



Tracheal diseases: endoscopic evaluation and treatment

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Abstract: Rigid bronchoscopy has historically been introduced more than 100 years ago and has successfully passed the test of time reaching present with renewed interest and usefulness. For long time it was mainly performed for therapeutic interventions of foreign bodies removal and dilation of stenosis. In the mid-1960s, the flexible bronchoscope appeared on the scene, bringing with its important changes: the audience of actors for bronchoscopic procedures expanded from surgeons to pneumologists too; the lower invasiveness of the procedure determined a clear reduction in the number of rigid bronchoscopies performed. A renewed interest in rigid bronchoscopy occurred around the mid-1980s: the need to provide the increasingly frequent diagnosis of lung cancer on the one hand, technological development and the subsequent advent of new endobronchial therapies on the other, have led to the genesis of a new specialty, interventional pneumology. Today, rigid bronchoscopy is used primarily as a means of access to central airways for the management of patients with difficult benign and malignant airway disorders. In this review we will analyse the different applications of rigid bronchoscopy in children, with a particular focus on interventional endoscopic procedures.

Keywords: Rigid bronchoscopy; paediatric; interventional bronchoscopy

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Introduction

The first successful bronchoscopy was performed by Gustav Killian in 1897 with a 9-mm tube (1). Eihorn in 1902 made the procedure much easier and safer by adding distal illumination. Another fundamental contribution to technical and instrumental development arrived from Pittsburgh, PA, USA: here Chevalier Jackson began working with bronchoscopes and, in 1907, he published “Tracheobronchoscopy, Esophagology and Bronchoscopy” (2) in which we can find his design and project to build new bronchoscope and accessory instruments.

Since then this technique has been used with alternating frequency: at first as the only means of access to the

central airways, then, after the introduction of flexible bronchoscopy, it was slowly set aside until the late 1980s when, a renewed interest runs over rigid bronchoscopy. The need to provide the increasingly frequent diagnosis of lung cancer on the one hand, technological development and the subsequent advent of new endobronchial therapies on the other, have led to the genesis of a new specialty, interventional pneumology.

Today, rigid bronchoscopy is used primarily as a means of access to central airways for the management of patients with difficult benign and malignant airway disorders. Various therapies such as laser photo-resection, endobronchial stents, balloon dilatation, argon beam coagulation and cryotherapy can be performed safely and

Table 1 Principal indications to rigid bronchoscopy

Foreign body removal
Massive hemoptysis
Tracheobronchial stenosis
Evaluation
Treatment (stent, dilating balloon)
Tracheobronchomalacia
Tracheobronchial obstruction
Extrinsic compression
Benign tumors
Malignant tumors

effectively with the rigid bronchoscope. the improvements in anesthesia and ventilation techniques rigid bronchoscopy have made nowadays the endoscopic procedures safe and easily tolerated despite the very low structural change to the original bronchoscope: the rigid instrumentation used today do not differ significantly to those thought and used by Jackson.

Indications

Various applications of rigid bronchoscopy in pediatric patients are either diagnostic or therapeutic and for either benign or malignant conditions as resumed in *Table 1* (3). Rigid endoscopy is ideal for the documentation of glottic and subglottic pathology (cleft, high fistula) and for interventions (e.g., foreign body extraction, stents, laser surgery). If surgical intervention becomes necessary, high-resolution delineation of the airway structures will often be required by the surgeon (4). It may be necessary to decide whether a stenosis is rigid or flaccid by directly probing the lesion. The use of the laryngoscope, with a short-acting anesthetic, and inspection through an ultra- thin rigid telescope, can rule out a subglottic foreign body in severe or atypical group without touching mucosal surfaces. This may sometimes be the safest option (5). Rigid bronchoscopy may also be necessary in some cases for transbronchial biopsy, fistula detection, and airway recanalization in tuberculosis (TB) or tumors.

Instrumentation

Today's instruments, although apparently do not differ

much from the rigid bronchoscope used in the 1950s, have reached an excellent quality thanks to the improvement of the optical technology and of the accessories that allow an excellent visualization of the operating field and the execution of bronchoscopic procedures completely safe.

Rigid bronchoscopes are hollow, straight stainless-steel tubes of various length and width. Pediatric bronchoscopes are from 20 to 43 cm long and range in diameter from 3.5 to 8.5 mm usually, used according to age of patients (*Table 2*). The thickness of the bronchoscope wall is 2–3 mm and the inner round lumen is uniform. The proximal end of the bronchoscope consists of a central opening and some side doors; through this end it is possible to introduce a rigid telescope and many accessory (e.g., forceps, suction catheters, laser fibers, silicone stent delivery systems). The proximal side ports are used to connect the patient to the ventilation system and the bronchoscope to an external light source. The distal end is usually blunt, beveled, and allows atraumatic opening of the vocal cords during the passage of the instrument through the larynx, as well as “screwing” maneuvers through strict stenosis or “coring out” of obstructive lesions.

Dumon has recently made some changes to the classic instrumentation, introducing also a “universal head” that accommodates and articulates with bronchoscopes of various lengths and diameters. This new end has dedicated ports for inserting suction catheters, laser fibers and telescopes.

The illumination for rigid bronchoscope is provided by a xenon light source. Rigid optical telescopes guarantee a slight magnification of the airway image. Depending on the interventional needs, zero-degree telescopes are used, suitable for most procedures, or angled one, at 30° or 45°, which allow the visualization of the bronchi of the upper lobes. Dedicated video cameras can be connected to the telescope, allowing the transmission of images on shared monitors and allowing the operating team to work together; the procedure can thus be recorded on digital media.

Foreign bodies

Foreign body removal was the first clinical application of bronchoscopy and is still an important indication for procedure. The inhalation of a foreign body in the child arise often in a dramatic way with the so-called “penetration syndrome” characterized by acute dyspnea, choking, violent cough and sometimes vomiting. Although the sensitivity of this clinical manifestation is particularly high,

Table 2 Characteristics of instruments

Age	Size	Length (cm)	ID (mm)	OD (mm)
Premature	2.5	20	3.5	4.2
Premature, newborn	3.0	20, 26	4.3	5.0
Newborn to 6 months	3.5	20, 26, 30	5.0	5.7
6 months to 1 year	3.7	26, 30	5.7	6.4
1–2 years	4.0	26, 30	6.0	6.7
3–4 years	5.0	30	7.1	7.8
5–7 years	6.0	30, 40	7.5	8.2
8 years to adult	6.5	43	8.5	9.2

ID, internal diameter; OD, outer diameter. Adapted from Tom LWC, Postic WP, Handler SD. Methods of examination. In: Pediatric otolaryngology. 4th edition. Philadelphia: Elsevier, 2003.

as it is reported in the various cases between 80% and 97%, its specificity is low, in fact the same symptomatology can also be manifested in absence of inhalation (6-8). The clinical picture that follows from the acute asphyxiated episode is variable. Dramatically, in some situations, complete obstruction of the airways (larynx or trachea) is followed by an insistent and violent cough but ineffective for the expulsion of the foreign body, with rapidly deadly acute asphyxia, which does not allow any therapeutic intervention; in such situations only the Heimlich maneuver, performed promptly and correctly, could solve the problem. In other situations, the violent and insistent cough causes the expulsion of the foreign body, with resolution of the clinical picture (9). Between these two extreme situations there are different clinical pictures that can appear at a variable distance of time from the episode of inhalation and depend on the age of the patient, the nature of the foreign body, its size and its positioning on level of the tracheobronchial tree. From the above it is evident the need for a timely diagnostic and therapeutic intervention, whenever there is a medical history or suspicion of an inhalation; signs and symptoms may not be indicative and it is therefore essential to perform bronchoscopy to reach a diagnosis of certainty (7,10). Inspiration/expiration chest radiographs may help suggest air trapping and support the decision to perform bronchoscopy.

Hemoptysis

Episodes of non-massive hemoptysis should be evaluated and treated by flexible endoscopy. In the case of massive hemoptysis, it is necessary to proceed with the rigid

bronchoscope. Endoscopic evaluation of episodes of hemoptysis, often associated with radiographic signs of pulmonary thickening, can reveal the presence of foreign bodies, tumors or vascular malformations.

Tracheobronchial stenosis

Evaluation and treatment

Tracheal and bronchial strictures can be devastating complication of trauma, certain infections, neoplasm of different origins and other causes: secondary laryngo-tracheal stenosis (SLS), in fact, is the most frequent severe laryngeal-tracheal lesion in the first year of life, with a general incidence between 0.9% and 8.3%. Ninety percent of SLS are the result of intubation damage, difficult intubations performed by non-expert, due to intubations performed for acute obstructive airway infections, or airway superinfection in intubated and high-risk patients. The endoscopic evaluation of the stenosis involves the identification of the site, the measurement of the extent, and the grade according to the Cotton-Myer classification (11).

Among several alternatives for treatment, dilatation offer prompt initial benefit and allow time to plane more definitive therapy. Bougies are available in serially larger sizes from about 6F to 20F. The maximum size is limited by the internal diameter of ventilated bronchoscope, but progressively larger bougies can be passed under direct vision. Another technique is to use the bronchoscope itself to dilate strictures. Successively larger bronchoscopes are inserted, while excessive force is avoided. Balloon dilatation of flaccid stenosis is described in several situation and

can be considered as initial treatment as well as the use of laser therapy for the deroofting of cicatricial subglottic narrowing, have been described. Lasers with mostly superficial and minimal deep tissue energy coupling should be used: this will avoid damage to the delicate structures of the larynx as well as the perichondrium of the airway, and the development of secondary stenosis. Lasers have been employed to remove granulation tissue (e.g., at the site of a tracheostomy before decannulation), or infectious tumors [e.g., nontuberculous myco-bacterial granulomas (12)], and cicatricial obstructing lesions in the trachea (13).

Airway stents

The use of airway stents has become routine in adults with malignant airway stenosis, and was recently described in a series of children after tracheoplasty (14,15). Also, children with severe trachea-bronchomalacia or obstructing malignancies have been successfully treated with temporary stents (16), but serious questions remain as to their long-term safety, particularly when extrinsic compression of the airway by a vessel is to be relieved by the stent (17). Technical improvements and better materials (18) may make them an attractive alternative to other interventions, such as aortopexy in children with intractable airway symptoms after repair of esophageal atresia, or in selected cases after cardiac surgery (19). However, their use remains experimental at present and should only be used as a last resort.

The tracheobronchial stents available are divided into two categories: silicone stents and metallic stents. The former is well tolerated by the tracheal mucosa so they can be left in place for a long time (20) and are easily removable (21). The main problem deriving from their positioning, if of an inadequate size, is migration due to easy sliding on the mucosa. At the opposite, the metallic stents completely epithelize making their removal extremely difficult (22), although it allows to maintain a better mucociliary clearance interrupted instead by the silicone stents. The metal stents are subject to further calibrations over time: this characteristic allows them to adapt to changes in the airways due to growth.

Expandable metal stents with balloon

The stent consists of stainless steel meshes and has varying lengths and diameters. The positioning of these stents is carried out under endoscopic control with rigid bronchoscopy (23,24) and radiographic, by inserting

the appropriate stent in the stenotic or malacic area on an angioplasty balloon. Once the exact position has been defined the filling of the balloon is controlled radiographically and then further observed by endoscopic vision.

The advantages of their use include: easy insertion, positioning in bronchial tubes also of small dimensions and possibility of adjusting their diameter based on the growth of the child. The disadvantages are represented by granulation tissue growth and the difficulty or impossibility of removal.

Self-expandable metal stents

These stents have a memory, the ability to return to their original shape after compression for positioning within the airway (25). They are self-expanding devices available with variable diameters from 8 to 20 mm. They have a flexibility that allows them to adapt to the complex stenotic forms, they do not migrate easily from the place of positioning and can be removed before complete epithelialization takes place. However, they exert a low radial pressure, therefore they are ineffective in the more tight cicatricial stenotic forms.

Silicone stents

They are easy to insert and just as easy to remove, but they have the disadvantage, if of an inadequate size, of determining granulation tissue which, in turn, requires bronchoscopic treatment. To obviate the risk of dislocation it is useful to follow the rule of using stents 4 mm larger than the theoretical caliber of the trachea according to age. They cannot be expanded and require removal and repositioning based on the growth of the patient. They cannot be placed in the bronchial tree for two reasons:

- (I) There are no adequate instrumental devices for the positioning of these stents in the child's bronchial structures;
- (II) Their entire structure without fenestrations or continuous solutions denies the ventilation of the bronchial structures starting from the prosthetic bronchus.

The use of the Fogarty and the angioplasty balloon favor their correct positioning.

The use of stents in pediatric represents a procedure in progressive and constant evolution. The common characteristic of pediatric patients subjected to airway stenting is the impossibility of a respiratory weaning with conventional methods or the impossibility of surgical

treatment of tracheobronchial stenosis, due to the patient's precarious general condition.

The characteristics of an ideal stent (26,27) for the airway should be:

- ❖ Ease of insertion;
- ❖ Minimal incidence of complications;
- ❖ Ease or no need for removal;
- ❖ Availability in various sizes;
- ❖ Absence of migration after positioning;
- ❖ Compressive strength;
- ❖ Sufficient elasticity to conform to the anatomy of the airways;
- ❖ Biological inertia of the material constituting the device (non-irritating to the airways, not stimulating granulation tissue);
- ❖ Absence of interference with the mucociliary function.

Currently there is no device that fully satisfies these ideal characteristics and that combines the advantages of silicone with those of metal stents.

Tracheomalacia (TM)

TM or tracheal dyskinesia refers to a congenital or acquired weakening of the tracheal wall that collapse during every breath. It can be:

- ❖ Partial: for obstructions >50% and <80%;
- ❖ Severe: for obstructions >90%.

In pediatric age TM may present as a sporadic and isolated malformation, primary TM, or secondary to neighboring compression-expansive processes, secondary TM (28). Malacia can also affect a short tracheal segment, segmental TM, or more rarely almost its entire length, generalized TM.

Endoscopically, the trachea is flaccid, with little tracheal ring contour, collapsible on expiration in its thoracic part and with evident posterior parietal bulging that can extend to the carina.

Clinical evolution is generally favorable, especially after the first two years of life, due to a natural tendency of the pediatric trachea to increase in consistency; a small percentage goes towards surgical treatment instead. We can therefore identify:

- ❖ Forms with spontaneous resolution within the first 2 years of life, where medical conservative treatment is essential (drug therapy, physio kinesiotherapy, etc.); there was rarely a need for endotracheal intubation;
- ❖ Forms that require medical-surgical treatment

(secondary forms of vascular rings, or severe secondary forms of tracheostomy or Tracheo-Esophageal fistula).

Discussion

Aspiration of foreign body resulting in upper airway obstruction is lead to a significant morbidity and mortality in children. As Jackson said in one of his first paper on rigid bronchoscopy *"In suspected cases of foreign body of air passages, bronchoscopy must be done as failure to do bronchoscopy is more disastrous than complications of bronchoscopy"*. Mortality remains low in patients with aspiration of foreign bodies, however the role of a multidisciplinary team composed of otolaryngologist, pediatrician and radiologist is central for a rapid diagnosis and prompt management of this clinical scenario. At the same time, the availability of the complete instrumentation with pediatric bronchoscopes along with various types of pincers and accessories for the removal of foreign bodies is essential. This condition alongside the operator's experience and anesthetic management makes the management of this emergency comfortable and safe for children. A competent anesthesiology management is very useful for the surgeon: by sharing the work space, the two figures must alternate to access the rigid bronchoscope; an experienced anesthesiologist will allow the surgeon to have more time available for diagnostic-therapeutic maneuvers, making all procedure safer.

In general, we can say that there are many advantages to rigid bronchoscopy.

The procedure allows optimal airway control, regardless of whether the obstruction is caused by a benign stenosis, a tumor or the inhalation of foreign bodies. The telescopes used then, allow a bright and magnified view of the airways. A further advantage of the interventional procedures performed with a rigid bronchoscope compared to the flexible one is the shortest duration; to this it is associated the fact that usually rigid bronchoscopy is performed under general anesthesia, and often with muscle relaxation, therefore with the suppressed cough reflex, which is therefore possible to perform longer and more complex procedures for patients who are still motionless.

What stands out and which has made the use of rigid bronchoscopy for therapeutic procedures so extensive is their relative simplicity: laser therapy, electrocautery, cryotherapy and positioning of the endobronchial stent are all procedures that find their perfect application by rigid bronchoscopy. In particular, the application of silicone

stents is almost the exclusive prerogative of bronchoscopy; the channel of the bronchoscope provides excellent access to the airways to grasp foreign bodies and can serve as a pack to compress in case of hemorrhage from a central lesion.

Conclusions

Pediatric bronchoscopy has now acquired concrete proof of validity and has assumed its independence and specificity with respect to standard bronchoscopy: it is used both for diagnostic and therapeutic purposes and in an ever-increasing number of clinical situations. Future perspectives concern the further analysis and validation of the efficacy and benefits for the patient in specific prospective studies, as well as the constant attention to technical improvement.

In the scientific field also, it has become a research tool increasingly used to better understand pathophysiological concepts, as well as assess the effects of the application of locally therapies.

What should never be forgotten is a suggestion handed down and confirmed by the experience that states that “bronchoscopy should be performed only if the information we expect to obtain or the awaited therapeutic benefits outweigh the potential risks for children”.

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