15 Benign Airways Stenosis

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Introduction and Definition

Tracheal or laryngotracheal stenosis and bronchial stenosis are non-specific terms implying the presence of airway compromise involving the larynx, trachea, laryngotracheal, or bronchi. It is the consequence of progressive reduction in the tracheal lumen, with multiple mechanisms depending on their etiology.

In general, there is an alteration of normal epithelium after an attack leading to an abnormal repair and a structural problem.

Scar formation is associated with different degrees of morbidity depending upon the location, extent, and degree of airway obstruction. The sequence of events that leads to tracheal stenosis in adults involves inflammatory reactions with associated granulation tissue, ulceration of the mucosa and the cartilage, fibrous tissue formation, and contraction of fibrous scar tissue.

The principal etiology of tracheobronchial stenosis is postintubation and post-tracheostomy. Other causes are idiopathic, infectious, chemical damage (such as gastroesophageal reflux or toxic inhalation), radiotherapy and systemic diseases (e.g., Wegener's granulomatosis, amyloidosis).

Clinically, tracheal or bronchial stenosis results in shortness of breath and is characterized by the progressive reduction in the airway diameter. Patients can present with variable symptoms, depending upon the severity of the stenosis and to his/her cardiorespiratory reserve: from no symptoms at all to dyspnea on exertion, progressive dyspnea, dyspnea at rest, wheezing, stridor, and a life-threatening situation such as respiratory failure or respiratory arrest.

Management of this condition is still not standardized or unified around the world, but it is well established that treatment of benign tracheal stenosis requires a multidisciplinary approach by a team of dedicated and experienced physicians.

Acute clinical situations can be handled by endoscopic treatment as tracheal dilatation or laser treatment, which solves the immediate problem in almost all cases. Although relapses are frequent, a percentage between 70% and 80% of non-surgical benign tracheal stenosis presents definitive cure with the support of endotracheal stents [1]. In our opinion, surgery must be addressed when cartilage destruction is diagnosed with rigid bronchoscopy inspection. Such compromise will not benefit from an endoscopic approach.

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The initial intervention and the type of treatment depend upon location of the stenosis, wall integrity, length, and severity, as well as to the presence of comorbidities and overall health status of the patient.

Traditionally, surgery has been the mainstay of treatment, with excellent results in 90% of cases [2–4]. However, surgery is not always definitive and there is a percentage of recurrence that can reach 10% in some series [5]. Surgery involves some risks, and associated complications have been reported to be greater than 8–12% with a mortality rate of 5% [6, 7]. Although in recent years, complications and mortality rates have decreased due to an improvement in surgical techniques, intraoperative and postoperative care [8]. Moreover, many patients are unable to undergo a surgical procedure because of underlying cardiopulmonary limitations and there is a non-depreciable number of patients that refuse the surgery. Endoscopic management of tracheal stenosis provides a safe and efficient therapeutic option and is often the first-line therapy in patients who are not appropriate surgical candidates or who have failure after airway resection. Several modalities have been used to relieve endoluminal obstructions, including mechanical approaches such as dilatation with a rigid bronchoscope or with balloon; heat-related modalities such as laser, electrocautery, and argon plasma coagulation; contact probe cryotherapy; and a variety of airway stents [9, 10].

Drug therapy combined with endoscopic treatment, as systemic steroids [11], intralesional injection of corticosteroids [12], topical application of mitomycin-C [13, 14], or other drugs as paclitaxel [15], is another option in the treatment of this pathology but experience is very limited and results are variable. So far none of these last treatments are curative.

Etiology

Congenital Tracheal Stenosis

Congenital tracheal stenosis is a rare but underdiagnosed anomaly which can present as life-threatening respiratory insufficiency in neonates and infants. Congenital anomalies are the most common cause of airway narrowing in the pediatric population. They are rare malformation, produced by the absence of most of the membranous portion of the trachea in the affected segment, and the cartilaginous rings extend along the entire circumference of the tracheal wall. Three anatomical types have been described which are as follows:

(a) Generalized stenosis, from the cricoid to the carina with possible bronchial involvement;
(b) Infundibular stenosis, where part of the trachea, proximal or distal, has a normal caliber.
(c) Segmental stenosis, with involvement of a short portion of the trachea.

These malformations can appear alone or, very often, associated with other abnormalities of the bronchovascular tree and other organ malformations, of which the most frequently seen is esophageal atresia [16].

Cardiac anomalies are frequently associated and may be addressed at the time of tracheal surgery.

Management of congenital stenosis is very challenging. Children can present stridor, recurrent pneumonia, cyanosis, wheezing, and sometimes respiratory failure.

Corrective surgery is the treatment of choice; in short stenosis, resection of the compromised segment and anastomosis is the best option. When the stenosis affects long segments of the trachea, anastomosis becomes difficult for excessive pressure on the suture line and the endoscopic approach can be an effective alternative to help these patients.

Iatrogenic

The causes of postintubation and post-tracheostomy tracheal stenosis are well established. Endotracheal tube (ETT) causes pressure injury to the glottis, subglottis, and tracheal mucosa and may result in severe scarring.

Physiologically, the healing of the ulcer formed by the cuff pressure in the mucosa involves regenerating epithelium (primary healing) and repair (secondary recovery), but sometimes the regeneration of the epithelium does not occur and leads to an overgrowth of granulation tissue. Eventually, the tissue subsequently becomes avascular resulting in a fibrous scar stricture.

Postintubation tracheal stenosis was recognized for the first time as an entity in 1880, after MacEwen instituted prolonged endotracheal intubation as a therapy in four patients with main airway obstruction [17].

Since then, many reports have been published on serious complications resulting from postintubation stenosis (PIS) or post-tracheostomy stenosis (PTS). The rate of presentation varies: among all intubated patients, 0.6–21% will develop tracheal stenosis. PTS in turn can present from 6 to 21% of all patients that have undergone tracheostomy [7, 17, 18]. Only a minority of them (1–2%) will present with symptoms or severe stenosis [19].

Currently, the calculated incidence of moderate or severe stenosis resulting from endotracheal intubation or tracheostomy is estimated at 4.9 cases per million per year in the general population [20].

Prolonged tracheal intubation can produce tracheal stenosis at many tracheal levels [21] from the tip of the endotracheal tube to the glottic and subglottic area, but the most affected places are the level of the endotracheal tube (ETT) cuff and around the stoma in tracheostomized patients.

The development of the stenosis has many stages; at the beginning there is mucosal ulceration due to decreased blood flow at the level of contact with the ETT cuff. Then, cartilage exposure and perichondritis develop, followed by granulation tissue formation, which over time becomes an established fibrous stenosis, which can be more or less fixed. In the worst cases, cartilage destruction occurs and the airway wall loses its support.

PTS usually affects the area of the stoma, where the tracheostomy tube curves down, following the same sequence mentioned above. Sometimes granulation tissue is formed above the bend of the tube and progresses toward fibrosis [22, 23].

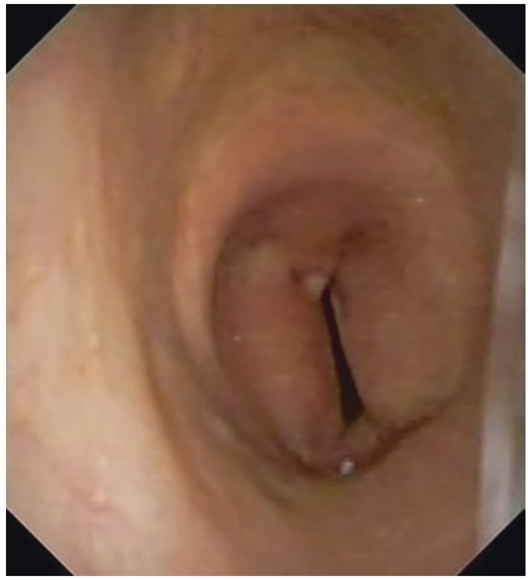

Fig. 15.1 Post-tracheostomy tracheal stenosis

The presence of infection, very common in ventilated patients (tracheitis, mucositis), is a contributing factor for the development of airway stenosis [24]. A common finding in post-tracheostomy patients is retraction of the tracheal cartilage at the area of the tracheostomy, producing different degrees of stenosis (Fig. 15.1). Surgery is the treatment of choice in these situations. When the patient is not a surgical candidate, an airway stent may be beneficial.

Percutaneous tracheostomy is a procedure that is increasingly indicated in the critically ill patient, and although the long-term complications of this procedure are infrequently mentioned in the literature, some published data suggests that the rate of tracheal stenosis is significantly higher than reported [25].

A publication on 100 patients that underwent percutaneous tracheostomy revealed that major postoperative complications presented in 2.4% of cases, and these included death, cardiac arrest, loss of the airway, pneumothorax, tracheoesophageal fistula, and injury to the posterior wall of the trachea (mucosal tear). Tracheal stenosis was reported in 31% of patients, 20% of which were symptomatic [26].

Other studies showed better results. Van Heurn et al. [27] found an index of stenosis greater than 10% in 26% of 80 decannulated patients after percutaneous tracheostomy, being moderate in 4% of the cases, and severe in 2%. Hill et al. [28] revealed that 8 of 214 (3.7%) patients with percutaneous tracheostomies developed symptomatic tracheal stenosis.

Therefore, iatrogenic airway injury after endotracheal intubation and tracheostomy continues to be a serious clinical problem.

In fact, nowadays because of the coronavirus disease (severe acute respiratory syndrome **coronavirus**-2 [SARS-CoV-2]) pandemic with an increase in intensive care unit (ICU) admission of patients with bilateral pneumonia (11% of all cases of pneumonia) [29], requiring prolonged intubation and tracheostomy, it is feared that an increase in cases of iatrogenic tracheal stenosis could be happened [30].

In addition to the most frequent causes of post-coronavirus disease 2019 (COVID-19) dyspnea such as interstitial or vascular alterations [31], this entity should be considered in patients with persistent dyspnea after prolonged admission in the ICU due to bilateral COVID-19 pneumonia. Some case reports with a few cases have been published since the end of the first wave [32–34].

In these patients, endoscopic treatments may be more relevant, because they can be in a poor physical situation or in a recovery phase.

Infectious

Many airway infections can cause damage to the tracheal mucosa, resulting in stenosis. Tuberculosis (TB), fungal infections, bacterial tracheitis, histoplasmosis, and diphtheria are some of them, being TB the most frequently seen.

TB is the most common infectious cause of airway stenosis. It usually produces distal stenosis (at the level of the bronchi), but central airway stenosis can also occur. This complication can present at the time of the active infection or long after that, up to 30 years [35]. The most important risk factor for developing airway stenosis is the presence of TB bronchitis, which is found in 10–37% of patients with pulmonary TB when bronchoscopy is performed [35, 36] In those cases, over 90% of patients will develop tracheobronchial stenosis in spite of correct TB treatment [37].

Infectious stenosis is more prevalent in underdeveloped countries, particularly in Asia and Africa. Active infection produces necrosis and ulceration of the bronchial mucosa, giving rise to granulation tissue and subsequent fibrous stenosis.

During fibrous, established stenosis, dilatation of the lesion is an option. When the stenosis occurs at bronchial level, balloon dilatation can be offered. At tracheal level, rigid bronchoscope dilatation is useful as well. Repeated dilatations or stent placement are often required, since recurrence rate is very high.

Idiopathic Tracheal Stenosis

The term idiopathic tracheal stenosis (ITS) is used to include patients with tracheal stenosis when all other etiologies have been investigated and ruled out.

ITS is a rare condition, characterized by circumferential fibrous stenosis beginning at the subglottic area and compromising the proximal segment of the trachea [38]. Typically, it affects women in their third to fifth decade, so it is thought that estrogens could play an important role [39]. Another hypothesis is that it is related to gastroesophageal reflux [40]. Clinically ITS is presented with months to years of symptoms such as progressive dyspnea, wheezing, stridor, or a combination of all of them. In many cases, patients are misdiagnosed as difficult to treat asthmatics [41].

Grillo et al. [41] presented 49 patients with tracheal stenosis where no etiology was found after extensive evaluation. They highlighted the need to pay special attention to the airway in chest radiographs or computerized tomographies when evaluating a patient with a history of prolonged dyspnea and wheezing. Also, the flow-volume curve and the bronchoscopy are essential for diagnosis.

Surgery remains the treatment of choice [42]. Some authors have shown that endoscopic treatment with mechanical dilation or associated with laser or electrocoagulation and stent placement could be efficient, but with recurrences during the follow-up, that also can be treated with endoscopic procedures [43].

Bronchial Stenosis Post-lung Transplantation

Since the first lung transplant in 1963, technical advances in thoracic surgery along with new immunosuppressive agents have made lung transplantation a more common indication for those patients with terminal lung disease. However, one of the main problems of this surgical procedure is the development of stenosis at the level of the suture.

Perianastomotic stenosis occurs in 12–40% of patients and nonanastomotic distal bronchial stenosis in 2–4% of all lung transplants [44, 45].

Bronchial stenosis is related to airway inflammation, with mononuclear cell injury to the epithelium and mesenchyme that is further complicated by endothelial injury on a poorly vascularized area. The severe blood-flow impairment may lead to bronchial cartilage ossification, calcification, or fragmentation, leading to stenosis [46].

Other factors increase the risk for suture stenosis, such as the use of a simple suture and prolonged mechanical ventilation. There is a very high risk of suture infection also due to low blood flow and the presence of inflammation. Infection should be looked for and appropriately treated before performing any endobronchial manipulation, particularly if a stent placement is considered.

Success depends primarily on the experience of the interventional pulmonology team and the medical resources available.

Distal Bronchial Stenosis

As mentioned previously, bronchial stenosis secondary to pulmonary tuberculosis is quite common. Approximately 43% of patients with pulmonary tuberculosis will develop stenosis at the distal bronchi [47, 48] (Fig. 15.2). This number corresponds to approximately 4.1% of all bronchoscopies performed in a hospital.

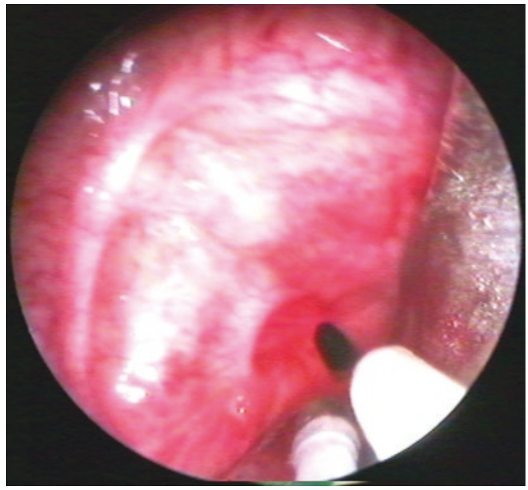

Fig. 15.2 Bronchial stenosis of the right upper lobe

Another cause for distal stenosis is bronchial anthracosis (called anthracostenosis) [49, 50].

As a result of bronchial stenosis, there exists difficult drainage of secretions and recurrent infections distal to the obstruction, with the development of bronchiectasis. In these situations, it is indicated to offer a dilatational therapy that can be performed via balloon dilatation with or without laser application. This treatment is simple to apply, and can be easily performed during a short procedure. It has good results, improving secretions clearance which in turn prevents repeated infections. In addition to bronchoscopy, three-dimensional helical tomography of the tracheobronchial tree can be very useful in the evaluation of this condition, since it allows a better distal inspection than bronchoscopy [51].

Another less common cause of airway stenosis is radiation therapy. The incidence of bronchial stenosis has increased following treatment with brachytherapy or external beam radiotherapy of malignant lesions of the airways, with an estimated incidence of 9–12% [52].

Bronchial stenosis is established within an average of 40 weeks after initiation of radiotherapy. Bronchoscopy can show the presence of a whitish-colored membrane covering the mucosa, with an important inflammatory response that ultimately results in fibrous stenosis [52]. Radiation therapy rarely compromises the tracheal mucosa.

Diagnosis Methods

Patient History

Due to the broad range of etiologies and the nonspecific nature of presentation, the diagnosis of airway stenosis may be delayed in time. A careful medical history should be obtained in patients suspected of airway stenosis, since background data is very important. Prior infectious diseases, history of airway intubation, prolonged mechanical ventilation, timing and severity of dyspnea, presence of dysphonia, etc., should be recorded and evaluated.

Symptoms develop gradually as progressive dyspnea until tracheal stridor appears; this could happen in most of the cases, when the diameter is affected around the 70% (diameter around 5 mm).

When patients present emergently, it is important to offer a therapeutic procedure to reopen the airway to avoid worsening of symptoms and serious complications such as respiratory failure or respiratory arrest. The goal of treatment is to restore and maintain patency of the airway as soon as possible and then a multidisciplinary team can decide which is the best long-term solution for a given patient.

In clinical practice, most of the patients present with symptoms of stenosis when they are in the fibrous phase of the stenosis, with minimal evidence of inflammation. They frequently have a history of a prior airway intubation or prolonged mechanical ventilation in the past. Many patients have been diagnosed and treated like asthma with difficult control and with minimal or no response to asthma therapy.

A significantly smaller number of patients will present within days or weeks from extubation, and in those cases an important airway inflammation can be seen.

Onset of symptoms is very variable. Baugnée et al. [53] described 58 patients with airway stenosis, 5 of them developed symptoms within 5 days, and 23 patients presented symptoms from 5 to 30 days of extubation, 19 patients from 30 to 90 days, and 8 patients took more than 90 days in presenting symptoms. Half of them went to the emergency room with acute respiratory failure.

Auscultation of wheezes, especially a fixed one, indicates that the passage of airflow through the airway is reduced, but its location does not always correlate with the site of airflow obstruction. When a fixed wheeze is heard over the trachea, it does not necessarily indicate that the source of the obstruction is the trachea [53, 54]. When wheezing is unilateral, it often suggests an obstruction of the airway distal to the carina.

The persistence of a fixed unilateral wheezing should always warrant bronchoscopy examination, paying special attention to the distal airway (segmental or subsegmental bronchi). Stridor is always a sign of severe laryngeal or tracheal obstruction and occasionally main bronchial obstruction.

Imaging Techniques

In the study of tracheobronchial stenosis of the airway, noninvasive imaging techniques have an important role. They help not only in the diagnosis but also in deciding the most appropriate treatment and assessing response to therapy during the follow-up period. These techniques were developed significantly in the past years [55] allowing a better approach to airway stenosis.

Simple chest-X ray is rarely diagnostic of central airway obstruction.

Computed tomography (CT) has been the most commonly used imaging test for diagnosis and evaluation of airway stenosis in order to have better information of the length and size of the stricture, degree of destruction of the airway wall, surrounding organ injury and also to have images controlled after treatments (Fig. 15.3).

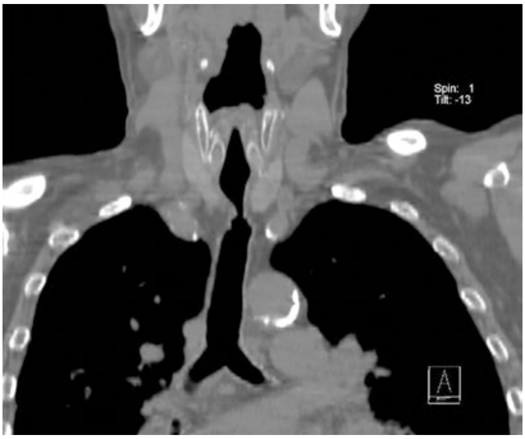

Fig. 15.3 Coronal CT image of benign tracheal stenosis

Although very useful, CT has some limitations particularly in the evaluation of subtle airway stenosis in axial images, underestimation of the craniocaudal extent of the disease, and generation of a large number of images for review [56].

The introduction of multiplanar reformatting (MPR) CT scans with option to generate three-dimensional (3D) images and virtual endoscopy (VE) provides additional information regarding airway pathology [57] bringing visual data that closely resemble the images obtained from flexible bronchoscopy [58].

MPR CT scan allows the acquisition of thin-slice axial sections of entire body volumes during a single breath-hold, thus eliminating respiratory artifacts [59].

This technique provides information on the length and caliber of the stenosis and the degree of compromise of the laryngotracheal wall. It allows visualizing lesions in depth, showing thickening or thinning of the tracheal wall, fibrous involvement of the submucosa, or disappearance of the tracheal rings. Also, the relationship of the injury to adjacent organs can be better evaluated.

Virtual endoscopy (VE) is a reconstruction technique that exploits the natural contrast between endoluminal air and the surrounding tissue [60], allowing navigation through the tracheobronchial tree with the same endoluminal perspective as an endoscopy [58] (Fig. 15.4).

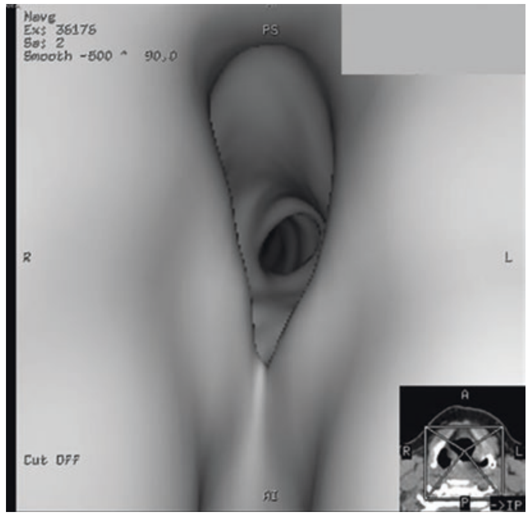

Fig. 15.4 Virtual bronchoscopy

Several authors have demonstrated the high diagnostic accuracy, sensitivity, and specificity of noninvasive, multirow detector CT virtual endoscopy in detecting and grading central and segmental airway stenosis and its close correlation with flexible bronchoscopy [57, 60–62]. However, it is slightly more accurate at assessing central airway stenosis than segmental airway stenosis [60].

The combination of axial imaging, multiplanar reformatting, and three-dimensional rendering is useful prior to tracheal intervention, especially when there is significant anatomical distortion or airway narrowing [61].

Recently, some authors advocate the use of MRI for diagnosis localization and extension of tracheal stenosis. MRI is a noninvasive procedure without ionizing radiation and can be used to identify the relationship of the trachea to adjacent vascular structures and to determine the degree and length of tracheal stenosis in high-resolution imaging with excellent soft-tissue contrast and without applying ionizing radiation or intravenous contrast medium.

Unfortunately, standard MRI has a limited ability to show dynamic organs.

The use of real-time, dynamic, cine MRI (CMRI) can achieve better results showing the mobility of the organs identified [63].

Bronchoscopy

Flexible bronchoscopy remains the primary diagnostic technique in the study of tracheal stenosis and is considered the gold standard procedure for this pathology, allowing direct visualization of the airway lumen and sampling, with possibility to perform biopsies and microbiological studies. However, when the patient is in acute severe symptoms, flexible bronchoscopy is best avoided due to the risk of precipitating acute or complete airway obstruction. In these cases, the best approach has to be rigid bronchoscopy [64].

Moreover, bronchoscopy offers information at different levels and can assess the mobility and morphology of the vocal cords and arytenoids in subglottic laryngeal stenosis. In tracheal stenosis, it allows location of the lesion and evaluation of the degree and length of the stenosis and notes characteristics such as the presence or absence of malacia, mucosal involvement in inflammatory disorders, granulomas, ulcerations, or established fibrosis (Fig. 15.5a–c). It also enables obtaining biopsies, a procedure that should always be performed in tracheal stenosis, to rule out other inflammatory conditions. Bronchoscopy is a minimally invasive procedure, with the additional advantage of not exposing the patient to ionizing radiation. One limitation of this technique is the inability to evaluate the distal airways in severe stenosis, since the bronchoscope cannot be further advanced from the stenotic area. In these cases, sedation during the procedure and the use of an ultrathin bronchoscope with external diameter of 2.1–3.2 mm can help interventional pulmonologists to explore tracheobronchial trees beyond the stenosis since the bronchoscopy is better tolerated.

New bronchoscopic technologies, however, permit a more accurate assessment of the airway wall structure and characterization of the stricture before, during and after treatment, since the correct evaluation of tracheal wall structures is necessary for optimal management of tracheal stenosis.

Endobronchial ultrasound (EBUS) has been introduced as an adjunct to diagnostic bronchoscopy. Radial EBUS helps evaluate the different tracheal and bronchial wall layers, as well as peribronchial structures. Cartilage damage can be better assessed, influencing the type of treatment that will be offered [65]. Also, EBUS could assess differences in central airway wall structure in patients with various forms of expiratory central airway collapse who can be identified by endobronchial ultrasound using a 20 MHz radial probe [66] (Fig. 15.6a and b).

Optical coherence tomography (OCT) is another bronchoscopic imaging technique that generated considerable interest since it has a much better space resolution than computed tomography. It is capable of generating high-resolution cross-sectional images of complex tissue in real time.

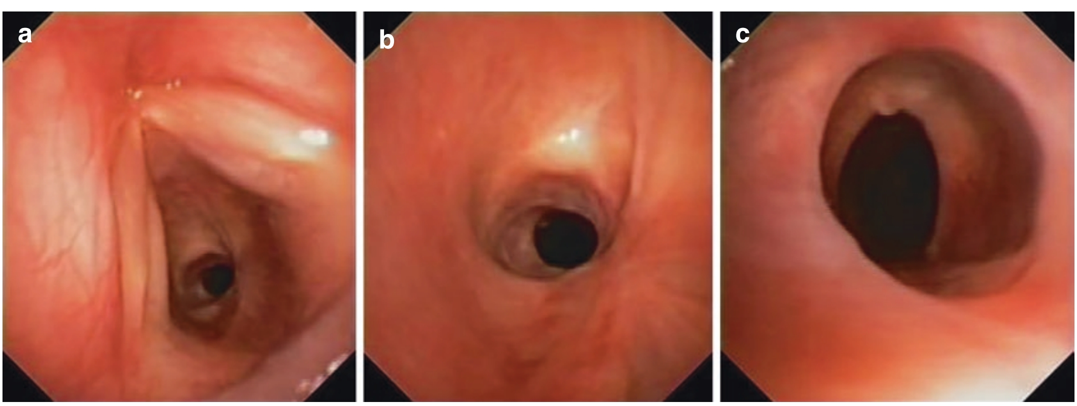

Fig. 15.5 Bronchoscopy allows the correct evaluation of the distance from vocal cords to stricture (**a**), the degree of compromise of the cricoid cartilage (**b**), the length of the stricture (**c**) and the distance from stenosis to main carina

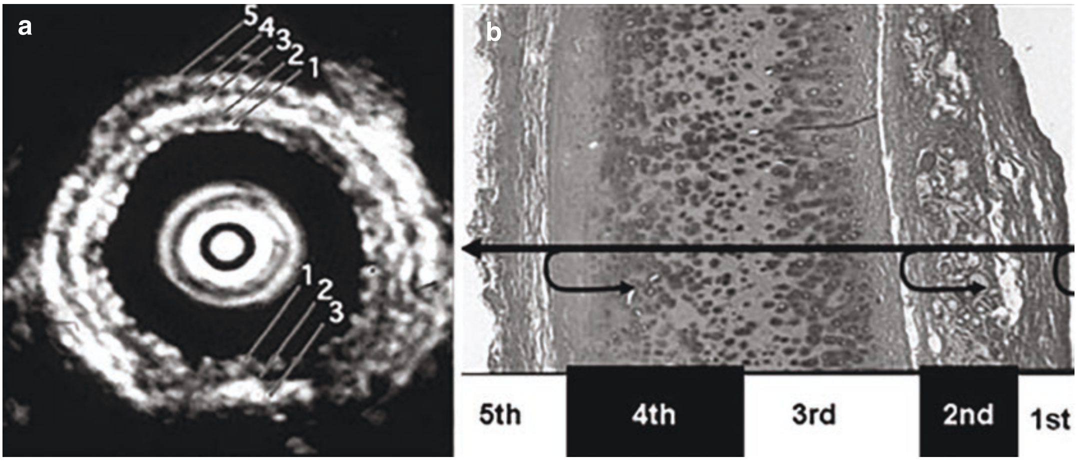

Fig. 15.6 Radial EBUS shows the different tracheal (**a**) and bronchial wall layers (**b**) [65]. (With permission)

Similar to ultrasound, OCT measures backscattered light intensity using coherence interferometry to construct topographical images of complex tissue. It can provide a micron level, real-time image of the airway wall structure with a resolution approaching histology [67]. It offers a unique combination of high resolution (1–15 mm) and in-depth penetration of 2–3 mm that is adequate for imaging superficial airway anatomy and pathology. OCT has the potential to increase the sensitivity and specificity of biopsies, create 3D images of the airway to guide diagnostic procedures, and may have a future role in different areas such as the study of tracheal stenosis. Some authors hypothesize that this technology may in the future provide a noninvasive "optical biopsy" [68], helping, as we said, in diagnosis and treatment of a number of conditions (Fig. 15.7).

Anatomic optical coherence tomography (aOCT), a modification of conventional OCT, is a light-based imaging tool with the capacity to measure the diameter and lumen area of the central airways accurately during bronchoscopy. This technique can measure tracheal stenosis dimensions, having good correlation with chest CT scan findings and guiding the selection of a proper sized airway stent [69]. Standard OCT also could obtain accurate measures of stenosis.

All these technologies are very promising and they are currently under active research to define their proper role in the study of airway conditions.

Though flexible bronchoscopy and the different imaging techniques have shown to be useful and reliable in the diagnosis of tracheobronchial strictures, they all have technical limitations that can lead to an inaccurate characterization of airway stenosis [70]. The best way to evaluate these conditions is to combine different diagnostic approaches in order to correctly define the injury and then plan the best procedure, case by case, based on clinical, endoscopic, and radiological findings.

Pulmonary Function Test

Regardless of the cause, tracheal stenosis causes increased airway resistance and decreased flows. A simple test such as spirometry can help diagnosing and characterizing a central airway stenosis. The shape of the flow-volume curve (F/V) obtained by spirometry and flow resistance (raw) calculated by plethysmography can give important information. For instance, flattening of the inspiratory loop with preservation of expiratory flow represents variable extrathoracic obstruction of the central airway. In turn, compromise of the expiratory loop with a normal inspiratory limb

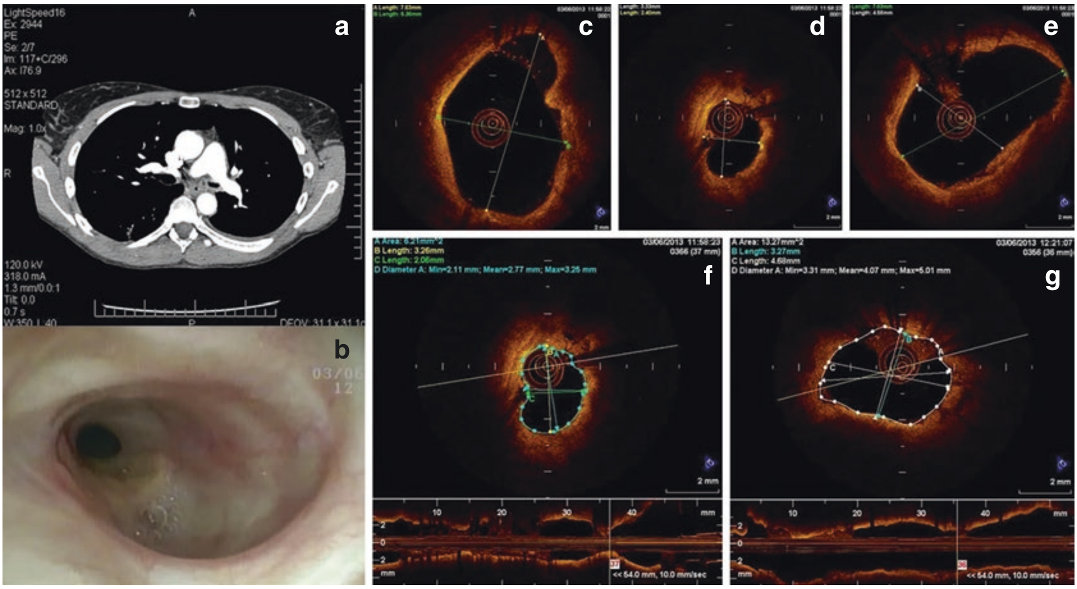

Fig. 15.7 Application of OCT image for measurement of tracheobronchial stenosis. CT scan (**a**) and bronchoscopic (**b**) image of left main bronchus stenosis. OCT images of normal bronchial lumen before (**c**) and after (**e**) of the bronchial stenosis (**d**). OCT allows accurate measurements pre (**f**) and post (**g**) treatment with balloon dilatation. (Courtesy from Dr. Shaipanich and Dr. Lam)

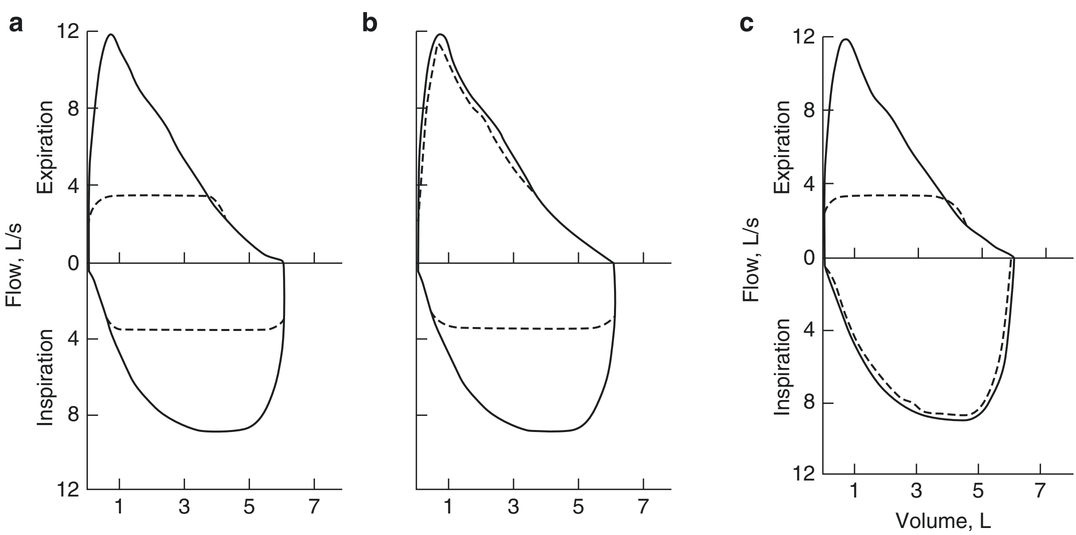

Fig. 15.8 Pulmonary function test. (**a**) Fixed obstruction. (**b**) Intrathoracic obstruction. (**c**) Extrathoracic obstruction

indicates variable intrathoracic obstruction. In a fixed obstruction (intra- or extrathoracic), both inspiratory and expiratory curves are affected, presenting with a classic flattening in the F/V loop [71] (Fig. 15.8). Other important information that can be obtained by spirometry concerns the functional status, and helps deciding whether or not the patient is a surgical candidate.

Spirometry can also be very useful in the follow-up of these patients after treatment [72].

Classification of Benign Tracheal Stenosis

Airway narrowing may result from intrinsic stenosis or extrinsic compression or for both. It has been classified following different parameters, in an attempt to design a useful algorithm for treatment.

Cotton et al. [73] in one of the first classifications of tracheal stenosis in 1984 used the cross-sectional area of the stenosis in a group of pediatric patients, and divided this condition into four grades:

1. 50% obstruction.
2. 51–70% obstruction.
3. 71–99% obstruction.
4. Complete obstruction.

In this classification, location and length are noted but without affecting the grading of the stenosis.

In 1992, McCaffrey [74] retrospectively reviewed the treatment of 72 cases of laryngotracheal stenosis. Although diameter and length were factors, the predominant predictor of outcome was location. Locations were confined to the glottis, subglottic area, and upper trachea.

Four stages were defined as follows.

1. Stage 1 in the subglottis or trachea, 1 cm in length.
2. Stage 2 in the subglottis, 1 cm in length.
3. Stage 3 in the subglottis and upper trachea.
4. Stage 4 in the glottis with vocal cord fixation and paralysis.

In 1999, Brichet and coworkers [10] proposed a classification based on three categories depending on bronchoscopic findings:

- Pseudo Glottic stenosis: defined as typically "A"-shaped stenosis due to lateral impacted fracture of cartilages in patients with a history of tracheostomy.
- Web-like stenosis: when it involves a short segment (<1 cm), membranous concentric stenosis without damage to the cartilages.
- Complex stenosis: all other stenosis were defined as such, including those with an extensive scar (≥1 cm), circumferential hourglass-like contraction scarring, or malacia.

Amoros Moya et al. [75] reviewed 54 patients that underwent surgery for laryngotracheal stenosis, and defined findings according to topographic and lesion criteria, incorporating three independent variables: stage of development (S), caliber (C), and length (L). Later, this classification was adapted and modified [76]. It is presented in Table 15.1.

In 2007, Freitag et al. [77] proposed a standardized scheme, presenting descriptive images and diagrams for rapid and uniform classification of central airway stenosis. Classification was based on the type of lesion, degree, and location. They divided airway stenosis into structural and dynamic, and they included malignant causes as well.

The structural group has four major types.

- Type 1: includes exophytic intraluminal malignant or benign tumors and granulation tissue.

Table 15.1 Classification criteria for inflammatory stenosis of the trachea. Adapted from Moya et al. [58]

Structure (S)		Caliber (C)		Length (L)	
Structure of the tracheal wall		Internal diameter (at the point of smaller diameter)		Axis of the larynx-trachea	
S1	Acute-sub acute inflammation	C1	>10 mm (area >25 μ)	L1	Stenosis ≤2 cm
S2	Organized scar fibrosis	C2	8–10 mm (area 16–25 μ)	L2	2–4 cm stenosis
S3	Malacia	C3	≤8 mm (area ≤6 μ)	L3	>4 cm stenosis
S4	Tracheoesophageal fistula				

- Type 2: stenosis is due to extrinsic compression of all causes, including non-pulmonary tumors.
- Type 3: stenosis is due to distortion, kinking, bending, or buckling of the airway wall.
- Type 4: shrinking and scarring are the predominant features.

Stenoses were further classified in dynamic if a malacic condition was found. Malacia causes changes in the shape of the airway with the respiratory cycle. They included two different types:

- Type 1: triangular (tent-shaped) benign stenosis in which the cartilage is damaged.
- Type 2: it is the inward bulging of a floppy posterior membrane.

In turn, the degree of stenosis was assigned a numerical code that could be applied to any site:

- Code 0: no stenosis
- Codes 1: 25% decrease in cross-sectional area
- Code 2: 50% decrease
- Code 3: 75% decrease
- Code 4: 90% decrease

They defined five locations within the central airways:

- Location I: upper third of the trachea
- Location II: middle third of the trachea
- Location III: lower third of the trachea
- Location IV: right main bronchus
- Location V: left main bronchus.

Fig. 15.9 Simple tracheal stenosis

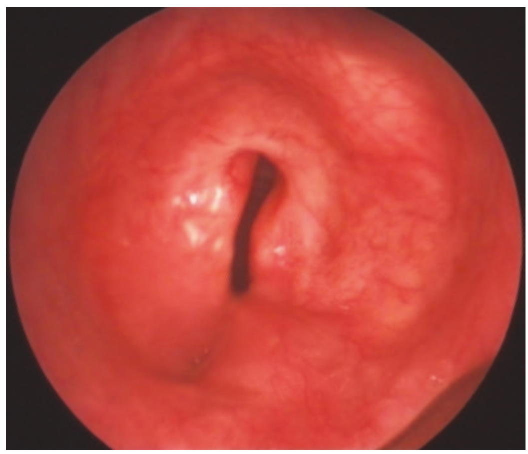

Fig. 15.10 Complex tracheal stenosis

In 2009, other authors [2, 78] classified airway stenosis into two groups, according to their morphological aspect in simple and complex, similar to the Brichet's classification [10]. Simple stenosis included granulomas, weblike, and concentrically scarring stenosis. All these lesions were characterized by endoluminal occlusion of a short segment (<1 cm), absence of tracheomalacia, or loss of cartilaginous support (Fig. 15.9). Complex stenoses were represented by a longer lesion (greater than 1 cm) with tracheal wall involvement and subsequent scarring contraction of the latter, in some cases also associated with malacia (Fig. 15.10).

Almost all of these classifications quantify the degree of the stenosis as a percentage, which is a subjective observation during bronchoscopy. Sometimes we can have an approximation with images such as a CT scan, but this method is not exact either since measurements vary according to the respiratory timing of image acquisition (inspiration, expiration).

Murgu and Colt [79] published a study on subjective assessment using still bronchoscopic images of benign stenosis, containing normal and abnormal airway cross-sectional areas, that were objectively analyzed using morphometric bronchoscopy. This method allowed to clasify the stenosis as mild (<50%), moderate (50–70%), or severe (>70%). These images were then subjectively assessed by 42 experienced interventional pulmonologists participating in an interventional bronchoscopy course. Only 47% of strictures were correctly classified by study participants (mean 16.48 ± 2.8). Of the 1447 responses included in this analysis, 755 were incorrect: 71 (9%) were over-classifications of strictures' severity and 684 (91%) were under-classifications.

In another paper, a similar survey of 123 members of the American Association for Bronchology (AAB) shows that the assessment in central airways obstruction (CAO) is currently performed in a visual manner (91% of the consulted clinicians). Eighty-six percent of the clinicians consulted agreed that there is an urgent need to avoid subjective visual evaluation and standardize calculations during in vivo explorations [80].

This demonstrates the importance of using systems that allow us to make a more objective measurement for conducting exploration.

Murgu and Colt propose the morphometric bronchoscopy [81] . They use an imaging system called Image J. During the bronchoscopy procedure, different captures are taken, in the center of the proximal airway, distal and directly into the lesion. Then after the procedure, with this manual method, it is possible to calculate the stenosis index (SI) (Fig. 15.11).

Other methods to calculate the stenosis index have been proposed as the one from the Computer Vision Center of Autonomous University of Barcelona (UAB) [82]. Recording a video during bronchoscopy procedure, this imaging system ana-

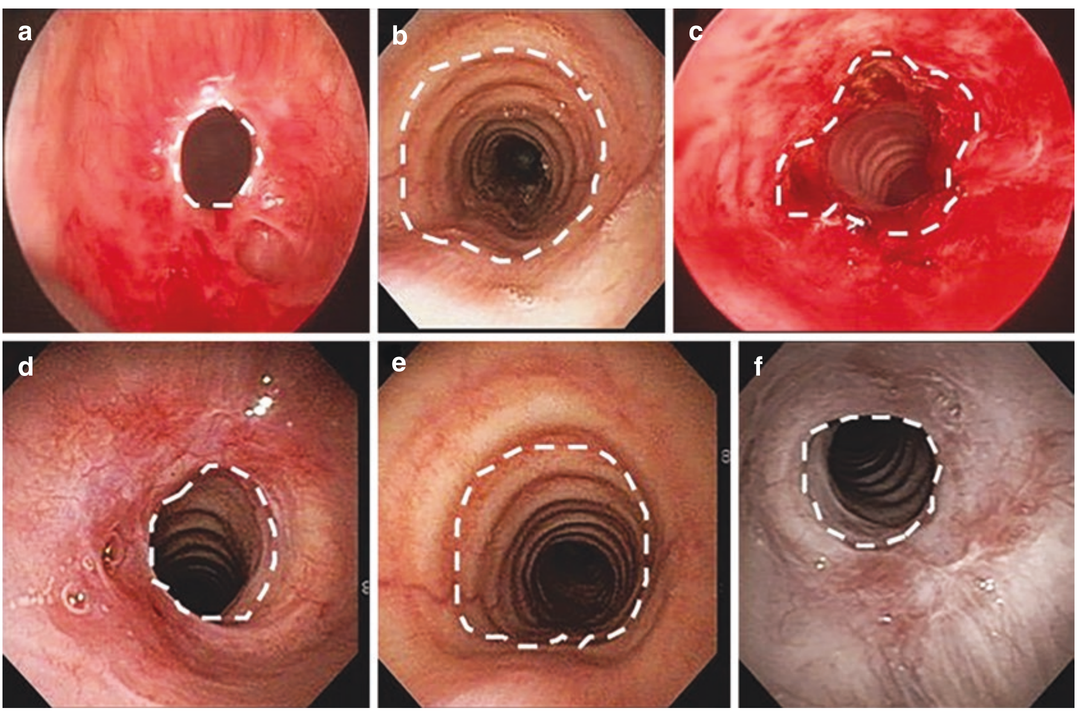

Fig. 15.11 Bronchoscopic images of idiopathic subglottic stenosis (**a**) and the normal distal tracheal lumen (**b**). The calculated stenosis index (SI) was 80%. SI improved to 30% after laser and rigid bronchoscopic dilation (**c**). The stenosis (**d**) and the normal distal tracheal lumen (**e**) at 12 months follow-up. The calculated SI was 50%. At 18 months follow-up the stenosis was stable with an SI of 50% (**f**). (Murgu [81] with permission)

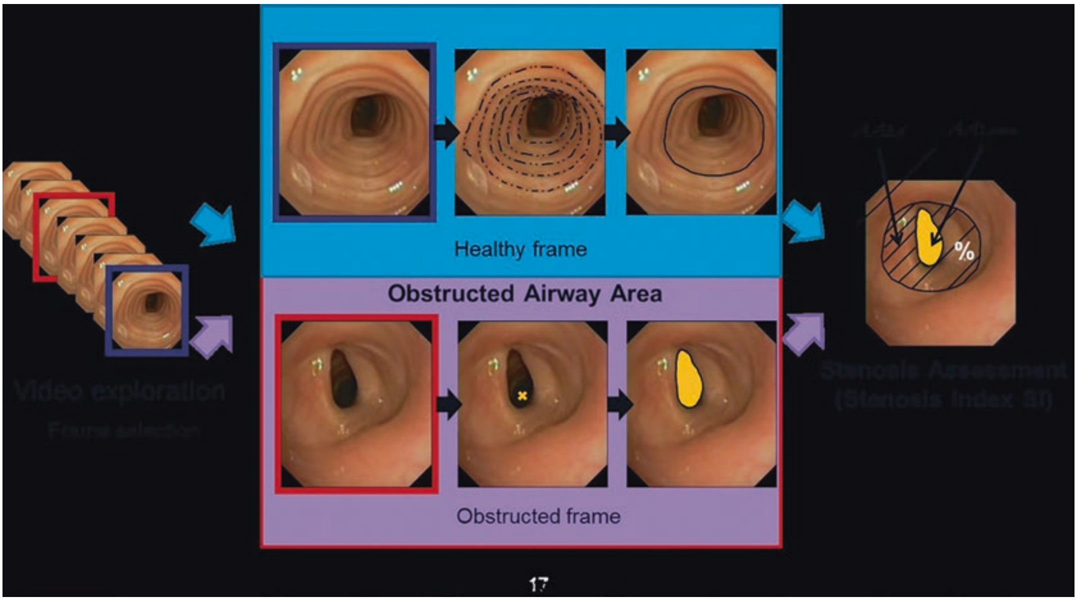

Fig. 15.12 Stenosis index using the Computer Vision Center of UAB method [82]. (With permission)

lyzes different cuts at the stenotic area level as well as at the normal tracheal level and subsequently, through a mathematical algorithm, calculates the area at the level of normal and stenotic trachea. Then it compares the caliber of stenosis with normal trachea giving us the real degree of stenosis (Fig. 15.12). This system was later validated in a pilot study, showing an objective SI measurement with a precision up to 99.5% and improving at least 15% from visual estimation [83].

The ultimate aim of the various proposed classification is to define a treatment algorithm accepted and followed by all physicians dealing with these complex conditions. It is also very important to use the same definitions in order to carry out research projects designed to identify the best, type-specific, therapeutic option.

In 2015, the European Laryngological Society published a consensus paper proposing a five-step endoscopic airway assessment and a standardized reporting system to better differentiate fresh, incipient from mature, cicatricial laryngotracheal stenosis, simple one-level from complex multilevel laryngotracheal stenosis and finally “healthy” from “severely morbid” patients [84].

Authors believe that, from the surgery point of view, this is an excellent article in order to choose the best treatment modality for each individual patient and assess distinct post-treatment outcomes accordingly.

Treatment

Most significant tracheal stenosis needs interventional bronchoscopy or surgical resection.

Effective management of tracheal stenosis requires a multidisciplinary assessment of a patient’s overall clinical status and medical history in addition to etiology and morphology of the stricture. When deciding the approach, the dedicated physician has to consider whether or not the patient is a surgical candidate, determine precise intraoperative technique, the extent of the resection, and an estimation of the risk for recurrence. Other treatments to consider are repeated dilatations or the placement of airway stents. Symptoms of patients with an airway obstruction are variable and depend not only on location, severity of the stricture, and the speed of progression but also on underlying medical conditions.

We cannot overemphasize that when an obstruction of the tracheobronchial tree is suspected, a careful review of medical history, patient examination and review of complementary methods such as pulmonary function testing and imaging studies (chest RX, CT scan) should be performed thoroughly. Virtual bronchoscopy can be used to have a preview of the airway, but it does not replace conventional flexible bronchoscopy as the most useful diagnostic tool to assess the extent of the stenosis as well as its severity, and to determine its cause by direct inspection and biopsies. Patient clinical status is the main parameter in deciding the next step, since it will determine how urgent the treatment is needed and which is the most appropriate instrument to perform the procedure.

Endoscopic Treatment

Rigid bronchoscopy under general anesthesia is an essential method in the treatment of severe symptomatic laryngotracheal stenosis. It allows a secure airway and the application of different interventional tools such as tracheal or bronchial dilatation with different sizes of tracheal or bronchial tubes or with occlusive and nonocclusive balloon dilatation, laser resection, electrocautery, placement of an airway stent, etc. It is an expeditious procedure to reopen the airway, very safe and effective when applied by a well-trained team. The flexible bronchoscope also has an important role, complementary to the rigid bronchoscope during the first approach.

Our recommendation when treating a patient with severe central airway obstruction is to provide appropriate oxygenation and ventilation by intubation with the rigid bronchoscope. The rigid tube serves two purposes: first, it secures the airway, and second, it can be used to dilate the airway. Once successful intubation is achieved, the flexible bronchoscope can be used through the rigid scope to inspect the stenosis and the distal airway, and to aspirate retained secretions.

The immediate therapeutic approach depends on the type and severity of the stenosis found. Many times, rigid bronchoscopy will resolve the acute situation by dilating the stricture, and will represent a bridge to definitive treatment to be performed electively.

According to the endoscopic findings, several steps can be followed. For instance, simple severe stenosis (concentric membrane) can be immediately resolved with laser resection and dilatation with the rigid bronchoscope. In this particular situation, that may be the only procedure that the patient will need. A close endoscopic follow-up is indicated to detect and treat recurrences.

Complex stenoses represent a different situation. They may be addressed initially with endoscopic therapy to overcome the acute respiratory failure, but the definitive solution is always surgery providing that the patient has a good clinical status.

Patients that present with progressive symptoms can be inspected with both the rigid or the flexible bronchoscope and a definitive procedure can be planned after discussing the case in a multidisciplinary team, once all information has been collected.

As we commented at the classification section, treatment algorithms based on different classifications have been recommended, to follow in benign tracheal stenosis, according to several defined criteria [2, 10, 76] (Fig. 15.13 and Table 15.2).

Dilatation

As we discussed above, in urgent cases the sole use of a rigid bronchoscope causes dilatation and enlargement of the airway, improving both extrinsic and intrinsic obstruction (Fig. 15.14a–c) shows the result of the dilatation of original tracheal stenosis (a), first time treatment dilatation with rigid bronchoscopy and two more dilatations after 2 and 3 months (b). Bronchoscopy control: stability after 24 months (c). No more recurrence at the present.

When a rigid bronchoscope is not available, dilatation can be performed by using progressive diameter balloons that are introduced sequentially, thus achieving a greater diameter of the tracheal (Fig. 15.15a–c) or bronchial lumen (Fig. 15.16a–c).

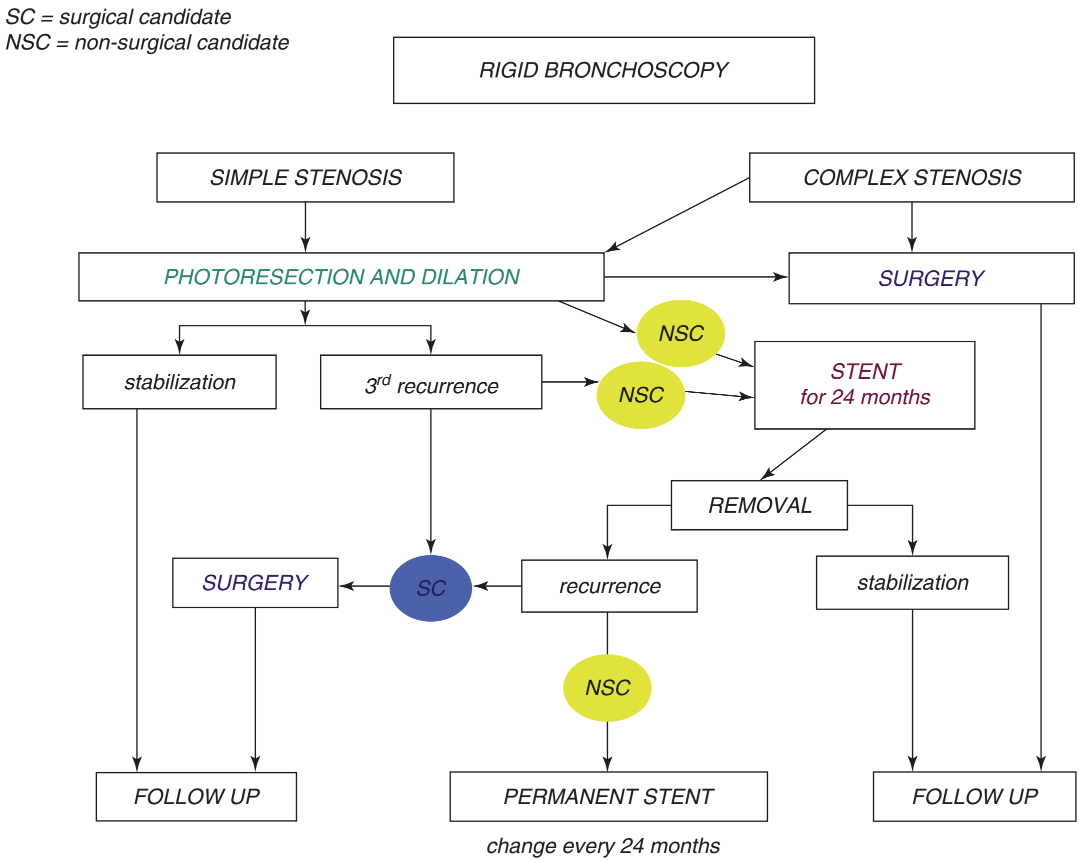

Fig. 15.13 Tracheal Stenosis Treatment Algorithm. (Modified from [2])

Table 15.2 Endoscopic treatment according to morphological criteria. Moya and cols.

Category	First option	Second option
S1/C1-2-3/L1-2	ET ± Laser ± Prosthesis	Surgery
S1/C2-C3/L3	ET ± Laser ± Prosthesis	-----------
S2/C2-3/L1-2	ET ± Laser	Surgery
S2/C2-3/L3	ET ± Laser ± Prosthesis	-----------
S3/C2-3/L1-2	Surgery	-----------
S3/C1-2-3/L3	Prosthesis	-----------
S4/C1-2-3/L1-2-3	Surgical correction of fistula + myoplasty	

S stage, *C* caliber, *L* length

Balloon dilatation does not have long lasting effects, and it is indicated to relieve the obstruction until a more definitive treatment can be offered.

Two types of balloon dilatation could be used, the occlusive and nonocclusive balloon dilatation. The second one has the advantage of allowing ventilation by anesthesia while performing the dilatation procedure, being more secure for the patient.

Laser Therapy

Laser treatment involves application of a laser light to the lesion. The effects of laser are deter-

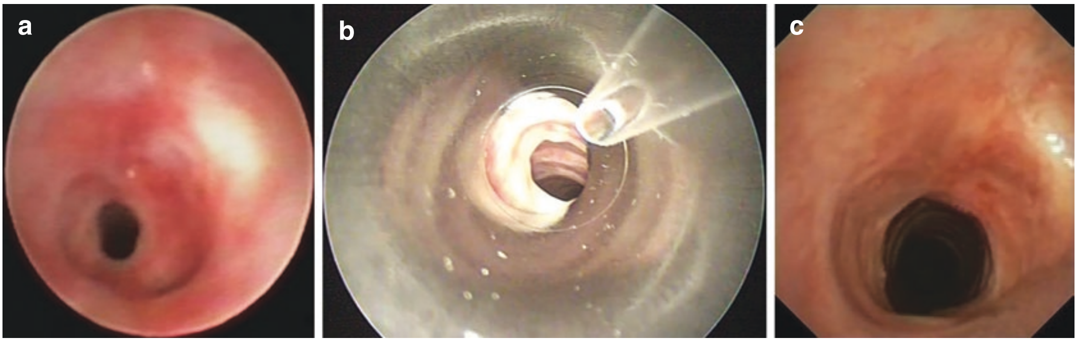

Fig. 15.14 (**a**–**c**) Dilatation with rigid bronchoscope

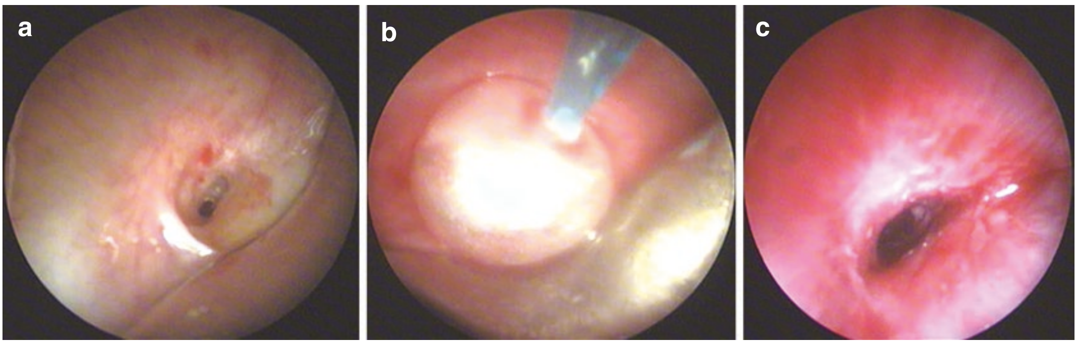

Fig. 15.15 (**a**–**c**) Occlusive Balloon Dilatation of iatrogenic tracheal stenosis (before, during and after treatment)

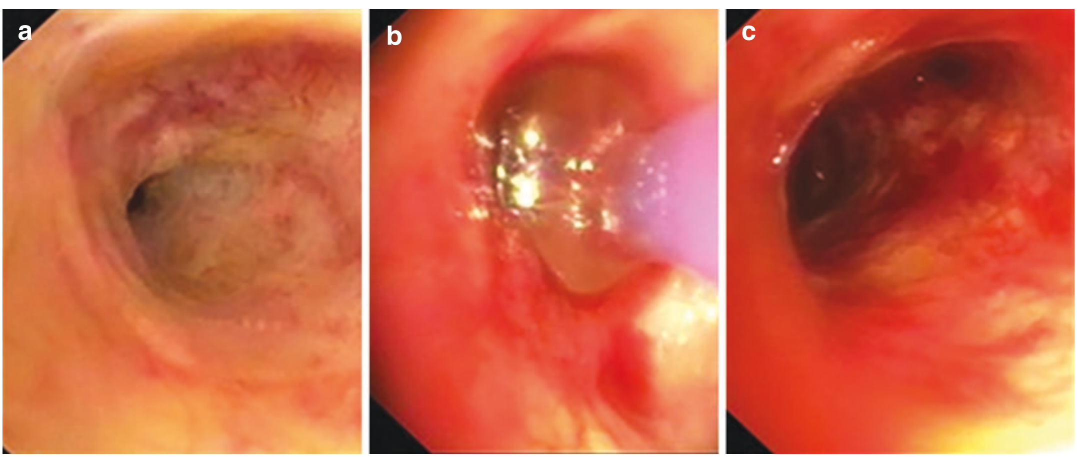

Fig. 15.16 (**a**–**c**) Occlusive Balloon Dilatation of bronchial stenosis cause by radiation injury

mined by many factors: type of laser applied, distance and surface of application, and target tissue. Some authors published their first experience with Nd YAG laser (neodymium, yttrium, aluminum and garnet) laser combined by tracheal dilatation [85, 86], in patients with benign tracheal stenosis. Our group also published the results of 400 cases of benign and malignant disease treated with laser [87]. Ninety-two patients were treated for benign tracheal stenosis, and received 113 laser applications. Laser resection was successful in obtaining a 50% increment on the tracheal diameter in most cases.

In another publication, we report our experience with laser resection followed by airway stents placement in 63 patients with no surgical benign tracheal stenosis [1]. About 79% of patients obtained a definitive cure.

In order to improve the opening of the airway and make easier the dilatation of the stenosis, some authors recommend to apply three or four radial cuts by laser (Fig. 15.17a–c) at the cardinal points of the stenotic circumference of the trachea and then to perform a careful dilatation with the rigid bronchoscope [88]. Other options to perform the radial cuts can be using other instruments as a rigid scissor, or a combination of a hand drill and rigid scissor [89, 90].

Vaporization of cartilaginous structures is strictly contraindicated because it results in weakening of the tracheal wall and potentially induces restenosis to a more severe grade.

The flexible bronchoscope can be used to apply a laser as well, and then use the rigid instrument to take advantage of simultaneous dilatation.

In case of severe subglottic stenosis, we recommend the use of a CO_2 laser to take advantage of its cutting capacities avoiding inflammation, or only dilation with the rigid bronchoscopy. Instead, Nd YAG laser can increase the stenotic area due to inflammation and put the patient at higher risk (Fig. 15.18a–c), where a worsening of stenosis can be seen, due to an increase in granulomatous tissue (Fig. 15.18a–c). In those cases, if there are no other options of treatment, tracheostomy is necessary as a first procedure of choice.

Cryotherapy, Electrocautery, and Argon Plasma Coagulation

Cryotherapy, electrocautery (EC), and argon plasma coagulation (APC) are methods that obtain variable results in tracheal stenosis treatment.

Results on the application of these techniques in tracheobronchial stenosis of different etiology are available. Fernando et al. [91] treated 35 patients with postintubation, post-tracheostomy, radiation induced, prior surgery, other causes, or unknown etiology of tracheal or bronchial stenosis with spray cryotherapy (SC). Seventeen patients (49%) required additional SC therapy. Only two complications occurred (3.2%) and these included pneumothorax and intraoperative tracheostomy. Twelve patients were asymptomatic, 16 improved, 4 had no improvement or were worse, and 1 patient died from an unrelated cancer.

They concluded that initial experience with SC for benign airway stenosis suggested that

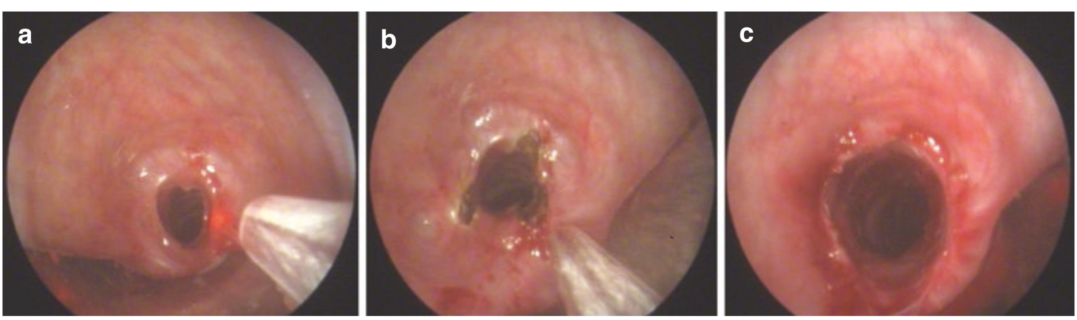

Fig. 15.17 (**a**–**c**) Laser application in tracheal stenosis

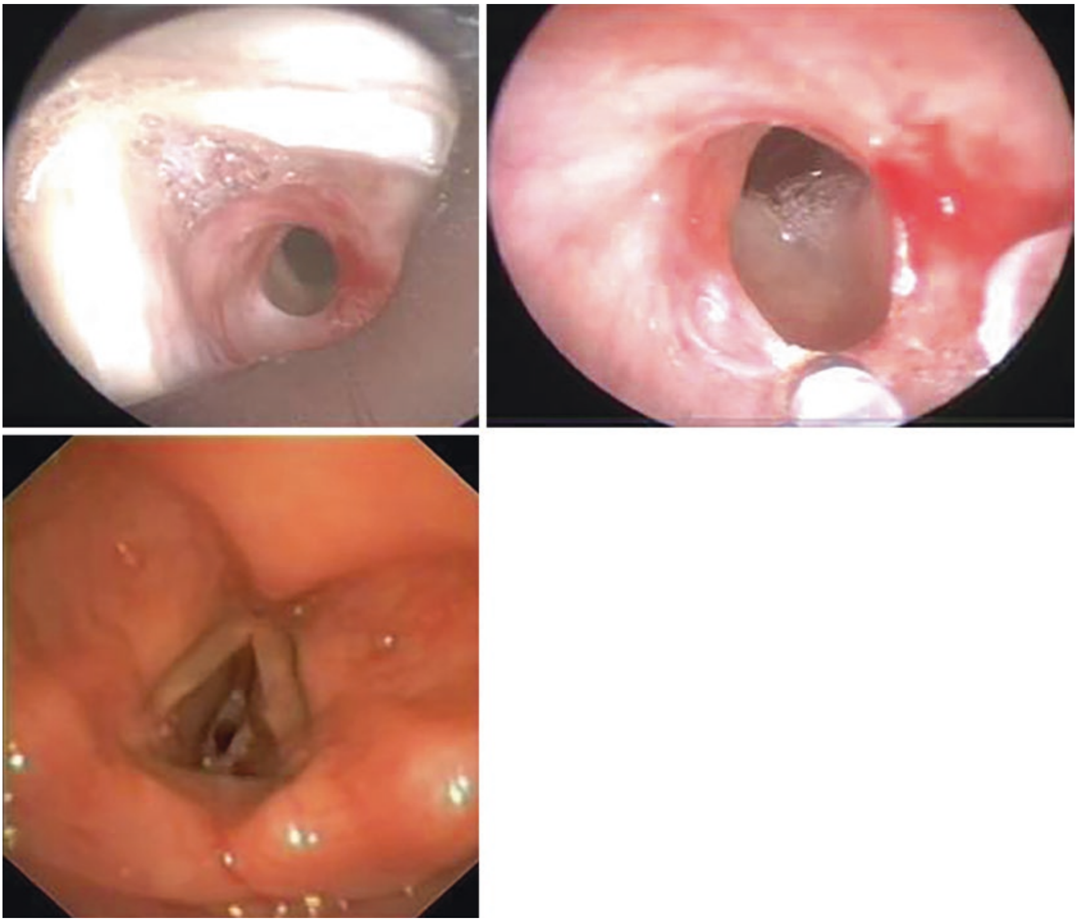

Fig. 15.18 Complication after laser YAG treatment in subglottic stenosis. Stenosis is worse, due to granulomatous tissue growing after laser therapy

this could be used safely, and could be effective in improving symptoms and reducing the severity of airway narrowing, but almost half of the patients required re-intervention.

Some authors agree that when applied to postintubation tracheal stenosis EC and APC can be fibrogenetic, causing more damage and scarring of the mucosa. Cryotherapy is almost ineffective given the paucity of blood vessels in the stenotic area.

These three methods, however, are very useful in granulomas, especially APC [92–94]. Laser therapy still has many advantages over all of them; since it is fast, it has high coagulation power and a minimal impact on surrounding tissues.

Stents

Airway stents are tubes of different shapes, sizes, and materials designed to stabilize or reconstruct the lumen of the airways.

In benign tracheal stenosis, tracheal stents placement may be considered when surgical treatment is not an option in the following situations:

(a) Treatment failure after dilatation of a simple stenosis.
(b) First option in cases of complex stenosis as a bridge to surgical treatment or as a definitive treatment when it is not possible.
(c) As the only option in unresectable disease (length >50% of the trachea).

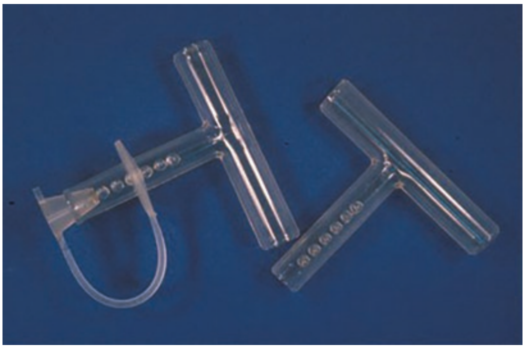

Fig. 15.19 Montgomery T-tube

Silicone stents are the stents of choice in benign tracheal stenosis, because despite the complications associated such as obstruction due to accumulation of secretions, colonization, granuloma formation, or stent migration [95, 96], they are easy to remove. Silicone stents are safe, well tolerated, and effective in the maintenance or airway patency [1, 97].

When the subglottic area is involved, a Montgomery T tube [98] should be used to avoid caudal migration (Fig. 15.19). A transcordal silicone stent [99] or a LT-Mold™ should be another option in severe glotto-subglottic stenosis [100]. Uncovered or partially covered self-expandable metallic stents (SEMS) are not recommended because of the difficulty in removal because of the granulation tissue formation and other complications associated such airway perforation and fatal hemoptysis [101]. In fact, the Food and Drug Administration (FDA) advised against metallic stent application in benign conditions in the year 2005 [102].

Since the development of the totally covered SEMS, different studies have been published showing good results in long-term follow-up. SEMS are easy to place and remove, but they are not free of potential complications [103–105].

New devices, currently under study, such as biodegradable stents or drug-coated stents may have a role in benign tracheal stenosis in the future [106–108].

How to Proceed

Rigid bronchoscopy and laser resection have been used for decades, showing excellent results on the treatment of endotracheal or endobronchial growing tissue.

Concerning treatment of benign stenosis, rigid bronchoscopy, and laser resection has virtually no morbidity/mortality when the technique is appropriately applied in carefully selected patients.

When implementing this treatment, we recommend to proceed as follows:

1. Careful intubation with the rigid bronchoscope, maintaining the rigid optic lens slightly behind the tip of the bronchoscope in order to have a broad view of the airway during the procedure. It is important to perform a planned intubation, and to take every possible precaution during the procedure, since these patients often have a history of difficult intubation and rush maneuvers can easily damage the upper airway, especially at the arytenoids and vocal cords area.
2. Once the lesion is on view, careful inspection of the area should be performed. Anatomic characteristics, extent, degree of compromise of the airway wall, and presence of inflammation should be recorded. It is important to touch the lesion with the tip of the suction catheter in order to test the nature of the stenosis, inflammation, fibrosis, cartilage affectation, etc.
3. When the tracheal caliber is equal or greater than half the diameter of the rigid tube in use, the stenosis can be dilated by placing the bevel of the bronchoscope at the beginning of the stenosis and then surpassing the stricture dilating. During the maneuver, a slight rotation movement is applied to the scope as it is advanced through the stenotic area. In case of bleeding, use the bronchoscope to compress the bleeding area for a few minutes. If the lumen diameter obtained after dilatation is not appropriate, it will be necessary to move on to a larger diameter bronchoscope.

4. When the stenosis has a caliber of less than half the diameter of the bronchoscope, a laser in cutting mode can be applied, performing three or four cuts at 12, 3, 6, and 9 o'clock of the stenotic circumference. Laser should always be applied parallel to the tracheal lumen, avoiding damage to the posterior tracheal wall and the esophagus that could result in a tracheoesophageal fistula. The anterior tracheal wall can also be accidentally damaged, injuring large vessels placed beyond the wall, such as the innominate artery.

   After several cuts, the stenotic tissue tends to open or is easily removed by the rigid bronchoscope, applying again a rotation pressure and resecting the stenotic membranes. Bleeding rarely occurs, or is minimal. Another option is to cut the membrane stenosing the airway with endoscopic scissors, minimizing laser application to avoid burn damage to the mucosa. After the incisions, the rigid bronchoscope is used to dilate the stenotic area.
5. Once the stenosis is surpassed, the flexible bronchoscope is passed through the rigid tube, to carefully inspect the distal airways and to aspirate retained secretions or detritus.
6. Finally, the rigid bronchoscope is withdrawn above the stenotic area, to check that the tracheal caliber remains appropriate. Given the case the lumen remains stenotic, one can assume that there is a complex damage to the tracheal wall such as cartilage disruption or malacia. Placement of an airway stent is then the safer recommendation, since it will allow solving the situation avoiding immediate recurrence of the stenosis. Also, it will give time to collect other important information and to discuss the case in a multidisciplinary fashion in order to offer a more definitive solution.

Stent Placement

When placing an airway stent, the first consideration to evaluate is whether or not the stent will really improve the clinical situation or make it worse.

Once risks and benefits have been evaluated and the assessment favored a stent placement, the dedicated physician should inspect the lesion again, noting carefully the size and length of the stenotic area and the characteristics of the surrounding healthy tissue. Two distances are particularly important: vocal cords to the beginning of the stenosis and end of stenosis to the main carina.

A stent positioned too close to the vocal cords will bring speech problems, and will be prone to granuloma formation leading to more stenosis. When the distance to the vocal cords is less than 2 cm, the best results are obtained proceeding directly to tracheostomy and placing a Montgomery T tube (Fig. 15.20a, b). In turn, when a low stent has to be placed, less than 2 cm from the carina, it is better to offer a Y stent, since a tubular stent will contact and irritate carinal mucosa leading also to granuloma formation and subsequent stenosis.

Placing a Montgomery T Tube

For the placement of a Montgomery tube in a high tracheal stenosis, it is advisable to treat the stenosis first and obtain a good caliber. Then measure the caliber of the trachea in that area as well as the distance between the vocal cords and the tracheostoma and between the tracheostoma and the carina to choose the most suitable Montgomery. The Montgomery tube insertion procedure should always be done with a rigid bronchoscope since all the movements of the insertion and the correct location of the tube can be ensured, with direct vision, by following the next steps in a simple technique:

1. Intubation with a rigid bronchoscope
2. Introduction of the distal portion of the Montgomery tube through the tracheostoma
3. Grasp it with the forceps and push it towards the distal portion of the trachea until the proximal portion enters into the tracheal lumen, then
4. Grab the proximal portion of the Montgomery and pull it towards the vocal cords
5. Check endoscopically if the proximal and distal positions are correctly placed

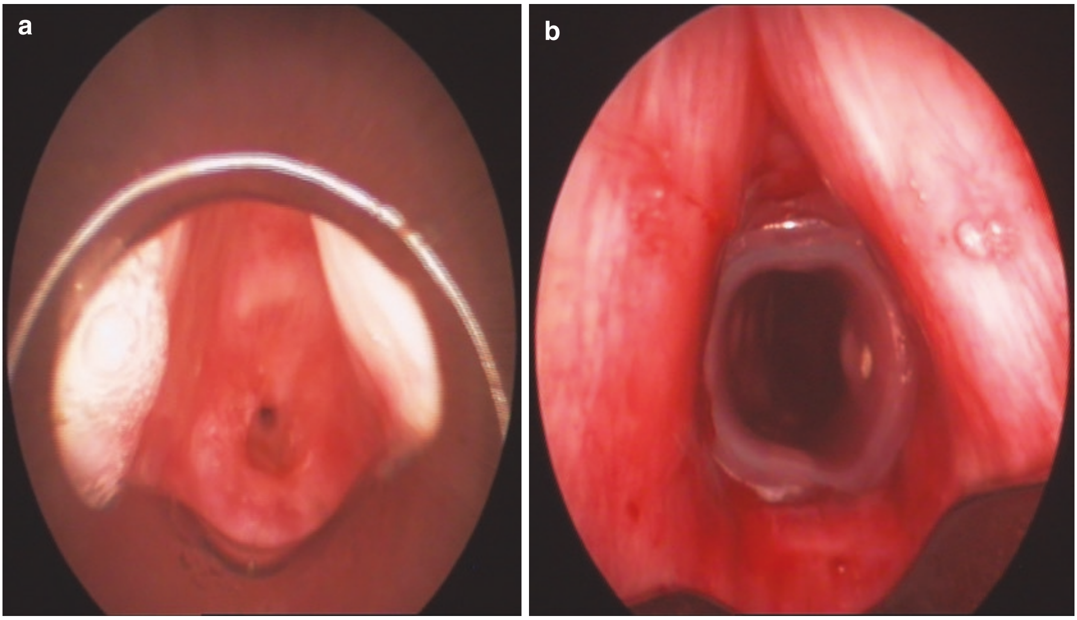

Fig. 15.20 (**a**, **b**) Tracheal stenosis less than 2 cm from the vocal cords (**a**) before and (**b**) after a Montgomery tube placement

During the entire procedure, the outer part of the Montgomery tube must always be firmly held with grasping forceps by an assistant (Fig. 15.21a–d).

Bronchoscopic follow-up: The Montgomery tube must always be closed to preserve the humidity of the respiratory system and avoid the formation of dry secretions that could cause obstruction of the prosthesis. Instillations of 2 cm of saline should be made twice a day, depending on the case. In case of acute obstruction, it should be removed urgently.

Bronchoscopic reviews should be done according to protocol and clinical criteria, in order to inspect the correct placement of the Montgomery, and to check the presence of secretions or granulomas. The bronchoscope must be introduced through the external branch of the Montgomery, and directed towards the vocal cords after tilting it downwards, to favor the view of the vocal cords from below. In the case of the inspection of the carina, which is easier, the external branch of the Montgomery should tilt slightly upwards (Fig. 15.22a–d).

The Rule of Twos for Benign Tracheal Stenosis (Fig. 15.23)

For a more effective and accurate tracheal stent placement and in order to avoid complications in relation to the vocal cords and main carina, we have designed a scheme that may obtain better results when a stent has to be placed near these areas.

With regard to the vocal cords:

In strictures close to the vocal cords, a placement of the stent can lead to the production of granuloma due to stent movement during breathing or to frequent coughing. The continuous rubbing of the stent with the vocal cords will generate granulomas that almost inevitably will cause new subglottic stenosis.

With regard to the carina:

The same scenario is possible when a stent has to be placed close to the main carina. Due to cough or breathing movements, continuous mucosal irritation will produce granuloma formation.

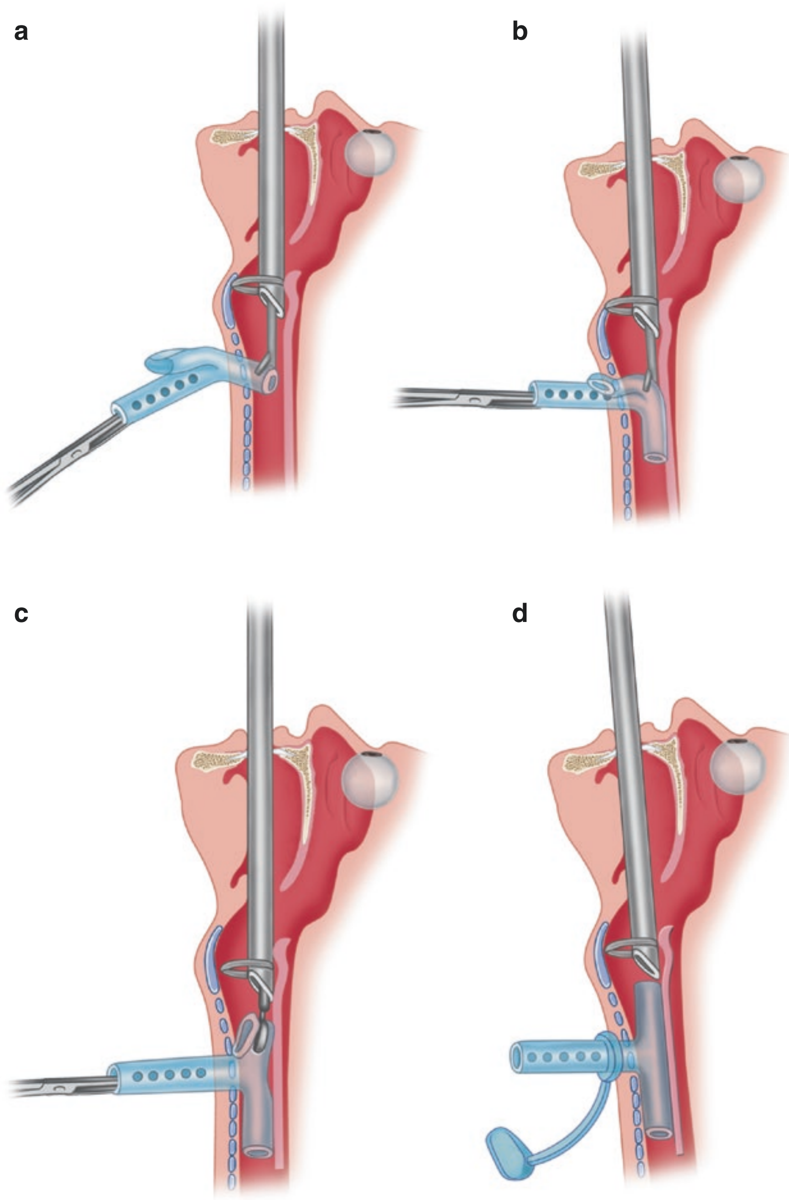

Fig. 15.21 (**a**–**d**) Placing of Montgomery T-Tube. After intubation with the rigid bronchoscope and the introduction of the caudal portion of the Montgomery T-tube we will procedure to grasp it with the forceps and push it towards the distal portion of the trachea until the proximal portion enters into the tracheal lumen, then grab the proximal portion of the Montgomery and pull it towards the vocal cords and check endoscopically if the proximal and distal positions are correctly placed. During the entire procedure, the outer part of the Montgomery tube must always be firmly held with grasping forceps by an assistant

After 35 years of experience in the placement of stents, we advocate that a 2 cm distance between the vocal cords and the proximal edge of the stent can prevent the production of granulomas on the vocal cords.

Same with the stenosis near the main carina: we advocate that a 2 cm distance between the carina and the distal end of the stent will prevent the production of granulomas at this level.

So, we suggest for approaching stenting:

When considering the vocal cords, stents should

1. Cover the affected area of stenosis and two additional centimeters above and below that area.
2. Respect the 2 cm of healthy mucosa, proximal to the vocal cords.

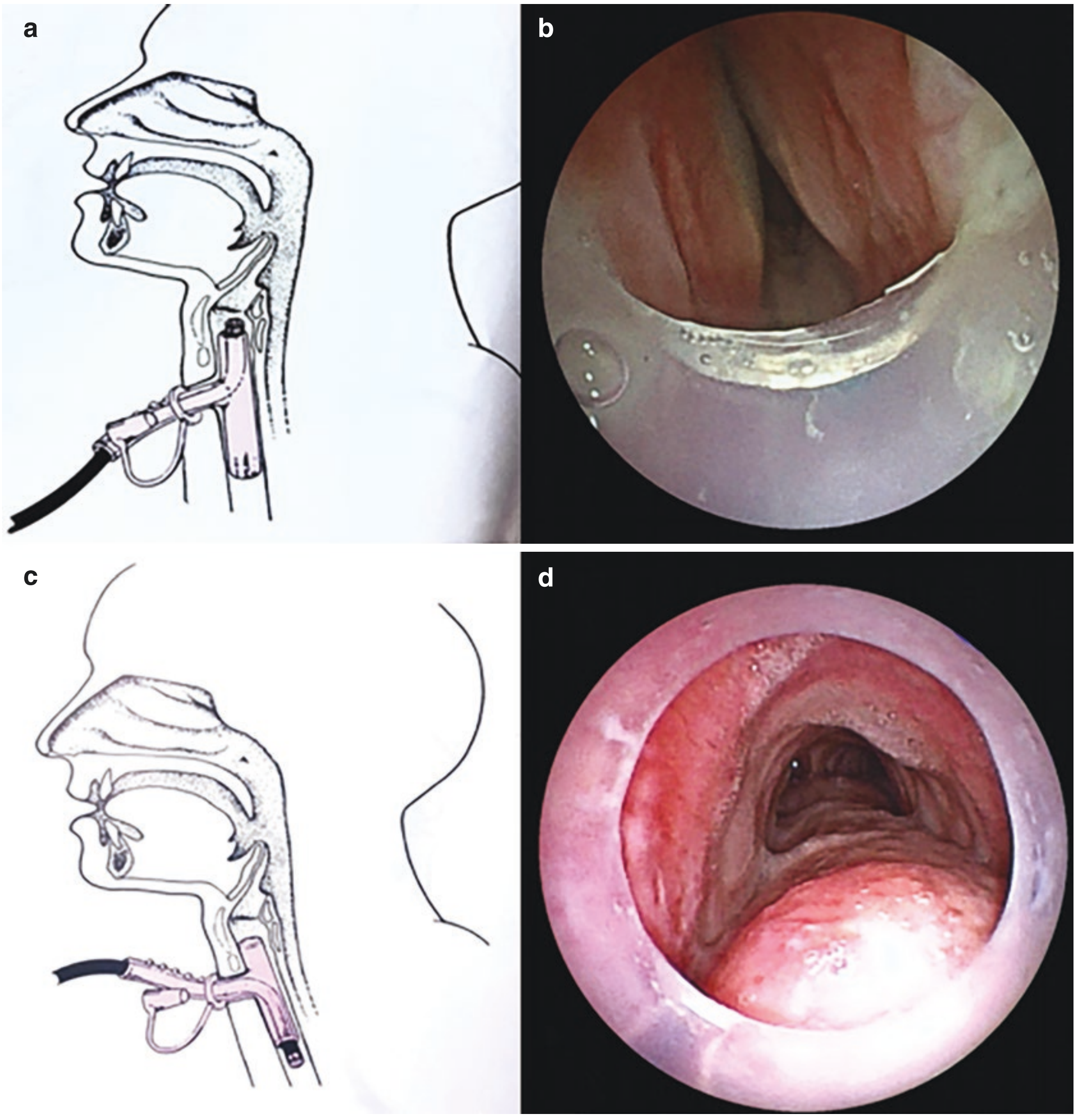

Fig. 15.22 (**a**–**d**) Montgomery T-Tube. Flexible ronchoscopic inspection from the external branch: vision towards vocal cords (**a**, **b**) and vision towards carina (**c**, **d**)

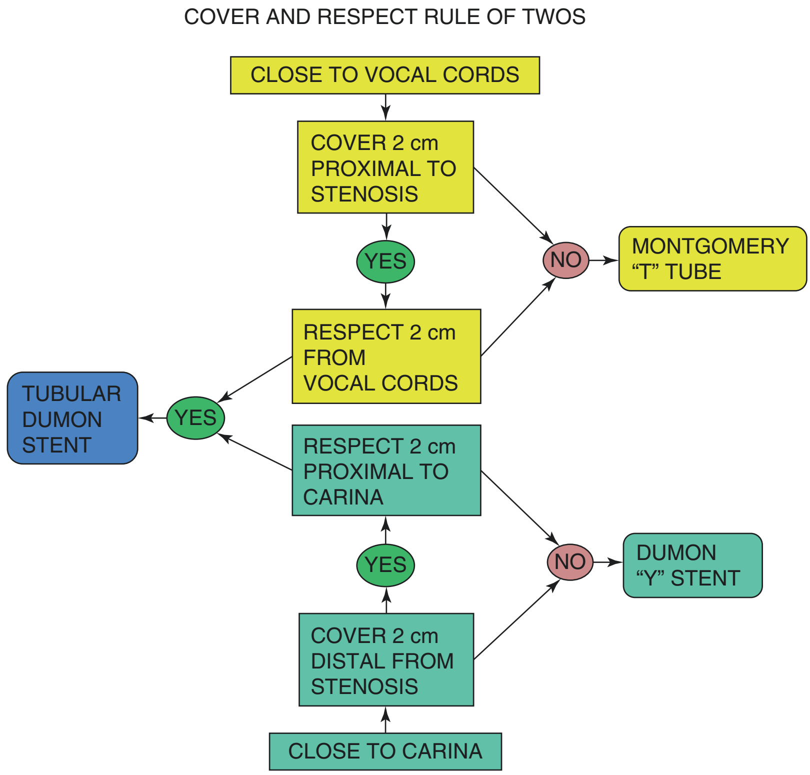

Fig. 15.23 Algorithm of stenting tracheal stenosis

If (1) and (2) are not possible, then a Montgomery T tube should be placed.

Related to the carina, stents should:

1. Cover the affected area of stenosis and two additional centimeters above and below that area.
2. Respect the 2 cm of healthy tissue proximal to the carina.

If (1) and (2) are not possible, then a Y stent should be placed.

Surgery

Surgical treatment of tracheal stenosis comprises a wide range of techniques such as tracheal resection and anastomosis or tracheal reconstruction.

It is necessary to perform an accurate selection of the patient. The choice of ideal treatment should be individualized, based on the characteristics of each patient after evaluating all the advantages and disadvantages of the procedures by an experienced surgical team to improve the success of the surgical procedures and to minimize complications.

In patients with more than 1 cm long stenosis and chondritis with malacia, dilation and laser are not effective enough to achieve a permanent good result, then surgery as a first option or stenting become necessary.

Complex tracheal stenosis affecting multiple rings with involvement at various levels and a large inflammatory component is usually an indication for surgery as a first step. Inoperable patients may benefit from a permanent airway stent.

Primary tracheal sleeve resection is considered the treatment of choice in patients who are operable. Other complex laryngotracheal techniques are necessary when the subglottic is involved. The Spanish Society of Thoracic Surgeons (SECT) [109] drafted a consensus document about tracheal and laryngotracheal surgery. They performed a surgical classification of the stenosis into five types depending on the affected area and the extent of the lesion, and they proposed different surgical techniques depending on the stenosis type: tracheal resection and anastomosis, Pearson surgery [110], Grillo surgery [111], Maddaus surgery [112], or Couraud surgery [113].

Some surgeons recommend avoiding endoscopic procedures in all patients who are potentially candidates for surgery, stating that laser treatment or stent placement can worsen the situation. However, there is no evidence to support that. In fact, most patients are immediately relieved of their symptoms after dilatation, laser resection, or stenting of the airway. Reevaluation of these patients after the acute distress is resolved will determine the next step.

Before the surgery, it is important to have control of the inflammation or infection or the airways to avoid complications. Antibiotic treatment should be administered in these cases. The principal complications related to surgical procedures are restenosis, granuloma formation on the anastomotic suture, infections, bleeding, and subcutaneous emphysema [4, 114]

Summary and Recommendations

Dealing with airway stenosis can be difficult. A variety of methods can be applied in order to relieve the situation. In fact, almost any technique discussed above is useful, and can be applied alone or in combination with other methods. A multidisciplinary approach will always bring the best results for patients; important considerations should be thoroughly discussed with the team:

- General status of the patient and his/her wishes.
- Type of injury (acute versus chronic, extrinsic or intrinsic obstruction, fixed or dynamic stenosis, benign or malignant stenosis).
- Equipment availability.
- Personal experience and expertise on a given method.

After that, the "best" approach for a given patient can be offered.

As we said, frequently best results are obtained with a combination of treatments, and better outcomes for the patient are achieved in multidisciplinary, referral centers that have both extensive experience and sufficient equipment to deal with these complex clinical situations. We believe that all the team implicated in the management of tracheal stenosis: interventional pulmonologists, thoracic surgeons, and otorhinolaryngologists must discuss thoroughly the indications, contraindications, and possible complications that can arise, case by case.

We favor that the interventional team should be well trained, able to apply both the rigid and flexible bronchoscope, and has to be also knowledgeable on handling airway stents. The American College of Chest Physicians (ACCP) guidelines to interventional procedures provide useful recommendations including training requirements and number of suggested procedures to become competent and maintain proficiency in all the procedures described in this chapter [115].

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