Benign Tracheal/Bronchial Stenosis

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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).

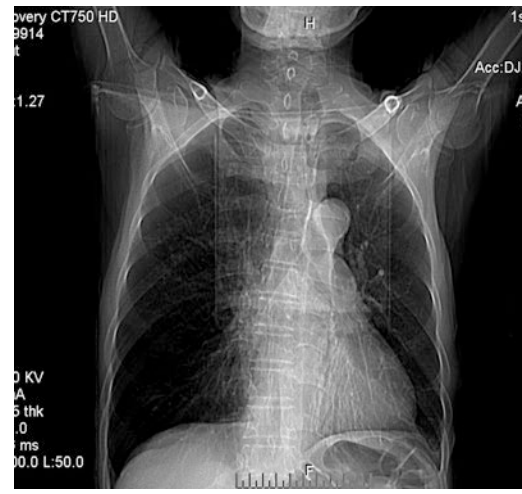

Fig. 7.1 Fluoroscopy shows an obstruction in the upper trachea (black arrow)

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.

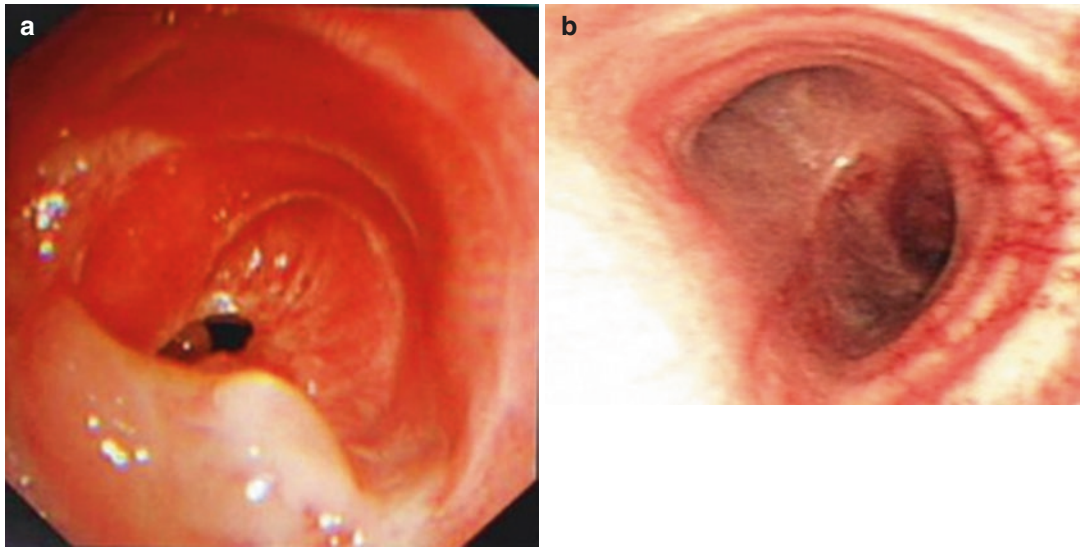

Fig. 7.3 (**a**) Severe throat stenosis; (**b**) airway patency distal to the stenosis

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%

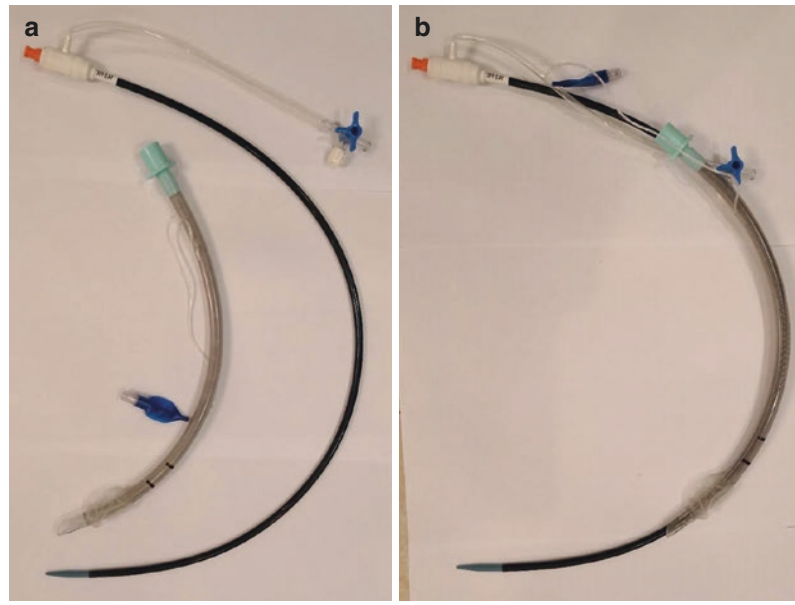

Fig. 7.4 (**a**) The14F sheath and tracheal tube; (**b**) the tracheal tube passed through the 14F sheath

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).

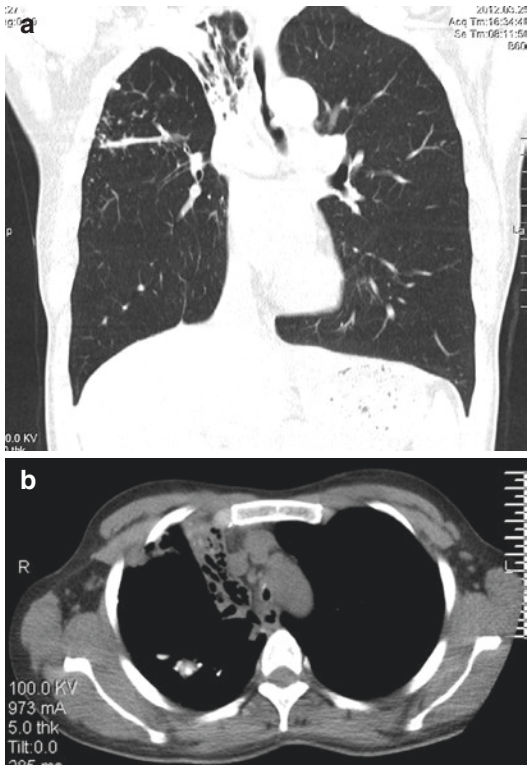

Fig. 7.5 (**a**) Tracheal stenosis (see fine line on chest CT scan, lung window); (**b**) the longitudinal diaphragm window shows severe tracheal stenosis

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).

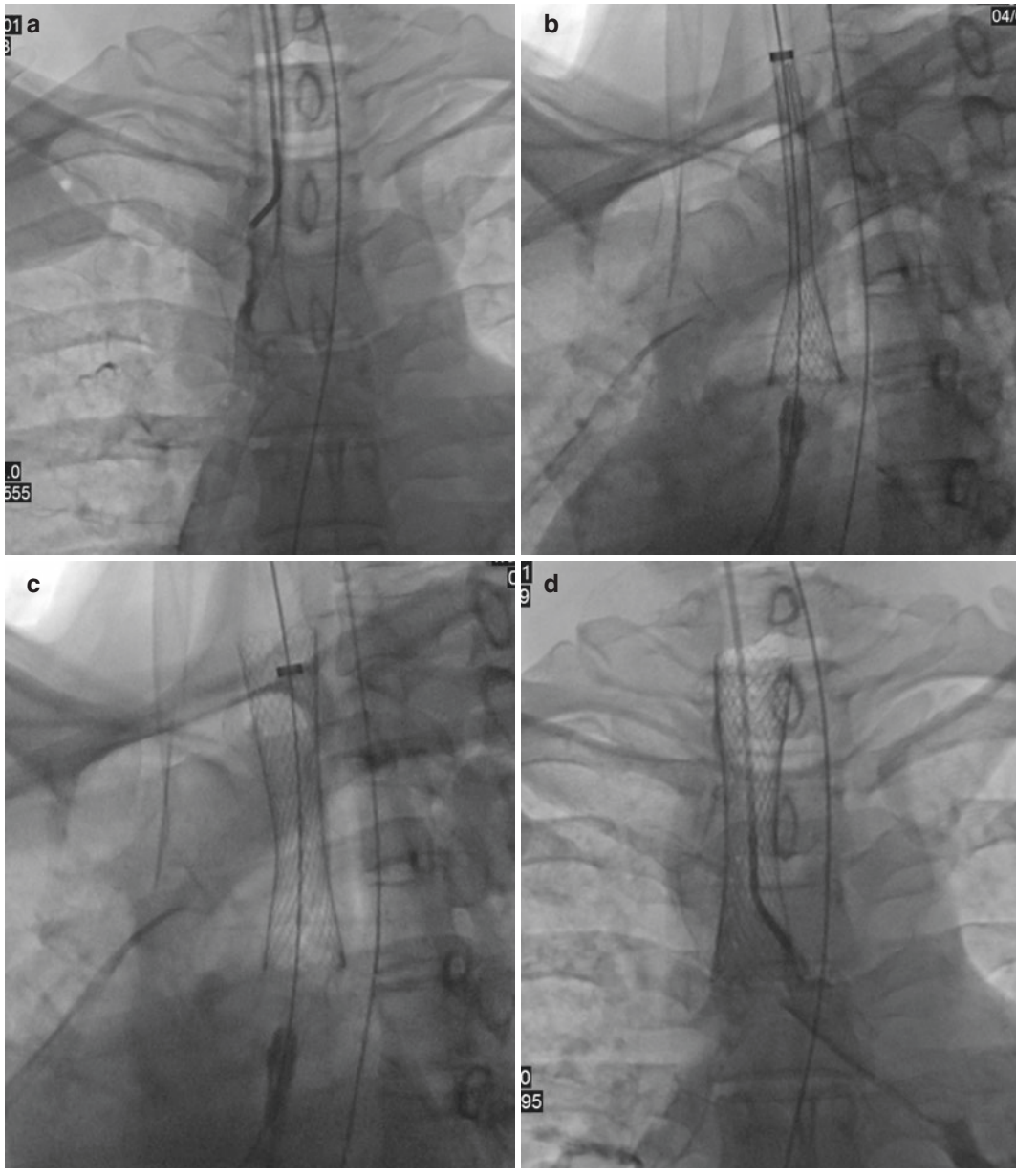

Fig. 7.6 (**a**–**d**) The process of tracheal tube stent implantation. (**a**) Transcatheter airway angiography shows upper and middle tracheal stenosis; (**b**) introduction of the stent delivery system and positioning of the stent across the stenosed section; (**c**) after release of the stent, stent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

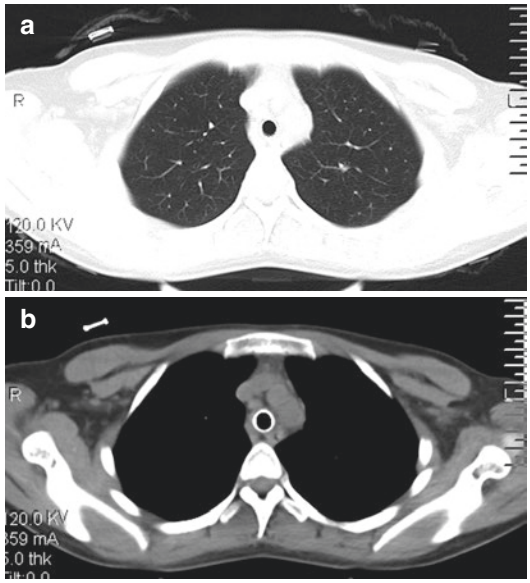

Fig. 7.7 Chest CT scan showing tracheal stenosis completely relieved 3 days after tracheal stent placement, (**a**) for lung window, (**b**) for mediastinal window

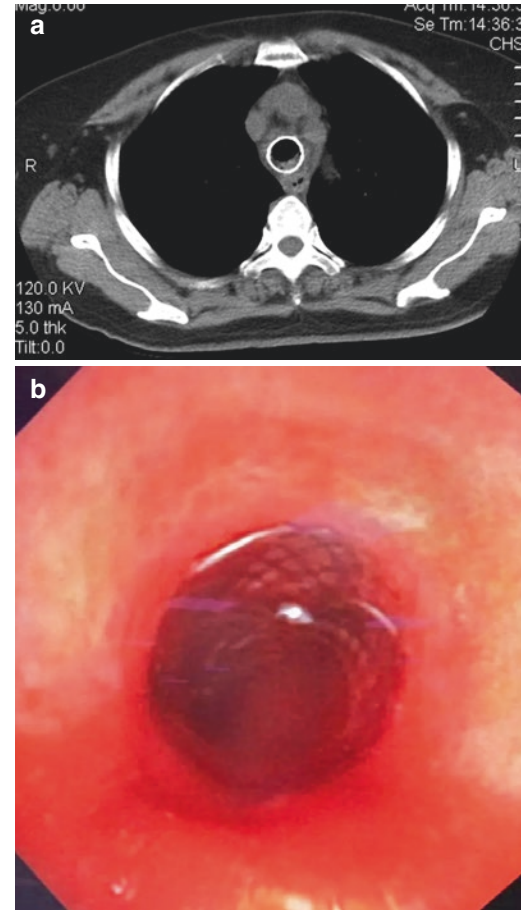

Fig. 7.8 Formation of granulation tissue 2 months after stent placement. (**a**) Chest CT scan shows new growth within the stent; (**b**) bronchoscopy shows marked granulation tissue proliferation, with the stent embedded in the endothelium

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).

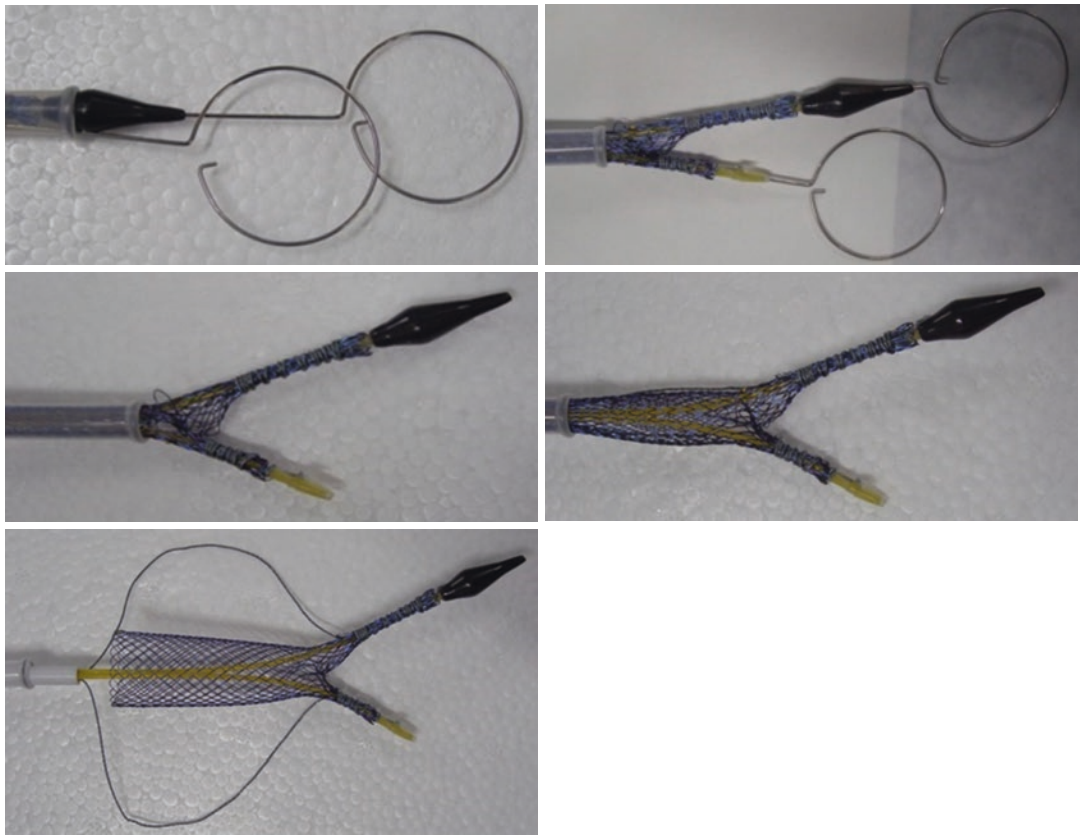

Fig. 7.9 The inverted Y-type stent delivery system with combination of the airway stent bundled and push release

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

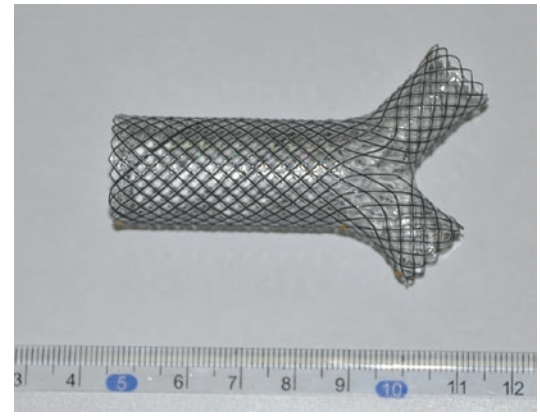

Fig. 7.10 The map of the inverted Y-type airway stent

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-

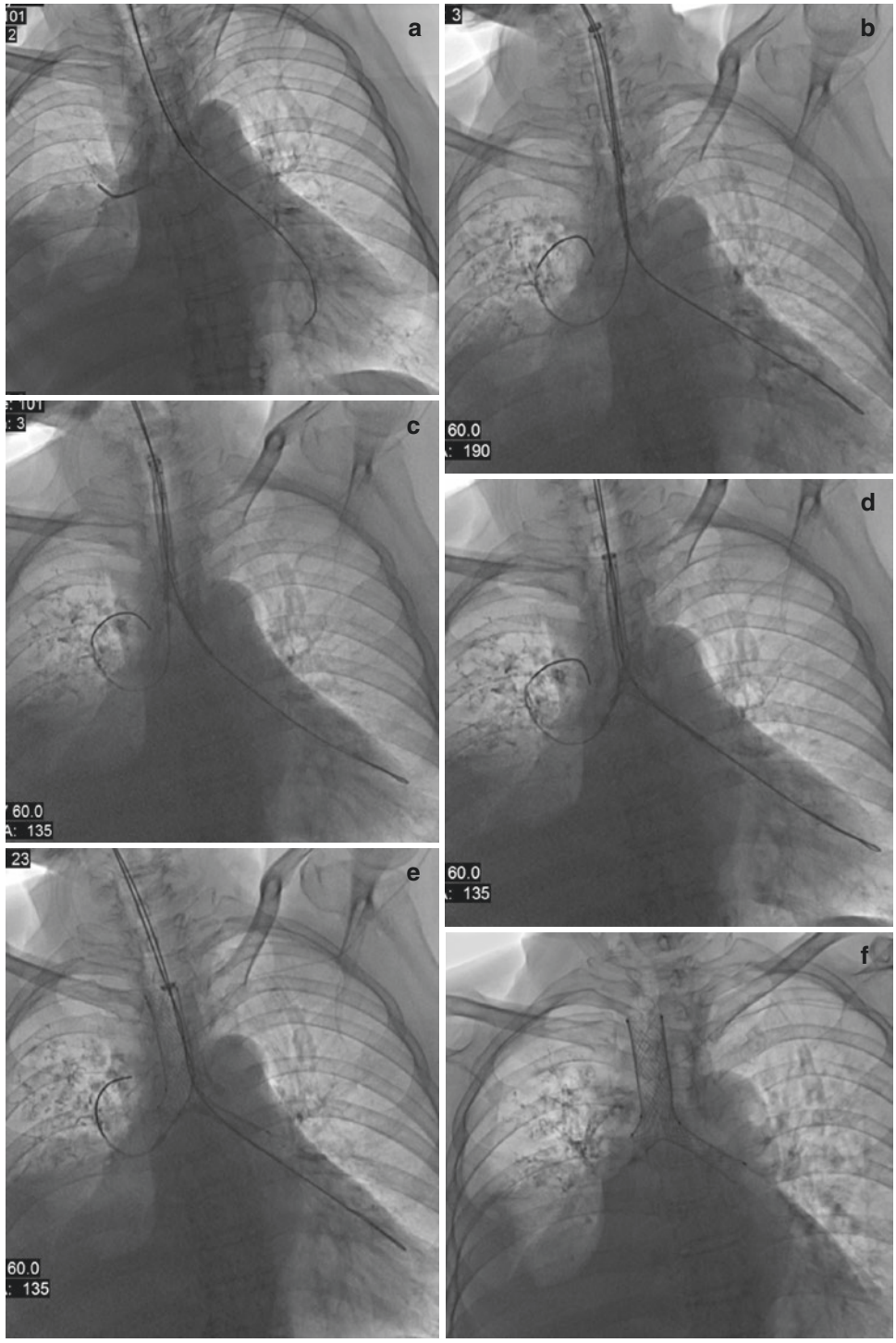

Fig. 7.11 (**a**–**f**) Process of the airway inverted Y stent placement. (**a**) Guidewires inserted into the left and right main bronchi; (**b**) the inverted Y-type bracket and its delivery system inserted along the two guidewires; (**c**) the delivery system rotated to align the left and right bronchus 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

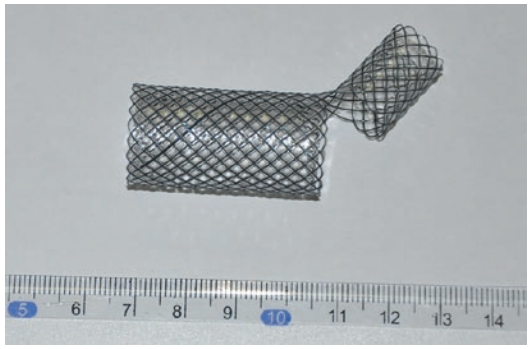

Fig. 7.12 The L-type anti-skid stent

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

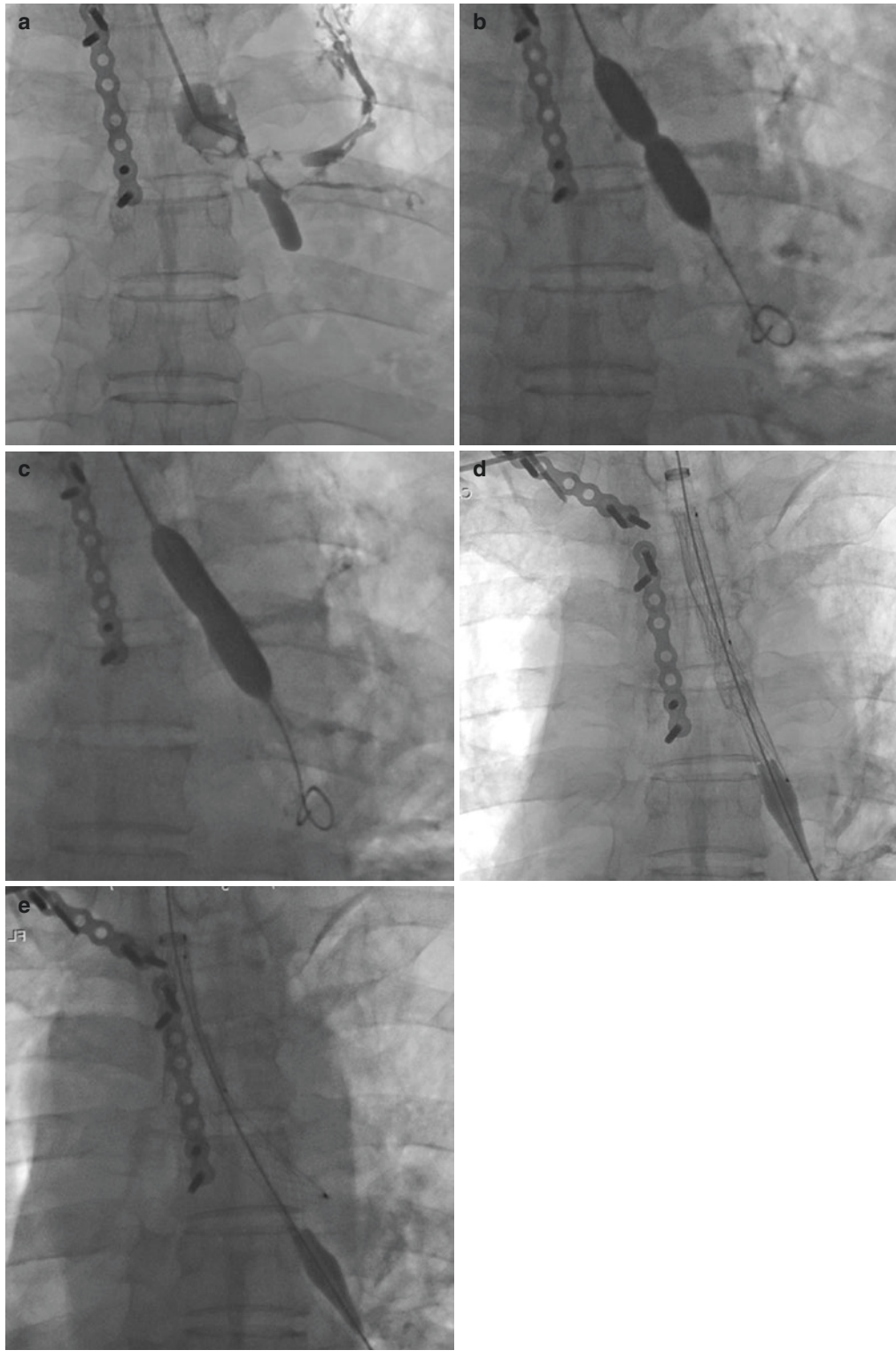

Fig. 7.13 The process of L-type anti-skid stent placement. (**a**) Transcatheter airway bronchography shows severe left main bronchus stenosis; (**b** and **c**) balloon dilatation of left main bronchus stenosis; (**d**) delivery system of L-type anti-skid stent being inserted; (**e**) fluoroscopy shows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

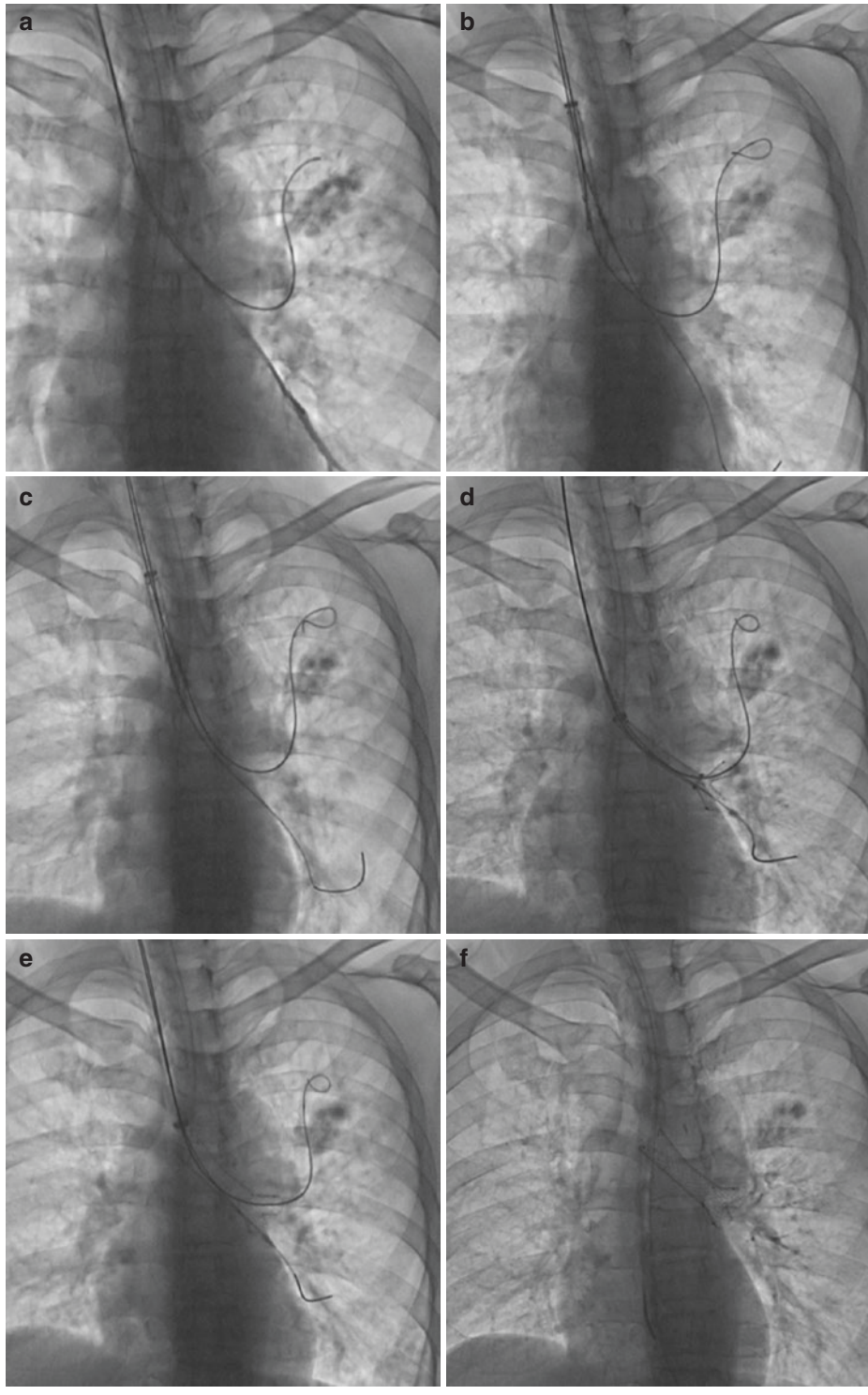

Fig. 7.14 (**a**–**f**) Process of the small Y-type airway stent placement. (**a**) Stiff guidewires were inserted into the left upper and lower lobe bronchi; (**b**) insertion of the small Y-type stent and its delivery system along the guidewire; (**c**) delivery system rotated to align the left upper 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)

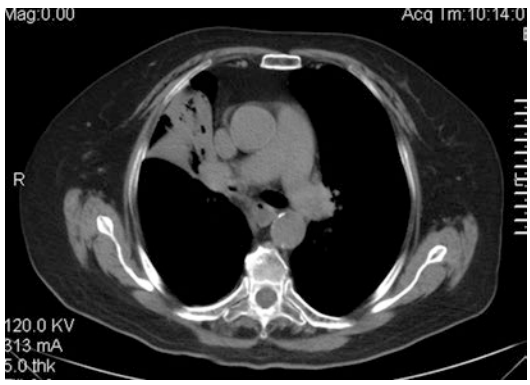

Fig. 7.15 Chest CT scan shows severe stenosis of the right main bronchus

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

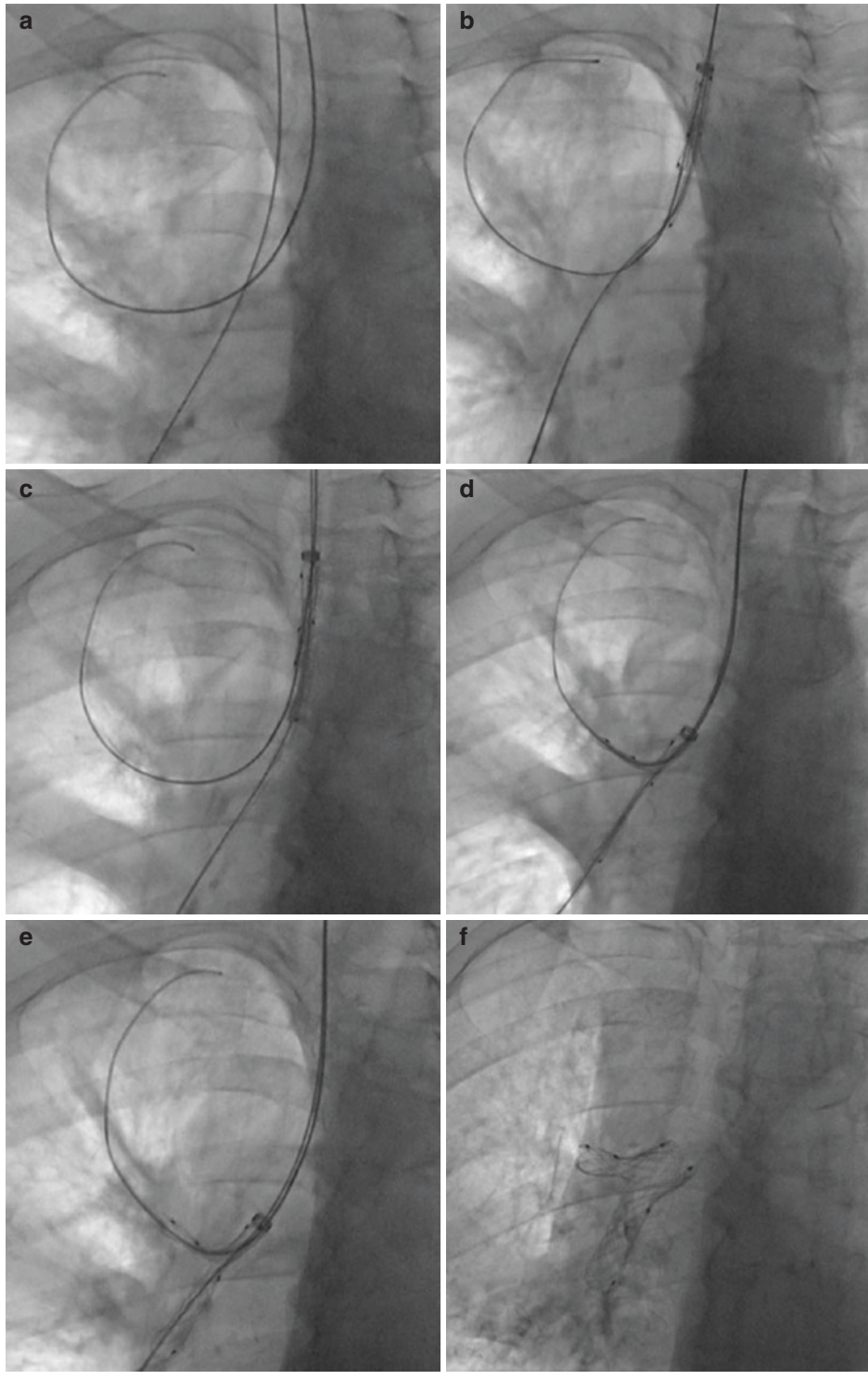

Fig. 7.16 (**a**–**f**) is the process of small Y-shaped airway stent placement. (**a**) The two stiff guidewires inserted into the right upper and right middle bronchial; (**b**) the small Y-type airway stent inserted along the guidewire; (**c**) the delivery system rotated to align the right upper 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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