Benign Tracheal and Bronchial Stenosis

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Introduction and Definition

Benign airway stenosis is characterized by the progressive reduction of the airway diameter. Following an injury of the tracheal or bronchial mucosa that produces an abnormal re-epithelization, a replacement of normal wall tissue by fibrous tissue takes place.

The most common cause is iatrogenic, as a complication of prolonged endotracheal intubation or tracheostomy [1, 2]. Other causes are idiopathic, infectious, chemical damage (such as gastroesophageal reflux or toxic inhalation), radiotherapy, and associated to systemic diseases (e.g., Wegener's granulomatosis, amyloidosis)

Patients can present with variable symptoms, depending upon to 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.

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% [2, 6, 7]. Moreover, many patients are unable to undergo a surgical procedure because of underlying cardiopulmonary limitations.

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 [1, 8].

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Drug therapy combined with endoscopic treatment (intralesional injection of corticosteroids or more recently topical application of mitomycin-C) is another option in the treatment of this pathology, but experience is very limited and results are variable [9, 10]. So far none of these treatments is curative.

Causes of Benign Airway Stenosis

Congenital Tracheal Stenosis

Congenital anomalies are the most common cause of airway narrowing in the pediatric population. They are rare malformations 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. There have been three anatomical types described: (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; and (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 [11, 12].

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.

Postintubation and Post-tracheostomy Tracheal Stenosis

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 [13].

Since then, many reports have been published on serious complications resulting from post-intubation 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, 14]. Only a minority of them (1–2%) will present with symptoms or severe stenosis [15].

Currently, the calculated incidence of moderate or severe stenosis resulting from endotracheal intubation or tracheostomy is estimated on 4.9 cases per million per year in the general population [16].

Prolonged tracheal intubation can produce tracheal stenosis at many tracheal levels [17], 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, cartilages exposure and perichondritis develop, followed by granulation tissue formation, which over time becomes an established fibrous stenosis, that 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 [18, 19]. The presence of infection, very common in ventilated patients (tracheitis, mucositis), is a contributing factor for the development of airway stenosis [20]. A common finding in post-tracheostomy patients is retraction of the tracheal cartilage at the area of the ostomy, producing different degrees of stenosis (Fig. 11.1). Surgery is the treatment of choice in these situations. When the patient is not a

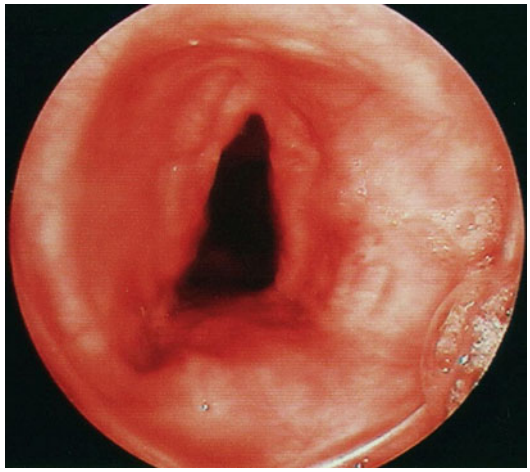


Fig. 11.1 Post-tracheostomy tracheal stenosis

surgical candidate, an airway stent may be beneficial.

Percutaneous tracheostomy is a procedure that is increasingly indicated in the critically ill patient, and it is associated to the development of tracheal stenosis as well.

A publication on 100 patients that underwent percutaneous tracheostomy revealed that major postoperative complications were 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). The rate of minor complications such as bleeding or cellulitis were present in 1.8% of cases. Tracheal stenosis was reported in 31% of patients, 20% of which were symptomatic [21].

Long-term complications of percutaneous tracheostomy are infrequently mentioned in the literature; however, some published data suggests that the rate of tracheal stenosis is significantly higher than reported [22].

VanHearn et al. showed that of 80 patients decannulated after percutaneous tracheostomy, an index of stenosis >10% was found in 26% of them, being moderate in 4% of the cases and severe in 2% [23].

Another study evaluating 214 of 356 patients with percutaneous tracheostomies revealed that 8 of them (3.7%) developed symptomatic tracheal stenosis [24].

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, TB being the most frequently seen.

Tuberculosis 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 [25]. The most important risk factor for developing airway stenosis is the presence of tuberculous bronchitis, which is found in 10–37% of patients with pulmonary tuberculosis when bronchoscopy is performed [25, 26]. In those cases, over 90% of patients will develop tracheobronchial stenosis in spite of correct TB treatment [27].

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 is often required, since recurrence rate is very high.

Idiopathic Tracheal Stenosis

The term idiopathic stenosis (ITS) is used to include patients with tracheal stenosis when all other etiologies have been investigated and ruled out. It is thought to be a result of an inflammatory process of unknown etiology. Since location and general characteristics are similar to inflammatory and post intubation stenosis, the investigation of potential causes has to be exhaustive before this term is applied.

ITS is a rare condition, characterized by circumferential fibrous stenosis beginning at the

subglottic area and compromising the proximal segment of the trachea. It typically affects women on their third to fifth decade and presents 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 [28].

Grillo et al. [28] presented 49 patients with tracheal stenosis where no etiology was found after extensive evaluation. A retrospective review of records showed that radiologic studies were still available in only 15 of the 49 patients with ITS. All 15 patients had radiographs and plain tomographies, and one patient had a computerized tomography scan of the neck.

Review of the available information showed that idiopathic laryngotracheal stenosis produced focal, 2–3 cm long stenosis at the cervical trachea. The lumen was severely compromised, measuring no more than 5 mm in diameter at its narrowest portion. The stenosis was concentric or excentric, presenting either smooth or lobulated margins.

Grillo's report 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. It is also important to consider ITS in the differential diagnosis of patients with focal narrowing of the airway.

A recent multicenter study described 23 patients, 96% of which were women aged 45 ± 16 years, endoscopically treated for ITS. Time between first symptoms and diagnosis was 19 ± 18 months. Bronchoscopy showed weblike (61%) or complex (39%) stenosis, located at the upper part of the trachea, mainly at the cricoid cartilage area.

Endoscopic treatment included mechanical dilation only (52%) or associated with laser or electrocoagulation (30%) and stent placement (18%). All procedures were efficient. Follow-up after endoscopic therapy was 41 ± 34 months, showing recurrence of ITS in 30% of patients at 6 months, 59% at 2 years, and 87% at 5 years. Treatment of recurrences ($n = 13$) included endoscopic management in 12 cases [29].

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 [30, 31].

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 [32].

Other risk 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 [33, 34] (Fig. 11.2). This number corresponds to approximately 4.1% of all bronchoscopies performed in a hospital.

Another cause for distal stenosis is bronchial anthracosis (called anthracostenosis) [35, 36].

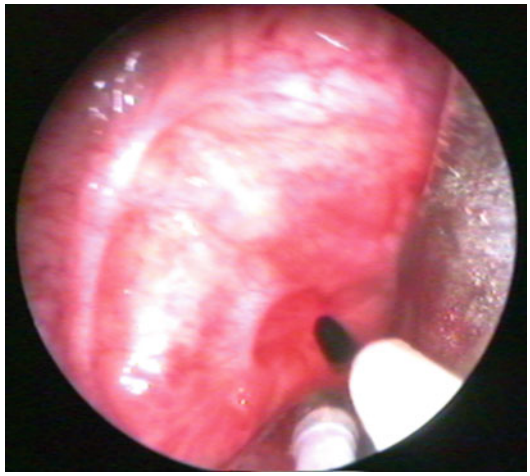


Fig. 11.2 Bronchial stenosis: right upper lobe

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 [37].

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% [38].

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 important inflammatory response that ultimately results in fibrous stenosis [38]. Radiation therapy rarely compromises the tracheal mucosa.

Diagnosis of Tracheobronchial Stenosis

Symptoms

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.

In most cases, symptoms develop gradually as progressive dyspnea until tracheal stridor appears. 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 for difficult-to-control asthma, 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. In a work of Marquette et al. describing 58 patients with airway stenosis, 5 of them developed symptoms within 5 days, 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 [39].

The 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. That means that when a fixed wheeze is heard over the trachea, it does not necessarily indicate that the source of the obstruction is the trachea [40]. 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 bronchoscopic 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 stenoses, noninvasive imaging techniques have an important role. They help not only in diagnosing but also in deciding the most appropriate treatment and assessing response to therapy during the follow-up period. These techniques have developed significantly in recent years [41] allowing a better approach to airway stenosis.

Computed tomography (CT) has been the most commonly used imaging test for diagnosis and evaluation of airway stenosis. Although very useful, CT has some limitations, particularly in the assessment 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 [42] (Fig. 11.3).

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 [43] bringing visual data that closely resemble the images obtained from flexible bronchoscopy [44].

MPR CT scan allows the acquisition of thin-slice axial sections of entire body volumes during a single breath-hold, thus eliminating respiratory artifacts [45].

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 [46], allowing navigation through the tracheobronchial tree with the same endoluminal perspective as an endoscopy [44].

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 [43, 46, 47]. However, it is slightly more accurate at assessing central airway stenosis than segmental airway stenosis [46].

Bronchoscopy

Flexible bronchoscopy remains the primary diagnostic technique [48] in the study of inflammatory tracheal stenosis, allowing direct visualization of the airway lumen. 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. 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.

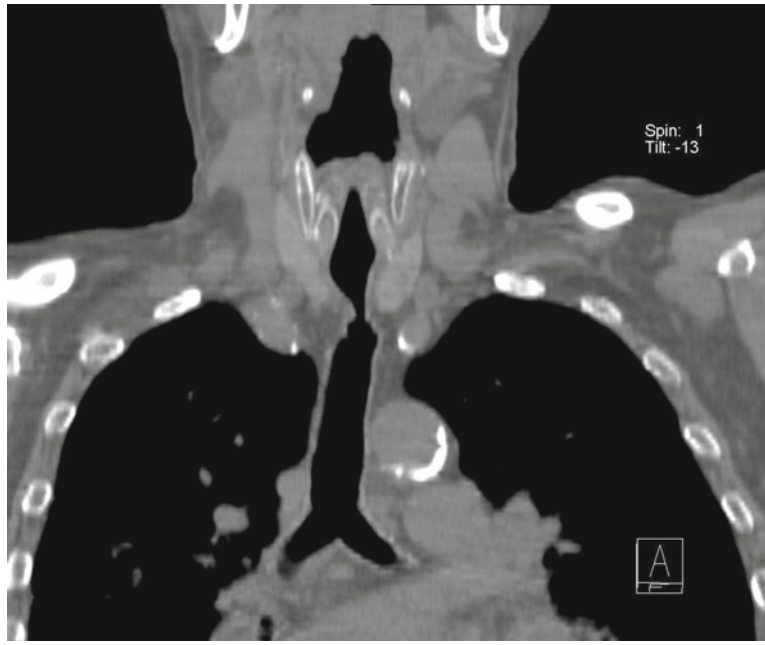


Fig. 11.3 CT scan tracheal stenosis

New bronchoscopic technologies, however, permit 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 in evaluating the different tracheal and bronchial wall layers, as well as parabronchial structures. Cartilage damage can be better assessed, influencing the type of treatment that will be offered [49].

Optical coherence tomography (OCT) is a new bronchoscopic imaging technique that has generated considerable interest since it has a much better space resolution than computed tomography. It can provide a micron-level, real-time image of the airway wall structure with a resolution approaching histology [50]. 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 and 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" [51], helping as we said in diagnosis and treatment of a number of conditions.

Anatomic optical coherence tomography (aOCT), a modification of conventional OCT, is a novel 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 [52].

All these new 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 stenoses [53]. 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 Tests

A simple test such as spirometry can help diagnose and characterize a central airway stenosis. 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 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.

Another important information that can be obtained with spirometry concerns to the functional status and helps in deciding whether or not the patient is a surgical candidate.

Classification of Benign Tracheal Stenosis

Airway stenoses have been classified following different parameters, in an attempt to design a useful algorithm for treatment.

Cotton et al. [54] 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 1999, Brichet and coworkers [8] proposed a classification based on four categories depending on bronchoscopic findings:

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

Moya et al. [55] reviewed 54 patients that underwent surgery for laryngotracheal stenosis and defined findings according to topographic and lesional criteria, incorporating three independent variables: stage of development (S), caliber (C), and length (L). Recently this classification has been modified. It is presented in Table 11.1.

In 2007 Freitag et al. [56] proposed a standardized scheme, presenting descriptive images and diagrams for rapid and uniform classification of central airway stenoses (Fig. 11.4). Classification was based on the type of lesion, degree, and location. They divided airway stenoses 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.
- Type 2: stenosis is due to extrinsic compression of all causes, including nonpulmonary 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 when a malacic condition that varied with the respiratory cycle was found. They included two different types:

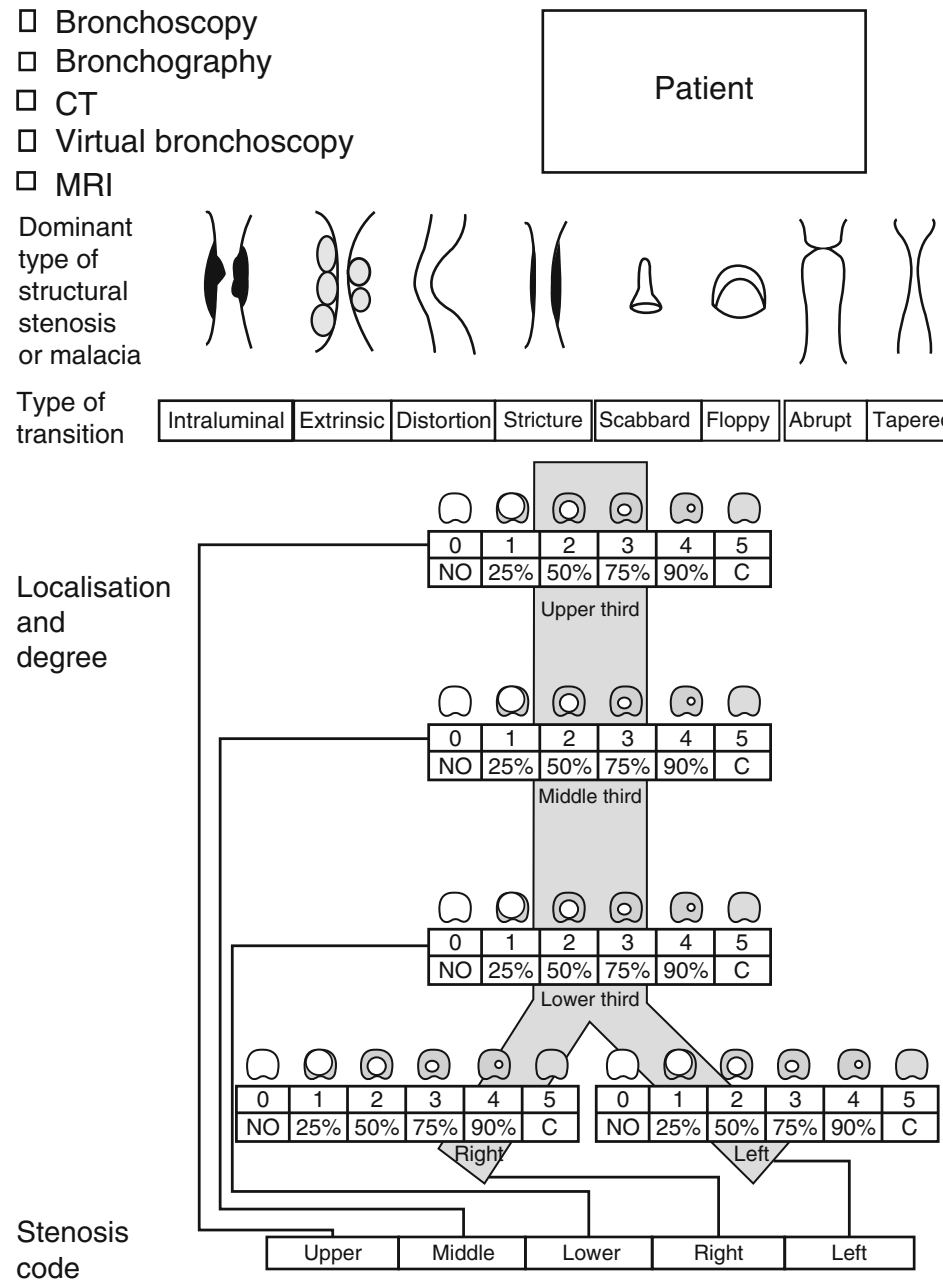
- Type 1: triangular (tent-shaped) benign stenosis in which the cartilage is damaged.
- Type 2: it is the inward bulging of a floppy posterior membrane.

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

Table 11.1 Classification criteria for inflammatory stenosis of the trachea

Classification criteria for inflammatory stenosis of the trachea					
Structure (S) Structure of the tracheal wall		Caliber (C) Internal diameter (at the point of smaller diameter)		Length (L) Axis of the larynx–trachea	
S1	Acute–subacute 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				

Adapted from Moya et al. [55]



A worksheet marking the location, degree and type of stenosis. CT: computed tomography; MRI: magnetic resonance imaging; C: complete

Fig. 11.4 Stenosis classification [56]. With permission

- 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

In 2008, other authors [1] classified airway stenoses into two groups, according to their morphological aspect in simple and complex, similar to the Brichet's classification. Simple stenosis included granulomas and weblike and concentrical 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. 11.5). Complex stenoses were represented by a longer lesion (>1 cm) with tracheal wall involvement and subsequent scarring contraction of the latter, in some cases also associated with malacia (Fig. 11.6).

The ultimate aim of the various proposed classifications 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.

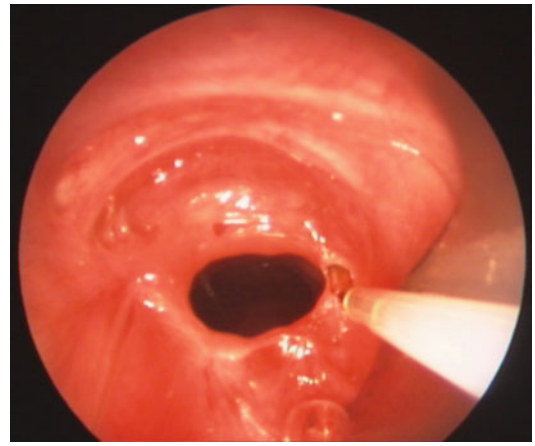


Fig. 11.5 Simple tracheal stenosis

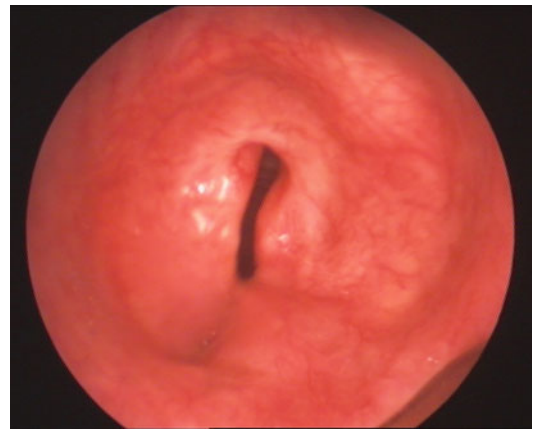


Fig. 11.6 Complex tracheal stenosis

Treatment

Effective management of tracheal stenosis requires a multidisciplinary assessment of 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 and 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 an airway prosthesis. Presentation of patients with an airway obstruction is variable and depends 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 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 balloon dilatation, laser resection, electrocautery, and placement of an airway stent. It is an expedite procedure to reopen the airway and very safe and effective when applied by a well-trained team. The flexible bronchoscope has also 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 intubating 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 dilatating 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 and the flexible bronchoscope, and a definitive procedure can be planned after discussing the case in a multidisciplinary team, once all information has been collected.

Some treatment algorithms have been recommended in benign tracheal stenosis, according to several defined criteria (Fig. 11.7 and Table 11.2).

Balloon Dilation

As we discussed above, in urgent cases the sole use of rigid bronchoscope causes dilation and enlargement of the airway, improving both extrinsic and intrinsic obstruction. 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 lumen (Fig. 11.8a, b, and c).

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

Laser Therapy

Laser treatment involves application of a laser light to the lesion. The effects of laser are determined by many factors: type of laser applied, distance and surface of application, and target tissue. The most commonly used lasers in interventional pulmonology are the Nd-YAP (neodymium, yttrium, aluminum, and phosphate) and the Nd-YAG (neodymium, yttrium, aluminum, and garnet). Diodos laser can be also applied to airway lesions with similar good results. Dumon published his first large series in 1982 [57]. This author presented 111 patients treated with laser to open the airway for both

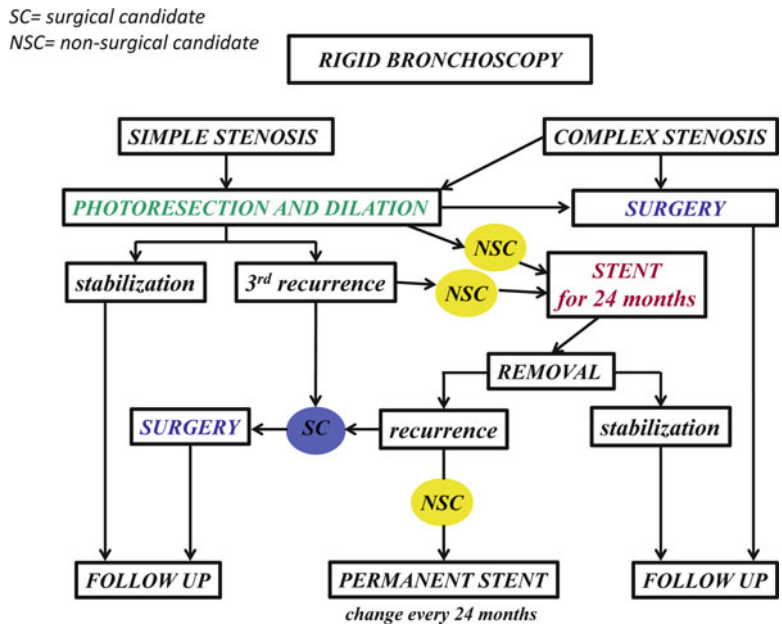


Fig. 11.7 Tracheal Stenoses Treatment Algorithm

Table 11.2 Endoscopic treatment according to morphological criteria [55]

Category	First option	Second option
S1/C1C"C3/L1L2	ET +/– Laser +/– Prosthesis	Surgery
S1/C2-C3/L3	ET +/– Laser +/– Prosthesis	–
S2/C2C3/L1L2	ET +/– Laser	Surgery
S2/C2C3	ET +/– Laser +/– Prosthesis	–
S3/C2C/L1L2	Surgery	–
S3/C1C2C3	Prosthesis	–
S4/C1C2C3/L1L2L3	Surgical correction of fistula + myoplasty	

Moya and colleagues
S = stage
C = caliber
L = length

benign and malignant lesions, 32 of them were benign stenosis. Cavaliere et al. [58] in turn presented their experience on 1,000 patients treated with laser for benign and malignant disease, obtaining cure in 34 of the 81 cases with benign tracheal stenosis treated with laser. We also published our series including 400 cases of benign and malignant disease treated with laser [59]. 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 prosthesis placement in 63 patients with benign tracheal stenosis [60]. About 79% of patients obtained definitive cure.

In order to open the airway with laser, we recommend to apply three or four radial cuts at the cardinal points of the stenotic circumference of the trachea (Fig. 11.9a, b, and c) and then to perform careful dilation with the rigid bronchoscope. The flexible bronchoscope can be used to apply laser as well, but we favor the rigid instrument to take advantage of simultaneous dilatation.

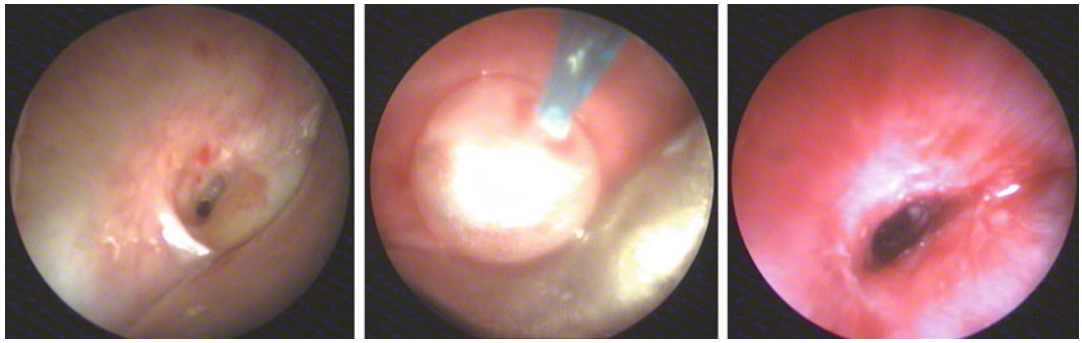


Fig. 11.8 Balloon dilatation (before, during, and after treatment)

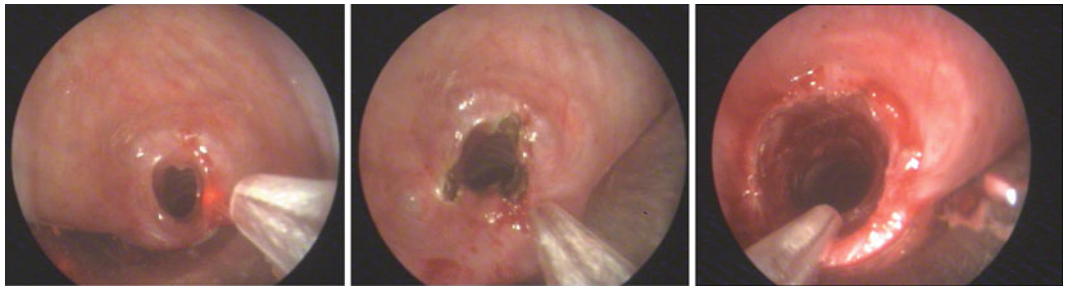


Fig. 11.9 Laser application in tracheal stenosis

Cryotherapy, Electrocautery, and Argon Plasma Coagulation

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

Results on the application of these techniques in tracheobronchial stenosis of varied etiology are available. Recently, Fernando et al. [61] treated 35 patients with a median age of 51 (18–81) years with Spray Cryotherapy (SC). Stricture etiology included postintubation, post-tracheostomy, radiation induced, prior surgery, other causes, or unknown etiology. 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 strictures suggested that 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 [62–64]. Laser therapy still has many advantages over all of them, since it is fast, and it has high coagulation power and a minimal impact on surrounding tissues.

Tracheal Prosthesis

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

Fig. 11.10 Montgomery T-tube

In benign tracheal stenosis, tracheal prosthesis placement may be considered in the following situations:

(a) Treatment failure after dilation of a simple stenosis
(b) First option in cases of complex stenosis as a bridge to surgical treatment
(c) As the only option in unresectable disease (length > 50% of the trachea)
(d) In inoperable patients

Metal, silicone, or other material endobronchial prostheses may be placed in the airways to relieve the obstruction caused by endoluminal tumors or extraluminal tumors that decrease the lumen of the airways by extrinsic compression. Likewise, benign conditions that diminish airway lumen can benefit of an airway stent as well.

Application of prosthesis is most effective when the stenosis occurs in the central airways (trachea or main bronchi). Their indication in distal bronchi stenosis is questionable.

The first airway prosthesis was developed by Montgomery and placed in 1965 [65]. The so-called Montgomery T-tube has an extraluminal portion and requires tracheostomy for placement (Fig. 11.10).

In 1990, Dumon introduced a totally endoluminal silicon-made prosthesis [66] and published his first experience on treating 118 patients with airway obstructions of different etiologies.

Since then, a large number of different airway prosthesis have been developed and are now available for medical use. However, at the moment the ideal stent has not been found yet. Many authors have listed the ideal characteristics for such a prosthesis:

– Easy to insert and remove
– Does not migrate
– Strong to support the airways
– Flexible enough to accompany the normal respiratory movements and cough and to allow adequate clearance of secretions
– Biologically inert (does not produce inflammatory response, avoiding granuloma formation)
– Available in different sizes and lengths

Published articles [60, 67, 68] reporting the application of airway stents in a variety of conditions including malignant and inoperable benign stenosis, tracheomalacia, tracheoesophageal fistula, and post-transplant stenosis showed remarkably positive results in more than 2,000 patients. Stent placement was associated with significant palliative benefits, improvement of dyspnea, quality of life, and performance status. Spirometric results, when available, also demonstrated improvement after placement. Associated adverse effects and complications listed on those reports were migration, granulation tissue formation, retention of secretions, airway perforation, and fatal hemoptysis.

A combined publication from 4 European centers reported the 7-year experience in the application of airway prostheses. A total of 263 patients had benign conditions, and they received an average of 1.6 prosthesis per patient. Duration of stenting ranged from 14 months to 6.2 years. Follow-up demonstrated treatment success in 66% patients, 24% of them had no recurrences after 1 year of stent removal [69].

Both metallic and silicone stents can be used for malignant obstructions of the airway. Silicone stents are favorites, however, since they have a low level of complications along with high efficacy and safety. They have been applied over the last 20 years with very good results.

Metallic stents have the theoretical advantage of being easy to place. In turn, they are very difficult to remove and we discourage their generalized use based on the level of complications they produce [70].

In fact, the FDA advised against metallic stent application in benign conditions in the year 2005 [71]. In malignant diseases, they are still acceptable if the expected survival period is short.

Procedure

Using the Rigid Bronchoscope

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

Concerning treatment of benign stenosis, rigid bronchoscopy 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 as you advance. 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 damage easily 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 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, 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 stricture 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 tracheal caliber remains appropriate. Given the case that the lumen remains stenotic, one can assume that there is a complex damage to the tracheal wall such as cartilage disruption or

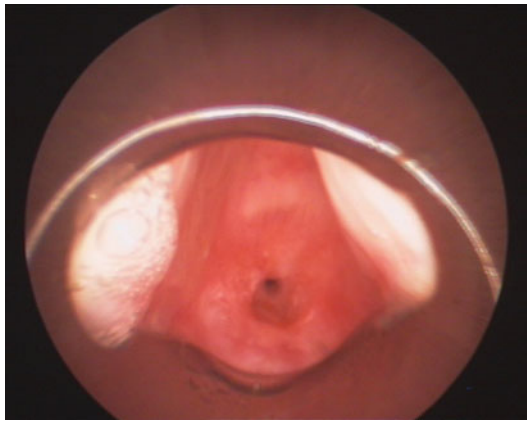


Fig. 11.11 Tracheal stenosis less than 2 cm from the vocal cords

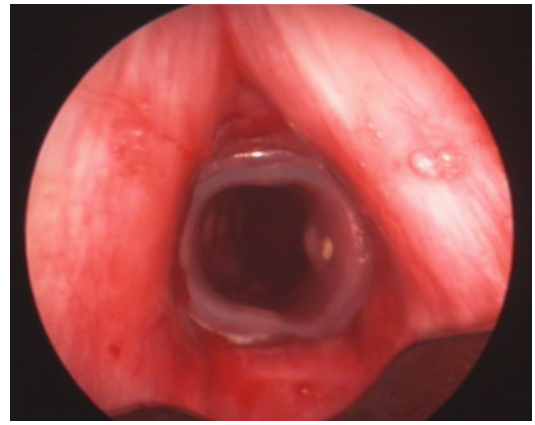


Fig. 11.12 After a Montgomery T-tube placement

malacia. Placement of an airway prosthesis 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 prosthesis 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 carina.

A prosthesis 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 <2 cm, the best results are obtained proceeding directly to tracheostomy and placing a Montgomery T-tube (Figs. 11.11 and 11.12).

In turn, when a low stent has to be placed, <2 cm from the carina, it is better to offer a Y prosthesis, since a tubular stent will contact and irritate carinal mucosa leading also to granuloma formation and subsequent stenosis.

Our recommendation is to always follow what we call the "cover and respect rule of twos" (Fig. 11.13) for tracheal stents that means:

When considering the vocal cords, stents should:

1. Cover 2 cm proximal to the stenosis.
2. Respect 2 cm from the vocal cords.

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

Related to the carina, prostheses should:

1. Cover 2 cm distal to the stenotic area.
2. Respect 2 cm proximal to the carina.

   If (1) and (2) are not possible, then a Y stent is in order.

Summary and Recommendations

Dealing with airway stenoses 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:

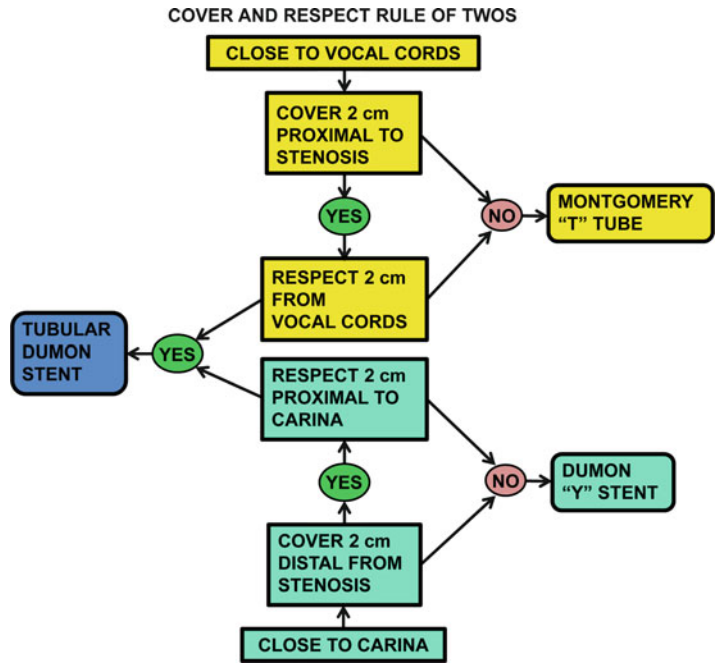


Fig. 11.13 Cover and respect rule of twos

- 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 interventional pulmonologists and thoracic surgeons 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 and able to apply both the rigid and flexible bronchoscopes and has to be also knowledgeable on handling airway prostheses. The 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 [72].

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