputum that accumulated in the deep airway is poured out and this can cause a blockage in the airway. For an irritating dry cough, the trachea is injected locally with 2–3 mL of 1–2% lidocaine to anesthetize the sensitive trachea. If accompanied by a large amount of sputum, pat the patient's back to encourage the patient to clear the airway. For weaker patients with poor physical condition, use the suction tube inserted into the left and right bronchi and remove the excess sputum. If the sputum is too thick and cannot be suctioned out, the sputum can be aspirated using fiberoptic bronchoscopy and bronchoalveolar lavage to completely remove the sputum.
3. *Dyspnea*: Tracheal covered stent implantation is used to block the fistula between the bronchial stump and the pleural residual cavity and reduce the ineffective lumen, which is beneficial for normal breathing and oxygenation of the patients. If dyspnea occurs immediately after stent placement, use fluoroscopy and tracheal angiography to observe the position of the three gold labeled points of the L-shaped stent and see if they are located on the lateral wall and whether the arc part is at the opening of the contralateral main bronchus. If the stent is not correctly positioned, immediately insert a stent removal hook to adjust and lift the stent or remove the stent.

If the respiratory status is improved after the covered stent is inserted, but the patient presents with dyspnea after a sudden severe cough, check that the stent has not moved down to block the healthy side of the main bronchus. The examination should consider that the deep alveolar, small bronchi, and other airways have retained a large amount of sputum and expelled this into the segment, lobar, the main bronchial and other airways, possibly blocking the airway. Extensive pulmonary wet rales can be heard if this has occurred. Immediately introduce an endotracheal suctioning tube into the left and right main bronchus to perform deep suction sputum treatment.

4. *Incomplete closure of the fistula*: If the thoracic closed drainage tube still has bubbles continuously flowing into it or contrast agent is seen to move through the fistula into the pleural cavity via endotracheal tube angiography, it can be confirmed that stent occlusion of the fistula was not successful. To fix this problem, first determine the position of the stent and degree of expansion of the stent to maintain adherence. If fistula blockage is incomplete, adjust the stent position. If the stent attachment is poor, replace with a stent with a larger diameter.
5. *Uncompleted or displacement of the stent*: If the stent was not released in the expected location, or there was incomplete closure of the fistula or obstruction of main bronchus, or the patient coughs severely and causes stent migration, adjust the stent position or remove the stent and replace with a new stent.
6. *Sputum obstructed stent*: This is the most common complication of tracheal covered-stent implantation. The covered-stent com-

pletely covers the endotracheal intima of the trachea. The ciliate movement of the epithelium and the function of the mucus blanket are completely lost. Expectoration is completely dependent on the force of coughing. If the cough is weak and the sputum is thick, the sputum adheres to the stent. A large amount of sputum attached to the stent causes a sputum plug and this will block the lumen of the trachea and cause stenosis of the trachea. Breathing becomes difficult. Use fiberoptic bronchoscopy to remove the sputum plug and sputum patches as soon as possible. This will restore patency of the trachea. Further treatment includes strengthening the aerosol inhalation, administering drugs to promote expectoration, and undergoing sputum training to avoid sputum retention.

7. *Tracheal granulation tissue hyperplasia causing stenosis*: In all physiological lumens of the body that undergo stenting, endothelial cell hyperplasia generally occurs. The trachea is an open-body lumen. After stenting, the foreign body reaction stimulates the tracheal endothelial cells to undergo inflammatory hyperplasia and this phenomenon is more obvious with an uncovered metallic stent, which causes hyperplasia for the full length of the stent as well as at both ends of the stent. In a covered stent, the area that is covered has almost no hyperplasia, but there is hyperplasia at both ends and this can form scarring stenosis. Mild tracheal proliferative stenosis does not affect the normal respite who do not have to deal with the severe stenosis affect the respiratory and expectoration function need timely treatment. General endoscopic ablation therapy, microwave, radio frequency, laser, frozen ablation, and other thermal ablation therapy can be used for treatment.

12.6.2 The Left Main BPF

The left main BPF forms a sinus between the left side bronchial stump after pneumonectomy of the left lung and the pleural cavity. Based on his studies on the special anatomic structures and pathological characteristics of the left bronchial stump fistula, Dr. Xinwei Han designed an airway L-shaped and Y-shaped bullet memory self-expandable covered metallic stent and stent delivery system to close the left main BPF.

12.6.2.1 Equipment Preparation

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation*: 4–5 F vertebral artery catheter 1 root, (0.035-in. × 120 cm or 0.035-in. × 180 cm) hydrophilic membrane guidewire 1 root, 0.035-in. × 180 cm reinforced guidewire, 1–2 customized inverted Y-shaped branch bullet covered stent and stent delivery system, stent removal kit two sets (spare), 9 F vascular sheath 1 set, 9–12 F long vascular sheath 1 set (spare), 6.5 or 7.0 endotracheal tube 1 (spare), mouth gag 1, suction device, ventilator, and other rescue equipment.
2. *Stent selection*: According to the chest MSCT cross section image of the fat window (window width 400 HU, window length −50 HU), measure the tracheal anteroposterior diameter and transverse diameter and measure the diameter and length of the bilateral bronchus. Then select or customize an inverted Y-shaped integrated covered self-expanding metallic stent. The stent parameters should be as follows: The diameters of the tracheal main bronchial stent is 12–20% greater than the diameter of the corresponding airway. The length of the trachea (main body) is 40–50 mm larger than the carina. The length of the right main bronchus is equal to the distance of the carina from the upper margin of the upper right lobe bronchial opening. The length of the left main bronchus is generally set at 20–30 mm.

12.6.2.2 Pre-procedure Preparation

1. *Laboratory exam*: Perform routine blood, urine, and feces tests as well as tests for four infectious diseases, liver function, renal

function, blood glucose, electrolytes, coagulation test and pulmonary function tests. Undertake a bacterial culture and drug sensitivity test using sputum or pleural cavity secretions.
2. *Imaging*: Perform a chest MSCT scan and make full use of MPR, CPR and other post-processing functions to analyze the image. Define the exact location, size, and the relationship with the surrounding carina fistula. Define the distribution and extent of pulmonary inflammatory lesions. Determine the severity of lung injury. Perform accurate measurements of the tracheal main bronchial diameter and length to aid in stent selection.

Perform fiberoptic bronchoscopy and fiber gastroscopy to comprehensively understand the condition of the chest and the trachealbronchus. At the same time, remove the large amount of sputum and phlegm in the bronchus.

3. *Cardiopulmonary function*: Undertake an ECG to understand cardiac function and reserves and to monitor pulmonary oxygenation function by multifunction physiological monitoring.
4. *Premedication*: 10–30 min before the interventional procedure, intramuscular diazepam 10 mg is administered to relieve the patient's anxiety. An intramuscular injection of anisodamine 10 mg relieves smooth muscle tension, reduces secretion of digestive glands and respiratory glands, and facilitates airway interventional radiology procedures. If the patient has severe pulmonary inflammation, poor respiratory function, or low levels of oxygen, an intravenous injection of hormones (dexamethasone 10 mg, or methylprednisolone 30 mg) can reduce the tracheobronchial and pulmonary exudation and inflammation, which improves their ability to tolerate stress and improves the patient's tolerance to the procedure.

Airway angiography and stent implantation requires patient hospitalization.

12.6.2.3 Interventional Radiology for Large–Down Y-Shaped Branch Single–Bullet Memory Self- Expandable Covered Metallic Stent Implantation Procedure

1. *Patient position*: The patient relaxes the body, removes clothing with X-ray-incompatible bodies (for example, a metal buckle) from the upper body and lies in a supine position on the DSA inspection table. Remove the pillow and slightly elevate their neck and shoulders. Lean their head back and to the right at 20–30°. The patient is covered with a large surgical drape. Fix the nasal oxygen tube and connect multichannel ECG monitoring. Administer lidocaine spray for local throat anesthesia. Insert the mouth opener into the patient's mouth and prepare the negative pressure suction device to clear airway and oral secretions, as needed.

The left side of the C arm is tilted at 20–30° (with the head angled to the right at 20−30°, this is equivalent to the head being angled at 50°). Adjust the X-ray vision field of the DSA to include the oropharynx, trachea, and bilateral main bronchi.

2. *Transcatheter angiography*: Under fluoroscopy, insert a 0.035-in. hydrophilic membrane guidewire and 5 F vertebral artery catheter through the mouth into the oropharynx. Adjust the catheter tip to above the throat and hypopharynx and ask the patient to cough or to inhale. When the glottis opens, move the guidewire through the catheter across the laryngeal cavity, then quickly move the catheter to the trachea. Remove the guidewire. Inject 2–3 mL of 2% lidocaine for airway mucosa anesthesia and 1–2 mL of 0.1% epinephrine solution to prevent airway mucosal bleeding from injury (Fig. 12.6a). The guidewire catheter is used to introduce the vertebral artery catheter into the right distal bronchus. Inject 3 mL of water-soluble contrast via the

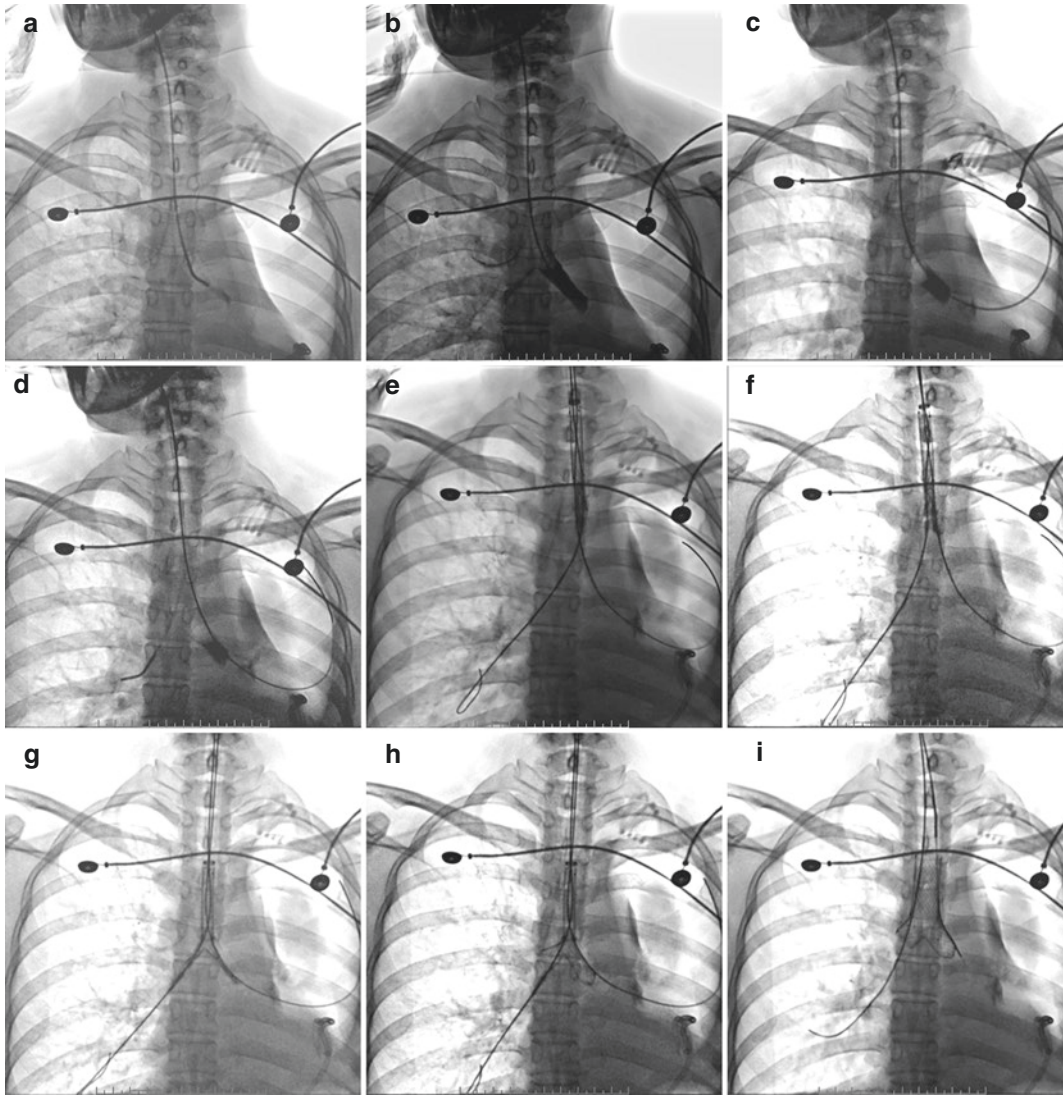

Fig. 12.6 The large–down Y-shaped branch single-bullet memory self-expandable covered metallic stent implantation. (**a**) Airway mucosal anesthesia; (**b**) esophageal angiography showed the right main bronchus proximal distance from the upper lobe opening length and left main bronchial opening; (**c**) the guidewire enters the left pleural cavity through the fistula; (**d**) the catheter enters the distal end of the right main bronchus; (**e**) the double guidewires are intertwined and adjusted repeatedly; (**f**) the golden mark points on both sides of the inner stent are located on the left and right sides; (**g**) fix the stent delivery system in a constant location; (**h**) successively pull the stent's tied wire to release the stent branch and the bullet head in the main bronchus; (**i**) tracheal angiography ensures that the fistula is completely blocked

catheter and this will show the right proximal distance of the main bronchus, the opening length of the upper lobe, and the opening of the left main bronchus (Fig. 12.6b). This angiography will also show the location and size of the BPF. Correctly determine whether the custom stent is appropriate based on the contrast image measurement data.

3. *Introduce reinforced guidewire*: The reinforced guidewire is introduced to the right main bronchus. Fix the reinforced guidewire in the catheter and introduce the 9 F artery sheath along the guidewire to the glottis. The vertebral artery catheter is introduced through the 9 F artery sheath. The 0.035-in. hydrophilic membrane guidewire leads to the 5 F vertebral artery catheter. Move the catheter to the left bronchial stump. The catheter is injected with 3 mL of water-soluble contrast, showing the distance of the left main bronchial stump, the length of the carina, and the location of the fistula. The catheter moves into the pleural cavity through the fistula and introduces another reinforced guidewire into the left pleural cavity through the fistula (Fig. 12.6c, d). Remove the 9 F arterial long sheath. The two reinforced guidewires in the affected side and the uninjured side are labeled and identified respectively. Adjust the DSA field of view so that the lower trachea, carina, bilateral bronchus, and distal wire are in the field of view.
4. *Introduce the stent delivery system*: In vitro, straighten and separate the two wires to avoid twisting (Fig. 12.6e) and send the Y-shaped single-bullet covered airway stent delivery system along the double guidewires through the lower segment of the glottis to the trachea. When the delivery system encounters resistance, the patient coughs and becomes agitated. The assistant or nurse instructs the patient to inhale deeply and to ensure that the patient's posture doesn't change. When the glottis opens during deep inhalation, take the opportunity to advance to the trachea dallon to above the delivery system. Pause the operation and fix the delivery system and guidewire position for 30 s to 1 min to allow the operator and patient to rest and adjust position slightly. Keep the inner stent delivery system set in the trachea. Check, using X-ray monitoring, that the stent position is adjusted clockwise or counterclockwise so that the support branch and the bullet head are parallel to the corresponding guidewire, and are on the same side. The gold mark points on both sides of the inner stent are located on the left and right sides (Fig. 12.6f). At this point, the Y-shaped stent is in place.
5. *Location and release stent*: Fasten the guidewire and the back handle of the stent delivery system and, under monitoring, maintain the depth and orientation of the inner stent, pull back the handle of the stent delivery system and the outer sheath to fully expose and release the stent branch and the bullet head. Maintain the position of the front and back handles of the stent delivery system and, along the guidewire, push the inner stent delivery system forward. This introduces the branch and the bullet head of the Y-shaped stent into the uninjured bronchus and the residual end into the affected bronchus. When the stent bifurcation is close to the bifurcation of the carina (the left and right main bronchial bifurcation), stop the advancement of the stent delivery system. Using fluoroscopy, firmly hold the stent delivery system in place (Fig. 12.6g). Rapidly release the stent bundled wire release bracket branch and the bullet head in the main bronchus. Then pull the back handle of the stent delivery system, pull back the front handle of the stent delivery system and the outer sheath to the fully expose and release the main stent (Fig. 12.6h). The Y-shaped stent is completely released in the airway. Under fluoroscopic monitoring, secure the guidewire and slowly and gently withdraw the stent delivery system. Avoid catching the Y-shaped stent with the head end hook inside the stent delivery system, which results in a shift of the Y-shaped stent. Pull out the guidewire carefully under fluoroscopic monitoring. Especially the guidewire was placed between stent and tracheal wall, the frication of stent and guidewire may cause stent migration.
6. *Transcatheter review of angiography*: After the introduction of the guidewire into the catheter, the catheter is injected with 3–5 mL of 30% water-soluble contrast to determine whether the fistula has been completely blocked, whether the position of the stent is correct, whether the stent is fully expanded, and if the carina, the right main bronchus and the lobar bronchus are unobstructed. If necessary, adjust the stent position or replace with a new stent.

7. *Full suction and hemostasis*: Using the loach guidewire, introduce the catheter to the contralateral distal bronchial catheter. Remove the catheter and insert a suction tube, along the guidewire. Thoroughly suction the endobronchial residual contrast agent and sputum, with chest and back patting to assist in dislodging sputum. Continue this until the pulmonary rales disappear and oxygen saturation is at or close to 100%. Encourage the patient to cough, repeat suction, and, if necessary, dilute the sputum with 3–5 mL physiological saline and aspirate. If there is blood in the sputum, introduce the guidewire again and administer an injection of 1–2 mL of 0.1% epinephrine solution hemostatic. Remove catheter guidewire once no blood is observed in the sputum.
8. *Replacement of thoracic closed drainage (if the pleural cavity is larger or has pus)*: To encourage stent occlusion of the fistula, the closed thoracic drainage tube can be changed into a multifunctional drainage tube (8.5–12 F), and with a purse string suture around the drainage tube, an external negative pressure suction device is attached to cause a certain amount of negative pressure in the chest cavity to promote the displacement of the mediastinum and diaphragm, the collapse of the thorax, and the closure of the pleural cavity. When necessary, the pleural cavity can be flushed or filled with antibiotics through the multifunctional drainage tube to control infection and promote healing.

12.6.2.4 Management After Stenting

Details as in Sect. 12.6.1.4

12.6.2.5 Complication Management

Details as in Sect. 12.6.1.5

12.6.3 The Right Main BPF

The right main BPF forms a sinus between the right bronchial stump after pneumonectomy of the right lung and pleural cavity. After the right pneumonectomy, there is no important anatomic structure around the right main bronchus and the right main bronchus can be completely isolated and removed after resection of the right lung. After resection, the residual length of the right main bronchus is short. Once the fistula occurs, a large amount of sputum enters the pleural cavity and mediastinum through the fistula. This results in severe infection, pericarditis, bleeding, etc. Based on the special anatomical structure of bronchial stump fistula and the pathological characteristics, Dr. Xinwei Han designed an L-shaped and Y-shaped single-bullet memory self-expandable metallic airway stent and stent delivery system for treatment of right main BPF.

12.6.3.1 Equipment Preparation:

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation*: 4–5 F vertebral artery catheter 1 root, (0.035-in. × 120 cm or 0.035-in. × 180 cm) hydrophilic membrane guidewire 1 root, 0.035-in. × 180 cm reinforced guidewire 1–2, customized inverted Y-shaped branch-bullet covered stent and stent delivery system, stent removal kit 2 sets (spare), 9 F vascular sheath 1 set, 9–12 F long vascular sheath 1 set (spare), 6.5 or 7.0 endotracheal tube 1 (spare), mouth gag 1, suction device, ventilator, and other rescue equipment.
2. *Stent selection*: Using the chest MSCT cross section image of the fat window (window width 400 HU, window length −50 HU), measure the tracheal anteroposterior diameter and transverse diameter and the diameter and length of the bilateral bronchus, select or customize an inverted Y-shaped integrated covered self-expanding metallic stent. The stent parameters should be as follows: The diameters of the trachea main bronchial stent is 12–20% greater than the diameter of the corresponding airway. The length of the trachea (main body) is 40–50 mm larger than the carina. The length of the right main bronchus is equal to the distance of the carina from the upper margin of the upper right lobe bronchial opening. The length of the left main bronchus is generally set at 20–30 mm.

12.6.3.2 Pre-procedure Preparation

1. *Laboratory exam*: Perform routine tests on blood, urine, and feces, as well as for four infectious diseases, liver function, renal function, blood glucose, electrolytes, coagulation test, and pulmonary function tests. Also undertake a bacterial culture and drug sensitivity test of the sputum or pleural cavity secretions.
2. *Imaging*: Perform a chest MSCT scan and make full use of MPR, CPR and other post-processing functions. Analyze the image and define the exact location, size, and the relationship of the tissue surrounding the carina fistula. Define the distribution and extent of pulmonary inflammatory lesions and determine the severity of lung injury. Use the image for accurate measurement of the tracheal main bronchial diameter and length and select the stent specifications from this information.

Undertake fiberoptic bronchoscopy and fiber gastroscopy to comprehensively understand the condition of the chest and tracheal-bronchus and to remove the large amount of sputum and phlegm within the bronchus.

3. *Cardiopulmonary function*: Use an ECG to understand the cardiac function and reserves and to monitor pulmonary oxygenation function using multifunction physiological monitoring.
4. *Premedication*:10–30 min before the interventional procedure (before the patient is admitted to the operation room, that is, while in the ward), intramuscular diazepam 10 mg is administered to relieve the patient's anxiety. An intramuscular injection of anisodamine 10 mg relieves smooth muscle tension, reduces secretion of digestive glands and respiratory glands, and facilitates the airway interventional radiology procedure. If the patient suffers from severe pulmonary inflammation, poor respiratory function, or low levels of oxygen, also administer an intravenous injection of hormones (dexamethasone 10 mg, or methylprednisolone 30 mg) to reduce the tracheobronchial and pulmonary exudation and inflammation, and to improve the patient's ability to tolerate stress.

12.6.3.3 Interventional Radiology for Large–Down Y-Shaped Branch Single-bullet Memory Self-Expandable Covered Metallic Stent Implantation Procedure

Due to the short bronchial stump, the L-shaped memory self-expandable metallic stent implantation is used in the right bronchial stump fistula. This method was detailed in Sect. 12.6.1.3. If the right bronchial stump is longer, the L-shaped memory self-expandable metallic stent implantation causes build up of bacteria in the stump, which is not conducive to the healing of the fistula. The large–down Y-shaped branch single-bullet memory self-expandable covered metallic stent implantation in Sect. 12.6.2.3 can be adopted to this type of BPF (Fig. 12.7) with the only difference being that the single bullet head is placed in the right bronchial stump.

12.6.3.4 Management after Stenting

Details as in Sect. 12.6.1.4

12.6.3.5 Complication Management

Details as in Sect. 12.6.1.5

12.6.4 The Right Middle Segmental BPF

The right middle segmental BPF is a sinus between the right middle segment of the bronchial stump and the pleural cavity after the right middle and lower lobe lobectomy. It rarely appears as a mediastinum infection, but more often as poor performance on the right side of the liquid pneumothorax or right upper lobe atelectasis and sustained bubble overflow in the closed thoracic drainage bottle when coughing or taking a deep breath. Based on the special anatomy of the right middle segment of the bronchial and the lesion characteristics, Dr. Xinwei Han designed the Y-shaped self-expandable covered metallic stent with a bullet head and L-shaped

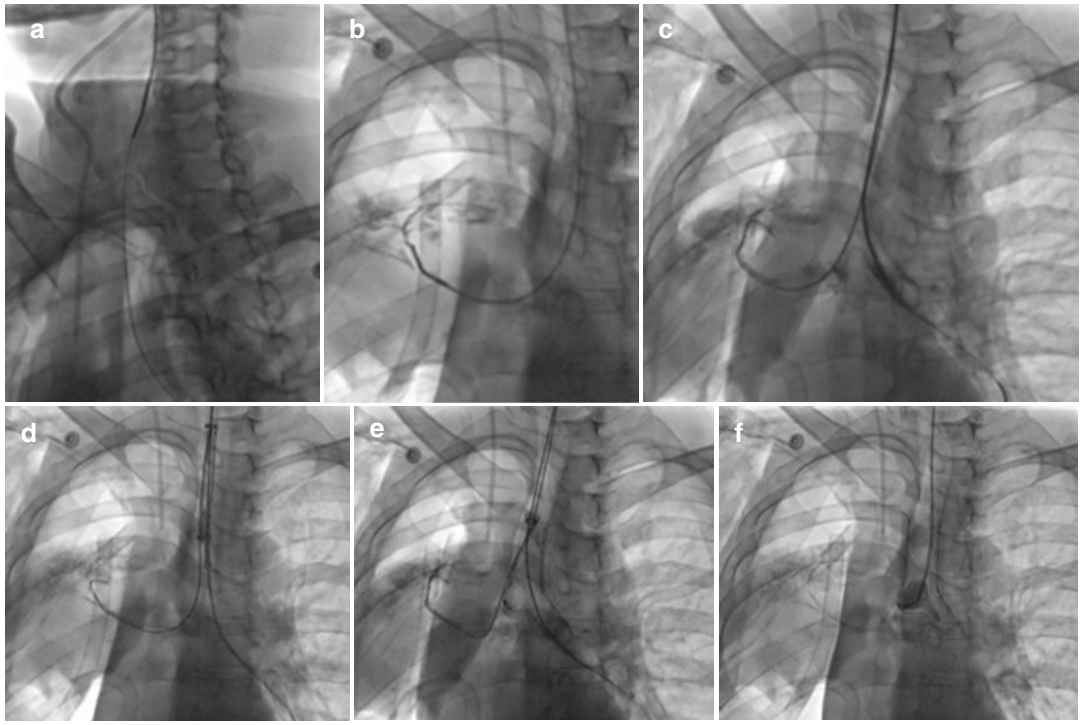

Fig. 12.7 The large–down Y-shaped branch single-bullet memory self-expandable covered metallic stent implantation in the right main BPF. (**a**) Airway mucosal anesthesia; (**b**) tracheal angiography showing the right main bronchus proximal distance from the upper lobe opening length and left main bronchial opening; (**c**) the guidewire enters the left pleural cavity through the fistula; (**d**) the catheter enters the distal end of the right main bronchus and the double guidewires are intertwined and adjusted repeatedly; (**e**) the golden mark points on both sides of the inner stent are located on the left and right sides; successively and rapidly pull the bound stent threads to release the stent branch and the bullet head in the main bronchi; (**f**) tracheal angiography ensures that the fistula is completely blocked

self-expandable partially covered metallic stent with a bullet head for treating this disease. The Y-shaped self-expandable covered metallic stent with a bullet head is used more frequently nowadays.

12.6.4.1 Equipment Preparation

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation*. A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 reinforced guidewire 0.035-in. × 180 cm, customized Y-shaped self-expandable covered metallic stent with a bullet head and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent selection.* Measure the bronchial diameter of the right main bronchus and the right medial segment according to the fat window (window width 400 HU, window length −50 HU) of the image of chest MSCT. Use this measurement to select or customize a Y-shaped self-expandable covered metallic stent with a bullet head. The parameters of the stent should be as follows: The diameter of the bullet head of the stent of the right middle segment bronchus is generally 10% larger than the corresponding bronchial diameter. The length does not exceed 80% of the total length of the corresponding residual bronchial stump.

The diameter of the right main bronchus (main body) of the stent is generally 12% larger than the right main bronchus and the length does not exceed the total length of the right middle bronchus.

12.6.4.2 Preparation Before Stent Implantation

1. *Laboratory examination.* Perform routine blood, urine, and feces checks, as well as four infectious diseases tests, liver function index, renal function index, glucose levels, electrolytes index, blood coagulation index, and pulmonary function tests. Undertake a sputum or pleural cavity secretion bacterial culture and drug susceptibility test.
2. *Imaging.* Obtain a chest MSCT scan and make full use of MPR, CPR and other post-processing functions to define the location and size of the fistula and the relationship with the surrounding adjacent tissues. Define the distribution and extent of pulmonary inflammatory lesions to determine the severity of the lung injury. Determine the distance between the fistula and the right upper lobe opening, bilateral main bronchus diameter, and the carina bifurcation angle. Design a customized L-shaped or Y-shaped self-expandable covered metallic stent with a bullet head.

If possible, undertake fiberoptic bronchoscopy and fiber gastroscopy to examine the condition of the stomach, trachea, and bronchi. At the same time, remove large amounts of excessive sputum and phlegm from the bronchus.

3. *Heart and lung function.* Test the heart function and reserves using ECG monitoring. Determine lung oxygenation function using multifunctional physiological monitoring.
4. *Premedication.* Administer an intramuscular injection of diazepam (10 mg) 10–30 min before the start of the operation to eliminate patient stress (this can be performed in the ward before the patient is transferred to the operation room). Administer an intramuscular injection of anisodamine 10 mg to relieve smooth muscle tension and reduce the secretion of digestive glands and respiratory glands. This will help to facilitate the respiratory interventional radiological operation. Steroids can also be injected intravenously (dexamethasone 10 mg, or methylprednisolone 30 mg) if the patient has a severe pulmonary inflammation, poor breathing function, or low blood oxygen levels. This will reduce tracheal bronchial and pulmonary exudation and inflammation, improve the patient's ability to tolerate stress, and improve the patient's tolerance to the intervention operation.

12.6.4.3 The Y-Shaped Self-Expandable Covered Metallic Stent with a Bullet Head Placement Procedure

1. *Patient's position.* The patient relaxes and removes upper body clothing with X-ray-incompatible bodies (for example, a metal buckle). The patient lies in a supine position on the DSA examination table, remove pillows, keeps their neck and shoulders slightly elevated, and leans their head back and to the right at an angle of 20–30°. The DSA C-arm is angled 20–30° to the left (with the patient's head tilted to the right at 20–30°, this is equivalent to angling the head at about 50° to the right). Cover the patient with a surgical drape. Fix a transnasal oxygen inhalation tube and link the multichannel ECG. Spray lidocaine in the throat for local anesthesia and insert a mouth gag. Prepare the negative pressure aspirator to remove airway and oral secretions as needed. Adjust the X-ray vision field to include the oropharynx, trachea, and right main bronchus.
2. *Transcatheter radiology.* Insert a 0.035-in. hydrophilic guidewire and a 5 F vertebral artery catheter into the oropharynx under fluoroscopic guidance. Adjust the catheter tip to be above the throat and hypopharynx. Instruct the patient to breathe or cough. When the glottis is open, pass the catheter and guidewire into the laryngeal cavity and trachea (Fig. 12.8a). Remove the guidewire and inject 2–3 mL of 2% lidocaine through the catheter to anesthetize the airway mucosa. Inject

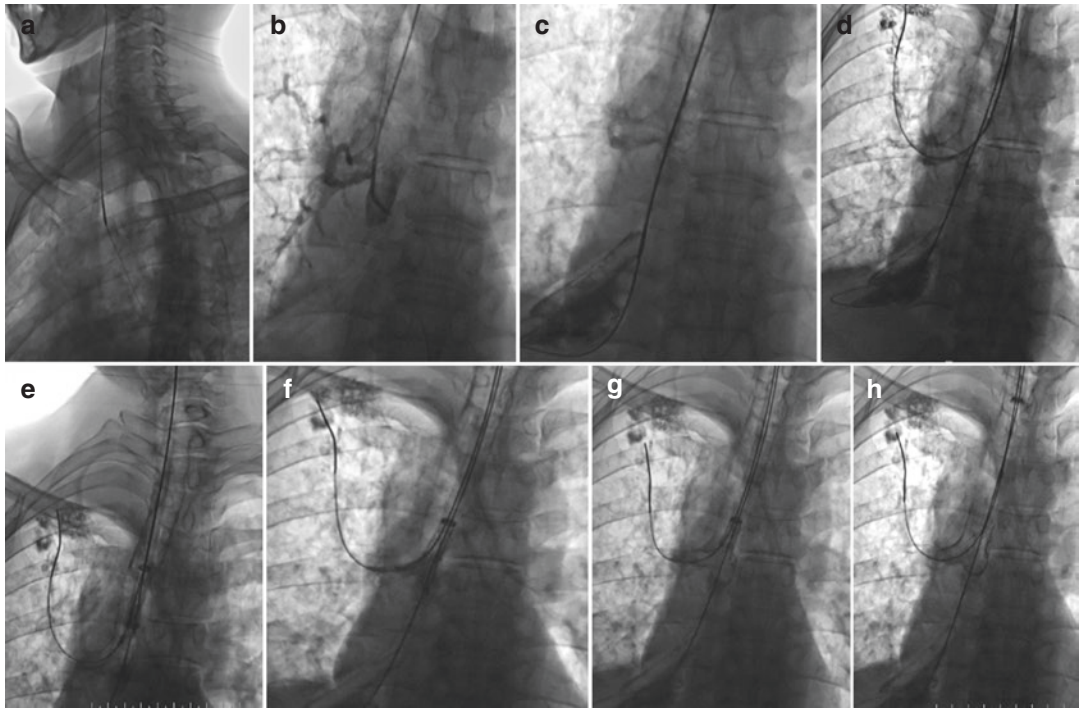

Fig. 12.8 The Y-shaped self-expandable covered metallic stent with a bullet head's placement operation diagram. (**a**) Anesthetizing airway mucosa; (**b**) injection of 3 mL of water-soluble iodine contrast through the catheter to show the right middle bronchial fistula position and the distance from right bronchus proximal to the beginning of the upper lobe of the right lung; (**c**) through the right middle of the bronchial stump to enter the pleural cavity; (**d**) insertion of reinforced guidewires to the right upper lobe of the bronchial and right middle segments of the bronchial stump; (**e**) adjusting the stent to the appropriate place, the gold mark points on both sides of the inner stent are located on the left and right sides; (**f**) the stent's bifurcation is close to the bifurcation of the right upper lobe bronchus and the right middle segment of the bronchial; (**g**) pull the ties to release the stent branch and the bullet in the right lung upper branch of the bronchial and right middle segments of the bronchus rapidly; (**h**) withdraw the lesion side guidewire carefully under fluoroscopy monitoring, avoid the excessive friction between the wire and the stent

1–2 mL of 0.1% epinephrine solution to prevent airway mucosal bleeding from damage (Fig. 12.8b). Insert the vertebral artery catheter into the right middle bronchus and inject 3 mL of water-soluble iodine contrast through the catheter to show the position of the right middle BPF and the distance from the right bronchus proximal to the beginning of the upper lobe of the right lung.

3. *The introduction of reinforced guidewire.* Insert a reinforced guidewire through the right middle of the bronchial stump into the pleural cavity (Fig. 12.8c). Fix the reinforced guidewire in place and remove the catheter. Introduce the 9 F artery sheath along the reinforced guidewire through the glottis. Introduce the vertebral artery catheter via the 9 F artery sheath. Insert the 0.035-in. hydrophilic guidewire and 5 F vertebral artery catheter into the upper right lung bronchus and introduce another reinforced guidewire to the distal end of the right upper lobe bronchus. Mark the two reinforced guidewires in the right upper lobe bronchial and right middle segment bronchial stump. Adjust the DSA field of view to include the lower segment of the trachea, carina, right main bronchus, and distal end of the guidewire (Fig. 12.8d).
4. *The introduction of the stent delivery system.* Straighten out and separate the double guidewires in vitro to prevent them from twisting. Insert the customized Y-shaped self-expandable covered metallic stent with a

bullet head delivery system along the double guidewires through the glottis to the lower end of the trachea. If the stent delivery system encounters resistance at this time or the patient coughs and is restless, ask the patient to inhale and ensure that their position does not change. When the patient breaths deeply, the glottis will open. At this point, push the stent delivery system to the right main bronchus. Pause the operation and fix the position of the stent delivery system and guidewire for 0.5–1 min, to give the operator and patient a rest. Maintain the depth of the delivery system setting in the right main bronchus. Using fluoroscopy, rotate the position of the stent clockwise or counterclockwise to align the support branch and the bullet head parallel to the corresponding guidewire on the same side. Ensure that the gold mark points on both sides of the inner stent are located at the left and right sides. At this time, the stent is positioned in the correct place (Fig. 12.8e).

5. *Location and insertion of the stent.* Fasten the guidewire and inner stent delivery system's handle in vitro. Maintain the depth and orientation of the stent unchanged under fluoroscopy monitoring. Pull back the handle and the outer sheath of the inner stent until the branch of the stent and the bullet head are completely exposed. Keep the relative position of the front and back handle of the stent delivery system unchanged, push the stent delivery system along the guidewire, so that the branches of the Y-shaped stent and the bullet head can be introduced into the upper right lobe bronchial and right middle segment bronchial. When the stent's bifurcation is close to the bifurcation of the right upper lobe bronchus and the right middle segment of the bronchial, stop pushing the stent delivery system (Fig. 12.8f). Keep the stent delivery system's position unchanged. Rapidly pull the ties to release the stent branch and the bullet in the right lung upper branch of the bronchial and right middle segments of the bronchus (Fig. 12.8g). Then fix the stent delivery system's rear handle, pull back the front handle and outer sheath to release the main part of the stent in the right main bronchial. Fix the guidewire under fluoroscopy monitoring, pull out the stent delivery system slowly and gently. Prevent the end of the stent delivery system hooking the Y-shaped stent, which would lead to the displacement of the Y-shaped stent. Withdraw the guidewire from the lesion side carefully under fluoroscopy monitoring, avoid excessive friction between the wire and the stent.
6. *Transcatheter reexamined radiological.* Introduce the catheter through the reinforced guidewire. Inject 3 mL of 30% iodinated water contrast medium through the catheter to check that the fistula is completely occluded (Fig. 12.8h), the stent position is correct, the stent is fully expanded, and the left and right main bronchi and right upper lobe bronchi are unobstructed. Adjust the stent position or replace it, if necessary.
7. *Sputum suction and hemostasis.* Insert the loach guidewire to the end of the right upper bronchus through the catheter, and then remove the catheter. Insert a suction tube along the guidewire to suction the residual contrast agent and sputum. Pat the chest and back to help the patient to discharge sputum. Suction sputum until the rales of the lungs disappear and the SpO_2 reaches or approaches 100%. Encourage patients to cough often. Undertake regular sputum suction. To help with this, inject 3–5 mL of saline to dilute the sputum and make it easier to suction, if necessary. If the sputum contains blood, the suction tube can be inserted using the guidewire. The catheter is guided into the airway along the guidewire and then injected with 1–2 mL of 0.1% epinephrine solution to stop the bleeding. If there is no blood in the sputum, pull out the catheter and guidewire.
8. *Replacement of thoracic closed drainage (if the pleural cavity is large or has pus).* To block the fistula after internal stent implantation, the closed thoracic drainage tube can be changed into a multifunctional drainage tube by the interventional department (8.5–12 F). A purse string suture is made around the drainage tube and an external negative pressure suction device is used to create a certain amount of negative pressure in the chest cavity. This promotes the displacement of the mediastinum

and diaphragm, collapse of the thorax, and closure of the pleural cavity. The pleural cavity can be flushed or filled with antibiotics through the multifunctional drainage tube to control infection and promote healing.

12.6.4.4 Proceeding after Stent Implantation

Details are as in Sect. 12.6.1.4

12.6.4.5 Prevention and Treatment of Complications

Details are in Sect. 12.6.1.5

12.6.5 The Right Upper Lobe BPF

The right upper lobe BPF is a sinus between the right upper lobe of the bronchial stump and the pleural cavity after right lung upper lobe lobectomy. The incidence of BPF after lobectomy was reported to be much lower (less than 1%) than that of BPF after pneumonectomy (4–20%) [1]. A possible reason for this is that after the lobectomy, residual lung expansion can directly cover the stump to protect it [2]. The right upper lobe bronchus and the right side of the main bronchial angle is an acute angle, so we can use a Y-shaped self-expandable covered metallic stent with a bullet head, placing the bullet head in the upper right lobe of the bronchus. For the smaller part of the stump, use the Y-shaped self-expandable covered metallic stent to directly cover the right upper lobe BPF, and keep the right middle lobe bronchus and left main bronchus open.

12.6.5.1 Equipment Preparation

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation:* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire 0.035-in. × 180 cm, customized Y-shaped self-expandable covered metallic stent and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent selection:* Measure the bronchial diameter of the right main bronchus and the right medial segment according to the fat window (window width 400 HU, window length −50 HU) of the image of chest MSCT. Measure the anteroposterior diameter and transverse diameters of the trachea and the anteroposterior diameter and length of the bilateral main bronchus. Then select or customize a Y-shaped self-expandable covered metallic stent. The stent parameters should be as follows: The diameter of the stent of the trachea and the main bronchus is 12–20% larger than that of the corresponding airway. The length of the trachea (main part) of the stent is 40–50 mm above the carina. The length of the stent of the right main bronchus is equal to the distance from the carina to the upper edge of the upper right lobe of the bronchus. The length of the stent of the left main bronchus is usually 20–30 mm.

12.6.5.2 Preparation before Stent Implantation

1. *Laboratory examination:* Perform routine blood, urine, and feces tests as well as four infectious diseases index, liver index, renal index, blood sugar index, electrolytes index, glucose levels, and pulmonary function tests. Undertake a sputum or pleural cavity secretion bacterial culture and drug susceptibility test.
2. *Imageology:* Undertake a chest MSCT scan and make full use of MPR, CPR and other post-processing functions to analyze the image. Define the location and size of the fistula and the relationship between the adjacent surrounding tissue. Define the distribution and extent of pulmonary inflammatory lesions to determine the severity of lung injury. Measure the distance between the fistula and the right upper lobe opening. Measure the bilateral main bronchus diameter and carina angle. Design a customized Y-shaped self-expandable covered metallic stent with a bullet head and L-shaped self-expandable partially covered metallic stent with a bullet head.

If possible, perform fiberoptic bronchoscopy and fiber gastroscopy to examine the condition of the stomach, trachea, and bronchus. At the same time, remove large amounts of sputum and phlegm in the bronchus.

3. *Heart and lung function:* Examine the heart function and reserves by ECG monitoring. Determine the lung oxygenation function by multifunctional physiological monitoring.
4. *Premedication:* Administer an intramuscular injection of diazepam (10 mg) 10–30 min before the start of the operation to eliminate patient anxiety. Administer an intramuscular injection of anisodamine 10 mg to relieve smooth muscle tension, reduce the secretion of digestive glands and respiratory glands, and facilitate an easy operation. Steroids can also be intravenously injected (dexamethasone 10 mg, or methylprednisolone 30 mg) if the patient has a severe pulmonary inflammation, poor breathing function, or low blood oxygen levels. The steroids reduce tracheal bronchial and pulmonary exudation and inflammation and improve the patient's ability to tolerate the operation.

12.6.5.3 The Y-Shaped Self-Expandable Covered Metallic Stent Placement Procedure

Because of the special anatomical structure of the upper right lobe bronchus, the Y-shaped self-expandable covered metallic stent is used to seal the fistula (Fig. 12.9). The placement method is

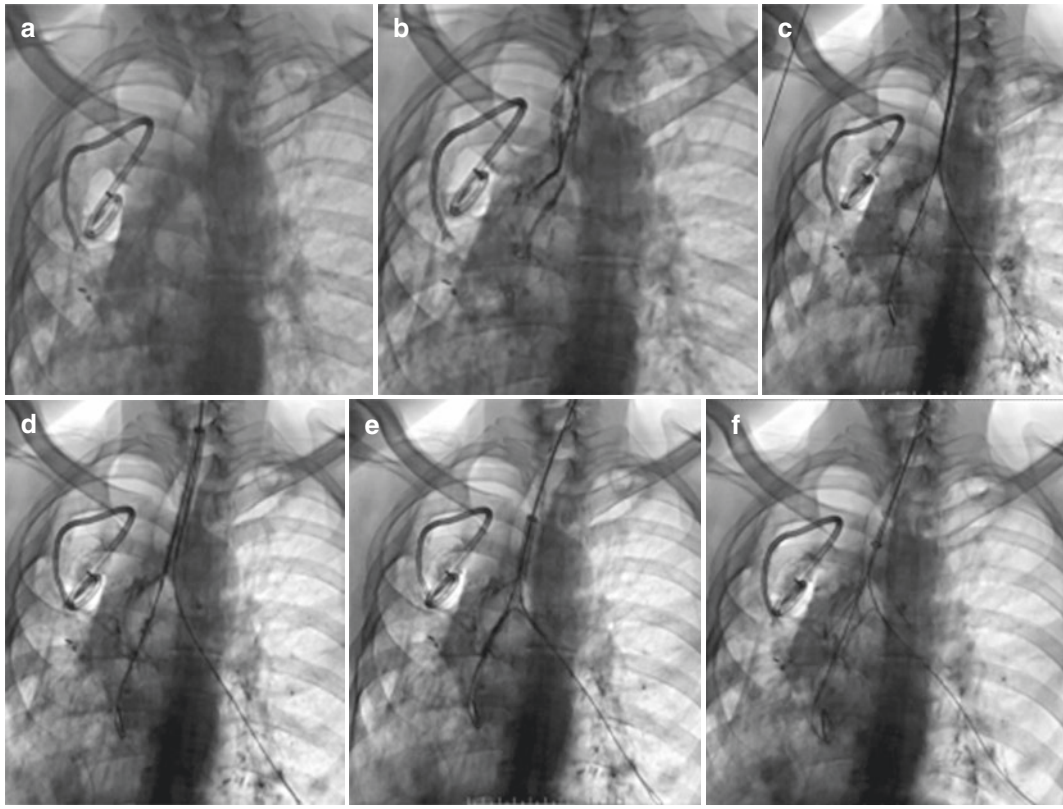

Fig. 12.9 The Y-shaped self-expandable covered metallic stent placement operation diagram. (**a**) Anesthetizing airway mucosa; (**b**) airway contrast radiography showing the distance between the proximal end of the right main bronchus and the bronchial stump fistula of the upper lobe; (**c**) the catheter enters the distal end of the right main bronchus, and the reinforced guidewires are introduced into the left and right bronchus; (**d**) the double guidewires are intertwined and adjusted repeatedly; (**e**) fixing the stent delivery system with a constant location; (**f**) pulling the ties to release the stent branch in the main bronchus

similar to that of the Y-shaped self-expandable covered metallic stent with a bullet head (detailed procedure is as in Sect. 12.6.2.3). The differences are that the points of the Y-shaped self-expandable covered metallic stent are in the left and right main bronchus, the right branch covers the upper right lobe bronchus opening, and the distal end of the stent is in the right middle segment of the bronchus.

12.6.5.4 Proceeding after Stent Implantation

Details are as in Sect.12.6.1.4

12.6.5.5 Prevention and Treatment of Complications

Details are as in Sect. 12.6.1.5

12.6.6 The Right Middle Lobe BPF

The right middle lobe BPF is a sinus between the right middle lobe of the bronchial stump and the pleural cavity after the right middle lobe lobectomy. The right middle segment of the bronchus is a direct continuation of the right main bronchus. Its length is 2–3 cm and the diameter is 1.1–1.2 cm. The right middle lobe bronchus and lower lobe bronchus gradually separate. According to the special anatomical structure and lesion characteristics of the right middle lobe bronchial stump fistula, the design of the Y-shaped self-expandable covered metallic stent with a bullet head's is used in treatment of this BPF.

12.6.6.1 Equipment Preparation (as in Sect. 12.6.3.1)

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation:* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire 0.035-in. × 180 cm, customized Y-shaped self-expandable covered metallic stent with a bullet head and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent selection:* Measure the diameter of the right middle bronchus, the right middle lobe, and the right lower lobe bronchus. Use these measurements to select or customize a Y-shaped self-expandable covered metallic stent with a bullet head. The stent parameters should be as follows: The diameter of the bullet section of the stent of the right middle lobe is about 10% larger than of that of the corresponding bronchi. The length does not exceed 80% of the total residual trachea stump. The diameter of the stent branch of the right lower lobe is 10% larger than the corresponding bronchial with the length not exceeding 80% of the total length of the bronchus. The right middle bronchus (main body) of the stent is about 12% larger than that of the right middle bronchial and does not exceed the total length of the right middle bronchus.

12.6.6.2 Preparation Before Stent Implantation

Details are as in Sect. 12.6.4.2

12.6.6.3 Y-Shaped Self-Expandable Covered Metallic Stent with Bullet Head Placement Procedure

The Y-shaped self-expandable covered metallic stent with bullet head placement procedure is basically the same as the operation of the right medial segment of the BPF (Sect. 12.6.4.3). The differences are as follows. In the introduction of reinforced guidewires, insert a reinforced guidewire into the right lower lobe of the distal bronchus and another reinforced guidewire through the right middle lobe bronchial stump's opening into the pleural cavity. Insert the Y-shaped self-expandable covered metallic stent with a bullet head along the double guidewire and put the branch into the lower right lobe of the bronchus, the bullet head into the right middle of the bronchial stump, and the main body into the middle bronchus.

12.6.6.4 Proceeding after Stent Implantation

Details are as in Sect. 12.6.1.4

12.6.6.5 Prevention and Treatment of Complications

Details are as in Sect. 12.6.1.5

12.6.7 Right Lower Lobe BPF

The right lower lobe BPF is a sinus formation between the bronchial and pleural cavity after lobectomy of the inferior lobe of right lung. According to the special anatomical structure and lesion characteristics of the lower right lobe bronchus, the Y-shaped self-expandable covered metallic stent with a bullet head was designed to treat the BPF of the right lower lobe.

12.6.7.1 Equipment Preparation (as in Sect. 12.6.3.1)

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation:* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire 0.035-in. × 180 cm, customized Y-shaped self-expandable covered metallic stent with a bullet head and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent choice:* Measure the diameter of the right middle bronchial, right middle lobe, and right lower lobe bronchial to help with the selection or customizing of a Y-shaped self-expandable covered metallic stent with a bullet head. The stent parameters should be as follows: The diameter of the bullet section of the stent of the right middle lobe is 10% greater than the corresponding bronchial diameter with the length not exceeding 80% of the total residual trachea stump. The diameter of the stent branch of the right lower lobe is 10% larger than the corresponding bronchial diameter with the length not exceeding 80% of the total length of the corresponding bronchi. The right middle bronchus (main body) of the stent is about 12% larger than the right middle bronchial diameter with the length not exceeding the total length of the right middle bronchus.

12.6.7.2 Preparation Before Stent Implantation

Same as in Sect. 12.6.4.2

12.6.7.3 Y-Shaped Self-Expandable Covered Metallic Stent with a Bullet Head Placement Procedure

The Y-shaped self-expandable covered metallic stent with a bullet head placement procedure is basically the same as the operation of the right medial segment of the BPF (Sect. 12.6.4.3). The differences are as follows. In the introduction of the reinforced guidewire, insert a reinforced guidewire into the lower right lobe of the bronchial stump and into the pleural cavity through the fistula. Another reinforced guidewire is inserted through the distal end of the right middle lobe bronchus. Introduce a small inverted Y-shape branch-type single-bullet head memory alloy self-expandable stent along the double guidewires and put the branch into the right middle lobe of the bronchial, the bullet section into the right lower lobe bronchial stump, and the main body is placed in the middle bronchus.

12.6.7.4 Proceeding after Stent Implantation

Details are as in Sect. 12.6.1.4

12.6.7.5 Prevention and Treatment of Complications

Details are as in Sect. 12.6.1.5

12.6.8 Left Upper Lobe BPF

The left upper lobe BPF is a sinus between the upper left lobe bronchus and the pleural cavity

after left upper lobe lobectomy. The left main bronchus is longer and slightly thinner than the right side and the trachea is angled at 40–50° with a length of about 4 cm and a diameter of 1.2–1.4 cm. The left main bronchus extends into the left upper lobe and lower lobe bronchus. The left upper lobe bronchus opens at the left anterior wall of the main bronchus, about 4 cm from the carina of the trachea. The left upper lobe bronchus is divided into two major branches at about 1–1.5 cm from the opening. Based on the special anatomical structure and pathological features of the upper lobe bronchus of the left lung, Dr. Xinwei Han designed a trachea—main bronchial forked Y-shaped stent to block the left upper lobe bronchial opening. Because the left bronchus is longer, the tubular covered stent is applied to seal it, but we should pay attention to the shifting of the tubular stent. If the upper left lobe of the bronchial stump is long, we can customize the Y-shaped self-expandable covered metallic stent according to this anatomy.

12.6.8.1 Equipment Preparation

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation:* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire (0.035-in. × 180 cm), a customized Y-shaped self-expandable covered metallic stent with a bullet head and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent choice:* Measure the anteroposterior diameter and diameter of the trachea, and the anteroposterior diameter and length of the bilateral main bronchi according to the fat window (window width 400 HU, window length −50 HU) of the image of chest MSCT. Use these measurements to select or customize a Y-shaped self-expandable covered metallic stent. The parameters of the stent should be as follows: The diameter of the trachea and main bronchus stent is 12–20% larger than that of the corresponding airway and the length of the stent (main body) should reach 40–50 mm above the carina. The length of the right main bronchus is equal to the distance between the carina and the upper edge of the upper right bronchial opening. Because the upper left lobe of the left bronchus is to be blocked, the length of the left main bronchus is generally 35–40 mm.

12.6.8.2 Preparation before Stent Implantation

Same as in Sect. 12.6.2.2

12.6.8.3 Large Y-Shaped Self-Expandable Covered Metallic Stent with a Bullet Head Placement Procedure

Same as Sect. 12.6.2.3

12.6.8.4 Proceeding After Stent Implantation

Details are the same as in Sect. 12.6.1.4.

12.6.8.5 Prevention and Treatment of Complications

Details are the same as in Sect. 12.6.1.5

12.6.9 Left Lower Lobe BPF

The left lower lobe BPF is a sinus that forms between the left lower lobe bronchus and the pleural cavity after left lower lobe lobectomy. The left lower lobe bronchus is the continuation of the left main bronchus, which extends downward, outward, and to the back. Based on the special anatomical structure and pathological features of the lower lobe bronchus of left lung, Dr. Xinwei Han designed the Y-shaped self-expandable covered metallic stent with a bullet head and L-shaped self-expandable partially covered metallic stent with a bullet head and stent delivery system to occlude the lower left lobe BPF.

12.6.9.1 Equipment Preparation

This includes interventional operation equipment and stent selection or customization.

1. *Equipment preparation:* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire 0.035-in. × 180 cm, a customized Y-shaped self-expandable covered metallic stent with a bullet head and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent selection:* Measure the diameter of the left main bronchus, the left upper lobe, and the lower left lobe using the fat window (window width 400 HU, window length −50 HU) of the chest MSCT scan. Use these measurements to select or customize a Y-shaped self-expandable covered metallic stent with a bullet head. The stent parameters should be as follows: The diameter of the stent of the left lower lobe bronchus is about 10% larger than the corresponding trachea and the length does not exceed 80% of the total length of the residual tracheal stump. The diameter of the stent branch of the left upper lobe is about 10% larger than the corresponding bronchial tube and the length of the bronchus is less than 80% of the total length of the bronchus. The diameter of the left main bronchus (main body) of the stent is 12% greater than the corresponding airway and the length does not exceed the total length of the left main bronchus.

12.6.9.2 Preparation before Stent Implantation

Same as in Sect. 12.6.2.2

12.6.9.3 The Y-Shaped Self-Expandable Covered Metallic Stent with a Bullet Head Placement Procedure

Because of the special anatomical structure of the lower left lung bronchus, the Y-shaped self-expandable covered metallic stent with a bullet head is used to seal the fistula. The Y-shaped self-expandable covered metallic stent with a bullet head placement procedure is basically the same as the operation of the right medial segment of the BPF (Sect. 12.6.4.3). During the introduction of the reinforced guidewire, insert a reinforced guidewire into the distal end of the left upper lobe bronchus and insert the other reinforced guidewire into the pleural cavity via the bronchial stump of the left lower lobe of the lung. Introduce a Y-shaped self-expandable covered metallic stent with a bullet head along the double guidewires with the branch in the upper left lobe of the bronchial, the bullet section in the left lower lobe bronchial stump, and the main body placed in the middle of the bronchial. If the left lower lobe bronchial stump is too long, a L-shaped self-expandable partially covered metallic stent with a bullet head is prepared for treatment. The placement procedure is basically the same as the operation of the right medial segment of the BPF (Sect. 12.6.4.3). The difference is that the bullet head section is placed in the lower lobe of the left lung, and the arc transition section is relative to the opening of the upper left lung bronchus.

12.6.9.4 Proceeding after Stent Implantation

Details are the same as in Sect. 12.6.1.4.

12.6.9.5 Prevention and Treatment of Complications

Details are the same as in Sect. 12.6.1.5

12.6.10 Segmental BPF

Segmental BPF is a sinus between the segmental bronchus and pleural cavity after segmentectomy. It may be due to pleural cavity infection, trauma, or surgery resulting in rupture of the visceral pleura and damage to the pulmonary lobe, lung segment. This results in segmental bronchial communication with the pleural cavity. Since the technology of the pulmonary wedge-shaped resection has improved (especially the application of the closure), the incidence of segmental BPF is low. The common causes of segmental BPF are pulmonary infection and trauma, incom-

plete closure of the bronchial stump, and impaired regeneration of the tissue because of preoperative or postoperative radiotherapy. The segmental BPF is usually small and most of them have pleural coverage. Conservative treatment requires early insertion of a thoracic drainage tube to make the fistula come into contact with the pleura, thus limiting the spread of infection. Most fistulas can be healed by actively pumping the suction stream. This type of BPF can cause slight infections to become aggravated, prolonged nonunion, recurrent pleural infection, tension pneumothorax, chronic consumption, or persistent fever. All of which affect the quality of life and can endanger the patient's life. Based on the special anatomical structure and pathological features of the segmental bronchus, Dr. Xinwei Han designed a self-expandable metallic stent with a covered bullet head to treat this condition. The covered bullet head of stent was used to occlude segmental BPF, while uncovered part was placed in the segment of bronchi to prevent migration. The application of self-expandable metallic stent with a covered bullet head could create a negative pressure in the pleural cavity, and boost the healing of BPF.

12.6.10.1 Equipment Preparation

This includes interventional operation equipment and special customized stents.

1. *Equipment preparation* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire 0.035-in. × 180 cm, customized tubular-shaped self-expandable covered metallic stent with a bullet head single bullet film stent and conveying system, 2 stent removal systems (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent selection:* This type of BPF is usually small and most of them have pleural coverage. The clinical manifestations include persistent gas overflow from the thoracic closed drainage tube or pneumothorax. It is difficult for the MSCT scan to show the size of the fistula and bronchography should be used to clarify the location of the lesion and the tissues adjacent to it. To confirm diagnosis and before the airway stent operation, perform bronchography and observe if the contrast agent flows directly through the segment of the bronchial stump into the pleural cavity. Define the fistula position and length from the segmental bronchial stump to the leaf bronchial for customization of a tubular-shaped self-expandable covered metallic stent with a bullet head (Fig. 12.10a).

12.6.10.2 Preparation before Stent Implantation

Same as in Sect. 12.6.2.2

12.6.10.3 Tubular Single Bullet Film Stent Placement Procedure

1. *Patient positioning:* The patient relaxes and removes upper body clothes with any X-ray-incompatible bodies (for example, metal buckles). The patient lies in a supine position on the DSA examination table. Remove pillows and keep neck and shoulders slightly elevated. Position the head backwards and angled to the right at 20–30°. Use a surgical drape to cover the body. Fix a nasal oxygen inhalation tube and link up a multichannel ECG. Spray lidocaine into the throat to anesthetize the throat. Insert a mouth gag and prepare the negative pressure aspirator to remove airway and oral secretions, as needed. The DSA C-arm is angled 20–30° to the left (with the head tilted to the right at 20–30°, this is equivalent to angling the patient's head at 50° to the right). Adjust the DSA X-ray field of vision to include the oropharynx, trachea, and right main bronchus.
2. *Transcatheter angiography:* Insert a 0.035-in. hydrophilic membrane guidewire and 5 F vertebral artery catheter into the oropharynx under fluoroscopic guidance. Adjust the catheter tip to be above the throat and hypopharynx. Instruct the patient to breathe or cough. When the glottis is open, quickly pass the catheter into the guidewire and cross the laryngeal cavity into the trachea. Then remove the guidewire and inject 2–3 mL of 2% lidocaine through the catheter to anesthetize the

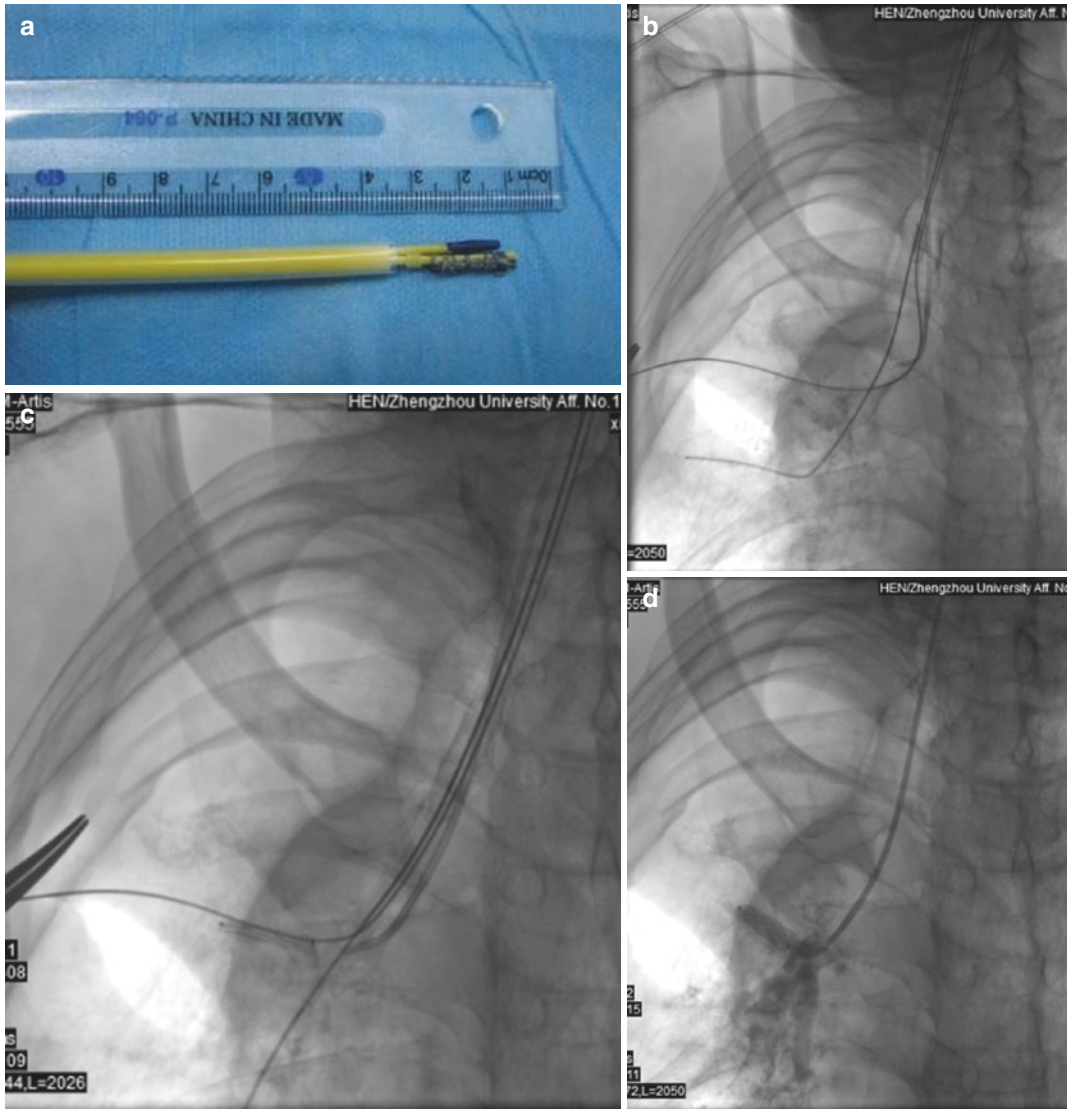

Fig. 12.10 The tubular-shaped self-expandable covered metallic stent with a bullet head placement operation diagram. (**a**) Customized tubular-shaped self-expandable covered metallic stent with a bullet head. (**b**) The two wires should be fixed and marked. The operation path of the airway stent is established. (**c**) The distal end of the airway stent is located in the fistula and the proximal end does not cover the adjacent bronchus (**d**) After stent is released, inject 3–5 mL of water-soluble iodine contrast through the catheter to determine whether the fistula is completely blocked

airway mucosa. Inject 1–2 mL of 0.1% epinephrine solution to prevent airway mucosal bleeding from damage. Insert the vertebral artery catheter into the pulmonary lobe of the affected side or in the bronchial stump of the pulmonary segment. Through the catheter, inject about 3 mL of water-soluble iodine contrast agent to show the position, length, and diameter of the BPF of the lobe or lung segment. Insert the hydrophilic membrane guidewire and the catheter into the pleural residual cavity through the fistula. Introduce the catheter into the pleural cavity. The reinforced guidewire is introduced into the pleural cavity through the lobe or segmental BPF. Another guidewire is introduced into the bronchus of

the adjacent lung segment and each guidewire should be fixed and marked. The operation path of the airway stent has now been established (Fig. 12.10b). Adjust the DSA field of view to include the lower segment of the trachea, carina, right main bronchus, and distal end of the guidewire.

3. *The introduction of the inner stent delivery system:* Insert the stent delivery system along the reinforced guidewires, through the glottis, and into the main bronchus and segment bronchial. Maintain the depth of the stent delivery system in the target section. The distal end of the airway stent is located in the fistula and the proximal end does not cover the adjacent bronchus (Fig. 12.10c). At this point, the tubular-shaped self-expandable covered metallic stent with a bullet head is positioned in the correct place.
4. *Positioning and releasing the stent:* Fasten the guidewire and inner stent delivery system's handle in vitro, maintain the depth and orientation of the stent unchanged using fluoroscopy monitoring. Pull back the handle and the outer sheath of the inner stent until the bullet section is completely exposed. Maintain the relative position of the front and back handle of the stent delivery system unchanged and pull the stent's ties to release the stent's bullet section in the pulmonary lobe or the bronchial stump of the lung segment (Fig. 12.10d). Fix the guidewire under fluoroscopy monitoring and pull out the stent delivery system slowly and gently to avoid the end of the inner stent delivery system hooking the stent and resulting in stent shift.
5. *Transcatheter cholangiography:* After the stent is fully released, keep the guidewire in the airway and carefully remove the stent delivery system. Through the catheter, inject 3–5 mL of water-soluble iodine contrast agent to determine whether the fistula is completely blocked. Urge the patient to cough or take a deep breath and observe whether the chest closed drainage bottle still has bubble overflow entering into it. If there is a continuous bubble overflow, the fistula has not been completely blocked. If there is small bubble overflow, which gradually reduces and disappears, this suggests that the fistula has been successfully closed (Fig. 12.10e). If there is incomplete closure, adjust the stent position, stimulate re-expansion, or replace the stent.
6. *Sputum suction and hemostasis:* The guidewire is moved to the distal end of the uninjured side of the bronchus through the catheter. Then remove the catheter and insert a suction tube along the guidewire to suction the residual contrast agent and sputum. Pat the patient's chest and back to help dislodge stubborn sputum. Suction the sputum until the rales of the lungs disappear and the SpO_2 reaches or approaches 100%. Encourage patients to cough regularly and continue to suction sputum frequently. Inject 3–5 mL saline to dilute viscous sputum before suction, if necessary. If the sputum contains blood, the suction tube should be inserted into the guidewire again. The catheter is guided into the airway along the guidewire and then injected with 1–2 mL of 0.1% epinephrine solution to stop the bleeding. If there is no blood in the sputum, pull out the catheter and guidewire.

12.6.10.4 Proceeding after Stent Implantation

Details are the same as in Sect. 12.6.1.4

12.6.10.5 Prevention and Treatment of Complications

Details are the same as in Sect. 12.6.1.5

12.6.11 Bronchiole BPF

A bronchiole BPF is a sinus between the bronchi and the pleural cavity. This type of BPF is caused by pus produced by an intractable infection of the residual cavity of the thorax after lobectomy or other pleural cavity surgery. The pus corrodes the surface of the lungs causing the lung layer, pleura, alveoli, and bronchioles to communicate with the pleural cavity. The pus is produced by anastomotic leakage of the esophagus and stomach or an encapsulated empyema and it corrodes the lung surface causing the bronchioles to

communicate with the pleural cavity, bunamiodyl breakdown, and trauma. Intervention techniques include pleural cavity abscess drainage tube placement, negative pressure suction drainage, and lavaging. In some patients, the cavity disappears and the fistula heals. For a stubborn bronchiole BPF and refractory pleural infection with nonunion fistula and aspiration pneumonia present in adjacent lobes or segments of the lung, use a tubular-shaped self-expandable covered metallic stent with a bullet head to occlude the corresponding segment of the bronchus. However, this blocking therapy may be accompanied by partial loss of function of the pulmonary segment.

12.6.11.1 Equipment Preparation

This includes interventional operation equipment and special customized stents.

1. *Equipment preparation:* A 4–5 F vertebral artery catheter, a hydrophilic membrane guidewire (0.035-in. × 120 cm or 0.035-in. × 180 cm), 1–2 plus stiff guidewire 0.035-in. × 180 cm, customized tubular-shaped self-expandable covered metallic stent with a bullet head and stent delivery system, 2 stent removal system (spare), 1 vascular sheath (9 F), 1 long vascular sheath (9–12 F) (spare), 1 tracheal intubation (6.5 or 7.0) (spare), 1 mouth gag, sputum suction device, ventilator, and other rescue equipment.
2. *Stent selection:* Because the section of the bronchial fistula is small and generally has a pleural covering, this condition normally presents as persistent gas overflow in a closed thoracic drainage tube or pneumothorax. It is difficult to find the fistula using an MSCT scan. Tracheal radiography is needed to define the location of the lesion and the adjacent trachea. A definitive diagnosis is when the tracheal radiography shows the contrast medium directly flowing into the pleural cavity through the section of the bronchial stump. Define the location of the fistula and the length between the stump and the bronchus and use these measurements to design a tubular-shaped self-expandable covered metallic stent with a bullet head.

12.6.11.2 Preparation before Stent Implantation

Same as in Sect. 12.6.2.2

12.6.11.3 Tubular-Shaped Self-Expandable Covered Metallic Stent with a Bullet Head Placement Procedure

Same as in Sect. 12.6.10.3

12.6.11.4 Proceeding after Stent Implantation

Details are the same as in Sect. 12.6.1.4.

12.6.11.5 Prevention and Treatment of Complications

Details are the same as in Sect. 12.6.1.5

12.7 Outlook

BPF research interest and treatment options have increased over time and the diagnostic ability has gradually improved. The wider development of the pulmonary resection method, postoperative radiotherapy, and other treatment methods has led to them being in common use. There are more and more clinical cases of BPF, and more and more airway stents are being used in treatment. But there are still many problems to be solved, such as: how to further improve the understanding of the disease, how to diagnose the disease in the early stage, what methods are effective in the treatment of lung chemical damage and the combination of multiple pulmonary infection, and how to improve the long-term efficacy and safety of airway stents as a foreign body in the airway.

The ideal airway stent should be easy to insert and remove, and it should have sufficient capacity to expand without causing damage to the tracheal mucosa. There are many different types of stents for all kinds of airway fistula positions. These stents should be able to firmly remain in place, not stimulate the airway mucosa, not aggravate infection or promote excessive granulation tissue formation, not obstruct the airway branch, and not inhibit the function of cilia movement and the removal of secretions.

A future direction for research is to develop new stents with greater hardness and flexibility, a better curative effect, and fewer side effects. Drug-coated stents, electrical decomposition stents, radioactive stents, and biodegradable stents are currently being developed and clinically tested. We hope that they can be used in clinical practice in the near future. Clinicians should constantly record their experiences of this type of treatment, strive to improve the treatment techniques, standardize the treatment, and thereby make stent implantation a safer and more effective way of treatment, so that more patients with BPFs can benefit from it.

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Pulmonary Emphysema

13

Yong Fan and Tian Jiang

13.1 An Overview of Pulmonary Emphysema

Chronic obstructive pulmonary disease is the disease characterized with airflow limitation that is chronically progressive and irreversible. Its high disability and mortality rate has a tendency to increase year by year, leading to heavy social economic burden [1, 2]. As a result, the disease is treated as a public health issue worldwide. Chronic obstructive pulmonary emphysema is the most common clinical manifestation. In clinics, pulmonary emphysema manifests progressive and irreversible airflow limitation. Pathologically, pulmonary emphysema shows elasticity attenuation and overexpansion in distal airway of terminal bronchioles and damage in alveolar walls and bronchiolar walls with no obvious fibrosis. An investigation of 20,245 adults in 7 regions showed that 8.2% of the adults aged over 40 years old suffered from chronic obstructive pulmonary emphysema. As estimated by the Global Burden of Diseases Study, it will be the third leading cause of death worldwide in 2020. The data of the World Bank and the World Health Organization show that the disease will be the fifth weightiest economic burden all over the world in 2020 [3, 4].

13.2 The Causes of Pulmonary Emphysema

13.2.1 Oxidative Stress in the Lung

Oxides, such as superoxide anion, hypochlorous acid, nitric oxide, hydroxyl group, and so on, can directly have an effect on and damage many biochemical macromolecules like protein, lipid, nucleic acid, and so on, leading to dysfunction or death of cells, damage of extracellular matrix, imbalance of protease and antiprotease, acceleration of inflammatory reaction, and participation in transcription of various inflammatory mediators.

13.2.2 Imbalance of Protease and Antiprotease

While proteolytic enzyme damages tissues, antiprotease would inhibit many proteases like elastase. Both an increase of protease and insufficiency of antiprotease lead to damage of tissues and pulmonary emphysema. Oxidative stress, smoking, and other risk factors can affect

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the activity of antiprotease. Congenital al-antitrypsin deficiency can affect a small proportion of the population.

13.2.3 Pulmonary Inflammation

The characteristics of chronic obstructive pulmonary emphysema contain chronic inflammation of airway, pulmonary parenchyma, and pulmonary vessels. Inflammatory cells in lungs with chronic obstructive pulmonary emphysema are mainly alveolar macrophages, neutrophils, and CD8 + T cells. The activated inflammatory cells release a variety of inflammatory mediators, including leukotriene B4, interleukin −8, tumor necrosis factor-α, and so on, which damage the structure of the lung and/or promote inflammatory reaction of neutrophils.

13.2.4 Other Causes

The pathogenesis of pulmonary emphysema is not fully understood. Besides the causes listed above, other causes such as respiratory tract infection, autonomic nervous system dysfunction, climate change, smoking, malnutrition, and so on also lead to the occurrence and development of pulmonary emphysema [5].

Abundant researches and clinical practices show that respiratory tract infection caused by various pathogenic microorganisms is the main factor that leads to the disease. Acute sufferers often have a cold first. Common viruses, bacteria, mycoplasmas, and so on can all result in the disease. So, prevention of cold and upper respiratory tract infection is one of the important principles. Climate change also has a great effect on chronic bronchitis and pulmonary emphysema. The noticeable characteristic of the illness is that it worsens in winter while takes a favorable turn in summer. Most attacks occur in early winter when temperature drops sharply. The reason is that cold air can cause spasm and ischemia of bronchial mucosal vessels which account for disturbance of blood circulation and function impairment of ciliated epithelium, weakening the effect of resisting external pathogenic factors. Smoking is regarded as the most commonly seen cause of COPD. Smoking can lead to bronchospasm, impairment of ciliated epithelium, goblet cell hyperplasia, and mucus secretion hyperfunction, thus aggravating airway obstruction and leading to high incidence of secondary infection. However, only a small proportion of smokers show this kind of symptoms. Air pollution, occupational exposure to dust or smoke, exposure to biological agents, and so on are all regarded as causes of COPD. Besides, genetic susceptibility can also lead to COPD.

13.3 Pathology of Pulmonary Emphysema

The American Thoracic Society defines pulmonary emphysema as persistent abnormal expansion of air cavity that links terminal bronchioles in the lung, with impairment of alveolar walls and without obvious fibrosis. Impairment of alveolar walls causes many tiny holes among alveoli, uneven expansion of respiratory air cavity, as well as disorder or even absence of alveoli and their structural constituents [6]. Therefore, gas exchange in alveoli is influenced. Pulmonary emphysema can be divided into homogeneity and heterogeneity according to the distribution of pathological tissues in the lung. It is difficult to alleviate the symptoms of COPD sufferers in the late stage because of the pathophysiological changes of the disease. COPD sufferers have the symptoms of airway fibrosis and stenosis, decrease of alveolar elastic recoil, and damage of alveolar support structure that keeps the opening of small airways. These changes would lead to irreversible decrease of forced expiratory flow rate and depression of maximal expiratory flow rate - capacity curve toward capacity axis. As a result, inspiratory muscle strength and diaphragm contractile force decrease in COPD sufferers. Pulmonary hyperinflation pushes the diaphragm down, leading to lots of side effects, such as decrease of diaphragm contractile force, poor function of abdominal pressure on chest walls when inhaling, obstruction of activity of ribs, for-

mation of endogenous PEEP, and so on. COPD characterized by uneven ventilation and imbalanced ventilation-perfusion ratio manifests the heterogeneity of the development of the disease. In the late stage, chronic obstructive pulmonary emphysema shows pulmonary hypertension, followed by chronic pulmonary heart disease and right heart failure, suggesting poor healing outcome [7, 8]. Chronic obstructive pulmonary emphysema leads to systemic adverse effects, including systemic inflammatory reaction and skeletal muscle dysfunction. It also promotes or aggravates the occurrence of complications.

13.4 Pulmonary Emphysema Diagnostics

13.4.1 Clinical Manifestations

1. Dyspnea: It is the most noticeable symptom of chronic obstructive pulmonary emphysema, mainly manifested as shortness of breath, asthma, labored breathing, and so on. In the early stage, the symptom occurs only when sufferers are tired. As time goes by, the disease aggravates, and sufferers feel shortness of breath even when at rest.
2. Chronic cough: It is often the first symptom. At first, the cough is intermittent and more severe in the morning. Then, patients cough every morning and evening, or all day, but night cough is not obvious.
3. Expectoration: A small amount of mucus sputum can be seen when coughing. For some sufferers, there tends to be more mucus sputum in the morning. An increase in the amount of sputum can be observed when concurrent infection occurs.
4. Gasp and chest congestion: Some patients, especially the severely ill ones, suffer from obvious gasp, which is the result of labored respiration and intercostal muscle contraction.
5. Other symptoms: Patients whose degree of chronic obstructive pulmonary emphysema is more severe may suffer from systemic symptoms, such as loss of weight and appetite, atrophy and dysfunction of peripheral muscles, deprementia and/or anxiety, etc.

13.4.2 Signs

There is no sign in the early stage. If the disease aggravates, the following signs would appear [9]:

1. Inspection: Anteroposterior chest diameter increases, intercostal space widens, and the lower angle of xiphoid substernum enlarges, thus forming the "barrel chest."
2. Palpation: Bilateral vocal fremitus abate.
3. Percussion: Unvoiced sounds pass through the lung, cardiac dullness narrows, and inferior boundary of the lung and hepatic dullness lower.
4. Auscultation: Respiratory sounds diminish, and expiratory period lengthens in both lungs. Moist rale and/or dry rale can be observed in some sufferers.

13.4.3 Imaging

13.4.3.1 Chest X-Ray

Chest X-ray of early-stage chronic obstructive pulmonary emphysema sufferers shows no obvious change, and then texture increase and disorder as well as other non-characteristic changes in the lungs are observed. The main X-ray features are pulmonary hyperinflation, enlargement of lung volume, increase of anteroposterior diameter of thoracic cavity, flattening trend of the ribs, increase of transparency of lung field, low diaphragmatic position, pendulous and narrow heart, nub-like texture of blood vessels in porta of the lung, thin vascular texture in the peripheral part of lung field, etc. Sometimes pulmonary bullae can be observed. If pulmonary arterial hypertension and pulmonary heart disease happen at the same time, besides the X-ray characteristic of right heart enlargement, cone-like distention in pulmonary artery, enlargement of vascular imaging in porta of the lung, widening of lower right pulmonary artery, and so on can also be observed [10].

13.4.3.2 Chest CT

High-resolution CT is sensitive and distinctive in distinguishing lobular center type or whole lobular pulmonary emphysema, as well as determining the size and number of pulmonary bullae [11].

13.4.4 Laboratory Testings

13.4.4.1 Pulmonary Function Testing

It is a reliable and objective indicator for the repeatability of airflow limitation. Airflow limitation is defined by the decrease of FEV1 and FEV1/FVC, which is a sensitive indicator of chronic obstructive pulmonary emphysema, for it can tell a mild airflow limitation. If the FEV1/FVC level of sufferers after inhaling bronchodilator is below 70%, persistent airflow limitation can be diagnosed. Normally as one grows older, lung volume and airflow may be influenced. As a result, if the fixed rate of FEV1/FVC<70% is applied, some healthy elders might be diagnosed with mild chronic obstructive pulmonary emphysema, and chronic obstructive pulmonary emphysema sufferers under 45 years might be underdiagnosed. The ratio of residual volume to total lung capacity rises.

Compared to pure DLCO, the ratio of DLCO to alveolar ventilation is more sensitive. Inspiratory capacity is the sum of tidal volume and inspiratory reserve volume. The ratio of inspiratory capacity to total lung capacity is the indicator to reflect lung hyperinflation, and it is meaningful for telling the degree of dyspnea and even predicting the survival rate of chronic obstructive pulmonary emphysema sufferers [12].

13.4.4.2 Pulse Oxygen Saturation

Monitoring and blood gas analysis are necessary for patients in the stable phase of chronic obstructive pulmonary emphysema. SpO2 should be monitored if the level of FEV1 is below 40% of predicated value or clinical symptoms show that there is a respiratory failure or right-sided heart failure. Blood gas analysis should be carried out if the level of SpO2 is below 92%. The diagnosis standard for blood gas analysis is that the level of SpO2 is below 60 mmHg when breathing at sea level, with or without the symptom that the level of PaCO2 is above 50 mmHg.

13.4.4.3 Other Laboratory Testings

Hypoxemia occurs if hemoglobin and red blood cells show an upward tendency when arterial partial pressure of oxygen is below 55 mmHg. If the level of hematocrit is above 0.55, one is diagnosed with polycythemia, and anemia can be observed in some sufferers. If patients are infected with both diseases, there are a large amount of neutrophils in sputum smear, and various kinds of pathogenic bacteria can be detected with sputum culture.

The diagnosis of chronic obstructive pulmonary emphysema is based on a comprehensive analysis of clinical manifestations, history of exposure to risk factors, signs, imaging examinations, laboratory testing, etc. Any patient who suffers the symptoms of dyspnea, chronic cough or expectoration, and has a history of exposure to risk factors should be considered as possible chronic obstructive pulmonary emphysema sufferers when giving diagnosis clinically. Pulmonary function testing should be carried out when diagnosing chronic obstructive pulmonary emphysema. If the FEV1/FVC level after inhaling bronchodilator is below 70%, there must be persistent airflow limitation. If there is no other disease, the person is diagnosed with chronic obstructive pulmonary emphysema. So, persistent airflow limitation is an essential condition for the diagnosis of chronic obstructive pulmonary emphysema. Pulmonary function is the golden standard in diagnosing chronic obstructive pulmonary emphysema. When giving diagnosis, chronic obstructive pulmonary emphysema should be distinguished from asthma, bronchiectasis, congestive heart failure, tuberculosis, diffuse panbronchiolitis and other diseases, especially from asthma.

13.5 Clinical Treatment of Pulmonary Emphysema

13.5.1 Medical Treatment

Conventional medical treatment methods for chronic obstructive pulmonary disease in the late

stage include spasmolysis, anti-bronchospasm drugs, oxygen inhalation, breath muscle functional training, and others. Bronchodilator inhalation and hormone medicines are therapeutic, but they are still unable to ease resting dyspnea for severe sufferers even though extreme quantities of medications have been used. It is difficult to alleviate the symptoms of COPD sufferers in the late stage because of the pathophysiological changes of the disease. The occurrence of dyspnea in chronic obstructive pulmonary disease is due to alveoli impairment and pulmonary dynamic mechanism damage. These changes can lead to irreversible decrease of forced expiratory flow rate and depression of maximal expiratory flow rate - capacity curve toward the capacity axis. As a result, inspiratory muscle strength and diaphragm contractile force decrease in COPD sufferers. Pulmonary hyperinflation pushes the diaphragm down and causes many side effects, such as decrease of diaphragm contractile force, poor function of abdominal pressure on chest walls when inhaling, obstruction of activity of ribs, formation of endogenous positive airway pressure, and so on. Medical treatment cannot change the anatomical structure of the pulmonary system. In 1997, Massaro declared that all-trans retinoic acid supplement could restructure emphysematous lung structure of mice and brought research focus on retinoic acid. All-trans retinoic acid is the metabolite of vitamin A. It was reported that all-trans retinoic acid could repair various cells, tissues, and organs, including the lung. There were also a few reports saying that retinoic acid supplement can improve pulmonary function of severe life-threatening COPD. Later, many scholars applied the method to various animal testings, including pulmonary emphysema model induced by smoking in guinea pigs, induced by damage of elastic fibers in mice, as well as others. No positive results were obtained in these testings which caused attention to treating pulmonary emphysema with retinoic acid. But the deviation was not clear. In 2008, Takahashi and others reported that proliferation of alveolar epithelium could be obtained by resorting to simvastatin in pulmonary emphysema model induced by damage of elastic fibers in mice; however, many later researches showed that damaged alveoli could not be repaired by using simvastatin. Up to now, no treatment that can restructure the air-blood exchange structure damaged by pulmonary emphysema has been found out.

13.5.2 Surgical Treatment

There are many surgical methods for pulmonary emphysema since the end of the twentieth century, including rib cartilage resection, sternum transverse dissection, thoracoplasty, phrenectomy, artificial pneumoperitoneum, folded lung resection in pulmonary bulla, and so on. Though surgeries alleviate the symptoms, except pulmonary bulla resection, all other surgeries have not been proven to be of benefit for pulmonary emphysema sufferers. The complication rates and operative mortality rates are very high, and severe sufferers are unable to endure surgical trauma for their weak constitution. Based on the pathophysiological changes of the disease, Brantigan and others first proposed open-chest lung volume reduction surgery in the late 1950s. By resecting overexpanded lung tissues, the treatment method improves the compensatory situation of the diaphragm and thoracic cage, which in turn improves ventilation-perfusion ratio. In this way, it is feasible to alleviate the symptoms of late-stage sufferers. In 1995, lung volume reduction surgery was successfully performed on 20 patients by Cooper and others, and their quality of life and lung function were all improved. In 2003, researching findings of the American National Emphysema Treatment Trial manifested that LVRS could significantly improve lung function of the heterogeneity type of the disease and evaluation of the therapeutic effect of LVRS became generally consistent. However, LVRS is treated for a few number of patients. Only COPD patients who suffer from lesion in the upper lobe of the lung and limitation of motion could resort to LVRS. Though there is desperate need for very severe pulmonary emphysema sufferers (forced expiratory volume in 1 s $FEV_1 \leq 20\%$, plus diffusing level of carbon monoxide DLco $\leq 20\%$ or the homogeneity type of pulmonary emphysema) to improve their lung function, LVRS could not be performed on them.

In 2005, Berger RL and others performed meta-analysis on eight randomized clinical trials and found that LVTS outperformed medical treatment. However, its postoperative complication rate was above 90%, its death rate of 90 days after surgery was 7.9%, and its postoperative rehospitalization rate was 22–28%. All these factors limit the clinical application of LVRS. In order to solve the problem, scholars began to explore minimally invasive technique to treat severe pulmonary emphysema sufferers. Later, thoracoscope-assisted lung volume reduction surgeries, including the use of a linear cut stapler, lung volume reduction surgery assisted by a vacuum pump, and so on achieve some effects, but the high complication rate remains. Lung transplantation is treated as the best method in treating severe pulmonary emphysema, but it cannot be carried out extensively due to complicated operation requirements and rare donors [12–14].

13.6 Pulmonary Emphysema Inner Stent Interventional Radiology

13.6.1 Preparation of Instruments

13.6.1.1 Instruments for Interventional Procedures

1. When placed with the assistance of bronchoscope: flexible bronchoscope (fibers or electrons); 5F single bend catheter or tracheoscope medicine delivery pipe; stent conveyer; balloon measurer (optional).
2. When placed by resorting to radiological intervention method: flexible bronchoscope (fibers or electrons); 5 F single bend catheter, 0.035″ super smooth guide wire; 0.035″ hardened exchange guide wire; 9 F/10 F bend-resistant sheath tube; stent push rod; balloon measurer (optional) (Fig. 13.1).

13.6.1.2 Choice of Inner Stents

One-way flutter valve stents should all be put at the opening of subsegmental bronchi. Usually one-way flutter valve stents are 5–6 mm in diameter and 8 mm in length. For severe pulmonary emphysema sufferers, stents can be selected based on the diameter of target bronchi because of the dilatation of their bronchi. As to reticular laminar one-way flutter valve stents that have no fixation hooks, usually stents whose diameter is 130–140% of the diameter of the bronchi are used to inhibit translocation (Fig. 13.2).

13.6.2 Preparations Before the Placement of Inner Stents

1. Laboratory preparations: Before the operation, blood routine examination, bleeding and clotting time measurement, arterial blood gas analysis, and pulmonary function examination should be conducted. Atrial natriuretic peptide, brain natriuretic peptide, and endothelin testings should be carried out on those patients who suffer from pulmonary arterial hypertension plus right heart insufficiency. Imaging examinations include CT scanning and colored Doppler pulmonary arterial

Fig. 13.1 One-way flutter valve stent placement instruments (10 F bend-resistant sheath tube and stent push rod)

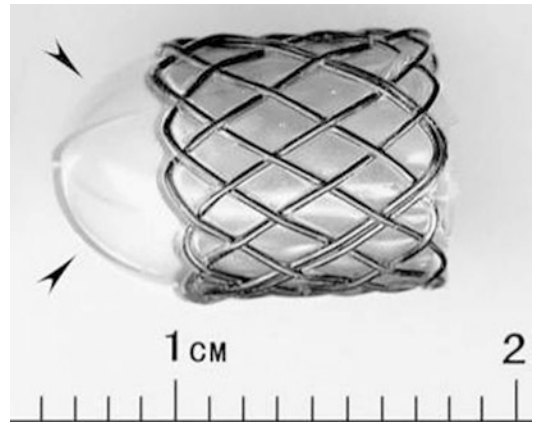

Fig. 13.2 One-way flutter valve stent

pressure estimation, and when necessary, radionuclide pulmonary ventilation-perfusion testing plus CT scanning could be performed to determine the target region.
2. Patient preparations: Before the operation, no smoking should last for more than 3 months. Also patients should receive a 6-minute walking test, dyspnea assessment, and life quality assessment. No food or water is allowed on the operation day.
3. Medications prior to surgery: Normally, general anesthesia and tracheal intubation are required because bronchoscope and stent conveyers need to pass through the airway frequently during the operation.

13.6.3 Placement Procedures in Inner Stent Interventional Radiology

1. Patient position: Patients are in supine, and the tubes link the trachea to the anesthesia machine. In order to prevent air leak when tracheoscope and stent conveyer pass through the airway, the tubes should have three ends. While the second end links the anesthesia machine, the third one links the flutter valve (the trocar on peritoneoscope can be used).
2. Flexible bronchoscope reaches target bronchi through tracheal intubation. Investigate the condition of subsegmental bronchi branches, and measure the subsegmental bronchi into which stent is about to be placed (either estimation through the lens of bronchoscope or balloon measurement is acceptable). The 5F single bend catheter enters through the working path of tracheoscope under the guidance of 0.035″ super smooth guide wire. Put the bending top of the single bend catheter into target bronchi. Determine the position through fluoroscopy plus lung markings and bony landmarks.
3. Once the position of the single bend catheter is determined, it reaches the distal end of bronchi under the guidance of fluoroscopic monitoring and super smooth guide wire. Replace the super smooth guide wire with hardened exchange wire. Take the bronchoscope and 5 F catheter out.
4. Under the guidance of fluoroscopic monitoring, 9 F/10 F bend-resistant sheath tube is inserted along the exchange guide wire. The top of the sheath tube is put at the positioning mark of the single bend catheter. Take the exchange guide wire and dilator inside the sheath tube out (Fig. 13.3; an informed consent was obtained from all participating subjects, and the ethics committee of the general hospital of Tianjin Medical University approved our study.) Put the valve end of the one-way flutter valve stent into the end of the sheath tube in a backward way. Take the stent out of the top of the sheath tube by using stent push rod. When the stent is in place, observe the position and shape of the stent as well as the activity state of the valve. If there is no problem, just adjust the position of the bronchoscope to put another stent in place. One-way flutter valve stents should be put into all subsegmental bronchi in the target section (the whole lung lobe).

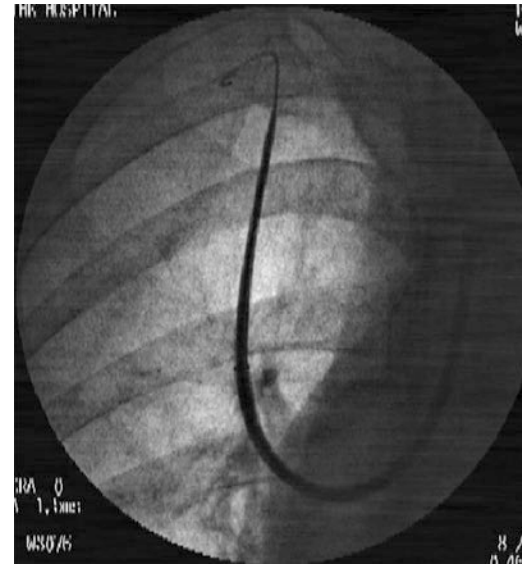

Fig. 13.3 Placement of bend-resistant sheath tube

13.6.4 Post-Stenting Handling

1. When the stents are in place, observe the position and shape of the stents as well as the activity state of the valves immediately (Figs. 13.4 and 13.5). The number, position, and shape of the stents should be observed and recorded through fluoroscopy, and CT scanning should be performed if necessary (Fig. 13.6).
2. Oxygen inhalation, cough-relieving, and phlegm-resolving treatments should be performed when the patients come back to consciousness. Encourage the patients to get out of bed in the early stage.
3. Blood gas analysis should be monitored after the operation. Pulmonary function and CT scanning should be performed 1 month after the surgery. A 6-minute walking test, dyspnea assessment, and life quality assessment in the recent period should be conducted.

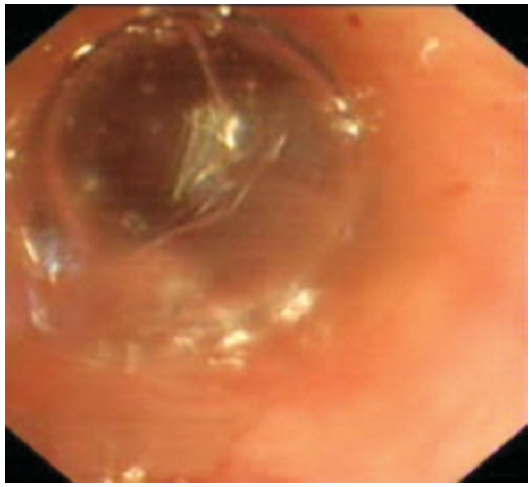

Fig. 13.4 Stent valve in opening state

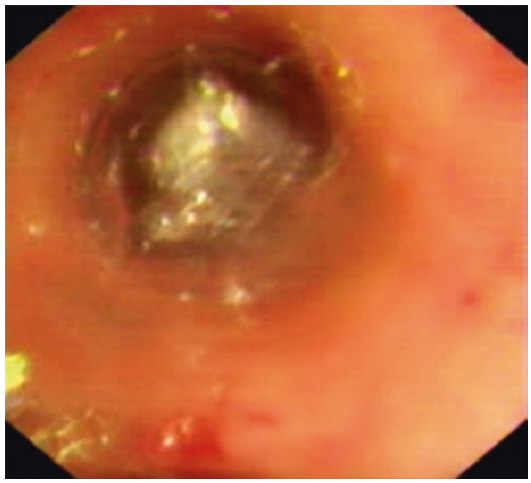

Fig. 13.5 Stent valve in closing state

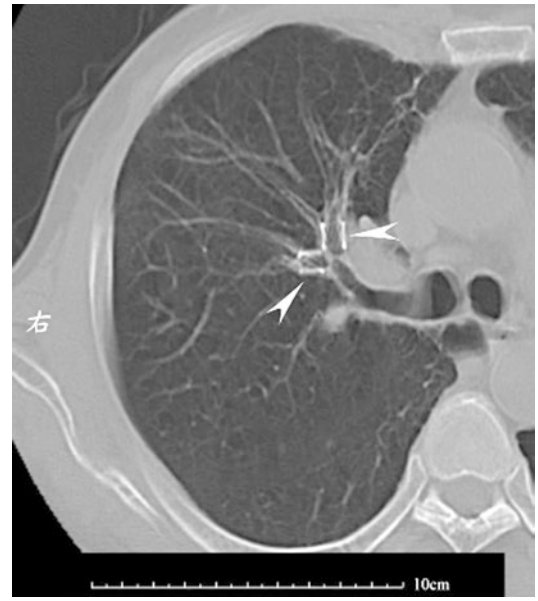

Fig. 13.6 CT scanning shows that the stents are at the opening of subsegmental bronchi

13.6.5 Prevention and Treatment of Complications

1. Self-limited pneumothorax: It is rarely seen. Act gently during the operation. X-ray fluoroscopic monitoring is required during the whole operation time when inserting catheter and guide wire. Usually the superior lobe is regarded as the target region, so sharp angles are often formed at the opening of the upper lobar bronchus and main bronchus. Therefore, hardened guide wire should never be inserted into the distal end of bronchi without the protection of catheter. Pneumothorax can be absorbed in some patients.

2. Acute exacerbation of COPD: If acute attack of COPD occurs in some patients, conventional anti-inflammatory and asthma-relieving treatments can be performed.
3. Pneumonia: Though postoperative pneumonia is not commonly seen, inflammation usually occurs in the nontarget region, for which the reason is not clear now. Maybe the redistribution of airway is responsible for it. The displacement of stent can obstruct the drainage of tracheal secretions, which usually results in inflammation in the target region. It is suitable to conduct flexible bronchoscopy and use bronchoscope foreign body forceps to adjust the position of the stent. If the stent is damaged, it can be took out and be replaced.

13.7 Future Prospects

In conclusion, despite many methods and devices, as well as the conduction of large amounts of experiments and their good clinical effects in lung volume reduction surgery under the assistance of flexible bronchoscope, there is still no adequate evidence to prove that it outperforms LVRS. Considering the fact that the theories and instruments improve gradually, especially that many patients are unable or unwilling to accept LVRS surgery, lung volume reduction surgery under the assistance of flexible bronchoscope will still have an important role to play in treating severe pulmonary emphysema sufferers.

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